Lifetime Achievement Award

For discoveries with impacts that have developed over more than 15 years, that have revealed profound new understandings of foundational science and/or theories within a given field and the resulting impact on society.

A Storied Career: Michael Himmel Has Unraveled Complexities of Turning Biomass Into Climate-Friendly Fuels

NOMINATION ABSTRACT:

Governments and industries seek affordable, scalable, and equitable solutions for quickly lowering greenhouse gas emissions from transportation. With carbon footprints many times smaller than fossil fuels, sustainable biofuels made from lignocellulosic biomass—the fibrous, often castoff parts of plants—could be critical for decarbonizing the aviation and maritime industries.

As a biofuels researcher at the National Renewable Energy Laboratory, Dr. Michael E. Himmel has redefined his field with insights on designing, modifying, and harnessing enzymes to turn such non-food biomass into a thriving sustainable fuels industry. During his 40-year career, Dr. Himmel has led hundreds of scientific studies in protein biochemistry, recombinant technology, enzyme engineering, microorganism discovery, macromolecules physico-chemistry, and all unit operations in biofuels production. In doing so, he has unraveled the chemical and biological complexities of using enzymes and bioprocessing techniques to turn lignocellulose into sugars—sugars industry can ferment to alcohols and then upgrade with catalysts into energy-dense fuels.

Dr. Himmel has written prolifically, producing 500 papers, 11 books, and 40 patents. His 2007 Science review article has alone achieved more than 4,600 citations—only a fraction of the more than 40,000 citations across his body of work. Dr. Himmel's library of publications is frequently cited in leading journals, informing agency priorities and guiding multimillion-dollar investments. Now, with an agreement signed by the U.S. Department of Energy, Southwest Airlines, D3MAX, and others, Dr. Himmel is seeing the fruit of his career ripen in the form of a pilot plant now underway in Nevada, Iowa. The 10-ton-per-day lignocellulosic ethanol facility is long anticipated in the push to turn agricultural waste—like corn stover—into sustainable aviation fuel. Analysis shows the fuel could be less expensive than petroleum-based jet fuel and reduce carbon intensity by up to 84%—a defining achievement in Dr. Himmel's already storied and impactful career.

NREL
Transforming ENERGY

Dr. Michael E. Himmel

GOVERNOR'S AWARDS FOR HIGH-IMPACT RESEARCH 2022

Started in 2009, the annual Governor's Awards for High-Impact Research celebrates the brilliant ground-breaking discoveries and innovative research from Colorado's ecosystem of federally-funded laboratories and institutions.

Organized by CO-LABS, each year's event spotlights the men and women creating our future through brilliant technological and engineering discoveries in aerospace, energy, agriculture, public health, weather prediction, wildlife ecology, communication, earth science and dozens of other fields of research right here in our communities.

CO-LABS
Promote. Educate. Connect.

GOVERNOR'S AWARDS FOR HIGH-IMPACT RESEARCH 2022

Lifetime Achievement - Dr. Michael E. Himmel

NREL Transforming ENERGY

DESCRIBE THE BACKGROUND CONTEXT SHAPING THE NEED AND INTEREST IN THIS RESEARCH.

The prospect of turning "lignocellulosic biomass" into energy-dense biofuels has both frustrated and inspired many scientists. Depending on the process used to make it, biofuel made from lignocellulose—the fibrous, woody, often castoff parts of plants—can net deep reductions in greenhouse gas emissions compared to fossil fuels and even first-generation biofuels. According to the U.S. Department of Energy's Alternative Fuels Data Center, for example, ethanol made from lignocellulosic biomass, rather than corn starch, can reduce emissions 88% to 108% on a life cycle basis.

And still—even as they have worked tirelessly to crack the code to economical, domestically produced, and climate-friendly biofuels—researchers have come up against a key barrier: biomass recalcitrance, or "the natural resistance of plant cell walls to microbial and enzymatic deconstruction."

That definition comes from a seminal article on the phenomenon published in Science in 2007. Cited over 4,600 times, the article has become a classic in the field. There is great promise in using biomass as an abundant and sustainable source of energy, it suggests. But researchers—and, more importantly, industry—must first take on recalcitrance if they ever hope to make it compete with fossil fuels.

As the first author on that formative paper, Dr. Michael E. Himmel, a senior researcher at the National Renewable Energy Laboratory (NREL), is keenly aware of the challenges of addressing biomass recalcitrance for the sustainable fuels industry. Much of his 40-plus-year scientific career has been spent unraveling its chemical and biological complexities. How can engineers cost-effectively wield enzymes, in combination with other preprocessing techniques, to break the chemical bonds of biomass and free the energy locked inside?

That mission, long the focus of Dr. Himmel and the countless colleagues, student researchers, and interns he has mentored, has received mounting attention in recent years. Just as the oil embargo in the 1970s helped stimulate a corn ethanol industry—one designed around using the plant's starchy kernels rather than its far tougher lignocellulosic leaves, stalks, and cobs—the specter of climate change casts a shadow over the global energy market. Governments and industries seek affordable, scalable, and equitable solutions for quickly lowering greenhouse gas emissions across economic sectors. While transportation rapidly shifts to electricity, key subsectors like aviation and marine have fewer pathways toward decarbonization.

Sustainable aviation and marine fuels made from lignocellulosic biomass could help fill the gap. Over 1 billion tons of biomass can be sustainably harvested every year in the United States without affecting food supplies, according to U.S. government analysis. Such a resource pool could support a 50-billion-gallon-per-year biofuel industry, more than enough to fuel all future domestic and international air travel.

Aware of this potential, the federal government is investing millions to enable that domestic supply chain, setting a bold but achievable goal to increase sustainable aviation fuel production to at least 3 billion gallons per year by 2030. It aims even higher in the long run: 35 billion gallons by mid-century, enough to cover 100% of projected aviation demand.

Still, at the center of this momentum and opportunity to create a thriving biofuels industry lie critical questions: What to do about biomass recalcitrance? How might enzymes and microorganisms be engineered to efficiently deconstruct the fibrous plant materials into simple sugars? Most pressing, how can an industry do all these things while making energy-dense biofuels cost-competitive with petroleum and far better for the climate?

"The cost-competitive production of biofuels is currently prevented by the high cost of biomass feedstocks and the processes for converting biomass to sugars," Dr. Himmel and coauthors argued in their 2007 paper. In other words, to overcome the natural chemical and structural designs that give lignocellulosic biomass its strength and rigidity in plants, energy researchers must take on biomass recalcitrance.

GOVERNOR'S AWARDS FOR HIGH-IMPACT RESEARCH 2022

Lifetime Achievement - Dr. Michael E. Himmel

NREL Transforming ENERGY

DESCRIBE THE COMPELLING FACETS OF THIS PERSON/TEAM'S, RESEARCH AND WHAT WAS THE ULTIMATE KNOWLEDGE AND INSIGHT DISCOVERED.

The great barrier to making fuel from the woody, fibrous parts of plants, biomass recalcitrance has brought a generation of researchers to the lab to understand how enzymes in nature work to break down the cell walls of plants. Given the right conditions, microbes in the soil naturally use their enzymatic toolkits to decompose the stems, leaves, and roots of trees and plants, making their nutrients available for other organisms. For biofuels researcher Dr. Michael E. Himmel, the problem is that enzymes tend to complete this task too slowly for industry. More often, they don't yield the right ratio of sugars and compounds to make an effective liquid fuel.

Since he started as a postdoctoral scientist for the National Renewable Energy Laboratory (NREL) in 1980, Dr. Himmel has led the charge to work around that framework—and he has been well-positioned to do so. He is as comfortable in esoteric protein engineering as in fast-paced, high-stakes applied science with industrial partners. By improving our understanding of enzyme action on biomass, he has shown how industry might use bioprocessing techniques to turn lignocellulose into sugars—sugars that can be fermented to alcohols in large tanks, like ethanol, and then upgraded with catalysts to sustainable aviation fuels.

Under Dr. Himmel's leadership, NREL researchers have provided clues on how to design, modify, and harness enzymes to maximize the production of sugars most prized for making fuel. For decades, he has supervised research applying protein design and "mutagenesis," or targeted genetic changes, to stabilize and improve those biomass-degrading enzymes most useful to industry.

A few specific examples stand out. Soon after the turn of the century, Dr. Himmel worked closely with two commercial enzyme companies, Novozymes and Genencor, to produce the first low-cost cellulase/hemicellulase formulations. This role earned him an R&D 100 Award in 2004, a prestigious honor in the research community. Over the next 20 years, he coauthored numerous studies, published in leading journals, that used computational and experimental approaches to better understand the structure/function relationships of cellulose-degrading enzymes. In doing so, he helped pinpoint regions he and his team could target to speed up their action on cellulose. In 2021, Dr. Himmel coauthored a paper on the role of iron uptake in yields of switchgrass. A promising perennial bioenergy crop, switchgrass can be grown on marginal lands, giving farms an additional source of income while reducing erosion and improving regional water quality. Described in a manuscript now in preparation, Dr. Himmel and his team demonstrate an unprecedented 1.55-fold performance improvement of the key fungal cellulase enzyme, called cellobiohydrolase I, using a genetic engineering approach to design and build a non-natural protein chimera.

While conducting such groundbreaking studies—the aforementioned being just a few kernels in a handful of accomplishments—Dr. Himmel was also developing innovative tools and research strategies. In more than one case, those he developed themselves became notable in the field, positioning NREL as a leader in biomass conversion and demonstrating new techniques to the wider research community. For example, in the 2010s, he pioneered the use of molecular dynamics simulation to model the conversion of biomass into fuel. In partnership with NREL staff he himself helped hire (many who have built their own illustrious careers), Dr. Himmel showed that computational models could rapidly unravel the biological barriers that reduce the efficiency by which enzymes break down cellulose—the main structural component in plants.

Mindful that even the most science-oriented brain craves more than equations and numbers, Dr. Himmel helped secure funding for NREL's state-of-the-art Biomass Surface Characterization Laboratory. There, researchers use sophisticated microscopes and imaging techniques to picture the action of enzymes on biomass and visualize plant cell walls. The results of the effort proved stunning: literal images showing composites of polysaccharides and lignin that enable plants to resist pathogens and enzymes.

Looking broadly at his career, Dr. Himmel has led hundreds of scientific studies in protein biochemistry, recombinant technology, enzyme engineering, microorganism discovery, macromolecules physico-chemistry, and all unit operations in biofuels production. These include comminution, thermal chemical pretreatment, enzymatic hydrolysis, and fermentation. Individually, each brought important insights on how to overcome biomass recalcitrance. Together, they have helped facilitate a phase change in the U.S. bioeconomy—pulling discoveries and technologies from the covers of scientific journals right up to the cusp of commercialization.

GOVERNOR'S AWARDS FOR HIGH-IMPACT RESEARCH 2022

Lifetime Achievement - Dr. Michael E. Himmel

NREL Transforming ENERGY

THE MANNER IN WHICH THIS WORK HAS INFLUENCED AND SHAPED THE PATH OF SCIENTIFIC RESEARCH, GUIDED POLICY DECISIONS AND/OR HAD IMPACTS ON PEOPLE'S LIVES OUTSIDE THE SCIENTIFIC COMMUNITY.

In the years since receiving his Ph.D. in biochemistry from Colorado State University, Dr. Michael E. Himmel has laid a foundation of service and scholarship in biomass conversion. Dr. Himmel's library of published works is frequently cited in leading journals, informing agency research priorities, and even guiding multimillion-dollar investments by Fortune 500 companies and the federal government. With a new agreement signed by the U.S. Department of Energy (DOE), Southwest Airlines, D3MAX, and other partners, Dr. Himmel is seeing the fruit of his career ripen in the form of a pilot plant now underway in Nevada, Iowa. The 10-ton-per-day lignocellulosic ethanol facility is long anticipated in the push to commercialize sustainable aviation fuel made from corn stover and other agricultural waste. In this way, Dr. Himmel's research has yielded concrete solutions for lowering the climate impact of moving people and goods around the globe.

Dr. Himmel's byline has become a placeholder for biofuels researchers everywhere, who frequently use his contributions as a springboard for further discovery and commercial application. He has written prolifically in both high-impact (Science, Nature, PNAS) and field-specific journals (Nature Biotechnology, Chemical Reviews, Biotechnology for Biofuels), producing 500 papers, 11 books, and 40 patents. His 2007 Science review article on biomass recalcitrance has alone achieved more than 4,600 citations—only a fraction of the more than 40,000 citations across his body of work. All said, Dr. Himmel has earned an h-index of 89 and an i10-index of 242—impact metrics rivaling the collective work of entire research teams and organizations. In 2008, Dr. Himmel edited a new book for Blackwell Publishers entitled Biomass Recalcitrance, which is listed as a top-selling science book and has now been translated into Chinese.

Indeed, Dr. Himmel's scholarship has helped define the science of biomass conversion. And still, his numerous other contributions—small and large—themselves exhibit a broader value to both the National Renewable Energy Laboratory (NREL) and the larger research community. Dr. Himmel has mentored countless interns, students, postdoctoral staff, and early-career researchers. In this way, he passes on his experience to a new generation of scientists working to realize the environmental and economic benefits of biofuels at a scale that matches the climate crisis. His insights and expertise are also sought after by research peers, industry, and government labs—influencing priorities for industry and federal programs. For example, in 2005 he co-chaired the workshop that helped develop DOE's Office of Science roadmap, Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda (https://genomicscience.energy.gov-/breaking-biological-barriers-to-cellulosic-ethanol/). The report defined barriers to the rapid expansion of cellulosic ethanol production and outlined solutions using modern biology tools. The insights from that exercise directly helped form DOE's Bioenergy Research Centers in 2007. Dr. Himmel also led DOE's Enzyme Engineering and Optimization Project for 25 years. The program yielded unprecedented insights into the molecular mechanisms behind cellulase enzymes, generating intellectual property that continues to empower biotechnology companies to innovate the marketplace. All said, Dr. Himmel has produced 101 innovation records at NREL, and the lab has filed 142 patent applications for his work.

Dr. Himmel has served on numerous program and proposal review panels in the bioenergy technology space—for the U.S. Department of Energy, U.S. Department of Agriculture, and the National Science Foundation. He is sought out by international funding agencies and journals for his expertise as a reviewer. From 2010 to 2015, he served on the reviewing editorial board for Science—a widely respected scientific journal. In addition, he is a founding co-editor-in-chief for Biotechnology for Biofuels and was recently appointed field chief editor for Frontiers in Industrial Microbiology. Dr Himmel has also assembled and funded an enviable collection of facilities and instrumentation to support his team, their collaborators, and federal agencies in the bioenergy space. These tools span a wide range of disciplines, from new biomass refiners to advanced microscopes and protein purification and characterization systems.

As Himmel himself put it, however, perhaps the defining moment of his long career occurred in 2022, accompanied by a news headline on NREL.gov: "SAFFiRE Sustainable Aviation Fuel Project Earns Government-Industry Boost." Short for "Sustainable Aviation Fuel From [i] Renewable Ethanol," SAFFiRE is a project backed by D3MAX LLC, the U.S. Department of Energy, Southwest Airlines, NREL, LanzaJet, and others to turn agricultural waste of little value—like corn stover—into profitable and environmentally friendly jet fuel. Using NREL's patent-pending deacetylation and mechanical refining process—a technology drawing liberally from Dr. Himmel and colleagues' knowledge and experience—the project sidesteps the expenses and challenges of previous efforts to turn lignocellulosic biomass into fuel. By doing so, it could boost ethanol yields by 14% and lower its cost by 33 cents per gallon.

A brainchild of Dr. Himmel, the co-principal investigator of the project, the technology behind SAFFiRE is an achievement with implications well beyond the lab. With a goal to create low-carbon jet fuel that could be used to fuel future Southwest Airlines flights, it is among a handful of economical, proven technologies needed to decarbonize the aviation industry. NREL analysis shows that sustainable aviation fuel created using SAFFiRE will be less expensive than petroleum-based jet fuel and reduce carbon intensity by up to 84%. Moreover, it could be a boon to agricultural communities across America's heartland—revitalizing existing ethanol facilities in the Midwest and offering farmers a new source of revenue for previously unused agricultural waste. So, while Dr. Mike Himmel's long career has delved into the furthest corners of biological sciences—into complex enzyme engineering and structural biology—his insights have become like basic ingredients for a complete and nourishing meal: just what is needed to build a robust, vibrant bioeconomy without the climate cost.

GOVERNOR'S AWARDS FOR HIGH-IMPACT RESEARCH 2022

Lifetime Achievement - Dr. Michael E. Himmel

NREL Transforming ENERGY

Related awards, recognitions and media about this research can be found below.

Dr. Michael E. Himmel has garnered numerous awards and honors, both internally at the National Renewable Energy Laboratory (NREL) and in the wider research community. At NREL, he has received the prestigious H.M. Hubbard Award for Outstanding Research Management, a Chairman's Award for Outstanding Performance, and various staff awards and technology transfer awards. Externally, Dr. Himmel has been honored for his scientific innovations. In 2004, he received an R&D 100 Award for "Advanced Cellulase System for Biomass Conversion." In 2011 and 2013, he was honored with the Battelle Memorial Institute Distinguished Inventor and Inventor of the Year awards, respectively. His service to the research community has been recognized through the American Chemical Society's Outstanding Service Award and the Society for Industrial Microbiology's C.D. Scott Award. His animation of an endoglucanase hydrolyzing cellulose won the Gold Screen Award - 1st Place from the National Association of Government Communicators.

For more information see the following media coverage hyperlinks relating to the nominated project/person(s).

SAFFiRE Sustainable Aviation Fuel Project Earns Government-Industry Boost, NREL News 2022 (https://www.nrel.gov/news/program/2022/saffire-sustainable-aviation-fuel-project-earns-government-industry-boost.html)

NREL Set To Receive $5.4 Million in Funding To Research Turning Buildings Into Carbon Storage Structures, NREL News 2022 (https://www.nrel.gov/news/program/2022/nrel-set-to-receive-54-million-in-funding-to-research-turning-buildings-into-carbon-storage-structures.html)

NREL Innovations Open Door to Industry Collaboration, Commercialization, NREL News 2022 (https://www.nrel.gov/news/features/2022/nrel-innovations-open-door-to-industry-collaboration-commercialization.html)

Groundbreaking research: White-rot fungi can use carbon captured from lignin as carbon source, Phys.org 2021 (https://phys.org/news/2021-02-groundbreaking-white-rot-fungi-carbon-captured.html)

CO-LABS
Promote. Educate. Connect.

About CO-LABS:

Started in 2007, CO-LABS is a non-profit consortium of federal laboratories, research institutions, businesses and economic development organizations that provide financial and in-kind support for programs that promote the retention and expansion of Colorado's federally-funded scientific resources. Through events, economic analyses, strategic communications and networking activities we work to:

- PROMOTE Colorado as a global leader in research and technology
- EDUCATE the public about federal research labs' and institutions' impact, and importance of sustained funding for research
- CONNECT the labs, universities, economic development organizations and businesses to facilitate partnerships and technology transfer

To learn more, visit www.CO-LABS.org.