FUEL FOR THOUGHT

Tim Donohue: The $134 Million Man

BY MICHAEL PENN

ON A SWELTERING JULY AFTERNOON IN 2006, WISCONSIN GOVERNOR JIM DOYLE strode into the spartan offices of the Madison biotech firm Virent Energy Systems and declared war on foreign oil. Addressing a small crowd—a peculiar mix of scientists, academics, government policy wonks, and reporters—Doyle outlined an aggressive agenda of energy independence that called for the state to produce 25% of its own transportation fuel and 25% of its own electricity by the year 2025.

To many of those gathered in the room that afternoon, the agenda sounded bold and inspiring. To most, it sounded impossible.

Bioenergy—the production of energy from such renewable sources as plants, trees, and agricultural waste—is a burgeoning industry in Wisconsin, but one that barely registers in the state's overall energy portfolio. Together with other, more familiar renewable resources like solar and wind power, bioenergy provides for less than 5% of Wisconsin's total energy consumption. It's a simple fact: Our state is hugely dependent on fossil fuels like coal, natural gas, and petroleum for our private sector and industrial energy needs. With no coal to mine or oil reserves to tap, Wisconsin, like most of the United States, currently has little choice but to import the vast majority of its fuel, spending close to $12 billion a year to keep its engines running and power lines humming.

Even Wisconsin's most visible and plentiful biofuel—ethanol produced from kernels of corn—will not get us even close to reaching Doyle's goals. While we doubled our ethanol output from 2002 to 2006, the 180 million gallons of ethanol we produced in 2006 were barely enough to supply 5% of Wisconsin's total need for transportation fuel. Nationally, ethanol from corn supplied just 2.9% of the fuel Americans pumped into their cars in 2005, and it required more than a quarter of the country's corn crop to

Photo credit: B. Wolfgang Hoffmann/UW–Madison accomplish this tiny contribution.

Even if we devote every last kernel of corn grown in the United States to ethanol production (an unappealing option that would likely wreak havoc on food prices and supplies), we would only make a 10% dent in our transportation fuel consumption. Biodiesel, produced from the oils and fats of such plants as soybeans, has a similar problem; there's not nearly enough vegetable fat out there to push Wisconsin anywhere near Doyle's target.

In other words, what Governor Doyle wants can't be done with existing technologies. "There's no question that we are not going to get there using corn kernels and soybean oil," says Tim Donohue, a veteran professor of bacteriology at the University of Wisconsin–Madison. "We're facing a reality where, in the past 50 years, we've gone through a very significant fraction of fuels that it has taken this planet millions of years to accumulate, and when those are gone, we're going to have to have entirely new technologies. This is an experiment we probably only get to do once."

This one shot to get it right is what keeps Donohue awake at night. As director of the University of Wisconsin–Madison's Great Lakes Bioenergy Research Center (GLBRC), Donohue has the charge of making the alluring dream of renewable fuel a commercial reality.

At the end of a long hallway on the fifth floor of the Microbial Sciences Building, a smiling Tim Donohue stands, ready to greet all visitors. This is not the real, in-the-flesh Donohue, but instead a rigid, cardboard facsimile of the professor dressed up as Superman, tugging back his office attire to reveal a superhero's crest on a muscle-bound chest. The life-size cutout is a gift from Donohue's admiring research team, in commemoration of his securing a five-year, $134 million grant from the federal Department of Energy's Office of Science to found the GLBRC. It's a fitting metaphor for the role Donohue now finds himself in: mild-mannered scientist, swooping in to save the planet from its energy woes.

While the DOE grant is one of the largest in UW–Madison's history, you wouldn't know it from talking to Donohue. He's the quintessential professor-type: peppery beard, casual-Friday attire, a quick, hearty laugh, and a genuine love for a good conversation, especially with students and junior scientists. For many years the head of UW–Madison's Biotechnology Training Program, Donohue has had a hand in shaping the careers of hundreds of graduate students that have gone on to

Photo credit: B. Wolfgang Hoffmann/UW-Madison

One of the goals of the GLBRC is to develop new kinds of plants that can be used as sources of bioenergy, such as the experimental variety of corn shown here. UW–Madison agronomy professor Natalia de Leon is studying the corn, which has been bred to be leafier and bushier than standard field corn, to see whether it can produce more biomass—and thus more energy—while still yielding the same amount of food per plant.

forge the nation's biotech industry.

Donohue's gregariousness and popularity with his students sometimes obscures the fact that he's a meticulous researcher and an expert in microbial metabolism and genomics. For the past two decades, Donohue has probed the mysteries of how photosynthetic bacteria extract energy from sunlight. The ability of these bacteria to turn sunlight into hydrogen is being explored as a possible energy source for wastewater treatment plants, where microbes may churn out fuel while simultaneously cleaning the water.

For much of Donohue's career, studying renewable energy meant piecing together small grants from federal and private sources. The public, for the most part, paid little attention to the scientific progress on alternative fuels. Then came $4-a-gallon gasoline. The ensuing economic chaos, coupled with diminishing supplies of crude oil worldwide, painfully demonstrated the fragility of our traditional energy framework. Suddenly, Americans discovered they had a new love for renewable energy. Even former Texas oilman George W. Bush saw the light, using part of his 2006 Presidential State of the Union address to declare that "America is addicted to oil," and to propose sweeping new investments in renewable fuels. In that address, Bush also mentioned the potential of one option that many Americans know little about: a form of renewable fuel called cellulosic ethanol made from the non-edible green and woody parts of plants.

Ethanol from cellulose—sometimes called "grassoline"—is an attractive option for several reasons. Cellulose, the stuff that makes up most of the non-edible parts of plants and trees, is the most common organic substance on the planet. Cellulosic ethanol is derived from the parts of plants that we don't rely on for food, ensuring that farmers won't have to choose between feeding people and feeding gas tanks. A state like Wisconsin—with abundant waste materials from agricultural crops, prairie grasslands, and forested areas—grows millions of tons of excess cellulose every year. Things like corn stover, grass clippings, wood chips, and paper waste are all materials that today aren't really plugged into the energy grid.

"It's like sitting on an oil reserve," says Brett Hulsey, an environmental consultant and author of a report on the potential of cellulosic ethanol. Hulsey's report, "Cellulose Prairie: Biomass Fuel Potential in Wisconsin and the Midwest," is now the corner-

No, the cars of the future won't run on ants. But leaf-cutting ants in UW–Madison bacteriologist Cameron Currie's lab may hold the secret as to how to make more renewable forms of energy. Currie is studying how the ants enlist the help of specialized microbes (visible here as white specks) to break down leaves in their nests, a process that approximates the kind of chemical reaction researchers seek in order to make fuel from plant material.

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stone of Governor Doyle's energy policy. "You've got fuel literally laying on the ground that could be used," he says. Hulsey estimates that if you take all of Wisconsin's excess plant material—collectively called *biomass*—and convert it to ethanol, you could reduce the state's gasoline needs by 40% and coal use by 50%. Not only is this good for consumers and business, but, as Hulsey notes, it's also good for the environment. By "investing in more biofuel use," Hulsey says that we can "reduce the largest sources of greenhouse air pollutants in Wisconsin and America." Fuels and coal are the largest sources of greenhouse gases in Wisconsin, according the DNR.

It sounds like a dream come true: reduce dependence on fossil fuels and help the environment. The only problem is that cellulosic ethanol is extremely difficult to make. Cellulose is tough—it has to be, to give plants form and structure—and it resists the fermentation techniques used to make ethanol from the simpler sugars found in corn kernels. Even the most refined methods for producing this so-called grassoline are expensive and inefficient, making it far from a cost-competitive option at the pump.

This is where Tim Donohue enters the picture. In 2005 the Department of Energy invited the bacteriologist to join an elite group of multidisciplinary scientists for a three-day brainstorming session on the steps needed to bring alternative-energy solutions like cellulosic ethanol to the marketplace. The fruit of that session was a 200-page report that called for a massive scientific quest on the scale of the Human Genome Project to study and overcome the bottlenecks that now make alternative fuels so expensive. Acting on the recommendations of the report, the DOE agreed to a nearly half-billion dollar commitment to establish three national centers for bioenergy research. Donohue took the lead on UW–Madison's proposal, assembling a project team composed of dozens of scientists from across campus. In the summer of 2007, UW–Madison learned that its proposal was victorious. When final selections were made, it turned out that the Great Lakes Bioenergy Research Center was the only bioenergy research center housed at a university; the others reside at the DOE's Oak Ridge and Lawrence Livermore National Laboratories.

Landing the federal center "is a very big deal that can have incredible long-term consequences for the university, Madison, Dane County, Wisconsin, and the nation," says David Mead, president of Lucigen, a Middleton-based biotech company that has received funding for bioenergy work through the GLBRC. Mead and others in the industry say that the GLBRC puts Wisconsin in a position to corner a significant share of the future biofuels industry, bringing high-tech jobs to the state and creating valuable energy reserves here at home.

Of course, this all depends on the GLBRC making some serious headway on the scientific knots associated with alternative fuels. For his part, Donohue has spent the past fifteen months assembling the intellectual firepower needed to untie those tangles. From an initial staff of nine part-time employees, the center has grown to employ more than 250 people at seven locations. Under Donohue, an unprecedented alliance of plant geneticists, microbiologists, biochemists, engineers, computer scientists, and agronomists are attacking the problem from different angles, and on multiple fronts. One team is working to breed plants better-suited for conversion into biofuels. Another team is looking for ways to improve existing processes for fermenting ethanol. Still another one is scouring the planet in search of microbes that can break down cellulose more efficiently, thereby reducing the high cost of turning fibrous plants into ethanol.

What unites these various experts

Researcher Hoon Kim examines a gel made from the components of a plant cell wall. Tough materials like lignin and cellulose give plant cell walls their structure, but they also stand in the way of converting plants into usable energy sources. Kim and biochemistry professor John Ralph are leading a GLBRC project to overcome that obstacle and get plants to more easily unlock their energy.

is an abiding sense of the moment. Donohue says he's struck by how many people have told him that they are motivated by the extraordinary mission of the center and the way it addresses the urgent need for sustainable, renewable energy solutions for everyday use. "As we've gone out around the country to recruit, many people have said to us, 'You know, I love my current job, but this is just such a compelling issue for me that I want to be part of it'," he says. "We've had people give up tenured faculty jobs at other institutions to be scientists in this center, and I think that speaks volumes for the fact that people here feel they are in a unique place and time."

This is true for Syd Withers, a chemical engineer who joined the GLBRC last year to head up a lab that screens microbes for ethanol potential. "Engineers have always been drawn to the thing that society has decided it needs the most, and right now this is it," says Withers, who left a job analyzing marine corals on Prince Edward Island to join the search for renewable fuel. "We have an energy-intensive way of life, and we have to have the means to support that."

In a brightly lit laboratory full of polished glass and steel, Withers fusses over a carousel that holds a stack of Pyrex lab plates. The carousel is connected to a giant robot, capable of handling and analyzing hundreds of microbe samples at once. The robot precisely replicates the work of ten bench scientists. It is also sparklingly new, so untested that "still gives the manufacturer headaches when we run this," Withers says. When he started his job last year, this room was a bare cube.

The hard-boiled science of bioenergy research takes place in labs like Withers's, where scientists conduct arcane interrogations of microbial gene pathways and gauge responses to various stresses. Scientists like Withers hope that these fundamental studies will lead to improvements in the ethanol process—either by identifying microbes that are better at ethanol conversion than the ones we now use or by showing us how to build a better microbe through synthetic biology. Of making fuels out of plant material, Withers says that "all the biochemistry is there, but it's not all put together the way you might want it. The process is not economically acceptable. What we're trying to figure out is how to put all the pieces together so that the process works better."

As daunting as the challenge of searching for and reengineering microbes may be, it is only one roadblock standing in the way reducing our dependence on fossil fuels. The other questions and challenges are no less complicated: *What plants should we grow as feedstocks for biofuels? Where should we grow them? How much of a corn plant can be removed from the land without harming soil or contributing to erosion problems? Are current ethanol refining facilities equipped to handle new types of inputs?*

Issues such as these are one reason why the GLBRC has a team devoted exclusively to studying the sustainability of a future biofuels economy. According to Donohue, the GLBRC's focus on sustainability is one aspect that set the university's proposal above its competitors.

And the questions about the long-term environmental impact of bioenergy are serious. Conservation groups have warned that a rush to biofuels might result in planting intensively managed crops on poor lands or cutting down rainforests to harvest biomass. Such uncertainties have led the United Nations to adopt a cautionary tone on the promise of bioenergy. The U.N.'s first public report on bioenergy, issued in May 2007, concludes that "unless new policies are enacted to protect threatened lands, secure socially acceptable land use, and steer bioenergy development in a sustainable direction overall, the environmental and social damage could in some cases outweigh the benefits."

Donohue agrees, and he says the report underscores the need for the kind integrated research on the topic they do at the GLBRC. "If we work in silos, we may make groundbreaking results in individual areas, but we will ultimately fail to bring new technology to the market," he says. "The only way we get there is to have people thinking about an integrated pipeline."

But that's not always easy in academia, where professors are somewhat accustomed to individually driven pursuits. Lucigen's David Mead notes how "the real challenge with academics is getting them [...] rowing together," adding that, "I am glad that is not my responsibility." It is Donohue's responsibility, however, and Mead believes that he is uniquely qualified. "I think one of Tim's greatest strengths is his ability to pull together disparate researchers and their individual strengths into a collec-

Interested in sustainability?

Join the BioPharmaceutical Technology Center Institute for a lively two days of information-sharing and discussion regarding this important—and often controversial—topic at the 8th Annual International Bioethics Forum. Packed with keynote speakers from across the biotech industry, this year's program is designed to allow participants to explore these questions:

- How do we define "sustainability" —and what are the causes of "unsustainability?"
- What are the most relevant technologies for us to understand?
- How are various sectors and organizations responding to these issues, *e.g.* governmental units, research/educational institutions, businesses and faith communities?
- What is the role of the individual decision-maker? Is one person's action (or nonaction) important?

The 8th Annual International Bioethics Forum will be held on April 23–24, at the BioPharmaceutical Technology Center in Madison. For more information or to register, contact Karin Borgh at 608-277-2508 or visit **btci.org**.

tive organization."

"Tim is considered fair, which is not something easily accomplished in faculty life," adds Irwin Goldman, associate dean in charge of research for UW–Madison's College of Agricultural and Life Sciences. But Goldman says Donohue brings something else vitally important to pulling off a task of this scale—a boundless sense of what is possible. "I would say that attitude makes a huge difference in leading a project like this," says Goldman. "Tim has a great attitude and a great sense of humor, and that's invaluable as the stress mounts."

And there is no question that the GLBRC has the burden of high, and immediate, expectations. A little over a year ago, then-U.S. Secretary of Energy Samuel Brodman predicted that cellulosic ethanol would be economically competitive with petroleum by 2012. This echoes the astoundingly ambitious goal set by the DOE panel on which Donohue served in 2005, which called for a 30% reduction in fossil-fuel dependence by 2030, and feeds the optimism of Governor Doyle, who is fond of saying that cellulosic ethanol will turn Wisconsin into "the Saudi Arabia of the Midwest."

Asked whether he thinks the GLBRC will succeed in ushering new biofuels to the market, Syd Walters says with some hesitation that "the timeline is tough, there's no question about that." He then pauses, summoning the stubborn determination upon which our bioenergy future may well depend, and continues, "But I have a feeling that we are going to have to get there. It's not going to be optional."

In the GLBRC, that resolute determination feeds from the top. "I would rather have us set lofty goals and see how far we get than set the bar low," says Donohue. "As a society, we have done that when we said we were going to go to the moon. We said that when we said we were going to sequence the human genome, and we actually did that faster than we said we would... This is like being in on the ground floor of NASA, or being there in the infancy of the Human Genome Project," says Donohue, his enthusiasm visibly building. "I really do think that we'll look back at this as a historically significant moment, when we put it on the agenda to diversify our energy portfolio."

Photo credit: B. Wolfgang Hoffmann/UW–Madison

John Ralph's lab is using plants like kenaf to try to better understand the biology of plant cell walls and how they can be converted into energy. Although it's unlikely that kenaf itself will become a bioenergy crop, it may yield insights that are valuable for using plants such as switchgrass or miscanthus to make fuel.