NREL
Transforming ENERGY


# Clean Energy Innovators:

## NREL People Working To Change the World

*Written by Ernie Tucker*

Cover photo: August 21, 2017 - NREL staff view the solar eclipse using pinhole technique outside the ESIF on the STM campus. *Photo by Dennis Schroeder, NREL 46841*


National Renewable Energy Laboratory sign shines at the South Table Mountain Campus. *Photo by Werner Slocum, NREL 63032*

**I've always been drawn to human interest stories. Long before I started at the National Renewable Energy Laboratory (NREL) in June 2009, I had interviewed and written profiles of many people. Among them were politicians, actors, athletes, authors, poets (including president-turned-artist Jimmy Carter, years after he envisioned the Solar Energy Research Institute), as well as everyday folks and heroes.**

While these tales were published in newspapers and other media, that type of news feature approach didn't seem to readily fit into publications at a national research laboratory. That is, until one day in April 2012 when I was interviewing solar researcher Bhushan Sopori, trying to understand his scientific background.

Somehow, sitting in his office, he revealed that music had been his first love—and, indeed, his family was famous. Music trained his mind to focus on research. I rushed back and told my Communications Office colleagues that I didn't know what we could do with this, but I felt we should share it in *NREL Now* (our internal news site) as a way to shed light on Sopori.

The result was a story headlined **Bhushan Sopori: Staying in Tune with His Culture** that was published on April 23, 2012, along with a photo of him playing an Indian musical instrument. It began, "NREL Principal Engineer Bhushan Sopori**,** whose career has spanned more than 25 years at the lab, is known for his solar innovations such as the Optical Cavity Furnace, which earned an R&D 100 Award in 2011. But it was not always a given that Bhushan would be a scientist. As a boy growing up in the Kashmir Valley in India, Bhushan was given the nickname "The Little Professor" for his musical skills on the tabla, an Indian drum he learned to play from his father, famed performer Pandit Shambu Nath Sopori."

From that point on, I was on the lookout for people at the laboratory who had compelling tales. My justification was simple: If an NRELian excelled at something outside the lab—say as an Olympic competitor or accomplished musician—that same level of achievement would be reflected at work. Besides, the stories would be fun, and readers would find them engaging.

I heard about **Tim Tetreault's** three Olympic contests in the grueling Nordic combined ski competition; and researcher **Gina Fioroni's** attempt to complete her 50th marathon in Boston the year of the bombing tragedy—as well as endurance runners who pace one another on 24-hour ultramarathons. I watched as engineer **Dave Corbus** played Frank Zappa's intricate rock/jazz live backed by a dozen or so musicians; and heard others perform rock, folk, and, in the case of **Dan Bilello's** Table Mesa Boys band (which included women), bluegrass. The same guy picking the mandolin also skied more than 200 consecutive months. I learned from information tech **Chen Qingchen** about his experience as a third-year medical student helping during the 1989 Tiananmen Square upheaval in China—and how he returned to his native country on medical missions.

As I listened, I marveled at the stories of NRELians doing outreach across the globe; members of our community worked for the Peace Corps in Nepal, a volunteer in an orphanage at the base of Mount Kilimanjaro, or on community water projects globally. The discoveries were breathtaking. **Imogene Manuelito** in finance smiled as she told me of her journey from Gallup, New Mexico, where she was born a member of the Navajo Nation, part of her mother's *Tódích'íi'nii* (Bitterwater) clan.

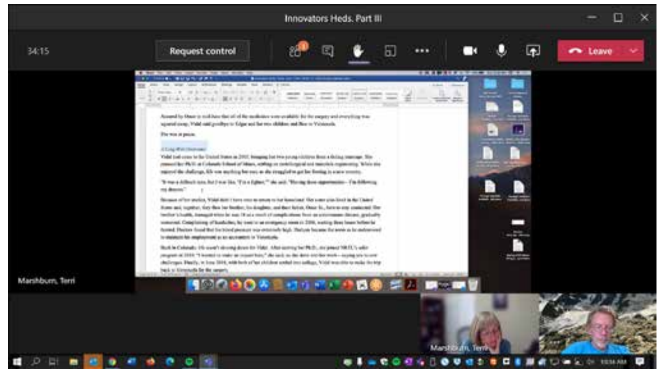
Through it all, I found a richness in the lives of the researchers and support staff who make up what we call the NREL family. I'm humbled by those who shared their personal stories.

Also, I'm fortunate to have so many understanding and talented colleagues in the Communications Office who encouraged my pursuits and helped make this collection of stories possible. They are almost too numerous to name individually, but I want to give a shout out to some: skilled writer **Carol Laurie** who told me about NREL; early editor and science mentor **Kevin Eber**; **Bob Noun**, **Tom Stites**, and **Sarah Sloan**, former Communications Office directors; group managers and supporters **Anne Jones** and **Chris Stewart**; science scribes and editors **Don Gwinner** and **Wayne Hicks**; history buff **Kim Adams**, who connected me with the legendary solar pioneer **Larry "Kaz" Kazmerski**; and photographer **Vern Slocum**. Big props to three editors who have most directly influenced the reporting of the initial stories for our internal publications: **Jennifer Berrie**, **Cassie Frankovich**, and **Sean Marchant**. And **Mike Meshek**, my first editor on an EERE newsletter, who I still refer to humorously as "Copy Boy" for keeping me grounded.

Thanks, too, to **Heather Lammers**, who steered this project; and to Communications Director **Amy Estes**, who resolutely backed this ambitious endeavor. I also want to tip my hat to some guy named **Dennis Schroeder**, who snapped most of the pictures before taking off in late 2021 to become a ski bum. I'm grateful to designers **Jennifer Breen Martinez** and **Joelynn Schroeder** who made the project look spiffy along with **Stacy Buchanan** for some last-minute production organizing. Bravo to **Tina Eichner** and **Ben Chambers**, who each gave the draft manuscript a final set of eyes while juggling their many other duties.

However, I would be especially remiss if I didn't single out two editors and friends who contributed mightily to this book: **Terri Marshburn** and **Michelle Kubik**. Terri, who actually hired me in 2009 and claims, to this day, I was her second-best hire (see "Meshek", Mike), took this fusion of stories and helped them make sense. Michelle, as she does in so many aspects of the Communications Office, simply put her head down to gently improve all aspects of the draft.

I'd also like to express gratitude to members of the NREL Leadership Team, past and present, who allowed me to pester them with questions. The impetus for this book came from our current laboratory director, **Martin Keller**. I met him during an interview his first week at NREL in 2015, only a month after my wife, Liz, and I returned from a bicycle trip to Germany that ended in his hometown of Regensburg. Years later, when I suggested to him that NREL produce a collection of my profiles, he agreed—with a twist.



Terri Marshburn and Ernie Tucker at work via Teams during the pandemic in 2021.

Martin asked that the stories paint a picture of how SERI and NREL people impacted the technologies to which they dedicated their work lives. That's what I've attempted to do here.

Finally, a disclaimer: I never set out to write a definitive history with these profiles. I did strive for accuracy, but any errors or oversimplifications of the technologies, are mine alone. Instead, think of *Clean Energy Innovators* as a snapshot of some of our researchers and staff—their accomplishments mixed in with a bit of their personalities. Truly, I want to again thank everyone who took the time to offer their stories.

To those NRELians I missed, I apologize. There have been more than 20,000 employees since SERI opened in 1977, and I couldn't capture everyone's journey. My hope is that other storytellers continue this tradition and share insights in as many formats as possible. I believe we owe it to the public that supports this institution to know that their tax dollars have helped create something unique and valuable that has enriched us all.

A sincere thanks to my inspiring wife, **Liz Kaufmann**—a published author herself—who first introduced me to SERI in 1980 when she profiled SERI Director **Denis Hayes** for *Rocky Mountain* magazine. Her steady encouragement during the unsettled COVID era allowed me to plow ahead.

Lastly, I want to mention **Dan Furey**, my lifelong friend, who loved the natural beauty of the West and appreciated those fighting to preserve its splendors. Dan read and listened to many of my stories, always saying, "Great story, Ern." Dan died on April 3, 2021, but his spirit continues to lift me.

Let's dedicate this book to all innovators and supporters—past, present, and to come—who are searching for ways to make the world better.

*Ernie Tucker*
*April 2022*

# Table of Contents

**For those of you who know the National Renewable Energy Laboratory (NREL) well or those curious about finding out more, welcome to *Clean Energy Innovators*.**

First, a bit of a qualification. This book isn't intended to be a comprehensive history of the Solar Energy Research Institute and NREL. True, it includes stories about SERI, backed by President Jimmy Carter and which officially opened its doors in Golden, Colorado, on July 5, 1977. The 300-acre site was designated a national laboratory by President George H.W. Bush on September 16, 1991. But the goal is to offer a broad picture based on profiles of NRELians that Ernie Tucker has written since he arrived at the lab in 2009. Although he never intended to chronicle NREL, he said that he was fortunate enough to encounter a number of people who have had a lasting impact on our mission.

We realized, too, that we will not be able to spotlight everyone who had a hand in the development of wind power and solar energy, of biofuels and transportation, and more. Nor can we highlight the many, many individuals who have supported the research in Site Operations, Safety, Legal, Procurement, Finance—and yes, Communications, among others. Yet it is my hope that, by reading this, you'll get an appreciation of how the Clean Energy Innovators in these pages came to NREL and how they furthered our goal of providing reliable clean energy to our country and the world.

This book also comes with a twist: We're trying not only to give readers a sense of these researchers, scientists, and leaders over the years, but tell how they shaped the progress of renewable energy technologies. As such, Ernie has taken parts of published profiles and woven them wherever possible into technology arcs beginning in the 1970s.

One more thing: Because he was around to write about many of us on the present Leadership Team—as well as some notable executives who retired after distinguished careers—we've included a chapter on that group. I hope it serves as an example of where we are as a lab today—and how we're planning to proceed in the coming decades.

Overall, I am proud to give the public a chance to get to know us and our efforts better. For those seeking a deeper dive into our research, I encourage you to visit our website at nrel.gov, where you can read more profiles, by many writers; find references for NREL research; and explore an array of topics about renewable energy and energy efficiency.

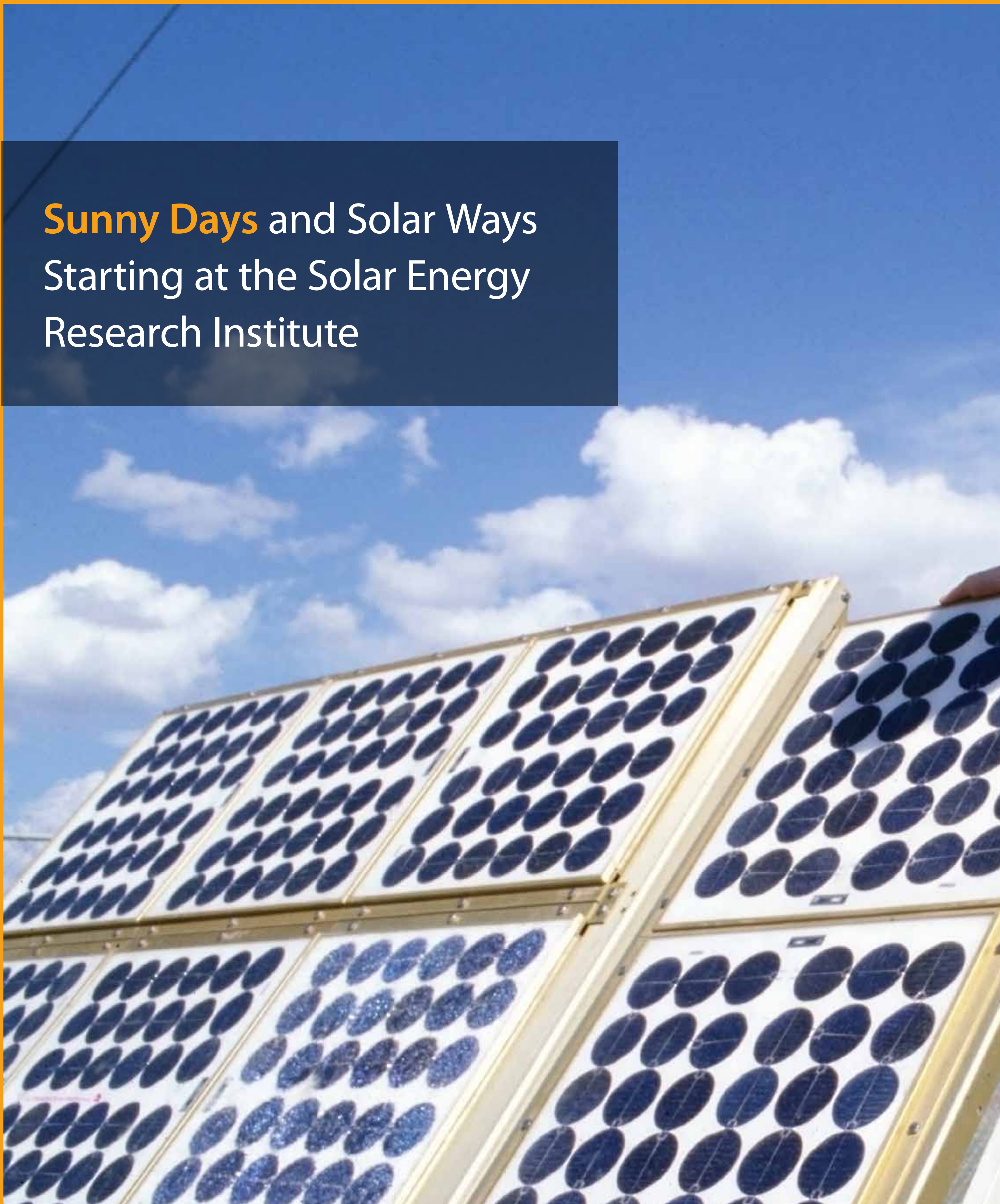
I hope you enjoy this book and come away with a sense of pride in the accomplishments of these individuals and their teams working on behalf of you and the United States.

Thanks to all of our innovators of the past and present who built the foundation for those to come.

*Director Martin Keller*

*Photo by Dennis Schroeder, NREL 39968*

# Sunny Days and Solar Ways Starting at the Solar Energy Research Institute



October 1990 - This SERI remote meteorological tower linked from South Table Mountain to a lab in Building 16 via radio telemetry—a computer in the lab recorded information about solar radiation and surface weather—the system was powered by a PV array. *Photo by Warren Gretz, NREL 00609*

September 1996. SERI's photovoltaic research laboratories used secondary Auger and secondary ion mass spectroscopy to evaluate the compositional qualities of thin-film solar cells. *Photo by Warren Gretz, NREL 00497*

**A suburban Chicago kid who discovered a passion for solar energy research at Notre Dame University. A young mother and dance lover in Washington, D.C., who joined the Solar Energy Research Institute (SERI) as an executive administrator but made the leap to operating a spectroscope during a 40-year career. A Maine forestry major turned photovoltaic (PV) pioneer. A reluctant piano student whose Harvard advisor mentioned a place in Colorado harnessing the sun.**

These are some of the innovators who sought out SERI and, over the course of more than four decades, transformed a nation's hopes for energy independence into a world of startling solar capabilities.

The progress of their journey is found in technical achievements known worldwide. As NREL scientists claimed a world record in spring 2020 with a solar cell registering an efficiency of nearly 50%, this new high mark for the six-junction solar cell shows how far research has come. For example, in 1954, Bell Labs announced the invention of the first practical silicon solar cell, with about 6% efficiency—that is, effectively converting into energy only a fraction of the sunlight striking the device.

"This device really demonstrates the extraordinary potential of multijunction solar cells," said **John Geisz**, a principal scientist in the high-efficiency crystalline photovoltaics group at NREL and lead author of a paper on the record-setting cell. Geisz and his colleagues fabricated a cell with a solar conversion efficiency of 47.1%, measured under concentrated illumination. This means the device is extremely efficient at harnessing the sun—it's a number unthinkable in the early days of SERI.

The NREL success in spring 2020 is part of a long series of achievements, starting when SERI, an upstart U.S. Department of Energy laboratory (DOE), opened on July 5, 1977, in Golden, Colorado. Of course, there were pockets of research scattered across the country—and the world—at that time. Solar energy was like a small club that benefited from the establishment of this new center as word spread from expert to expert.

At first, there was a small pool of visionaries who wanted to tackle the single biggest source of energy. These scientists and their many associates helped solar energy move from a novelty to a major energy source in the United States and across much of the world.

While SERI and NREL have many achievements, one area worth noting is the advancement of III-V cells. These are photovoltaics composed of chemical elements in Group 3 and Group 5 on the periodic table. These high-efficiency multijunction devices use multiple bandgaps, or junctions, that are tuned to absorb a specific region of the solar spectrum to create solar cells. This is one of many branches in the laboratory's solar tree. And woven through it all is a single thread: Kaz. For many years, **Lawrence L. Kazmerski**, better known simply as "Kaz," provided a through-line for SERI's solar research. To understand Kaz is to understand how SERI evolved—creating and recording a legacy of records—and, in his case, colorful sun-themed neckties and scarves.

## Giving Birth to SERI Research

Kaz, who graduated in 1970 from Notre Dame University with a Ph.D., actually began to work on PV in his junior undergraduate year. By the time he was a postdoc, he was working on solar thin films. "The same thing I did my whole career in PV," he said.

From there, Kaz said he "went off as a very naïve faculty member to the University of Maine in Orono." While there, he advanced his research and was invited to participate in a group of about 150 researchers at a workshop on solar energy for terrestrial applications in 1973 at Cherry Hill, New Jersey. Organized by the National Aeronautics and Space Administration (NASA) and the Jet Propulsion Laboratory, it gave the nascent PV industry in Kaz's words, "a big push."

His list of contacts grew, which is how he came to have a technical conversation with SERI's first director, **Paul Rappaport**, in 1979. As Kaz recalled, "I said, 'What's this thing about the Solar Energy Research Institute?' He replied, 'Hey, you want to come out here and talk?'"

Kaz arrived at SERI for interviews when there were about 25 employees. After meeting with Rappaport and others, he was offered a job. Returning to Maine, he accepted the offer, though he had a brief scare.

Weeks later, Kaz and his wife stood in the empty house. "The two kids were with us. At that moment, someone delivered a copy of the Bangor Daily News. I started looking through it and, on page 27, at the bottom of the page was a small headline that said, 'Solar Energy Research Institute to close.'" He laughs now (not so much then). "This is what's happened to this laboratory," he said. "It's always been on a roller coaster, with ups and downs, and downs and ups."

Yet he doesn't regret the move. "The optimism and enthusiasm of the staff are the things that really keep it going," he said, "And SERI-NREL has always been a joint internal effort. The science and engineering base are facilitated and made better by other priority programs in communications and administrative services."

Kaz started as a senior scientist, with SERI badge number 70. "My first job here was really as head of the measurements and characterization part of the laboratory."

President Jimmy Carter (left) visits the Solar Energy Research Institute as Lab Director Paul Rappaport (far right) looks on. *Photo by Dana Moran NREL*

Then, in December 1977, Kaz ordered one of the first major pieces of equipment for the lab—a scanning Auger microprobe that cost about $330,000. "It cost more than all of the furniture, and everything else, at SERI at the time," Kaz laughed. "Nobody knew if there was any money." But the purchase went through. Kaz and SERI were in business.

### Overall it Was a Magical Time

"Analogous to your first love, your first director is the greatest. The operation was new, and everyone was figuring out what to do, and the people were dedicated and empowered. These were really committed people who came to SERI. There was always an uncertainty, but with lots of hopes. And we were building programs, and that was the whole focus. The enthusiasm, the morale, everything was extremely high," Kaz said. "Solar was our future."

Standards at SERI were less buttoned-down than they are for national labs today. When NREL fellow emeritus **Richard (Dick) Ahrenkiel** joined SERI's measurements and characterization branch in 1981, he encountered a stimulating setup under Kaz.

"Kaz was a laid-back manager, and it was a good environment to invent things," Ahrenkiel said. "I asked him, 'What do you want me to do?' Kaz replied, 'Something useful,'" he recalled with a laugh.

A notable contribution of SERI during the 1980s into the 1990s was the concern for staff and professional development. This included establishing collaborations and programs with universities—(e.g., Colorado School of Mines, University of Colorado-Boulder, and Regis College)—to create a talented workforce. But not everyone arrived in a traditional fashion. **Pat Dippo** is a prime example, and her journey was the equal of any questing explorer.

## Pat Dippo—A Female Pioneer Carving Her Own Path

As a teen growing up outside Washington, D.C., Pat Dippo was familiar with the Capitol. She'd even skateboarded at the Pentagon when going to visit her mother. Yet, despite her mom and others working in federal offices, "I said I would never be a secretary or work for the government," she said.

But life has a way of throwing curves.

Years later, when the then-single mom with two young daughters followed her retired parents to Colorado, she needed a job. "I started in 1980 as a temp at SERI," she said. Soon thereafter, Kazmerski asked her to be his administrative assistant. "Kaz was wonderful," she said of the lab icon—"but not always easy to track down. There were times I'd have to call travel agencies to find out where in the world my boss was," she laughed.

After about 13 years as an "admin," she was looking for a change, so she went back to school to earn an associate's degree. "I think the admins are really great," she said. "But after doing the job for so long, I wanted to try something different—though I really didn't want to leave NREL."

Pat Dippo (center) saw plenty while working for Larry "Kaz" Kazmerski (right), including the time Colorado Senator Ben Nighthorse-Campbell (left) visited the laboratory in 1993. *Photo by Warren Gretz, NREL 00778*

Always good with her hands mechanically and equipped with an aptitude for fixing things, Dippo looked around for a new opportunity. "There was an opening in **Keith Emery's** group [doing characterization to give independent efficiency measurements of PV devices and modules], so I started working for him half time." Then, a full-time technician position opened up in Ahrenkiel's group, and she made the transfer. "It was mostly on-the-job training," a leap that launched her 25-year career as a spectroscopy technician in electro-optical characterization.

"If it weren't for the support of Kaz, Dick Arhenkiel, and **Brian Keyes**, I wouldn't have been able to make it. Such a transition would have been nigh unto impossible," she said. "You have to have really good advocates."

Still, this unfamiliar path was plenty challenging. "Definitely a steep learning curve," Dippo recalled—so much so that after a few years, when asked what her performance goals were regarding acquiring new skills, she honestly replied, "I really don't want to learn anything new. I'm full!"

During the bulk of her career, Dippo deployed energy-resolved photoluminescence spectroscopy to measure material quality, determine bandgaps of solid-state materials and devices, identify defects and impurities, and analyze recombination mechanisms. Photoluminescence uses coherent light—that is, a beam of photons that are all at the same frequency—on semiconductor materials that are already electronically active for solar thin film.

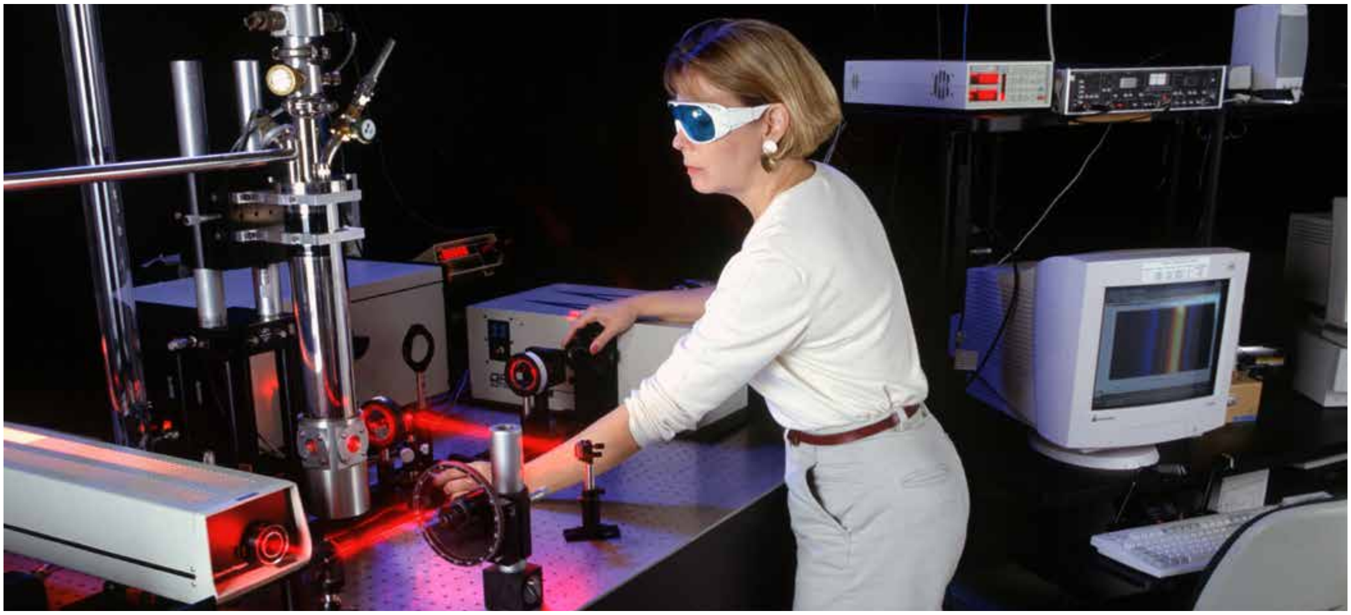
Dippo described it for a layperson: "You shoot light at them. This excites electrons out of their holes, and the electrons go up. Their holes are empty and they're flying around." Then, she explained, when the electron goes back into its hole, it emits a photon. "That tells researchers what the bandgap is." With this information, researchers can determine if there are lower-energy photons that indicate a defect.

"A lot of materials are new recipes for the materials, so we determine bandgaps for the properties and see if there are defects," she said.

For multijunction devices, there can be two bandgaps for the different layers in the solar cell. This gives researchers information about the electronic properties of the material tested. "Much of our testing has to do with what wavelength of the solar spectrum researchers want to use," she said. "The bandgap makes the electrons move along paths in the solar cell to create electricity."

Her impact is tangible.

Over the course of her career, Dippo has co-authored dozens of papers, collaborating with researchers at NREL and across the world. For example, she was a co-author of a *Journal of Applied*



Pat Dippo using energy-resolved photoluminescence spectroscopy in 1999 to measure material quality, determine bandgaps of solid-state materials and devices, and identify defects and impurities. *Photo by Jim Yost, NREL 07100*

*Physics* article titled "Defect-mediated metastability and carrier lifetimes in polycrystalline (Ag,Cu)(In,Ga)Se2 absorber materials." In the article, Dippo and the team described using a combination of optical and electrical measurements to develop a model for defects in a leading thin-film photovoltaic material.

**Pete Sheldon**, center director for Research Operations–Materials and Chemical Science and Technology, agreed that her journey was exceptional. "Pat is one of the rare few who have successfully transitioned from serving as an administrative assistant to a research technician," Sheldon said. "It's a difficult transition to make, but one that she was able to navigate and ultimately thrive in." Sheldon added that in her final position as a senior research laser optics technician she performed photoluminescence measurements on a variety of photovoltaic and semiconductor materials. "Pat has often told me that she has, in her words, the 'best job in the laboratory!'"

Her persistence paid off, and she earned a Staff Award in 1996, a peer-nominated honor given yearly since 1980. Dippo, a true NREL pioneer, ended her 40-plus-year career in July 2020.

She is pleased with her association with NREL. "You get up every day knowing you're not strip mining," she said. "You're trying to make the world a better place." And that approach has helped her make the right steps in a pioneering career.

## Assembling a Talented Team

Speaking of pioneers, Kaz' story has a lot more twists and turns (along with scarves and ties). From 1977 until about 1980, it was a time of building for the laboratory, Kaz said.

"NREL had extremely good scientists," Kaz said. "**Tim Coutts**, **Mark Wanlass**, **Mowafak Al-Jassim**, **Gene Blakeslee**, and **Jerry Olson**, on the early side of things, were accountable for a lot of records with III-V [solar] materials. Later, Jerry Olson and his group carried that on, with **Sarah Kurtz**, to become the technology for space photovoltaics," he said. "Then there was **Rommel Noufi**, this quirky and talented chemist-type person, who carried the copper-indium-selenide stuff up to the next levels."

Kaz said they were fortunate to have **Ted Ciszek**, a world-leading scientist in silicon technology, and **Alex Zunger** who provided theory guidance for experimental directions and understanding of cell performances. The first PV research management came from a scientist "stolen" from Bell Labs, **Sigurd Wagner**, who was a colleague of Kaz's before SERI. Key at this time was Keith Emery—who impressed NASA so much that they transferred their responsibilities for terrestrial standard solar cell efficiency measurements to SERI, an operation that has had high visibility and credibility ever since. Finally, guiding SERI in the national PV program were **Tom Surek** with **John Benner**, **Ed Witt**, **Satyen Deb**, **Don Feucht**, and **Jack Stone**—helping to ensure U.S. leadership in PV research and development.

In Kaz's opinion, it was about getting the best people—and not just in solar, but wind energy, biofuels, and other renewable technologies—that helped distinguish NREL. Kaz himself had plenty to do with the lab's reputation, publishing more than 300 papers during his career on a range of solar technologies—and becoming the first staff member to be elected to the National Academy of Engineering.

"You can see a progression of my career through the work I did at NREL. First, there were solar energy materials, such as cadmium sulfide and copper indium selenide. Then I got interested in the science of surface analysis, looking at instrumentation, developing instrumentation—all the way from the microscale down to the atomic scale, then single atoms, and, finally, returning to devices on photovoltaics," said Kaz.

He cited NREL's leadership in solar panel reliability; that is, "things that affect photovoltaics that people don't really look at as being big stuff. And looking at soiling of modules by dust. In North Africa, the Gulf Region, and India, huge markets that are growing up there now because of energy needs and exceptional solar resources. But these regions are also the ones that have the major concerns for reliability because of environmental aspects." In his words, he said he "spent his entire career looking to increase the efficiency of a solar cell by a tenth or two-tenths of a percent to get on that NREL chart that we started in 1984. Then we found that a system could lose 30% of that in a month due to soiling!"

**Kaz designed silk scarves and ties with images of bright suns, gifts valued by PV communities worldwide.**

Things weren't always smooth. In 1981, there were budget cuts at the federal level. Kaz recalled the lab letting go hundreds of employees in one day. "At the time, that was a huge reduction in force," he said. "However, photovoltaics research at the laboratory continued to grow."

One reason was that SERI had an ardent supporter in Fred Morse, a solar pioneer himself, who at that time was with the DOE. "I protected SERI as if it was my child," Morse said in 2020. "In a sense, it was." As federal funding dried up at the other national laboratories, it continued to feed SERI.

Still, Kaz felt a cloud had passed over the lab. "I think that incident probably gave a lot of other countries a chance to catch up and start moving ahead of us on these solar technologies," he said.

But NREL's spirit prevailed. It became a national laboratory in 1991 under President George H. W. Bush, who was good for photovoltaics, too. By 1997, the program was designated as the National Center for Photovoltaics (NCPV) and it was truly a national center. Of course, other national laboratories, including Sandia National Laboratories, also did groundbreaking solar research. And Kaz acknowledges that.

"They were the two big powers at the time in PV," Kaz said. "NREL did a lot of the work on device development and testing, while Sandia studied on the balance of systems and silicon development."

"It was really a true team of people. They developed the cad-tel area," he said, in collaboration with other labs. The staff had grown, from about 20 people in solar research to perhaps 185 in the NCPV. The first leader? "I was fortunate enough to become the founding director for the National Center for Photovoltaics; I lasted about 10 years in that position," Kaz said.

Among the accomplishments he cited, through 2008, are "probably 40 or 50 records for photovoltaic solar cells," he said. "New technologies from organic photovoltaics came into the portfolio, and there were innovations in reliability and standards."

Even as production of PV cells shifted to Europe and then China and Asia, Kaz applauded the steep reduction in costs. Following his retirement from the lab in 2013 (though he retained an emeritus appointment), he kept busy with projects in India and Brazil. "At that historical Cherry Hill Workshop that initiated the U.S. terrestrial program, we boldly predicted PV at hundreds-of-megawatt levels. We are now approaching cumulative terawatt installations—something that was not fully envisioned in those beginnings."

During his tenure at NREL, there was another mark Kaz left: a series of silk scarves and ties he designed using images of bright suns. Getting a "Kaz-designed" article was a point of pride for many at the lab—and for PV communities worldwide.

Even as he enjoys giving out such mementos, Kaz realizes NREL will be judged on its science. In that realm, he still looks to NREL to provide cutting-edge science and build the future for his grandchildren and their grandchildren. "You have to keep your staff aimed at this long-term goal, to look at our progress, knowing that out of this laboratory, maybe the next Nobel Prize, the first Nobel Prize in photovoltaics will come," he said. He would love to see that. For now, Kaz is proud that "what we at the lab are doing is really laying the groundwork for the future."

## Pete Sheldon Learns Survival Skills from Kaz

If there was any doubt about Kaz's lasting legacy, Pete Sheldon would dispel it in a blink. Sheldon said he learned much from his mentor, Kazmerski, since the two met more than 40 years ago. However, "there are many lessons I wouldn't put in print," Sheldon said with a smile.

But, of those lessons that can be shared publicly, the most important would be "the value of a sense of humor," Sheldon said. "It's a survival skill."

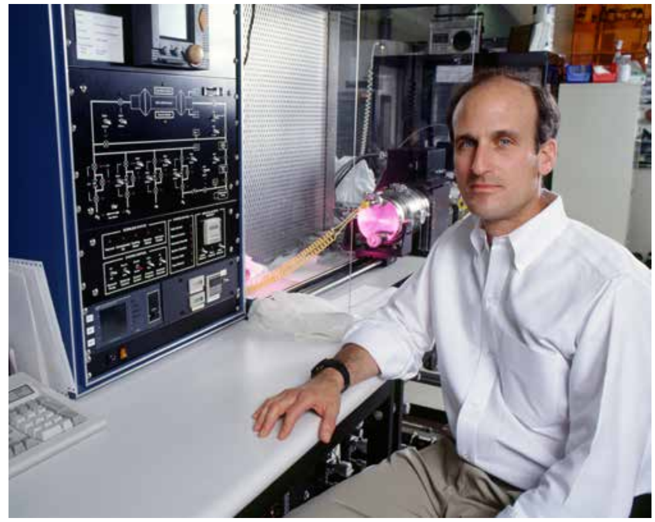
He said he believes others perceive him as a serious guy, but spend any time with the director of research operations for Materials and Chemical Science and Technology (MCST) and you'll hear laughter punctuating many of his statements. Multiply those guffaws through more than 40 years at the laboratory and that's a ton of stress relief. "I remember when I had my 20th anniversary [at the lab] and I thought, 'Who stays in a place 20 years?' And here I am," Sheldon said in 2019 with a grin.

While Sheldon's admirable career earned him, among other things, NREL's Distinguished Innovator of the Year Award, it hasn't been all glory. Kaz is quick to point out that Sheldon has a unique, and possibly infamous, place in SERI's history. "Pete was a student working on emerging solar cell devices— and the SERI staff knew that he would be extremely valuable in initiating important photovoltaic research programs," recalled Kaz. He recounted that Paul Rappaport agreed to hire Sheldon in 1978, from the University of Maine, as the laboratory's initial "co-op student," a title suggested by the staff.

"But this did not last long," Kaz said. "The newly created U.S. Department of Energy did not like the term—so Pete also holds the distinction of being the laboratory's first and last co-op student."

Sheldon returned to the University of Maine to finish his electrical engineering degree. He and Kaz (who was an electrical engineering professor there before joining SERI) had been making and reporting on the first copper indium diselenide (CIS) thin-film solar cell.

It didn't take Sheldon long to find his way back to Colorado, though. The New Jersey native, who was such an avid outdoorsman that he served as a junior guide in the Maine wilderness, loved Colorado and SERI's mission.



Pete Sheldon uses a close-space sublimation reactor in June 1997. The device helps to make high-efficiency (cadmium telluride) (CdTe) devices. *Photo by Warren Gretz, NREL 04834*

On July 9, 1979, he became an associate scientist in SERI's surface analysis group. He still possesses badge number 284, issued the year before.

"We're very fortunate to have Pete at NREL because he's a vital leader contributing to our technical productivity, intellectual property, and operational excellence, as well as planning, program execution, and program/business development," said Associate Laboratory Director **Bill Tumas**. "He does all of this with creativity, patience, and responsiveness, taking a level-headed approach combined with hard work."

### Sold on Thin-Film Solar Cells

Sheldon started college as a forestry major at the University of Maine, but switched after a couple of semesters, concerned about job prospects.

PV research fascinated Sheldon, and SERI seemed like the place to be to pursue a career in the field. The CIS work gave him, he said, "the foundation of what most of my career at NREL is built on."

Early in that career, Sheldon conducted research on III-V materials and devices. Though costly and used so far for things such as specialized military functions, these devices have produced record efficiencies over 45%. They exceed the maximum theoretical efficiency that a single-bandgap solar cell can achieve with nonconcentrated sunlight, which is about 33.5%, primarily because of the broad distribution of solar-emitted photons. This limiting efficiency, known as the Shockley-Queisser limit, arises from the fact that the open-circuit voltage of a solar cell is limited by the bandgap of the absorbing material and photons with energies below the bandgap are not absorbed.

Sheldon described his transition from that area to CadTel research as exciting and impactful. It happened in the early 1990s. A group of researchers was looking at polycrystalline thin film. "The techniques being used to deposit CdTe materials were not very refined or controllable," Sheldon said. "I had the chance to apply some of what I learned exploring epitaxial growth of III-V materials and devices to CdTe thin-film devices."

He helped design and build a series of close-spaced sublimation, or CSS, deposition systems. These new reactors not only provided a cleaner environment, but also included automated process control capabilities that allowed for a more controlled and repeatable deposition process. "You could plug in recipes and do a growth run from start to finish—and monitor and log important deposition parameters," Sheldon said.

> Sheldon's nine U.S. patents have been cited more than 700 times by other patent applicants.

This proved to be successful, and many of these systems are still in use today.

Sheldon said his "sweet spot in the patent space was 1993 to 2000, which I spent with the CadTel program and ended up leading." With that, the group went from a team that wasn't well recognized to one that achieved a world record in CdTe PV device efficiency. "That record lasted for about 10 years before it was eclipsed in 2011," Sheldon said.

His most important intellectual property relates to his contributions on cadmium stannate transparent conducting oxides and zinc stannate buffer layers for CdTe devices. Three of his patents were licensed to First Solar, a company that made foundational advances in the PV market. "It was fun to be involved in a program that was just starting off," Sheldon said. "I was able to contribute and partner with a great team."

His group tried to do things a little differently than others were doing at the time. "To see it take off and have an industrial base with First Solar, which figured out how to manufacture CdTe modules at a grand scale, was gratifying," he said.

Sheldon's nine U.S. patents (spanning a variety of PV-related material systems) have been cited more than 700 times by other patent applicants—by far, the largest such number at the laboratory. "I didn't know that fact until I got the Innovation Award," he said.

## Side Jobs Keep Him Busy

While holding down his managerial and research work, Sheldon found time to tackle some major extracurricular projects over the years. He provided input on the design of NREL's Solar Energy Research Facility, was the technical lead for the design and construction of the Science & Technology Facility (S&TF), and was instrumental in the development and implementation of the S&TF's Process Development Integration Laboratory.

The S&TF process took about six years from concept in 2006 to its conclusion. He suspected it would be a building he'd work in—and it is—though the view from his office has now been blocked by another addition, the Research Support Facility.

These construction projects gave Sheldon a taste of the architectural career he once considered. His love of design is a trait he may have inherited from his mother, who wrote and illustrated children's books. His father was a chemical engineer. "Being involved in the design of several research facilities has been fun," Sheldon said. "It was a little window into the world of architecture."

It certainly has not curbed his rise in the leadership of AVS, an organization formerly known as the American Vacuum Society, that focuses on basic science, technology development, and commercialization of materials, interfaces, and processing.

Sheldon became a fellow in the 5,000-member international organization in 2001. Then, at the urging of colleagues, he ran for—and was elected—president of AVS for 2019. In this role, he oversaw all aspects of the society, including conferences, education, outreach, the publication of four existing journals, and the launch of a new journal, called Quantum Science.

Overall, there have been, in Sheldon's words, "a constant stream of projects to renovate and repurpose." And while Sheldon and Kaz saw the steady march of solar innovation, some of the pioneers made their marks by pushing specific technologies where they'd never been before.

One such person is an innovator of multijunction cells in the mid-1980s. And if the piano had been more to her liking, that era of solar discovery may not have unfolded so smoothly.

# Sarah Kurtz Knows the Power of Math and Music

Despite perceptions that she never stops working—a suspicion spawned by emails sent to her colleagues in the wee hours—Sarah Kurtz knows she cannot survive long on only four hours of sleep a night.

"I can quantify that because I've done the experiment," said Kurtz, who spent 30 years at NREL and was a research fellow with the NCPV. "I can function on five to six hours a night for short stretches, but you don't want to work with me if I'm trying to survive on four hours a night."

But the issue is not about her being well rested. Instead, Kurtz is compelled by the mission. It's been that way since she arrived at SERI as a postdoc in 1985. "The work we're doing is something that makes a difference," she said. So the need to press on is urgent because there's so much to be done to keep renewable energy blossoming."

Ironically, such passion burns in someone who said that "it was an accident that I ended up staying this long at NREL." Kurtz descends from a long line of teachers—and early on, she thought that teaching would be her calling. "I had always wanted to get a job at a university."

Born in a small Indiana town next to South Bend, Kurtz grew up in Defiance, Ohio. Her father taught physics before he became an academic dean at Defiance College, a liberal arts school, and her mother was also a teacher.

As a young girl, she assumed that she would major in math—which she enjoyed—as well as music. "Teaching piano was what I saw the women in that area doing at that time." But reality unfolded differently, in part because Kurtz admits she wasn't the most cooperative piano student.

If music wasn't Kurtz's ticket, numbers were.

She was drawn to the world of green possibilities. "I was born a little too late to be a full-fledged hippie. But I was close," Kurtz said, laughing.

Her interests led her to earn a Ph.D. in chemical physics from Harvard University in 1985. Her advisor there, whose research was funded by SERI, told her that the Colorado lab would be a good fit.

"I think I was pretty lucky," she said.

In 1994, Jerry Olson and Sarah Kurtz look at a solar cell with an efficiency greater than 30%. *Photo by Warren Gretz, NREL 03302*

She started to work with Jerry Olson in 1986, when Olson had just invented a two-junction III-V PV cell using gallium indium phosphide and gallium arsenide that could convert light more efficiently into electricity than previous attempts at using other materials.

"It was a good thing waiting to happen. I walked into that situation and had the opportunity to help that blossom," Kurtz said.

In 2007, Kurtz and Olson were honored by peers for advancing their III-V work on next-generation multijunction cells. The cells are now used on commercial satellites, and NASA selected multijunction solar cells to power some of the Mars rovers based on the NREL team's invention.

## Lessons Learned about Reliability and Unreliability

Kurtz's work with multijunction cells began a string of successes. "I've had a lot of other people give me opportunities—like working with the reliability group at NREL," she said. That transition, in particular, representing a major change in research direction, wasn't easy. But it was eased by a common thread Kurtz finds throughout the lab: "Just the dedication, commitment, sense of vision to improve the world—I think NREL is really a special place," she said.

Before making her move into reliability research in 2007, Kurtz said she surveyed the PV landscape. "I looked at the 40%-efficient cells. I looked at the world and said, for these to be worth anything to anybody, we need to get them into systems," she said. Around that time, she was part of a DOE strategic planning process that addressed the question: To be successful in the future, how does NREL need to change?

"It's like when your baby grows up and goes to college, and you still want to treat him as a 12-year-old. NREL needed to be ready to understand this situation, now that industry had grown up, and a lot of the PV action was out there in industry instead of here. It used to be that all of the action in PV was here at NREL," Kurtz said. She decided to look at reliability issues as manager of the lab's PV Module Reliability Test and Evaluation Group.

"That was a very difficult transition. I didn't have any experience there," she said. But she was able to hire some very talented and experienced scientists to supplement the team."

That included collaborations and partnerships. Kurtz noted that the industry finds international standards far preferable to a formidable array of national standards. (She cofounded and was a leader of the International PV Quality Assurance Task Force, which seeks to do collaborative research as the basis for creating international standards that will be the foundation of the next stage of growth for the PV industry.)

Among the things Kurtz has learned is to be prepared for unexpected outcomes of experiments.

> "As solar energy and prices drop to levels that were previously said to be impossible, our role has to change."
>
> —Sarah Kurtz

That's a theme Kurtz has seen repeated over the years. For example, in a presentation in China, she noted that the Jet Propulsion Laboratory (JPL) conducted a series of experiments years ago with PV modules. At that time, JPL reported—surprisingly—that "the major cause of module failure to date was by gunshot" because round, black or blue cells on a white background made good targets. "That's a good representation of why it's dangerous to try to predict things," she said. "People historically look at something, analyze it, and try to come up with a conclusion. In the end, when you do the work, you find that things come out a little differently than you expected." Gunshots, for example—though in the European Union, another report identified hurled beer bottles as the culprit.

As for changes she's seen, Kurtz paused.

"There are so many to choose from. If you look at the long-term projections for the PV industry, it has grown faster than every long-term projection, largely because of peoples' enthusiasm for solar energy," she said.

While some investors chose solar because they found a lucrative investment, in other cases, questionable business deals moved forward because they were going to create jobs or energy security for a developing country rather than because of being less expensive than the competition.

"Conventional business models often don't match reality, which is that the world is adopting solar. And, as solar grows and prices drop to levels that were previously said to be impossible, our role has to change," she said.

Kurtz has often been recognized for her work. The U.S. Clean Energy Education & Empowerment Initiative gave her a Lifetime Achievement award for her continuing contributions to knowledge about photovoltaics. In 2020, she was elected to the National Academy of Engineering (NAE) for her contributions to the development of high-efficiency solar cells and leadership in solar cell reliability and quality.

And, although she joined the School of Engineering at the University of California, Merced, in 2017, she continues her links with NREL.

She has collaborated with NREL in a project funded by the California Energy Commission to study the value of long-duration storage in support of California's efforts to transition to zero-carbon energy. This new project represents a second major career change for Kurtz, so it will be very challenging, but also a very interesting and important research direction for both her and NREL.

Another leader in solar energy followed a path from exploding things as a boy to the realm of silicon grain properties, expanding the boundaries of efficiency—part of the march of improvements that SERI and NREL contributed.

## Freezing Wood and Splitting Water—Dave Ginley's Ticket to NREL

If Sarah Kurtz found her inspiration in music, the source of **Dave Ginley's** passion for science is another set of sounds. As a 4-year-old, his parents gave him a chemistry set. "Back in those days, chemistry sets were far more interesting than they are nowadays. I got hooked on blowing things up, or at least pyrotechnics, at an early age," he chuckled.

Ginley wasn't trying to set the family home in southeast Denver ablaze with his experiments (twice). He was merely testing a model rocket engine he had built when "things kind of went awry. I had to clean up the basement for the next month" from the fire extinguisher powder he sprayed. Such mishaps didn't deter the future NREL research fellow and chief scientist. "I knew I was going to be a chemist," he said.

In high school, Ginley grew curious about energy and alternative approaches and, as a senior, he took first place in the Colorado/Wyoming Science Fair for his project to freeze-dry wood instead of kiln-drying it to make it stronger (an approach verified at Colorado State University). The prize was his first jet trip a year later to the American Association for the Advancement of Science (AAAS) convention in Dallas, Texas—unaware that years later, in 2014, he would be named an AAAS fellow. It was an experience similar to one he had as an undergraduate student at the Colorado School of Mines, attending a science week at the California Institute of Technology. "You realize you are a part of something bigger and very exciting," he said.

Ginley continued to follow the chemistry path, which eventually led him to the Massachusetts Institute of Technology (MIT), where he earned his Ph.D. in inorganic chemistry, contributing to key papers in the then-nascent field of photoelectrochemical water splitting.

## Knocking on Wood as a Family Business

In part, the reason Ginley tested wood back in high school was that he was familiar with lumber. His father owned a construction company, and Ginley spent most summers working on commercial projects. "It taught me to strive," he said, smiling. "Dad built everything in the house, so I just grew up with tools." At one point, he was a journeyman carpenter—and, to this day, he enjoys woodworking.

Ginley takes a lighthearted approach to life, signaled by a collection of Dilbert cartoon strips taped to his office door.

"It's always been fun. I am extraordinarily fortunate and have done what I dreamed I would do," he said. His early career led him to Sandia National Laboratories when solar research was becoming a priority. It was an era when that laboratory was run by Bell Labs with a can-do philosophy.

Ginley's work in the development of photoelectrochemical cells, polycrystalline solar cells, conductive polymers, semiconductor growth and processing, and advanced sensors is at the forefront of energy research. In a 2012 Sandia Lab News article about the laboratory's historic impact, Ginley was mentioned for his breakthroughs in silicon grain boundary properties in the late 1970s and early 1980s. All the while, SERI was also on the horizon.

## Homecoming to Denver and NREL—and a Passage to India

SERI, then NREL, made several offers to Ginley over the years. "My whole career was a long date with NREL," Ginley said. Finally, in 1992, he decided to return to his roots in Colorado. At NREL, Ginley has surely made his mark. He's been part of the research team investigating what makes perovskite device structures valuable.

The team is looking at how the material, when processed in a liquid solution, has unusual abilities to diffuse photons a long distance, potentially creating a more effective solar cell. Senior Scientist and Group Manager **Phil Parilla**, who has known Ginley since he first came to NREL, said, "Dave is a mover and shaker, moving things forward and shaking things up."

> Dave Ginley said he was merely testing a model rocket engine as a boy when "things kind of went awry."

Among the many honors Ginley has received are four R&D 100 Awards, beginning in 1993 with one for New Etch Technology, an innovative etching process used to develop microelectronic circuits, high-temperature superconductors, and optoelectronic devices. In 2004, he earned NREL's Hubbard Award, given annually to a researcher for high-level research contributions.

Ginley's office is filled to bursting, not only with journals, but with family photos and decorations such as a rubber Yoda doll head, a pink solar-powered baseball cap with a "no smog" emblem, cartons of ramen noodles, and an illustration of a fantasy wizard. There's a plaque for a patent he received in 2012 for "conformal coating of high structured surface"—one of more than 30 patents he holds. The stuffed bookshelves include a few tomes he has either authored or co-edited.

There are also photos of India. Ginley codirected an effort by scientists from the United States and India—the Solar Energy Research Institute for India and the United States (SERIIUS)—to bring low-cost renewable electricity to thousands of villages in India without any electricity as well as to provide reliable electricity to cities. SERIIUS makes Ginley proud. "It's a time in your career

Ke Yi, researcher (left); Dave Ginley, NREL fellow; and Joe Berry, NREL fellow, view a pulse laser that deposits material on a solar cell at NREL's Pulse Laser Deposition Lab. *Photo by Dennis Schroeder, NREL 17598*

when you can potentially make a big difference," he said. "This truly can be transformative."

## The Elemental Formula for a Life

There's still plenty to explore, and he's happy to do it. Ginley is active in the area of the general class of defective transition metal oxides, including high-temperature superconductors and rechargeable lithium battery materials. His most current passion is combining computational materials design with high-throughput experiment and characterization as part of the NREL-led Center for Next Generation of Materials Design, an Energy Frontier Research Center.

He also serves as a mentor in his role as chief experimentalist in the Center for Next Generation of Materials Design. In the center, Ginley works on the development of novel, functional, metastable materials.

Overall, Ginley continues on a life path that started as a curious 4-year-old. "You don't go into science for money—that was never the goal," he said. Ginley's time in science, and at NREL, remain as fascinating as messing with rocket engines as a boy. That big world he's part of has also shrunk, because he knows most of the people in his field worldwide. "I could not have asked for more," he said, simply.

## They Dig Solar Materials

A fundamental part of SERI, then NREL's, progress in solar energy is tied directly to materials research—a field given to the experimental, theoretical, and simulation research on the processing, structure, and properties of materials. Some of NREL's most notable contributions have come in this area. The names of Mowafak Al-Jassim, **Nancy Haegel**, and **Matt Beard** are among those who have advanced the science.

# Mowafak Al-Jassim—A Starry-Eyed Childhood

It didn't take much to lure Mowafak Al-Jassim from the dark winter in Sweden to SERI.

The young materials scientist had accepted a position at a Swedish university in the early 1980s—after years in the English countryside while getting his Ph.D. at Oxford University. But he found it hard to adapt to the short days of Scandinavian winter.

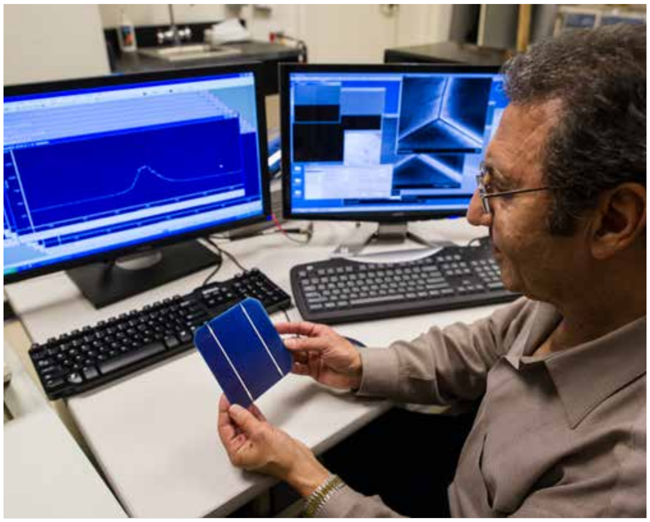
"At about 10 a.m., it was getting less dark. Not bright—less dark. By 2 p.m., it was getting darker again, with a low cloud ceiling, often drizzling." So, when a telephone call came from SERI in 1983, Al-Jassim said, "I thought: Solar energy in a sunny place? Ahh! Now that sounds great."

And for Al-Jassim, an NREL research fellow, this sunny place became the center of a global scientific network.

Al-Jassim was interested in science from a very early age, though neither his mother nor businessman father were so inclined. "When I was in junior high school, while most of my classmates were playing soccer in the summer (that was really the passion there at that time), I would be reading books on circuitry," he said. "I didn't have much money. I would go to used stores and try to buy components for radios. Or buy older radios and dismantle them."

Eventually, the world wasn't big enough to contain his curiosity. "I became obsessed with astronomy in high school," he said. He joined an astronomical association and received charts for constellations as well as instructions on how to build telescopes. "I'd polish chunks of glass to make a concave mirror out of it so that I could assemble what we call a Newtonian, reflecting telescope. Those have big tubes and mirrors at the bottom and at the top," Al-Jassim said.

So, infatuated with the universe, he trotted off to Imperial College in London to study physics, hoping to become an astrophysicist. He planned to get his degree and return to Iraq. However, as part of an on-going struggle between Iran and Iraq, Iran military forces mistook a huge telescope under construction and bombed it, destroying a potential world-class facility in Iraq. His hope faded. "I switched into material science," he said—and began his solar surfing career.



Mowafak Al-Jassim holds a TetraSun PV cell in the Cathodoluminescent Lab in the SERF. NREL performed characterization and reliability measurements on modules manufactured with TetraSun cells and collaborated with the company's technical team to develop modifications to the measured modules. *Photo by Dennis Schroeder, NREL 27974*

In a way, materials science was a return to his earliest love. "I went back to what I was in elementary school. What did I do then? I enjoyed crystals—like many kids, I'd grow salt crystals," he said. So, with the path to a career in astronomy blocked because of the wartime destruction, he pivoted, talking with a professor at Imperial College who was focused on crystal growth. "I started working with him on growing crystals for optical applications but, of course, crystals are used in so many applications," Al-Jassim said, "and not just decorating the body."

That era allowed him to learn a variety of methods for growing crystals. Around that time, growing crystalline thin films was becoming increasingly important for semiconductors. Eventually, Al-Jassim moved into semiconductors, developing electronic devices for optical communications using fiber optics. "Certain wavelengths have minimal absorptions," he said. Light-emitting diodes (LEDs), or laser diodes paired with photodetectors, were in the early stages of development.

"I consider myself a very lucky person. Sometimes by design, sometimes fortuitously, I landed in a technological area that was in its early stages, and I rode the wave," he laughed. "I'm a surfer, but I can hardly swim. I just surf the science waves."

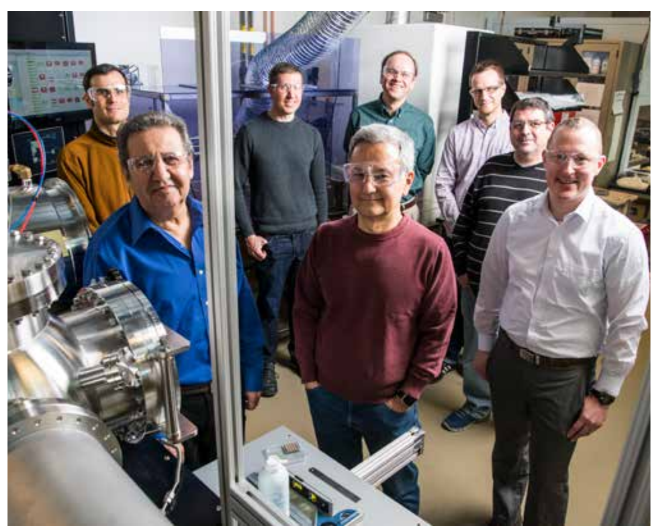
## Al-Jassim Makes SERI His Home Base

Beckoned by A. E. "Gene" Blakeslee, Al-Jassim arrived in Colorado on October 24, 1983, in a new environment that was nonetheless familiar. "It was pretty much the same approach with high-efficiency solar cells as LEDs," Al-Jassim said. There was a well-established research group in the area of high-efficiency III-V solar cells. "That group still exists and they're still doing pioneering, cutting-edge research."

His career impact is clear—more than 500 peer-reviewed papers, two R&D 100 Awards, and countless global connections over decades.

Looking back gives Al-Jassim a sense of amazement. "An overall accomplishment is joining a field in its infancy in the early 1980s. At that time, the deployment of solar energy was at the hundreds- of-kilowatts level. To see it now approaching the terawatt level is enormous progress," he said. He values NREL's unique role. "Being able to be part of both the R&D aspect of the technology and its commercialization is really exciting. A lot of the work we did here was foundational science, but it also connected with the U.S. PV industry."

Al-Jassim added, "It has been a great privilege to be part of that whole value chain—foundational science, all the way to the most applied, and how that affects market penetration and deployment. That is really important, and I am very privileged to be part of that very broad spectrum." He sees this arc as "the core of our mission."



From left: John Moseley, Mowafak Al-Jassim, Joel Duenow, David Albin, Wyatt K. Metzger, Eric Colegrove, John Moseley, Helio Moutinho, and Steve Harvey co-authored the paper, "Overcoming Carrier Concentration Limits in Polycrystalline CdTe Thin Films with In Situ Doping" published in *Scientific Reports*. They are in the Thin Film Deposition Lab at the S&TF in 2019. *Photo by Dennis Schroeder, NREL 55298*

Along the way, Al-Jassim has embraced another aspect of lab life. "I love mentoring and team building. That is, transmittance of the little wisdom I have. I enjoy working with grad students, postdocs, and young scientists," he said. Over the years, he has guided more than 30 such new researchers.

"Mowafak is a great mentor," said **Nick Xiao**, who first worked under him at NREL in 2014. "He provides an excellent platform for my growth from a young student to an independent researcher. I always remember the very first lesson from Al-Jassim: 'You will not be trained to be only a scientist but will also be a salesman that sells science.' It turns out that I learned not only science and technologies from him, but also the art of writing, presentation, and communication. He's very knowledgeable and helpful—his door is always open to me whenever I have questions," said Xiao.

For Al-Jassim, the path goes on. "I'm seeking new challenges," he said. There are extensive collaborations with groups in Europe, Asia, and Australia. Global outreach is what I enjoy and will continue to pursue for years to come."

"Mowafak is a citizen of the world and a great ambassador for NREL and its mission. He and his team have led the way in making NREL a world leader in PV characterization," said Nancy Haegel.

## Nancy Haegel—From Space to Subatomic Exploration

Some NREL pioneers did amazing things before joining the lab. Take Materials Science Center Director Nancy Haegel, a semiconductor pioneer. She was not asleep during the wee hours of August 25, 2003.

Instead, that day Haegel—then a physics professor at the Naval Postgraduate School in Monterey, California—was monitoring NASA's dawn launch of the Space Infrared Telescope Facility, taking place nearly 2,900 miles away at Cape Canaveral Air Force Base in Florida. The $750-million satellite was designed to see the optically invisible universe, piercing through dust and clouds.

Her fingerprints were on some semiconductor light detectors aboard the craft (later renamed the Spitzer Space Telescope). During that time, Haegel also worked on semiconductor materials for solar cells, radiation detectors, and light emitters—all areas that have helped inform her activities at NREL.

"Semiconductors are wonderful things, right?" Haegel said. "They absorb and emit light and can be used in integrated circuits as well as in space astronomy to detect light of all wavelengths."

Haegel had begun researching semiconductors during graduate school at the University of California, Berkeley, years prior. She explored ways to use them to detect far-infrared light. The study was fruitful because semiconductor materials absorb far-infrared wavelengths, a region in the infrared spectrum of light, and can create electrical signals.

For five years after the Spitzer Space Telescope launch, the satellite sent back vital data while drifting in an Earth-trailing orbit around the sun before NASA retired Spitzer in January 2020.

While the Spitzer chapter has ended, Haegel's quest that started with grade-school science projects in Ohio is still going strong.

Born in New Haven, Connecticut, Haegel moved with her family to Ohio as a girl when her accountant father was transferred there. Her mother, a former Latin teacher, looked after their three children.

Although not determined to be a scientist, "I did enjoy the science fair part of school," Haegel said. In high school, she formally encountered physics, aided by an excellent teacher. "I liked the elegance of it," she said. "Physics is a discipline where you try to simplify things to their most fundamental."

The concept resonated with her personality. When she chose to attend Notre Dame University as an undergraduate, she weighed the idea of majoring in engineering or physics, although she also liked history. "It occurred to me that I could read history and enjoy it on the side. It was going to be a little harder to do some of the experimental science as an avocation," she said.

NASA's Spitzer Space Telescope whizzes in front of an infrared view of the Milky Way galaxy plane in this artistic depiction. *Photo illustration from NASA*

Nancy Haegel speaks to NREL postdocs. *Photo by Dennis Schroeder, NREL 61281*

Instead, she chose to major in materials science. Haegel's mentors saw great potential and urged her on. She applied for and won a National Science Foundation (NSF) graduate fellowship. Berkeley became a natural next step, as an institution that collaborated closely with Lawrence Berkeley National Laboratory (LBNL).

And it was then that she learned about NREL. "LBNL was also strong in the semiconductor field, and my thesis advisor had ties to NREL's **Alex Zunger** and the early III-V solar work done here," she said. At the time, she did not envision coming to Colorado. By 1985, she had finished her Ph.D. in materials science and eventually landed a position at the University of California, Los Angeles (UCLA), as an assistant professor of materials science. It began a pattern of teaching—and changing jobs every 8 to 10 years.

From 2003 to 2014, she was at the Naval Postgraduate School. She heard from NREL Associate Laboratory Director for Materials and Chemical Science and Technology Bill Tumas. His message: NREL wanted her.

## Becoming "the Grease" at NREL

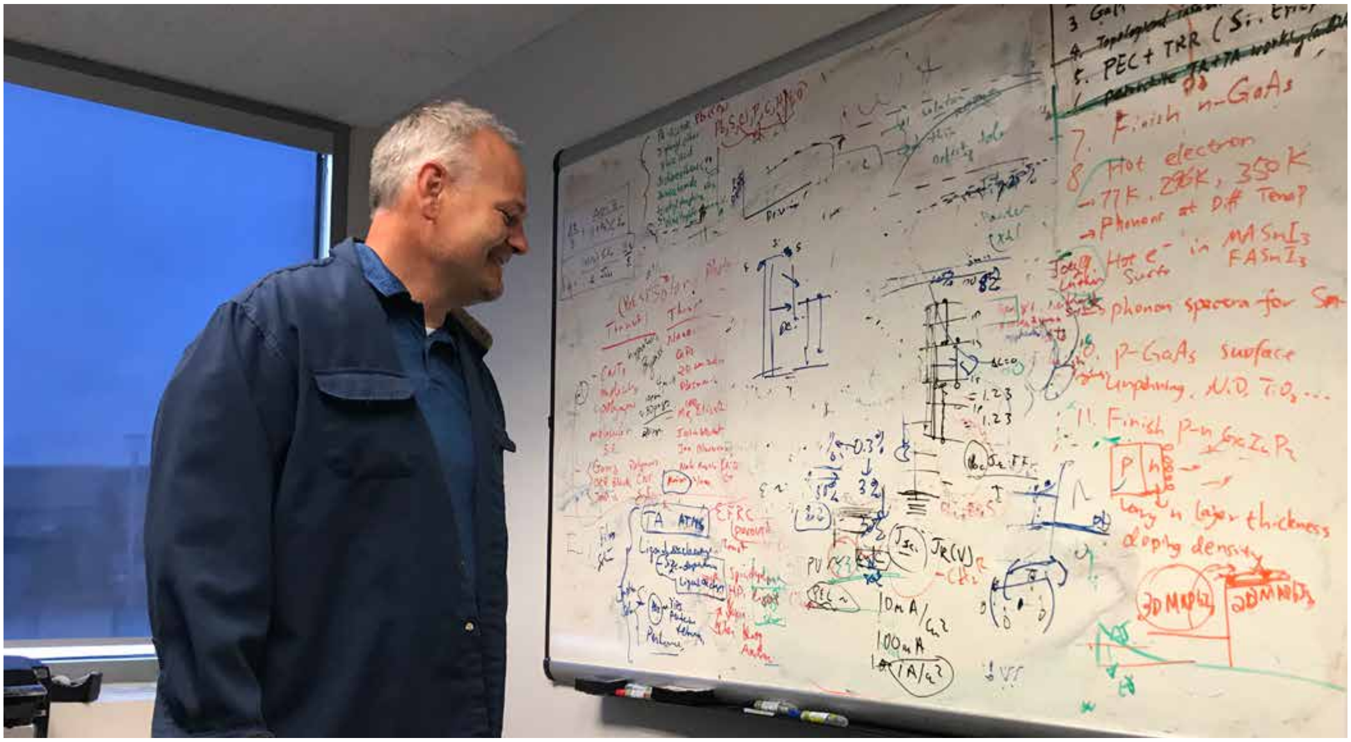
Haegel arrived at NREL in 2014. She's become a leading mentor of younger researchers. "My group is calm, confident, focused, and efficient right now. Much of that is due to her leadership," said NREL Group Manager **Teresa Barnes**. "Nancy supports our principal investigators regularly, understands our challenges, knows our early career scientists, and is genuinely interested in our work," Barnes said. "We know she has our backs, always wants to help us get better, and appreciates our work."

For her part, Haegel is a bit more reserved, especially when referring to mentorship. "I've always seen it as a key part of my vocation and whatever I'm doing, as a faculty member or in management. I don't use the term 'mentor' a lot myself," she explained, because she came of age before talking in those terms was common. "I see it more as being part of the team. If you have a little more experience, or are a little older, then maybe that's the role you take on as a member of the team. Everybody on the team should be trying to help everyone else in whatever way they can."

> When NREL research evolves, Nancy Haegel said she is "willing to get in and push to make sure it happens."

In recognition of her ability to inspire, NREL presented her with the 2019 Van Morriss Award, given annually for a technical or administrative staff member who is a leader in the growth and development of NREL as well as the two contractors that run the laboratory in partnership, MRI Global and Battelle.

Thanking her colleagues at the awards assembly, Haegel quipped, "As a professor, I could always tell people what I did. When people ask what I do here, I'm never quite sure what to tell them. And so, in our center, I think the joke is that I am expensive grease"—pushing to help projects go forward with less friction. She added that Laboratory Director Martin Keller's list of her accomplishments



**Matt Beard's office whiteboard may have seemed a bit messy in 2019, but it contained keys to puzzles he hopes to solve.** *Photo by Ernie Tucker, NREL*

when introducing her for the Van Morriss Award "makes me feel a little better." After the crowd finished laughing, she concluded, "I enjoy every day being expensive grease for such bright, committed people who are doing such great work." Her role, overall, she said is to "make sure people don't get stuck."

Additionally, she has spearheaded two Terawatt Workshops. She led the preparation of two manuscripts that were published in *Science*, summarizing the results of each of the first two workshops. Her reach is not limited to NREL, either.

A number of Haegel's center's activities were called out by the DOE in its fiscal year 2019 assessment, including a *Nature* CdTe paper with collaborators First Solar and DuraMAT, though Haegel credits that work entirely to the teams involved. Additionally, Haegel was named an American Physical Society (APS) Fellow. A University of Iowa professor wrote that "Nancy's service to society and profession, through the APS Committee on the Status of Women in Physics, is just a part of her broader service, research, and pedagogical contributions."

Haegel wants to move ahead, keeping people on track. But things are not finished. "As Bill [Tumas] would say, 'We're not done yet.' We'll hit the terawatt milestone for solar global installation in a couple of years," she said. When NREL research evolves, she will be the grease. "I'm willing to get in and push, grease, to make sure it happens. It's the same with the *Science* papers. Those are a real group effort; papers can have 20 co-authors, but generally someone has to help keep it moving."

Scanning the horizon, Haegel sees that there is plenty of research to go around with global challenges for renewable energy adoption. "It'll take all hands on deck, to use a naval phrase," she said. "I think NREL's impact historically has been quite strong. We want to keep it there and do work that matters for the country and the world."

## Matt Beard—Measuring Leads to Advances

Senior Research Fellow Matt Beard had 4-year-old squiggles on his office whiteboard. It's not that the chemist is sloppy. He was just mildly irritated in 2019.

He and his NREL team had embarked on a complicated synthesis of 5-nanometer-diameter lead sulfide nanostructures. They were trying to create a nanoplatelet of the material. Instead, they made something different—probably because of an impurity in one of the reagents, the mixtures used in chemical analyses.

"We had this mystery compound that we didn't intend to make," Beard said. "So, we were listing all of the reagents on the whiteboard that went into the synthesis, trying to figure out what it could be."

But they failed and finally decided the pursuit was a rabbit hole—not exactly a scientific term, but close enough. "I'm still bugged that we can't solve this," he said. As a result, he hasn't erased the notes, which taunt him daily. "It's one of those things that if all the other projects we're doing die down a little bit, we'll go back," he said.

Despite receiving a 2019 honor from the Royal Society of Chemistry, the oldest chemical society in the world, Beard is not what most people think of when they picture a typical chemist. For starters, Beard doesn't usually make compounds. Instead, he measures processes and develops nanomaterials. Such basic science—looking at the foundations of materials that someday could translate into renewable energy sources—is central to his investigations. And while he is extremely precise, he is also realistic.

"Sometimes you do things by accident and it's great," he said. "Other times …" His voice trailed off.

Beard is used to pondering unknowns.

In his intellectual explorations, he has served as director for the Center for Hybrid Organic Inorganic Semiconductors for Energy (CHOISE), an Energy Frontier Research Center funded by DOE's Office of Science.

He's led about 40 researchers at some 15 institutions to further CHOISE's mission: To accelerate the discovery of, and uncover design rules for, unprecedented control over emergent properties involving electron spin, charge, and light- matter interactions—an 'emerging' field.

"We're trying to develop whole new concepts that can impact all sorts of different energy technologies—not just solar cells," he said. "We're looking at things beyond PV, such as spin-based technologies, or 'spintronics.'"

As Beard explained, "Most devices usually rely on charge—an electron has a negative charge, and a hole has a positive charge. You want to separate charges and move them about." Yet, electrons also have spin, a "magnetic component," he said.

"We want to understand, within our material set, how to control and manipulate spin for different types of applications," Beard said. Light emission is one possible use, but the inquiry is too new to predict what technologies could potentially benefit. "We're still developing the science of this. Ultimately, there could be all sorts of spin-based technologies. [Everything] depends on how you design materials."

If Beard seems on a quest into unexplored places, it may be partly due to an encounter he had with another NREL pioneer in photoelectrochemistry, Senior Research Fellow Emeritus Art Nozik.

## Disciple of an NREL Disrupter

While getting his Ph.D. in physical chemistry at Yale University, Beard was part of a group that developed a new type of ultrafast spectroscopy. In his final year there, Beard attended a presentation by Nozik.

"I was impressed by his message about renewable energy," Beard said. Nozik, for his part, was struck by Beard's innovative skills. After Beard earned his doctorate 15 years ago, Nozik invited him to join NREL as a postdoctoral fellow.

"I've been working with Art since then," Beard said. "He's a fantastic scientist and person."

Nozik returns the praise. "He's quiet and reserved, but rigorous, creative, and productive," he said.

Nozik was an early investigator of quantum dots, and Beard became a strong ally. The two teamed up in an array of research, such as the study of semiconductor nanostructures. A paper they co-authored in 2004 about multiple exciton generation—which involves the generation of more than one electron-hole pair (an exciton) from the absorption of a single packet of light energy (a photon)—has been cited several thousand times.

"I am always impressed with the breadth of knowledge that Matt has," said researcher **Joey Luther**. "He knows more subjects of science in greater depth than nearly anyone else at the laboratory. I assume this is because he is so capable of learning new subjects. I often find out that, in a very short period of time, he has found, read, and absorbed all of the papers pertaining to some different field of research. It's simply amazing."

## A Scientist Thriving at NREL

While Beard is modest about the amount of work he's published, it has had an impact. He, along with Nozik and three other NREL scientists, were named to the 2018 list of Highly Cited International Researchers—something achieved by only 1% of scientists globally in each of the list's categories. He's reserved about the accomplishment.

Keith Emery in 2001 at NREL's outdoor test beds to characterize the performance and reliability of PV cells, modules, and small (1-5) kilowatt) systems. *Photo by Warren Gretz, NREL 10750*

"You want to make an impact, not just be published," he said.

Meanwhile, Beard—who said he probably works too much—said that he remains pleased to be at NREL.

"There's the science and then there's the technology of solar energy," he said. "NREL has done a great job of leading in both of these areas." So far, Beard has played a major role, but also sees many challenges ahead to tackle.

And if things slow down a bit, there's always that messy white board to work on.

## Keith Emery—The Policeman of Solar Achievement

If Beard represents those who have taken deep dives into the subatomic world, others have made sure that the reports of those solar explorers are verified. Nobody in the laboratory's history—and possibly anywhere—attained the stature of **Keith Emery**.

While researchers toiled at improving the efficiency of devices, NREL was also a leader in characterizing those efficiencies, helping set and maintain standards. In that realm, the name Keith Emery is almost synonymous with accuracy. For 36 years, until retirement in 2016, he was the bedrock.

Not surprisingly, in a competitive industry, Emery has been called many things during his career: policeman, the Truth, guru—as well as a few not-so-complimentary names. "I try not to remember some of them," he laughed.

He's a well-known commodity because, beginning with SERI in 1980, Emery has been instrumental in building a world-class testing facility for PV and solar modules. "We started it back in the 1980s, by not giving anybody, internationally, an excuse to simply announce a new efficiency number as 'the best,'" he said.

"We were always available at NREL, or SERI, to give independent efficiency measurements for any PV cell or module technology."

Whether a device comes from a major corporation or the garage of some inspired inventor, Emery's approach to characterization is the same. "They ship it here. We calibrate, following our normal, standard procedures, then send it back to them with our results. Good, bad, or indifferent," he said. "It's not a judgment call about which technology is worthwhile. I view our lab's position as a calibration lab, like the National Institute of Standards and Technology."

His philosophy has remained constant, underpinning an industry that has grown into a multibillion-dollar global powerhouse. "Trust, but verify," as Emery is fond of saying.

And verify he has. "Accredited measurements from Emery's laboratories are considered the gold standard by the U.S. and international PV communities," said his NREL colleague, Pete Sheldon, who became director of Research Operations in Materials and Chemical Science and Technology. "Keith has developed many of the cell and module-performance measurement techniques and methodologies that have been the foundation for the credibility of PV efficiency standards for over a quarter century. He is a world-renowned leader and an icon in the PV community."

Still, at times, even for an icon, there is pushback from people who believe their PV device has a higher efficiency than NREL reports. "We get that about once a year," he said. "What I do is sit down and put all of the information on the table and say 'Here's how we did it. Here are the standards. Let's talk about how you got your numbers and where you are coming from.' I'm happy to go into it at whatever depth they want," he said. "We'll talk about how [their reported efficiency] number was obtained, the procedures, errors, everything else. Usually, after that, they walk away satisfied."

After decades of helping shape PV standards globally, Emery decided it was his time to walk away from daily work—something he's known since beginning his Detroit Free Press paper route as a 9-year-old. In 2016, the guru handed over his responsibilities to his successor and retired.

## A Nerdy Kid Steeped in Science

Emery's father was a professor of dairy science at Michigan State University (MSU), and his mother was a nurse. Their house in Lansing was filled with scientific journals and copies of *Scientific American*. It's probably a good thing.

"I wasn't an athlete. I was a nerdy kid and hung out with nerdy kids," he said. He enjoyed reading about space missions. But just because he wasn't kicking the pigskin doesn't mean he wasn't having fun in his own way.

In a bit of foreshadowing, Emery said he tested things from the time he was around 10 until his midteens. This included checking "my first solar cell in 1967 after I purchased a small silicon cell at the Chicago Museum of Science and Industry during a 7th-grade science club field trip." Curious Emery also was happy "taking apart all of the electronic appliances I could get my hands on and salvaging speakers, magnets, and spare electronic parts," he said. "I made a five-tube 'junk box' amplifier out of old TV set vacuum tubes. I built the audiophile classic RCA 50-watt hi-fi amplifier, but it never worked very well because I used old parts and had a near-zero budget."

Not surprisingly, there were computer-like machines around. Early on, he owned a 4-bit analog binary adding machine—basically a device on which he pushed levers and set pins to add. Next came an analog computer. By the time he was in high school, he was using his school's computer to program in the COBOL language—solving for pi.

Though he knew his dream of becoming an astronaut wasn't likely—in his mind, he's too klutzy—his skills did draw attention. His senior year, he was one of two Michigan high schoolers picked by Bell Labs for a three-day trip to their research labs in Murray Hill, New Jersey. "I was blown away. I saw their lasers," he said, and he also learned about the space-time continuum that exists when a New York cabbie with a $30 tip makes a cross-town trip at rush hour to allow terrified passengers to catch a flight.

Emery was on his way in a hurry.

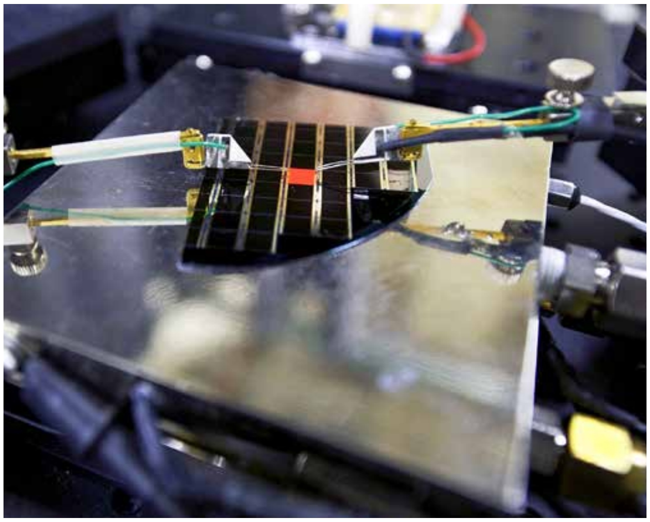
## From Star Wars Lasers to SERI PV

Emery recalled watching a YouTube video on the Strategic Defense Initiative, also known as Star Wars, an antiballistic missile system. As he said, "It reminds me of why I didn't want to work on that. It was fun though." Indeed, at MSU, Emery was in a Ph.D. program in high- energy lasers and computer modeling in support of the initiative. But then the first "Sun Day" occurred May 3, 1978 (organized by a young Denis Hayes, who would later become the second director at SERI—and whom Emery would hear give a stunning farewell speech in 1981). Everything changed.

> "I tend to give people lots of information—way more than they ask for," laughs Keith Emery.

"That's what started piquing me. What kind of career did I want? The Arab oil embargo was happening. The worse the gas shortages became, the better my job prospects looked in renewables," he reasoned. He didn't want a job in the military-industrial complex, so after "convincing" his MSU mentor to let him graduate with a master's degree, he applied to Colorado State University to gain experience in building solar cells. "I'm not that good at making them," he admits. "Maybe one out of 50 devices turns out right. I had to decide: Do I want to fabricate cells or measure them?"

Still, he values the CSU experience. When funding got cut for his program, Emery applied to SERI. "I also interviewed with a major manufacturer that gave me a job offer within a week and a half. It took SERI about five months to get back to me because Human Resources was so backlogged. But I held out because I really wanted to go to SERI. I felt that was the place to be," he said. And for Emery, the new lab was perfect, even if there were no credit cards so that basic supplies, such as resistors, had to be purchased with cash out of pocket.



Solar cells, such as this wafer of multi-crystal silicon produced by CaliSolar, were tested in March 2011 by Keith Emery at NREL's One-Sun Solar Simulator. *Photo by Dennis Schroeder, NREL 18581*

"It was wild," he said. "Very collegial." In those days, there was plenty of low-hanging fruit in the nascent PV industry—a time when many played fast and loose with measurements because there weren't any formal standards. "Efficiency depended on what light source you used; what procedures; even error estimates were all over the map, and typically none of them were done correctly," he said.

A key breakthrough came in 1983 when colleague **Carl Osterwald** derived the current formulation for correcting spectral error, a problem that the PV community had recognized as coming from incorrect spectral irradiance in tests and had tried to come up with an error term for this uncertainty. Once the SERI team had developed a way to correct efficiency measurements in a way that made it less sensitive to measurement errors, anyone could measure relative or normalized parameters.

The drive to become the go-to place for testing became a mission. Emery and his team were meticulous and systematic. "An actual measurement may only take 5 to 10 seconds. But we need information, such as the response versus wavelength, which might take another 30 minutes; and we measure the area, another 30 minutes; and log in the sample. The whole process takes about 8 hours," he said. "Further, all data are reviewed before going to a customer. No data leaves our group that hasn't been reviewed—two people are supposed to look at it and say 'yes, we agree that's a valid number,' whether it's a temperature or efficiency."

The NREL group relies on the ISO-9001 quality system that backs up claims—a part of the international family of quality management systems standards designed to help organizations ensure that they meet the needs of customers and other stakeholders while meeting statutory and regulatory requirements related to a product.

Yet Emery is clear that the industry remains self-policing. "I want it that way. We have no enforcement power here at NREL over the domestic and international community," he said. Over the years, there have been a handful of hyperbolic or even fraudulent claims. Those outliers usually find a chilly reception in the global community when it is revealed that they don't have NREL's stamp of approval.

There are some situations where enthusiastic inventors are merely misguided. For example, there was a high school science teacher in the 1990s who brought in a ballerina cell—a solar cell mounted on a record player, that showed odd fluctuations in measurements. After examining it, Emery patiently showed how the device was merely changing the temperature of the cell—not improving efficiency. Another group submitted a contraption they claimed could easily increase any solar cell's efficiency by 30%. "They were measuring the wrong temperatures and parameters," he said. Once Emery talked to the engineer in charge of the flawed tests, the issue was squared away.

"I don't approach those questions with 'I'm right, you're wrong.' I've never done that," he said. "I can see testing as an opportunity to educate whoever is asking the question. And when someone argues that 'I got 50% efficiency, so how come you're saying it's 30%?' I ask, 'What's the efficiency? How accurate? What errors did you make?'"

"I tend to give people lots of information—way more than they ask for. My mother used to say, 'Ask Keith the time, and he'll tell you how to build a clock.'" Emery's persistence and value became evident. As Kazmerski, his long-time friend and former director of the National Center for Photovoltaics said, "Keith Emery was the best investment the laboratory ever made."

## Characterizing the Future

Emery also lauds the metrology team, and the relationship between that group and his group, which has continually advanced their respective state-of-the-art measurements. "NREL people are a real joy," he said simply.

His legacy is inspiring, and that not only includes numerous awards, but also 387 co-authors from NREL and all over the world. "This outreach through publications is one of the things that I am most proud of at NREL. I have never asked for or expected a publication [credit] in exchange for calibration work," he said.

A measure of his impact is that he was on the Thomson Reuters list of highly cited researchers for several years. "I find this a bit strange because I am not a very good writer, but NREL's editors have worked wonders with my writing over the years."

Emery is also proud of the time he spent transferring knowledge of calibration, as well as the many years he's been an active, eager participant on NREL tours—often starting up machinery to create a dazzling display for visitors.

He said he looks forward to keeping tabs on advances in both solar cells and the ways to test them. "They can be challenging, but we're engineers, and we can figure it out. Otherwise, we're saying there's nowhere in the world they can be tested," he said.

And, in a pinch, Emery can always chip in on a measurement. "I still have the only meter I had way back in 1968, a classic Simpson volt ohm milliamp meter," he said. With that handy, the lab can rest assured that the Truth is never far away.

## Dave Moore—From Jazz to Perovskites

While Emery and his team assured accuracy, others continued to search for the next big avenue to solar efficiency. Nobody followed a more artistic path than **Dave Moore**.

Starting college as a 40-year-old might be considered a disadvantage, but NREL researcher Moore didn't see it that way. Instead, he thinks it gave him an edge, becoming an experienced man who happened to be a freshman at the University of Washington (UW).

"You have the advantage of being memorable. Professors and speakers remember you. There are no real disadvantages," he said. "Well, my memory was not as good—but my organizational skills and focus were better than students half as old," Moore said, with a laugh. "The energy of academia is awesome and contagious. It keeps you young to hang around young people and keep learning."

Although his was a checkered high school academic record prior to stepping on the college campus, he fit right in when he arrived at UW. His decision to pursue chemical engineering was strategic. "I didn't know if I'd be good at school, or continue on to get a Ph.D., or be a scientist. So, I wanted a degree that would be marketable. Chemical engineering is the most marketable engineering degree," he said.

By that point in life, Moore wasn't particularly worried about his ability to learn. He had always been good at figuring things out, but he did so in his own style, which often involved trial and error. "There's an adage: Good decisions come from experience. Experience comes from bad decisions," Moore said.

Indeed, Moore piled up plenty of experience along the way to becoming a researcher. He loaded shipping containers on a dock, drove trucks, worked in a warehouse, managed a Domino's Pizza store, and ran a bar, among other things.

His first big experience, though, was in music.

### Early Days as a Jazzy Guy

Moore grew up in then-gritty Sacramento, California, the youngest of three boys whose single mom was also a student. "We weren't below the poverty line, but we could see it from our house," he said. Moore went to inner-city schools. "I was a horrible student. I thought I'd be a jazz cat and just hang out with Miles Davis, so I didn't care about academics."

> "I wanted to be a mechanic because I figured I'd learn to fix my car and save money."
>
> —Dave Moore

The adage about bad decisions proved true for him. "I wasn't that good at music," he admits. Upon graduation, with a less-than-stellar 2.8 grade point average, Moore found that he needed a job, so he enlisted in the Army. Even though his test scores would have allowed him to become a helicopter pilot, "I wanted to be a mechanic because I figured I'd learn to fix my car and save money," he said. "I didn't figure that I could make enough money to pay someone to fix my car." Instead, Moore was assigned to signal intelligence, working on encrypting and decoding transmissions. "I got some marketable skills out of it."

Eventually, he drew on that foundation to design lighting-control equipment, such as dimming systems, switching, building management, and daylighting controls—turning off lights in response to available daylight—for various functions. "As part of that, I needed to know about energy markets and global energy demand," Moore said. "That's where I first learned about the

NREL researchers Dave Moore, (left) and Obadiah Reid work in 2016 with a perovskite solution in their lab at the SERF. *Photo by Dennis Schroeder, NREL 41460*

energy crisis." And that's when he first heard about NREL, while reading a paper by Art Nozik, now a senior research fellow emeritus.

Nozik's paper noted that the way to penetrate the energy market was for PV to increase in efficiency or be lower in cost—or some combination of both. "I'd never thought about that," Moore said. "I decided to go the science route. My dream job would be to get a Ph.D. and become a staff scientist at NREL."

At the time, he was running a boutique software company. "Then, I got bored," he said. "That's what happens to me. I didn't know what to do. I thought about what I wanted to do next and decided to go to school." After selling the software company he'd started, he took a long cruise in the South Pacific—then began college.

## The Material Path to NREL

Moore was up for the challenge of higher education, egged on by an adviser who suggested he might not be good enough to hang with elite students. Whether intentional or not, the adviser's strategy worked. When he suggested that Moore might not fit into a quantum physics class, or be part of a research group, it fired up Moore. "I'd say, 'I'm not dropping your class. I'm not going anywhere else.'" When he graduated in 2009, Moore had compiled an impressive body of work, including publishing a paper and being part of a patent. Confidently, he headed to Cornell University to pursue his Ph.D. Again, his experience led him down a new path.

Now deeply engaged in perovskite research, Moore initially tackled quantum dots—but things were tough in a lab. "Quantum dots don't like me," he said. "Any scientist who tells you science is completely pragmatic and empirical and fixed in nature is lying to you. There is an art to it. In fact, there is a personality to it. Some science likes you and some science doesn't. I could not get a single experiment to work with quantum dots for a year and a half." Then, in 2012, through Henry Snaith, a pioneer of thin-film perovskite solar cells, Moore learned about this promising solar material. "When I switched over to perovskites, 90% of everything I tried worked. Perovskites just like me better."

Though not new, perovskite materials have been found to provide excellent light absorption, charge-carrier mobilities, and lifetimes, resulting in high device efficiencies with opportunities to realize a low-cost, industry-scalable solar technology.

By the time he completed his Ph.D. in materials science, Moore said he was "the only one on campus looking at perovskites. It was still this outlying technology that people weren't sure yet was going to make it. " To further his study, he did a six-month research fellowship under Snaith at Oxford, before realizing his aspiration to come to NREL on a Director's Fellowship in January 2016.

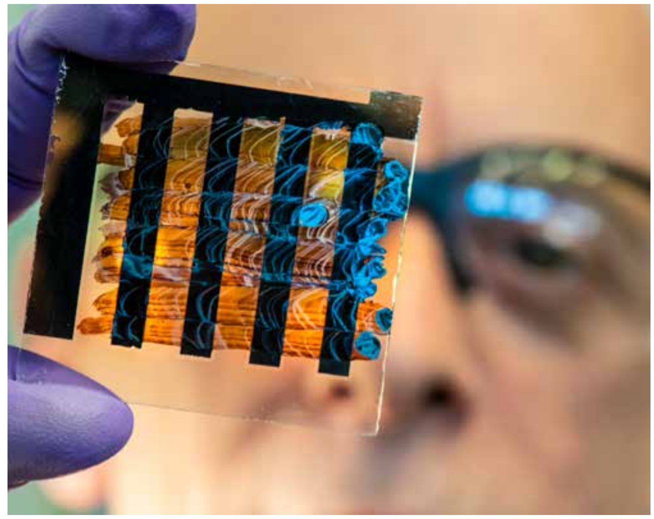
## Perovskites and the Future of PV

Perovskites still like Moore—and he's fond of them, too. He's also fond of NREL's perovskite researchers. "The team here should be an example for any other general research areas. I'm sure there are other groups here that are similar to the perovskite team, but on our team, the distinction between bosses and employees is pretty blurry. Nobody's staking their claim. There's no territorialism," he said.

He notes that the perovskite principal investigators—Joe Barry, Joey Luther, Maikel van Hest, and Kai Zhu—all have graduate students and postdoctoral researchers, and all are part of the effort. Moore said, "Everyone gets in a room and says, 'What's the right thing to do next?' It's pretty cool in that respect."

The progress has been impressive. "Perovskites absorb sunlight very, very strongly. You can make the thinnest layers of any of the many PV technologies, and still absorb light." All of this promise leads to what Moore calls his bold statement: "I believe that perovskite technologies are going to be the future of PV, and probably the future of most optical electronics. Twenty-five years from now, the bulk of the market share being produced for PV will be perovskites. And 50 years from now, silicon will be used for computer chips and basically nothing else because perovskites work for PV, for photodetectors, LEDs, and lasers. It is a really interesting material."

To evangelize the possibilities, Moore created an award-winning demonstration that allows visitors to paint using perovskites—anticipating a time when service providers might roll up to houses



**Moore holds a perovskite ink painted cell. NREL researchers have developed an interdigitated back contact solar cell design in which the metals and transport materials are solution-processed by either ink jet or spray coating.**
*Photo by Dennis Schroeder, NREL 52760*

and turn any surface into a PV, spraying the perovskites on wood or brick. "If I didn't think that, I would be working on whatever material I thought was that material. Right?" he asked.

When Moore is not researching perovskites, he does have his music—playing guitar. He also joined NREL's curling teams. But his commitment to change in the environment is foremost. "I want people to stop burning oil to make electricity," he said. "I want the fastest route to do that. I want to be working on a job that I think will be the most helpful in enabling that kind of solution."

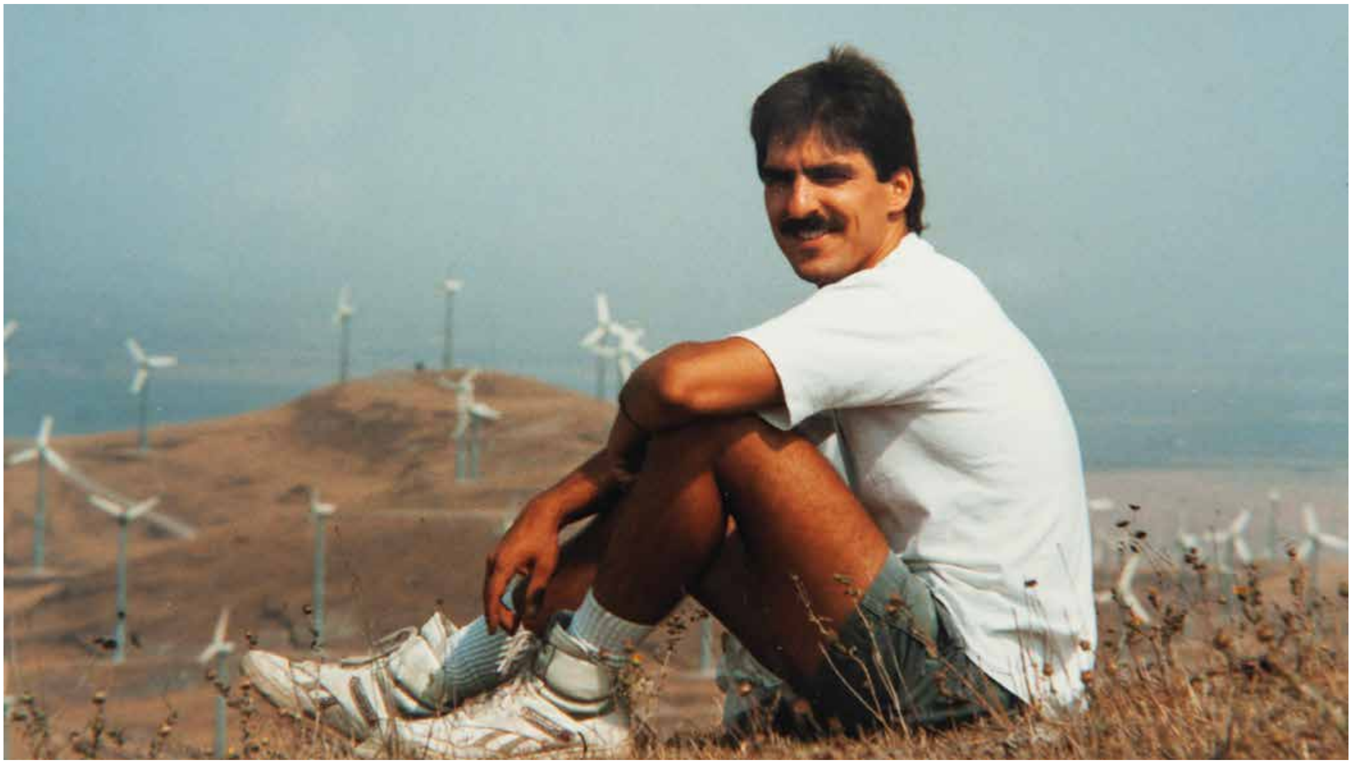
And yes, he did meet Nozik at NREL, one of the many reasons he enjoys the laboratory. Everything continues to click for the collegiate late bloomer. As Moore said, "I work on perovskites because I think that's it. I could be wrong. Until I know I am, I'm going to keep going as if I am right."

These are some of the bright lights who helped SERI and NREL shine.

And all of them—and countless others who are advancing the science of solar energy—believe that the future will only get brighter as solar energy spreads.

# The Wild West of Wind

Tehachapi Pass Wind Farm in California. The 705-megawatt farm is composed of about 5,000 wind turbines. *Photo by David Hicks, NREL 18459*



Walt Musial in 1987 at Altamont Pass at the top of Patterson Pass Road in Northern California. *Photo by Walt Musial, NREL*

*We live in times where remarkable strides are taking place in renewable energy in the United States. In 2020, the U.S. Energy Information Administration reported that renewable energy consumption surpassed coal for the first time in more than 130 years.*

*In particular, progress in wind energy has outstripped what even the most optimistic early backers predicted and, today, the cost of producing wind energy has decreased nearly fourfold since 1980, according to the Electric Power Research Institute—making wind energy the fourth-largest source of electricity generation in the United States.*

*Consider that:*

- *Electricity generation from wind surpassed hydropower for the first time in 2019 and is now the most-used source of renewable energy for electricity generation in the United States on an annual basis.*
- *The United States Wind Turbine Database in the fourth quarter of 2021 included data on 70,808 wind turbines located in 44 states (plus Guam and Puerto Rico). The oldest wind turbines in the dataset were installed prior to 1990. Database administrators caution that the earliest numbers are incomplete because of a lack of reliable data.*
- *The National Wind Technology Center (NWTC), now located on NREL's Flatirons Campus, was built in 1993. Since then, the NWTC has attracted many dedicated scientists, researchers, and supporters.*

*Interesting facts, to be sure.*

*However, behind these facts are real stories about the pioneers and researchers in the field of wind energy; their tales are inextricably woven into the advancement of wind power in the United States. Their paths weren't always obvious and, like the wind itself, there were moments of turbulence and frequent direction changes—in short, it wasn't a career for the faint of heart—and no one with knowledge of this history would call it a breeze.*

## Born at the Right Time for a California Wind Rush

A shadow flashed over **Brian Smith's** shoulder as he walked the 210-acre Maeva Windpark near Palm Springs, California. It was 1984, the year of George Orwell's famed novel and Apple Computer's groundbreaking, dystopian TV commercial. Fresh out of a master's program at the University of Massachusetts–Amherst (UMass), it was Smith's first day on the job as chief engineer, and his boss was showing him the layout of the wind farm, home to more than a hundred windmills, as Smith called them then, located in Southern California's windy San Gorgonio Pass.

A minute later, another silhouette flashed behind him.

Startled, Smith looked up, then turned to his boss who shrugged and said, somewhat too nonchalantly for Smith, "Those are blades flying off the turbines." The 20-foot-long fiberglass projectiles were airborne daggers. "We have a fix in," the boss said, "but for now, the wind turbines have to keep turning to sell power—even though the technology is a little shaky."

Around the same time, **Walt Musial**, a college buddy of Smith's, started work in Northern California, in the Altamont Pass area. He had been hired by **Sandy Butterfield**, another UMass engineering grad (a few years earlier than Smith and Musial) who was now working at Energy Sciences, Inc. (ESI), a company he had cofounded, and one of many newly minted, innovative wind turbine manufacturers.

"We were born at the right time to enter that world," Musial recalled. "As a 25-year-old, I walked into a job at ESI in engineering product support." Smith later switched jobs and ended up at Altamont Pass as well.

All three young men were aware that the U.S. government had opened the fledgling SERI in 1977 as part of a federal response to oil shocks earlier in that decade—but their sights were not aligned with the bright promise of solar energy.

They were drawn to the Wild West of wind power.

In the late 1970s and early 1980s, a combination of federal and state incentives, such as investment tax credits and guaranteed power purchase agreements—along with abundant natural resources in windy passes—created a renewable energy stampede in California. It was as if a sudden rain had brought the desert alive with exotic, pinwheeling gizmos. In 1981, the earliest year for data available from a Lawrence Berkeley National Laboratory survey, 3,202 wind turbines popped up in the Golden State. California's wind power output had been targeted in three primary regions: Altamont Pass (east of San Francisco), Tehachapi Pass (southeast of Bakersfield), and San Gorgonio Pass (east of Los Angeles). The latter, as an example, is a natural wind tunnel, with annual average wind speeds clocked between 15 and 20 miles per hour. In 1982, the California Public Utility Commission set off a "wind rush" by creating the first 30-year Standard Offer Contracts, which required California utilities to make long-term purchases for alternative energy.

Brian Smith in 2014. *Photo by Dennis Schroeder, NREL 28977*

As in its gold rush more than a century before, California's wind rush attracted a colorful cast of characters.

Smith, employed by an underfunded company that, like many, would soon be bankrupt, found himself hanging out with speculative investors. The upstart industry was filled with dreamers who believed in alternative energy; tax scammers, wearing gold chains around their necks, seeking quick scores; and even bikers, handy with wrenches (i.e., motorcyclists who rode Harley-Davidsons long before the bikes were either reliable or trendy). A few unscrupulous characters erected turbines any way possible, sometimes using temporary two-by-four planks as blades in order to have these pretend machines counted by the Internal Revenue Service for tax credits during their annual helicopter flyovers.

According to Smith, performance standards were in their infancy, and design standards simply didn't exist. The terms and labels used inside the industry reflected the speculative nature of it all:

- LOMA—loss-of-machine accidents;
- LOBA—loss-of-blade accidents;
- LORA—loss-of-rotor accidents;
- Runaways—unstoppable wind turbines that spun out of control, often leading to catastrophe.

Still, with incentives covering so much, risk-takers saw a chance to make guaranteed money, even if their machines didn't generate much revenue—or energy.

It's important to note that neither Smith nor Musial considered themselves occupational adrenaline junkies. They weren't actively seeking the thrills that the U.S. wind industry offered at the

Blade washing crews working on ESI-54 wind turbines on Jess Ranch in Altamont Pass, California in 1985. *Photo by Walt Musial, NREL*

time—turbine towers crashing to the ground, untethered blades flying through the air, electrical fixtures throwing out fiery arcs.

"I think we just thought those things were the job," Musial said. "Building better wind turbines meant eliminating these catastrophic failures." But they were aware of the potential. "You don't appreciate how much power there is in wind until you experience runaways," Smith said. All three of them—Smith, Musial, and Butterfield—had left the relative calm of academic life to face the fury of nature firsthand.

To somewhat understand what they were up against, consider this statement from Henrik Stiesdal, retired chief technology officer for Siemens Wind Power: "The weight of the air mass passing through the rotor every one second is more than the weight of the turbine itself. For modern turbines, that's like the weight of a locomotive. That's a lot of power!"

Truly, the 1980s were a time of Darwinian technological development in the wind industry.

"To call it a time of experimentation implies there was some order to the process," said Musial. "There wasn't."

## Testing Unproven Technologies Meant Learning Fast

At the time, technological development meant a test of contrasting designs. For example, heavy, bulky-yet-strong, sturdy wind machines from Denmark were slowly spinning near rows of higher-technology, U.S.-designed machines that borrowed technology from the aerospace industry. No common design process had emerged among the pioneering engineers leading the charge.

With little experience, young engineers had to find solutions to tricky problems—quickly. There had already been fatalities in the wind industry. In one notably gruesome incident, a technician whose harness became tangled was drawn into a slowly turning rotor and crushed to death. In another, a naïve engineer climbed a tower in light winds to stop a slowly rotating turbine with a potential runaway blade, by catching it with his bare hands; he was swept off the tower.

"You learned faster than you could ever learn working at NREL's wind site now," said Musial, "because there were no rules. Most engineers today don't know what a runaway is—but we would see them every day," he said. "We had to figure out how not to get killed by them, or how to stop them so they didn't cause property damage."

Even so, damage was often unavoidable. According to Smith, "If there was a good 'blow' [their term for a high-wind day], you'd come into work and it wasn't a question of, 'Is there a turbine running away?' or 'Is there a turbine on the ground?' It was, 'How many?'" Indeed, an inside joke was that one turbine brand, the Dynergy American Windshark 80, had been dubbed a "sand shark" because the early models tended to leap off the tower onto the desert sands below. The Palm Springs-based company is no longer in business.

Of course, the industry was aware of many of the issues. Some believed the risk of failure was built into a turbine's operation. When the wind blows and turbine blades turn a rotor, that rotation is resisted by a generator, thereby creating electricity through torque. The way to keep the rotor from going too fast is to adjust the current in the generator to create more or less torque, as needed. However, as Musial explained, "If you lose that connection [to the generator], the rotor just goes." Blades speed up, becoming a blur—and nothing good can result.

At the time, preventive safety measures were ineffective, leading technicians to attempt bizarre-sounding stopgaps during emergencies. Smith personally witnessed such solutions, including:

- Lassoing the blades.
- Shooting an arrow with a fishing line through the blades—with the line catching in a moving rotor and pulling a trucker's rope attached to the line that would wrap around the shaft to slow the blades, acting as a friction brake.
- Wedging a 4-by-4-by-8-foot piece of lumber into the mechanism between the rotor shaft and mainframe.

None were textbook solutions.

Technicians even tried using a crossbow, which Smith himself shot on occasion. "Engineers were hands-on in those days," said Smith. "We had to try out what we designed." Improbably, the crossbow method was officially approved by the safety officer of the company that Smith and Musial worked for. "He wrote a memo saying that, while the approach was somewhat sketchy, it was okay to use," Musial recounted. However, the safety officer added one caveat: "Just make sure you don't get your foot tangled up in the rope," Musial laughed.

Nobody in the industry seemed certain about anything.

Some built-in overspeed protections were under-engineered so that, at the moment of truth, a key hinge on a blade tip might fatigue and fail, or a plate wouldn't be adequate to stop a turbine's out-of-control spinning. Smith recalled a Danish wind turbine

**Delivery of the first blade test stand at SERI during Desert Storm 1991. Walt (third from left) noted that his team was being guarded and the guard (left) posed for the picture.** *Photo by Walt Musial, NREL*

reference manual stating, "If a rotor's rotational speed were to reach 10%–20% above normal, the tip brake device would activate." The manual then cautioned against evaluating such automatic overspeed controls ahead of time, issuing a blunt prohibition: "Never try this on your own."

"You were never supposed to test the equipment," Smith said. "If you had an emergency, you prayed."

In those early days, Smith may have said a few supplications himself. Although the 80-kilowatt (kW) wind turbines in California were smaller than today's behemoths—standing only about 80 to 100 feet tall—they still were intimidating. And extremely dangerous. On lattice towers, workers climbed on the outside of a leg, rung by rung, clipping and unclipping a climbing lanyard. The steel could be hot, the winds fierce. Sometimes, Smith climbed 20 or more towers per day for inspections.

Once, Smith got a call from a site where several machines were "running away." He drove to the desert, along with some company executives, who tasked him with replacing the controllers as a means of recapturing the renegade machines.

"The winds were howling," Smith recalled. "I'd have to be upwind of the turbines, hiding behind structures, with new controllers. When the winds lowered, I'd climb up to the control panel, take out the old controller, and put in a new one," he said, hoping that a rotor didn't fly apart as he stood exposed.

Although Musial wasn't at ground zero as often as Smith, he did have some close calls. "I was always afraid of heights when I started," Musial said. "They would say, 'Go up there.' Nobody taught me how to climb a tower or how to use a climbing belt. 'Just go,' they said." During one climb, he was hooked onto a tag line that got snared in a slowly turning rotor—a recipe for disaster. He quickly managed to unclip and avoided being slowly spooled into the rotor.

Still, the upside of joining this frenzy was tremendous.

"Within a year, we were in an elite group of experts," Smith said. Wisdom was hard-earned, with many battle scars, especially because companies were testing unproven technologies.

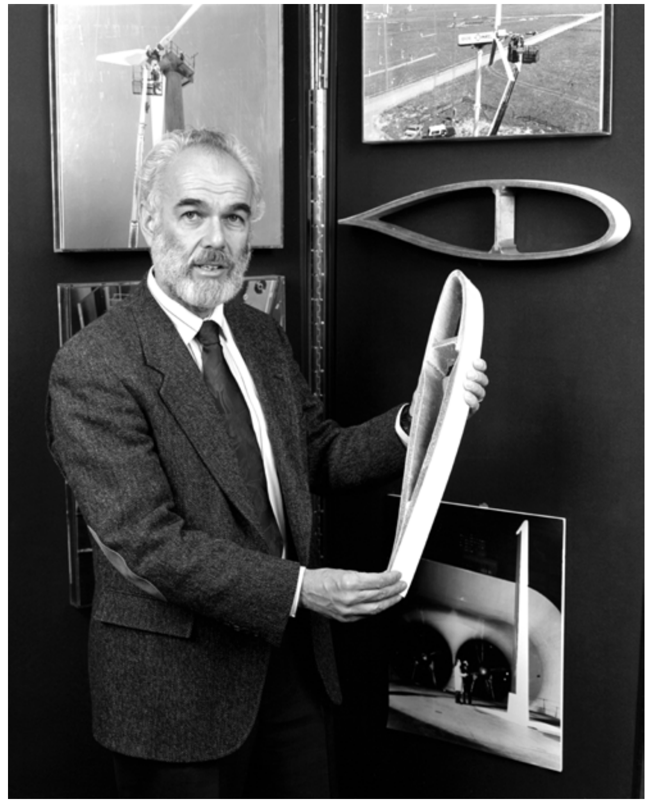
## Butterfield—A Wind Turbine Test-Design Explorer

Sandy Butterfield grew up on the water in Massachusetts and worked around boats. He thought he would end up designing boats, not wind turbines. But Bill Heronemus, a former Navy captain and inventor now known to some as "the father of wind power," had formed a wind group in the engineering department at UMass Amherst in 1972.

"It was unique—far ahead of its time," said Butterfield. "He persuaded me to join the team and take a naval architecture class." As soon as Butterfield walked out of Heronemus' office, he knew he was hooked. Though he never lost interest in sailboats, his career was forever redirected.

The small graduate team was a new family for Butterfield, each member trying out recently acquired engineering skills in an environment where there were no rules other than physics. They had no idea what they didn't know, but they marched on with a can-do attitude, a trait that became the hallmark of most UMass Wind Program graduates. Today, the fingerprints of this program can be traced through much of the wind industry.

Design challenges captured Butterfield. After graduation, he worked as a designer for the Energy Research and Development Administration (ERDA), at the Rocky Flats test site near Boulder, Colorado. He was tasked with the riddle of designing a wind turbine's gearbox, a crucial component that helps convert the power of rotating blades into electricity.



Bob Thresher holding a model of a blade section to show the aerodynamics and structure of a turbine blade in 1995. *Photo by Warren Gretz, NREL, 09818*

"I broke a lot of those early gearboxes," he said. "The learning curve is very steep when you make something. If it doesn't work, you find out immediately, and you're back at the drawing boards. All you know is that what you did before was wrong."

During ERDA's peak of operation, in 1979–1980, researchers were testing as many as 23 small wind turbines of various configurations, including commercially available machines and prototype turbines.

On Butterfield's first day at work, he was to meet a camera crew from a local Denver television station to watch the sun rise behind one of the test turbines. He arrived predawn to find the wind turbine laying on the ground with wind howling over its demolished components. After that, Butterfield would wait to see if a new turbine design would survive its first windstorm. If it wasn't laying on the ground, he would fit the turbine with instruments and begin testing. In those days, most turbines at Rocky Flats didn't pass this initiation test.

By 1980, Butterfield and others testing machines at ERDA decided they could learn from their own—and others'—mistakes to design and build better wind turbines.

He was recruited by a handful of coworkers to cofound and become vice president of engineering for a new company called ESI. His tenure with the startup lasted five years, when the operators sold the company, and had included run-ins with the shady buyer who sent out mafia-like characters to intimidate him into settling a lawsuit over payment for the sale. The tables turned, however, when FBI agents witnessed the goon's intimidation. After that, smart lawyers on both sides quickly settled in favor of ESI's prior owners.

After selling ESI, Butterfield decided to move down the road (literally) to NREL, where he was hired by **Bob Thresher** to run the newly inherited National Aeronautics and Space Administration (NASA) large turbine program. (In the early 1970s, engineering students' work on small wind turbines had been overshadowed by large turbines designed by aerospace giants, such as Boeing, NASA, and General Electric, known as GE). These designs fizzled because, in hindsight, the turbines were too expensive and undone by the riddles of the physics that produce wind. Thresher had been lured to SERI, from a full-professor role at Oregon State University, to help integrate NASA's large machine program that was being phasing out into the SERI wind program.

Thresher became Butterfield's new mentor. He gave Butterfield the task of figuring out how to fix the pitch bearings on NREL's fleet of three wind turbines located in Washington state's Goodnoe Hills, east of Portland, Oregon. When Thresher discovered it would cost more to fix the bearings than he had been allotted for the entire budget of the DOE wind program that year, and that the new bearings would only survive six months of operation, he sold the wind turbines for scrap.

Next, Thresher redirected Butterfield to chase down the long list of technical knowledge gaps he had been confronted with at ESI, starting with why the aerodynamics of wind turbines didn't seem to obey helicopter experience, and why wind turbine gearboxes kept breaking despite all of the experiences of other industries using the same gearboxes. Butterfield recalled that Thresher inspired him with ever-present enthusiasm and inspiration. Butterfield's early work leading aerodynamics testing and research eventually led to deeper understanding of wind turbine aerodynamics, which improved predictive design codes.

While many of the early wind warriors were male, females also shared a major role in advancing the field.

## Sue Hock—A Systems Innovator Who Caught the Wind

When your father is a nuclear physicist, the odds of you turning out to be a scientist are probably pretty high. That was the case for **Sue Hock**, who found math and science a natural fit while growing up in Colorado Springs, Colorado. Couple that with environmental passion, and renewable energy makes sense. Hock recalled that, as a teen, "I had lofty goals like a lot of young people—to help the world reduce pollution. All those good things I wanted to do with my life," she said.

She enrolled at Colorado State University and took Professor Byron Winn's freshman Introduction to Engineering class. "He guided me through engineering," Hock said. "I was so lucky to have him as a mentor and a professor." Though in a distinct minority as a woman, she didn't really notice. "I was used to it," she said.

When she graduated in 1978, her degree was in systems-based engineering and optimization, "which gave me a broad base," she said. She went to Johns Hopkins Applied Physics Laboratory for defense work, which Hock said "was interesting but wasn't what I wanted to do with my life. I was really happy to get a job back at SERI."

In December 1979, she began her more-than-30-year NREL career, which would span a range of technologies and functions—solar energy, economic analysis, wind power, and hydrogen research. She loved them all, she said. But while she defies easy categorization to one technology, wind research does have some memorable highlights, particularly a summer in 1985 spent in Medicine Bow, Wyoming, as a wind test engineer. She paired with Thresher as part of a new wind group.

They were monitoring the innovative WTS-4 turbine prototype, which had an 80-meter rotor diameter and could generate 4 megawatts of energy in a 36-mph wind. Created by a veteran of the American helicopter industry, Glidden Doman, the machine was manufactured by Hamilton Standard Company, a maker of airplane propellers.

"We instrumented it and collected the data on structural load analysis," Hock said. "We recorded it on tape and had to bring the tape back to the lab to read it on the computer."

Thresher recalled spending hours plugging into various sensors on the turbine and running them through a 2-channel spectrum analyzer. The spectrum analyzer allowed them to determine the

SERI Wind Systems Branch staff at the drawing board in the mid-1990's, From left: Palmer Carlin, Bob Thresher, Sue Hock, Darrell Dodge and Peter Tu. *Photo by Warren Gretz, NREL 33077*

energy in any of the turbine's motions or loads and also to look across the spectrum between signals to see how well they were correlated. "It was a great, almost magical, learning experience for me," Thresher said.

Although Hock and others didn't share the truly wild and wooly exploits of Smith and Musial's early California adventures, there were accidents—blades falling off or hitting the towers. Hock said, "We had to wear hard hats, and I remember thinking, 'What good is a hard hat if a blade comes flying at you?'"

"We felt like wind had a lot of promise and what we were doing was a start," she said. "It was a great, fun job. It felt like we made improvements." They also partnered with industry to help make design improvements. At times, NREL researchers would join industry members in a remote Vermont cabin. "We'd all be together for days on end, reviewing designs and making suggestions," she said. "It felt like you were part of a skunkworks" (the term for an autonomous group pursuing a secretive project).

Hock retired in January 2012, remains in touch with NREL friends and said she is "proud of having pushed the needle forward… to where the wind industry is today."

## Musial—Blazing a Trail in Wind Energy

Walt Musial's path to a career in wind energy may have had a kick start. After all, the Massachusetts native's dad was an engineer. But Musial insists he was no prodigy, preferring to build forts outside rather than tinkering with techy gizmos.

"I got out of high school, didn't know what to do, and they said, 'You're good at math and physics. Be an engineer.' So, I said, 'That sounds okay. What's an engineer?'"

He chose UMass Amherst because the engineering program offered Musial various tracks: two basic routes and an energy option.

"They started talking about wind power and solar power. That sounded more interesting than the others," Musial said. "And this was right in the middle of the Carter administration's push to develop alternative energy sources."

Spurred on by friends, Musial discovered his "why" for engineering—wind studies—and, after graduating in 1980, he stayed on to pursue a master's degree. His motives were simple: "It wasn't a good year for getting a job in engineering. And nobody knew what wind energy was in 1980," he said.

## Smith—Prospecting for Gold in the Air

As a kid in upstate New York, Brian Smith was pretty good at taking things apart and skilled at math, so he pursued mechanical engineering. However, after graduating from the University of Vermont (UVM), he took a year off to ponder his future. He knew he couldn't stay at UVM because the graduate program was limited to materials science, focusing on drill bits for oil and gas exploration.

As Smith observed sagely, "I really like materials science, and I love steels, but being a drill-bit expert wasn't my idea of something exciting."

Smith narrowed his next step to finding a graduate program in renewable energy and wind, or ocean/marine energy. It came down to a choice between pioneering programs at UMass Amherst and Oregon State—the latter had a catalog featuring a photograph of a dapper, turtleneck-wearing instructor named, well, Bob Thresher (who would end up at SERI).

Accepted at both schools, Smith made a deeply intuitive decision: UMass Amherst—because he and his wife, Kristin, felt that their Volkswagen Rabbit with a rusty bottom wouldn't make it to Oregon.

### Adventurers Together at UMass

About five years after Butterfield graduated from UMass, Smith and Musial shared an office and worked together as teaching assistants. "It was a small group interested in wind energy. Probably a dozen of us, at any given time," said Musial. Smith joked that his friend's job in a pickle factory during graduate school gave him perspective. "After the pickle business, the wind industry seemed fairly stable," Smith laughed.

Both heard from naysayers about careers in wind energy. "Maybe it was a lack of vision on their part," Musial said, "but I just don't like working on things that have already been figured out." Thus, the pickle industry was a nonstarter.

Smith theorizes his career was due to chance as much as anything. "We were naïve and just stumbled into things," he said. Nevertheless, he loves engineering and didn't give a second thought to following in the footsteps of his businessmen father and brother.

### Smith and Musial Sail to SERI

Smith and Musial survived those early days in the wind industry by moving from company to company, witnessing plenty of mishaps, and learning; always learning. With such industry volatility, they were constantly on the lookout for other, more stable opportunities.

By 1986, Smith and Musial were both working for Kenetech Windpower, Inc., a San Francisco-based manufacturer. Then, SERI started hiring. Smith was familiar with the lab and had heard talk about a possible SERI office opening in Livermore, California. There also was a classified ad for wind personnel, published in a San Francisco newspaper.

Unbeknownst to each other, Smith and Musial applied. Both were offered interviews, and neither told the other until their wives inadvertently outed them on a chartered sailboat cruise on San Francisco Bay. The old buddies, already wind veterans at age 30, came clean. "I guess I lied, "Walt guffawed. Brian copped to having had some insider information he kept to himself.

> "To call it a time of experimentation implies there was some order to the process. There wasn't."
>
> —Walt Musial

As it turned out, the proposed Livermore project fell through when a partner backed out, but Smith was still interested in SERI and told the laboratory that he'd be willing to move to Colorado. "That's where I wanted to be, anyway," he said, having previously lived with a sister in Evergreen, Colorado.

Smith and Musial joined the lab in 1988. Musial arrived first; Smith followed a week later. They would work under the tutelage of Thresher, as had Butterfield, who had already been at SERI for two years.

"Brian and Walt were hired during the years when the SERI wind program was transitioning from researching large megawatt-scale research turbines to doing cooperative research with members of the nascent California wind industry to help solve their problems," said Thresher.

At that time, SERI was looking for engineers who had hands-on experience with the technical problems faced by the industry. "Walt and Brian were a perfect fit," Thresher said. "They had personally dealt with low energy production, gearbox and blade failures, and the ubiquitous runaway turbines of the California wind farms. They were also good at ducking flying blades," he laughed.

Smith and Musial started work in Building 15 in the Denver West office complex that SERI occupied in Golden, Colorado, and they had an immediate impact. They brought all of their safety manuals to help the program get up to speed with best practices in safely controlling speed.

"Runaways are no longer an option, but that time in California is how we learned to build machines that don't run away," Musial said.

Musial's first job was to work with Butterfield on an aerodynamics test he was leading. Once again, these two were solving problems they had faced at ESI, but now with all the resources SERI could offer for testing and analysis.

Ultimately, the aerodynamics research turbine was tested in the NASA Ames 80-foot-by-120-foot wind tunnel. To this date, it remains the largest turbine ever tested in a wind tunnel. The test yielded the greatest body of public domain wind turbine aerodynamics reference-grade data used throughout the world to validate performance prediction models.

## Professor Thresher's Arterial Pressure Leads to Career Opportunity

Not everyone's path started at UMass. For some, the launch into wind energy occurred earlier.

The global oil embargo in 1973 made Thresher angry—a feeling he still hasn't gotten over—but it also helped launch his career in renewable energy.

"I sat in a gas line for five or six hours as many other people did," the NREL research fellow said. "I just didn't see any reason why we should be dependent on other people. It seemed like we should be able to generate our own energy one way or another."

A mechanical engineering professor at Oregon State University at the time, he experienced a kind of a catalyst.

"I vowed that the first opportunity I got, I was going to try to do something about energy independence," he said. He didn't have to wait long. Thresher volunteered on an Oregon State effort to find out if there was enough wind to warrant building what were then called wind machines—rather than current term, turbines—on the coast.

Suddenly, it seemed, after years of neglecting the potential of alternative energy in the United States, interest was being awakened.

One response was that DOE and SERI had both been established in 1977.

Thresher, who had grown up in Tulsa, Oklahoma, at the center of the oil patch, and who had been in high school when the Russians launched Sputnik, used his mechanical engineering degree to work on the Saturn booster for the Project Apollo moon shot. He was ready for the next global challenge. At Oregon State, he had worked with SERI "in a very small piece of the wind program," so when he received an offer from SERI to join, he jumped.

### SERI Rolls Out the Welcome Mat

"I was absolutely insane to come to SERI," Thresher half-joked, calling his decision heart-over-head. Yet, to him, it made sense. "I always claim I'm from the lunatic fringe. I like things that are high risk—they're a lot more fun when you don't quite know what you're doing. That's where I like to work."

He arrived at SERI in 1984, lured by **Bob Noun**, then the group manager for the wind program at SERI. Noun had tried to get Thresher previously, and finally landed him by calling while Thresher was mired grading final exams. Things were uncharted. SERI had been given only a very small piece of the government's wind program to work on. Ideas were percolating. "It was all inventors and people with ideas," Thresher said. That remains constant. "Even today, [devices] are being reinvented. There are all of these great ideas that people come up with," he said.

Thresher felt SERI was the place to be for wind energy research because of the freedom. In those uncertain times, jobs were being consolidated and eliminated. Thresher had to figure out new approaches to the many challenges faced by the laboratory and the wind industry.

"If I did anything, I guess I came in with a fresh look," he said. "We evolved away from the big machines and started working with the embryonic small wind industry [50-, 100-, and 200-kW machines] that was building wind farms in California."

This is when Butterfield was hired. Thresher was co-leading the new SERI Wind Program with Noun. The program had inherited most of DOE's wind research labs because DOE had been downsized during the Reagan administration.

Wind research was picking up in the last quarter of the 20th century.

The National Science Foundation had put some solar and wind teams together in the mid-1970s, and Thresher had played a part. He knew of energy trends and was aware of studies by companies, such as GE and Boeing, indicating that larger-size wind turbines would be more economical. These studies ultimately turned out to be right, but they didn't predict the development path well.

Rather than developing large turbines from the beginning—as NASA, Boeing, and GE had attempted—the industry evolved designs through incremental improvements leading to ever-increasing-in-size turbines that ultimately surpassed the original NASA wind turbine designs but at a fraction of the cost. The test facilities south of Boulder included a main laboratory building dedicated in July 1981 and operated by the Rocky Flats Plant until 1984. At that point, the SERI and Rocky Flats wind energy programs were merged and transferred to SERI. The renovated site was dedicated as the NWTC in 1994.

The problem early on, Thresher recalled, was that researchers were trying to build machines out of aluminum and steel, or even wood and concrete, for the rotors.

"It was very experimental, and we really didn't understand fatigue damage," he said. "We didn't understand the dynamic loads very well, so we had a fair number of machines that had problems." To overcome this, researchers ran early computer simulations using codes borrowed from the helicopter industry. Thresher said those codes continually underestimated the actual loads they were able to measure on the real machines when they built them.

"We helped industry apply the new data to those machines to get better predictions," Thresher said. "Here at SERI, we also worked on atmospheric models, fatigue models, and advanced electric generators."

In the mid-1990s, global investment was picking up, and companies and government programs were starting to push wind energy technologies. Some companies failed; some were bought up. Still, Thresher continued to promote the promise of wind energy by speaking at conferences and collaborating with Europeans through the International Energy Agency (IEA) Wind Energy Agreement.

## The Ups and Downs of Wind Programs

Budgets were tolerable if not extravagant.

According to Thresher, "We started doing new turbine development in the 1990s, with the industry that existed, to develop a new class of turbines. This gave us an advanced turbine program to work on with industry to improve that technology. And it ended up that we started scaling up turbines, making them bigger and bigger."

"There were missteps by people with high hopes who were pushing too hard," Thresher said. What they realized was that, rather than being propellers or helicopter rotors, which operate at very high speeds and benefit from higher aerodynamic lift forces, wind turbines don't benefit from higher lift.

Butterfield's early aerodynamic testing showed dynamic-stall and deep-stall behaviors that were completely different from helicopter behaviors and largely ignored by the early codes. Results like this persuaded researchers to develop their own design tools specifically suited to the wind industry's unique needs.

Researchers at SERI began rethinking the aerodynamic design and tailoring airfoil shapes specifically for wind turbines. This resulted in the development of the S-series airfoils that allowed the forces on the blade to be tailored for better energy capture and benign-stall behavior in high winds. Researchers also had to combat sensitivity to roughness—even incidents such as bug hatches and grit added roughness to the blades, causing them to stall prematurely.

Another big change during that era was refining drivetrains. "Typically, in the 1980s, we would put a simple induction motor on the back of a speeded-up gearbox," said Thresher. "The turbine rotor rotates fairly slowly, and the gearbox changes the revolutions per minute to make it run faster so it's compatible with conventional induction generators." However, these caused problems for utilities in terms of requiring reactive power, he explained.

U.S. Wind Power, which later became Kenetech, developed a variable-speed drive. "What enabled this was a big change in how power could be controlled," said Thresher. "New power electronics changed generator technology so that we could run the turbine at variable speed, which improved the efficiency."

Also, it was great for load control, because when a gust came in, a big gust, the operator could just let the rotor speed increase to absorb the gust energy and it didn't create big loads, he explained.

Thresher said that NREL supported the development of the global wind energy industry by designing custom airfoils just for wind turbines. The SERI S-series airfoils were the first designed for wind energy applications. Researchers also tackled the development of variable-speed technology and advanced multi-input-multi-output control strategies for wind turbines.

"We advanced highly reliable wind turbines by developing innovative, accelerated blade-fatigue testing methods, like blade resonance testing, as well as full-system testing of wind turbine drivetrains, to prove their operating efficiency and durability under operating conditions," Thresher said.

These kinds of design and testing approaches are all standard practice now, but NREL, sponsored by the DOE Wind Energy Technologies Office, developed, perfected, then transferred them to the wind energy industry.

## The Trials of Perfecting a Wind Machine

In the early 1990s, the fledgling U.S. wind industry was struggling to find other ways to keep costs down and to ensure that the energy it was then developing at $0.12/kilowatt-hour (kWh) could compete with the average $0.04–$0.06/kWh generated by fossil fuels. A major expense in those early wind machines was for repair and maintenance of gearboxes, along with supporting components such as shafts, generators, brakes, and the lubrication system. This was a concern because the gearbox can make up about 25% of a typical turbine's price tag.

The industry was facing two major challenges: rotor aerodynamics and gearbox reliability.

In 1992, while at NREL, Butterfield developed an aerodynamic experiment that Musial also worked on.

"We were able to describe the fundamental physics of wind turbine stall behavior at SERI, which changed the way all turbines were designed around 1992," Butterfield said. "It greatly reduced uncertainty in predicting performance and failure rates."

These first aerodynamic experiments were like those carried out on helicopters with hundreds of pressure measurements on a blade rotating on the turbine in the field. With detailed mapping of pressures acting on the blade, aerodynamics experts could begin to understand where the gap between traditional aerodynamic theory and wind turbine aerodynamics was failing.

Early results clearly showed that dynamic stall was occurring over much of the blade. This is a dynamic effect that helicopters experience, but one that wind turbine designers had ignored. Also, wind turbines commonly experienced deep stall but none of the expected load relief that typically results from stall in other aviation applications. They were a different beast.

> "We advanced highly reliable wind turbines by developing innovative, accelerated blade-fatigue testing methods."
>
> —Bob Thresher

Both of these early discoveries were leading to underprediction of dynamic loads. Also, researchers discovered that the turbulence hitting the rotor was much greater than expected. Combine these effects of under accounting for turbulence, misunderstanding deep stall, and ignoring dynamic stall and load predictions, and, in Butterfield's words, "you woefully underpredict dynamic loads and incur a lot of fatigue failures."

(Danish designs were compensating for these deficiencies in engineering insight by heaping huge safety factors on their designs. This explains why their early designs were so heavy, but U.S. designs suffered from underpredicting loads and, hence, failed from misunderstood fatigue loads—that is, the continuous loading of a material with some force until it experiences a crack.)

Meanwhile, gearbox reliability was costing the industry significant downtime and financial losses. In the 1980s and 1990s, wind turbines were experiencing 100% failure of gearboxes after just a few years of operation, requiring costly repairs. Operators sued turbine manufacturers, who sued gearbox suppliers. The largest German gearbox supplier was almost forced out of business. The causes were not at all clear—only the frustration was.

Gear suppliers used the best practices they had used in other successful applications. Bearing manufacturers did the same. Oil suppliers were scratching their heads. Some gearbox suppliers insisted that wind turbine designers provided inaccurate loads to design to.

Clearly, all of the stakeholders were missing important technical issues in the design process, and no wind-turbine-specific gearbox design standards existed to help them out.

Once again, the wind industry had to solve its own problems without help from long-standing successful industries. Nor was there a single, smoking-gun issue or one guilty supplier that caused the gearbox failures. There were a number of issues unique to wind turbines that were conspiring to cause early failures, but what were they?

There were no clear answers.

What was obvious was that all of the stakeholders had pieces of the answer, and they would have to collaborate to get the whole solution. Furthermore, it was apparent that missing materials-science answers in gearing materials and bearing materials were baffling gear and tribology experts (those who study friction, wear, lubrication, and the design of bearings). Why were bearings failing from surface fatigue cracks with white etch crack, a microscopic metal fatigue crack that only the most esoteric researchers knew about? Reliability experts were screaming for DOE to assist the industry with answers—Musial and Smith among them.

Butterfield agreed to take up the mantle and head a program to get answers. He called it the Gearbox Reliability Collaborative (GRC) to recognize that no single stakeholder was at fault and that answers would depend on industry collaboration along with DOE-funded research.

Butterfield rallied DOE support for the GRC, which allowed companies to compare their data with each other as well as to analyses, dynamometer testing, and field testing on a gearbox that had no financial significance to any of the stakeholders. It was a test of the full design process with a microscopic lens searching for gaps in the industry's understanding at each step.

Questions piled upon questions. It took persistence, or stubbornness, to keep after answers.

Was the design analysis failing? Could stakeholders use dynamometer testing (employing a device used to test performance) to reveal these gaps? If not, why not? Could they observe the same gear stresses in an operating turbine in the field? Where were the gaps?

NREL was in a unique position to be an objective leader among stakeholders with significant investments at stake. Through the GRC, NREL invited all stakeholders to observe the DOE-funded experiments as long as they contributed by offering their own experience. Butterfield arranged workshops with the world's leading experts on bearings, gearing, lubrication, and tribology.

Operators welcomed the chance to offer their own experience in trade for exposure to the unvarnished technical experience from core domain experts. Some of the discoveries were easily corrected and led to early improvements in reliability, such as lubrication cleanliness, condition monitoring techniques, and appropriate bearing selections.

But others, such as white etch cracking, required electron microscopes and sophisticated test techniques that only government research labs had available—as well as the experience to use such techniques to solve esoteric problems. In some cases, new testing techniques needed to be invented to duplicate the loads to which wind turbine bearings were being subjected. These efforts took years to bear fruit, but bear fruit they did.

Many U.S. and international stakeholders participate in the GRC; it has helped researchers and industry understand and solve numerous gearbox and drivetrain problems. The group has also led to an international standard for wind turbine gearboxes that continues to improve as more insight is gained by the ongoing materials research conducted under the GRC program.

As part of this evolution, NREL researchers enabled turbine builders to expand their options from single-speed to variable-speed wind turbines, taking advantage of lower wind conditions. As with previous innovations—such as the NREL airfoil patents, which were licensed by GE and others—this variable-speed innovation allowed GE to continue refining its 1.5-MW, 3-blade, upwind, horizontal-axis wind turbines and build global market share.

Incremental improvements were combined so that GE and others can now deliver land-based wind power at between $0.04 and $0.08/kWh—more than competitive with other fuels. And, even as GE expands and deploys its next-generation 2.5-MW installations, it turns to NREL. In 2009, GE installed a 1.5-MW turbine at the NWTC to continue this research.

## A Passion for Work, Wind, and Seawater

While Thresher doesn't dwell on it, he has faced adversity during his career. In the 1990s, while director of the NWTC, a job he held from 1994–2008, he was diagnosed with leukemia. Among the treatments he received was experimental stem-cell therapy. Due to a compromised immune system, he contracted Guillain-Barre syndrome, which left him with some peripheral nerve damage. "I walk like I got wooden legs or something. And I don't run," he said.

Through it all, Thresher tried to stay engaged. "I missed being at work and really wanted to be there," he said. In 2001, the American Wind Energy Association awarded Thresher a Lifetime Achievement Award.

Also during this time, Thresher, Musial, and others started laying the groundwork for support of ocean energy—offshore wind, wave, and tidal power—as that industry slowly gained traction. Shortly after 2000, Thresher and a DOE program manager traveled to Europe to look at offshore wind turbines.

"I was interested because it was a new technology. Nobody had these kinds of devices that were fully commercial at that time—and it's still true," Thresher said. "We went over there to talk about wave and tidal power. Tidal power is basically a wind turbine, but the fluid is different." Obviously, there are some differences: the density is 800 times greater, current velocity is lower—but starting with a wind turbine as the basis, experts can get to tidal technologies pretty quickly. Thresher described ocean energy devices as "underwater wind turbines."

Eventually, the message got through and, in response to a DOE solicitation in which Thresher and Musial highlighted NWTC assets, NREL received funds in 2008 to conduct research on ocean energy and offshore wind—one of the few national laboratories to receive such funding.

The team has grown to about 30 researchers. A major contribution has been the Wave Energy Converter SIMulator (WEC- Sim), the code for which was developed in collaboration with Sandia National Laboratories and funded by DOE's Water Power Technologies Office.

Thresher is optimistic about wave and tidal power as future technologies. "I suspect these have the potential to really contribute in locations such as coastal areas. Early markets are likely to be remote areas: island communities, Alaska, maybe some rivers. Now, it is high cost," he said.

## Which Direction Will the Wind Industry Blow?

Thresher admitted to some frustration with the pace of progress in the industry.

"There are bright spots," he noted. For example, there has been dramatic progress in terms of rotor control and blade size. "I never thought we would get to turbines that were over 1 or 2 MW," he said. "And now we're talking about 5 MW for land-based applications and 15 MW for offshore—very large rotors. The

**Research Fellow Robert Thresher in 2015.** *Photo by Dennis Schroeder, NREL 35213*

surprise has been that we can actually manage the loads and build reliable equipment at that kind of a scale."

He understands the challenges inherent with large, utility-scale turbines, including transporting blades that are as long as football fields using conventional truck trailers and railroad cars. He sees innovations, such as blade segmentation, as possibilities. Researchers are exploring ways to manufacture blades in two parts, then either glue or bolt them together in the field. Another option is to fabricate the entire blade on site in a movable blade plant possibly using 3D printing for some of the blade subcomponents.

As the landscape has changed, so have approaches at the laboratory. "The issue now in research is not about the individual turbine," Thresher said. "It's about running a wind facility or a wind farm as an aggregate 'wind power plant' (the new term for wind farms), and the way the turbine groups interact. The turbines in front block the ones behind and reduce the wind speed of the latter—in effect, reducing the power generation of the entire wind plant."

Thresher believes NREL is still the place where these challenges will be solved. "I think the absolutely great thing about NREL is the people. They're dedicated to a certain purpose, and it's not about

NREL wind experts in 2013 included (L-R), Kevin Standish, Sandy Butterfield, Tom Fischetti, Tom Darin, Terry Oliver, Jim Walker, Pat Wood and Amir Mikhail at what was then called the National Wind Technology Center (NWTC). *Photo by Dennis Schroeder, NREL 28246*

making money," he said. "It's basically about changing the world, changing the way we get energy, and making it different and not as invasive on the planet. And you get a lot of enthusiasm around that."

Young researchers inspire him. "They want to contribute to improving the planet and the generations that come next," Thresher said. "And, by and large, everybody that's here has some kind of motivation like that, so you get a lot of energy."

He likes to recite this motto: "I teach them old tricks, and they teach me new tricks." Butterfield has heard Thresher say that "technology managers need to be shrinks first and managers second." Butterfield also said, "This exemplifies Bob's secret to success as a mentor for so many in NREL's wind program. Bob has been a people person first and a manager second."

Thresher's focus remains on the laboratory, which he thinks is crucial. "It's a great investment in the future. That's exactly what these young folks want," Thresher said. "That's why they're here. People at NREL are like-minded and determined. The intent is to do something new, different, that's going to help the planet. What a great idea!"

Butterfield has stayed active in wind, helping the IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications (IECRE System), which sets global standards and certification rules for equipment involved in the production of renewable energy. As he explained, wind turbine makers dominated the business. Now, IECRE includes them, yet expands the conversation to all turbine stakeholders, including grid operators and utility owners, all of whom share the record of any failures. "The group allows an ongoing dialog, giving all a voice in forming certification rules while providing a transparent certification process that is recognized throughout the world," Butterfield said.

Heavy seas engulf the 30-MW Block Island Wind Farm in October 2016. The first U.S. offshore wind farm came online several months later, located 3.8 miles from Block Island, Rhode Island in the Atlantic Ocean. *Photo by Dennis Schroeder, NREL 40481*

## The Wild West of Wind Gets Tamed

Smith began as a test engineer for advanced airfoil blades, then moved up to project leader for advanced wind technology development and field verification partnerships with industry. He served as NREL's laboratory program manager for Wind and Water Power Technologies from 2002–2014 and even as acting NWTC director for a time. In his current role as laboratory program manager for Wind Energy Technologies, he focuses on portfolio diversification, capability enhancement, and strategy.

Musial, who holds two patents and has authored more than 100 publications, veered into offshore wind when Thresher suggested in the early 2000s that NREL could make an impact in this novel offshoot. It was a natural fit and, in 2003, Musial initiated the laboratory's offshore wind energy research program. Over time, he has become a go-to expert in the field and is frequently quoted in media and asked to serve on panels.

For example, in a podcast about deep sea turbines, Musial offered this assessment: "It's a big deal because floating technology is just starting to come around, so it's really the next phase of wind energy development and may be the end game for wind energy."

The fact that a guy who once described himself as "not smart enough" to have foreseen the future of wind energy is now participating in the industry's evolution may seem amazing. Musial is less impressed with his tale. He said he is merely enjoying the challenge of figuring out something new. "I would never have anticipated the impact we could have. What gets me up and into work each day now is to see renewable energy become the world's primary source of energy in my lifetime," he said.

And Smith, who starts each day when the alarm clock rings at 5 a.m., feels that after three decades, "you can find a lot of happiness" at NREL. And speaking like the guru he's been called, he outlined his path to energy enlightenment lyrically: "You gotta' let life flow. Make adjustments. Like floatin' down a river—skiin' through the trees—workin' at NREL."

Now, at some of those land sites where 80-foot towers were first erected, larger machines—up to 80 and 100 meters—have replaced the older ones. The NWTC has evolved into the Flatirons Campus, a systems engineering approach that integrates different renewable energy technologies onto the grid; it's called integrated energy systems at scale. The old days of a lone mobile home, once the only structure on site, are gone.

## The Industry Matures as New Frontier Await

NREL's wind pioneers, having ducked blades and outrun scammers, see a bright future. Though more mature, the wind industry still faces challenges. The next generation will further seek to optimize power output across the entirety of a wind plant instead of at the individual turbine level.

In a nutshell, researchers are focusing on three areas:

- Validating multiple wind technologies at scale to achieve an integrated energy system that can meet the complex energy challenges of the future
- Developing taller wind turbines with larger rotors to capture greater wind resources at higher elevations
- Lowering the levelized cost of wind energy.

Of course, researchers want to develop innovations for offshore wind, such as floating platforms, scaling solutions for larger offshore designs, advanced turbine controls, and lightweight drivetrains.

NREL's wind energy veterans still feel the excitement they did 30 years ago. And, if you inquire, they'll say they are ready for the next 30 years—while the newest cadre, perhaps deprived of the Wild West experience, still has frontiers to conquer.

## New Sheriffs Ride into Town

NREL wind researchers have followed various jet streams to arrive at NREL. Here are some recent stories from those making a difference in transforming wind technology.

Each of them—NREL fellow **Paul Veers**, former NREL engineer **Katherine Dykes**, engineer **Ismael Mendoza**, as well as current researchers **Amy Robertson** and **Jen King**—spent significant time at DOE's National Wind Technology Center on NREL's Flatirons Campus. Like thousands of others, they helped further the progress of the wind industry with a view toward the future.

For Veers, the state of the wind energy industry is filled with challenges. The growing scale and deployment expansion will push the technology into areas of both scientific and engineering uncertainty.

Veers was the lead author of a 2019 *Science* article analyzing three challenges to wind energy potential. It followed a 2017 event at NREL that convened more than 70 wind experts, representing 15 countries, to discuss a future electricity system where wind could serve the global demand for clean energy.

"People think that because wind turbines have worked for decades there's no room for improvement. And yet, there's so much more to be done," Veers said. "We distilled all the information into three big things connected to wind energy—the atmosphere, the machine, and the wind plant system, which includes the grid."

The article, co-authored by Dykes and several others, focused on three interdependent, cross-disciplinary grand challenges:

- The need for a deeper understanding of the physics of atmospheric flow in the critical zone of plant operation
- The science and engineering of the largest, dynamic, rotating machines in the world
- The optimization and control of fleets of wind plants working synergistically within the electricity grid.

According to the article, these grand challenges must be addressed to enable wind energy to supply 33% to 50%, or even more, of the world's electricity needs.

# Veers Learns Lesson on a Farm

Tending cows on a Wisconsin dairy farm taught Veers the value of hard work—and also that he didn't want to be a dairy farmer.

"The routine starts at 6 a.m. and ends at 8 p.m., seven days a week," he said.

As Veers was finishing his bachelor's degree, his father offered him a chance to take over the 160-acre farm, saying he'd keep the 35 cows around until his son decided. "I thought about it for a millisecond, "Veers smiled. "I said, 'Go ahead and sell the herd. I'm going elsewhere.'"

After studying engineering mechanics at the University of Wisconsin—a degree he said "allows me to not do anything practical whatsoever; it's really fundamental, the mechanics of engineering"—he earned a doctorate from Stanford University.

In 1980, a rural connection helped launch Veers' career in science and wind energy research when he interviewed for his first job at Sandia National Laboratories in New Mexico. He met with "an old Tennessee farmer" who was impressed with Veers' background. "He knew that on a farm, when the machinery breaks, the farmer had to get out there and fix it. There's nothing else you can do," he said.

Yet Veers' experience was different.

"My family wasn't very mechanical," Veers admitted. He claims to have landed the job under false pretenses because his family relied on a friend who had a garage and could fix machines much more quickly.

Nonetheless, Veers joined Sandia's applied mechanics department, which consulted on projects across the laboratory. While he worked on a large assortment of technologies that included nuclear reactors, he also encountered wind turbines, and his future career took off.

"Wind energy was hands down the most interesting," he said. "The field was wide open."

In the early 1980s, the question was: Why are these machines breaking, and how do we figure out how to build them so they don't break? "No one really knew how to do that," Veers said. "That's what drew me in."

## Leaning into the Turbulent World of Wind

Heading into the field of wind energy for a career wasn't exactly a safe choice at the time. Veers recalled that, early on at Sandia, he was introduced at a cocktail party to a senior staffer in nuclear weapons research. "He asked me what I was focused on, and I said wind energy," Veers said. The would-be mentor paused a moment, then said, "Oh, that is truly, truly trivial. You ought to find something worthwhile. That is never going to turn into anything."

> "How do we figure out how to build them so they don't break?"
>
> —Paul Veers

Doubters did not deflect him. Veers persevered in the wild days of wind when researchers did "dangerous stuff" with these balky new machines. And when federal funding became iffy for renewable energy development, he stayed put even as managers suggested staffers look elsewhere for secure jobs.

"I wasn't bright enough to realize this could be a problem," he said. Still, he was not convinced that wind energy was the solution.

"I really didn't know if wind would become a major player," Veers said. "I didn't have a passion. Originally, I thought wind energy was an amazingly interesting problem to solve."

Gradually, his viewpoint shifted. "The more I learned, the more I thought this could work," he said. "This could make a difference."

At that time, the general vision was that someday wind power might provide 5% of electricity in the United States. "Wouldn't that be a wonderful success?" he recalled thinking. Now, it's surpassed that figure and keeps climbing.

"Our sense is we're going to hit 10% easily," Veers said. "The goal is closer to 50%. We now have the vision if we keep pushing the frontiers with the technology, that it is going to increase to 20% or 30% globally."

For Veers, it is amazingly satisfying to see that this work is paying off.

While based at Sandia, Veers had frequent contacts with NREL. "I worked with NREL from day one," he said.

Early on, he established himself as an expert in vertical-axis wind turbines (VAWTs) and wind inflow numerical simulation tools. Sandia operated one of the largest research VAWTs in the world, and Veers was one of the lead research engineers in that program.

Brian Smith recalls meeting Veers in the 1980s. "Unfortunately, VAWTs never reached the commercial promised land," Smith said. "And Paul, always taking the long view, adeptly switched to horizontal-axis wind turbines without a hitch in his recognized expertise."

Still, Veers did make a trip to the Flatirons Campus to check on the one VAWT located there.

Also, while at Sandia, his investigations of wind turbine fatigue helped him realize the assumptions regarding turbulence were inadequate. As a result, Veers developed one of the first numerical simulation capabilities that modeled upwind flow characteristics. He also contributed to wind turbine system design tools that predict aerodynamic and structural dynamic performance.

The system to simulate turbulence can be applied to wind turbine computational models, an approach often referred to as the "Veers Method." Variations of it are still in use today.

Aside from his technical talents, colleagues and peers value Veers' communication skills.

"Paul has the uncanny ability to understand the physics of wind energy across many scientific disciplines and communicate the complexities to nonexperts in writing and in words," Smith said. "This skill set is truly unique in the world and extremely valuable."

Eric Simley, Katherine Dykes, Eric Lantz, and Paul Veers developed WISDEM a set of models for assessing overall wind plant cost of energy. *Photo by Dennis Schroeder, NREL 53316*

Take Veers' explanation of a wind turbine, for example: "It's a big piece of machinery that takes energy in one form and makes electricity."

For a variety of reasons, Veers impressed many at NREL early on. NREL fellow Thresher met Veers at a wind turbine dynamics workshop in 1984. "Even then, as a young researcher working at Sandia, he stood out as a clear and careful thinker with great ideas to drive wind energy research forward," Thresher said. "Over the years, Paul has tirelessly worked across the national laboratory complex, contributing to the advancement of wind energy science and technology development," he added.

Thresher described Veers as an enthusiastic collaborative partner in the creation of the North American *Wind Energy* Academy. Veers skillfully brought university researchers together with national laboratory and industry researchers to address the longer-term research issues facing wind energy today.

Veers made it a point to reach out. "I was trying to make the other labs successful," he said. "Unless we do that together, we're not going to have a mission that's fruitful."

With his ability to network, as well as his connections to NREL, it was only a matter of time before Veers headed north to Colorado.

## Veering Off to NREL

When the chief engineer position for NREL's wind program opened up in 2010, Veers jumped at the chance. United with old friends, such as Thresher and Smith, Veers was set to join an established group. In his view, a major draw was—and still is—NREL's close-knit wind energy workforce.

"We all have to work together to make something that's useful," he said. "That's often why this group is like a family. The teamwork that goes on here is really exceptional."

Veers has tackled leadership roles. He represents NREL on DOE's Atmosphere to Electrons (A2e) Executive Management Committee. And for 12 years he was chief editor for Wind Energy, an international journal for progress and applications in wind power.

"Addressing these challenges by taking an interdisciplinary wind energy science and engineering approach will lead to solutions that advance the state of the art in wind plant energy output," said article co-author and NREL Associate Laboratory Director for Mechanical and Thermal Engineering Sciences **Johney Green**.

For Veers, the challenge is real. It keeps him showing up for work. He remains modest about his achievements and believes the key to his success is the team. "It's an attitude that attracted me to NREL and this wind group in the first place," he said. "That attitude is where the mission is much more important than personal glory or success."

For Veers, choosing wind farms over dairy farms allowed him to milk his talents and contribute to an industry he sees as vital to a renewable energy solution.

# Dykes Catches the Updraft of Wind

Katherine Dykes seemed headed for a career in solar research in graduate school—but like a weathervane in a summer thunderstorm, her path shifted when she connected with a nonprofit organization promoting sustainable energy in her home state. Wind power was the cause.

"I said to Green Energy Ohio that I'm really into renewables and would like to get involved," Dykes said. "They didn't have any need for someone with technical skills on the solar side, but they had all this wind data." The problem was, the organization didn't have anyone on staff who knew what to do with the data, but they had reports and analyses due.

So even though she had been in a solar car competition as an undergraduate and was working on a master's degree in solar at Ohio State at the time, she jumped into the new field. "I had the technical skill set, so I started getting into wind," said Dykes. "I got excited about the complexity of wind energy."

That fervor carried over to her study of systems engineering at the Massachusetts Institute of Technology. "I decided to switch from solar to wind for my Ph.D. work," she said. Systems engineering was a relatively unknown field in the wind industry at the time—but it proved to be a boon for wind study.

"A systems-level approach for a technology like wind makes sense—there is more dynamic coupling of different physics than possibly any other large-scale complex system in the world," Dykes explained. "You've got everything: aerodynamics, atmospheric science, electrical engineering, controls, thermal, mechanical, and civil engineering. All these things come together," she said, "it's a huge, huge system."

As she showed since arriving at NREL in 2011, Dykes' training is beneficial. "To really understand systems-level performance and cost, you have to do a lot of multidisciplinary and systems engineering," she said. And that means being good at math. Fortunately, that's a trait Dykes demonstrated early.

## A 'Mathy' Girl in Suburban Columbus

She had a bit of a head start growing up outside of Columbus, Ohio. Her mom taught math, and Dykes played math-based games at home. "I was a mathy kid, always into mathematics," she said. "I was interested in computers and things like that. I enjoyed science, but math was always a passion."

Despite her upbringing, Dykes didn't know what an engineer was. "At one point, I'm sure I considered different aspirations before I knew what engineering was," she said. Then her high school physics teacher nominated her for an Engineer for a Day program at Battelle Laboratories. "That inspired me to apply to engineering programs for college," she said, which led her to the University of Pennsylvania's Jerome Fisher Management and Technology program—combining engineering and business, with the latter half emphasizing business statistics (she also snuck in a minor in math).

The fit was perfect. "I'm very happy to be an engineer," she said. "Engineering is a great place to be, where you can affect the world."

## Winds Sweep West to NREL

Another benefit of Dykes' time at Green Energy Ohio was making a connection to NREL. Among others, she met Walt Musial. After talking, NRELians encouraged her to come to the laboratory for a workshop on systems engineering in 2011—her first visit to Colorado. That visit led to a white paper, co-authored with NREL engineers **Maureen Hand** and **Pat Moriarty**, to help explain the benefits of systems engineering to the wind industry and especially wind turbine manufacturers. Next up was an NREL Research Participant Program (RPP) internship. "I came out for that RPP," she said, "and ended up staying for seven years."

Her contribution at NREL was immediate. "Katherine has worked tirelessly in an incredibly short amount of time to create a new way of thinking in the wind industry that crosses disciplines and will continue to be a driving force for increasing wind energy acceptance and reducing cost," said Moriarty. "The contributions that Katherine has made through her leadership and technical skills will continue to change the industry." Among her engagements, she served as project lead for the DOE Wind Energy Technology Office's Atmosphere to Electrons initiative.

Her NREL highlights include, in 2019, organizing the wind industry's top minds to create the "Wind Vision: A New Era for Wind Power in the United States." This provides a roadmap to 2050.

Dykes and her team were also part of the first cohort of Energy I-Corps (then known as Lab-Corps) to advance the deployment of WISDEM®, a commercialized version of an NREL research tool that creates a virtual, vertically integrated wind power plant. The software, which was a finalist in the annual R&D 100 Awards, uses combined physics and cost modeling to help analyze various trade-offs in wind plant operation.

A key part of WISDEM was a collaboration that started during the tool's development (in late 2011 and early 2012) with staff at the Technical University of Denmark (DTU). "Early on in our WISDEM activities, we found out through Patrick Moriarty that DTU Wind was developing similar capabilities, and he put me in touch with researchers who were leading the DTU effort for the plant and turbine," she said.

The group started sharing experiences of using the common software platform OpenMDAO and eventually established a memorandum of understanding to collaborate on a framework (FUSED-Wind) to help standardize the way turbine and plant models are connected. As Dykes explained, this enabled a more seamless transfer of information as well as encouraged collaboration across disciplinary areas and organizations. That collaboration continues to this day and is now supported through the IEA Wind Task 37 on systems engineering.

### Beginning a New Chapter in Denmark

Perhaps she was destined to go to Scandinavia. Dykes first went to Denmark in the very cold winter of 2009 as part of an MIT student delegation, a side event to the highly anticipated United Nations' Conference of the Parties (COP) 15 on climate change.

Later, Dykes went to Norway to work on a grant funded by the Norwegian research council through the U.S. National Science Foundation. "I was lucky to find an offshore wind research group at the Norwegian University of Science and Technology in Trondheim. To this day, I collaborate with people I met during that 6-month stay," she said. She took advantage of the close proximity to Denmark to make several trips there as part of her doctoral research on modeling innovation and deployment of wind energy.

"I even had the opportunity to take a remote sensing course at DTU," she said, "and was able to meet many research staff during that stay, some of whom are now my colleagues. The wind world is small. Once you are in it, you start to run into the usual suspects no matter what continent you are on." Overall, the 6-month stay in Norway, with visits to Denmark, eventually led to Dykes leaving NREL and taking a permanent position at DTU.

"In the end, I realized I wanted a more permanent opportunity that would allow me to fully experience the new organization as well as a broader international living experience in Denmark—culture, travel, and more," she said. "When a management position opened up at DTU in loads and control, I decided it was the right opportunity to make that change."

In March 2019, Dykes became a section head at DTU Wind Energy. Like NREL, the Danish institution has capabilities that span all of the relevant research areas for wind energy. Similarly, it also participates in large projects that engage experts from many different domains to tackle the complex multidisciplinary research challenges associated with wind energy.

However, unlike NREL, DTU is a university which presents interesting opportunities and challenges, according to Dykes. Still, she has found her new role to be rewarding because she engages with young, talented people who are excited about getting into wind energy.

"We really are helping to create a paradigm shift for energy systems," Dykes said. "It will be great to look back 50 years from now and see how far we've come."

## Mendoza Finds Path to a New Country

Growing up in Juarez, Mexico, Ismael Mendoza never thought he'd leave his town—let alone his country. He figured that maybe he'd be a mechanic like his father, or perhaps an electrician. Instead, he became an engineer and now works at NREL.

As a curious 7-year-old, Mendoza was fascinated by how things worked—which was why he disassembled electronic devices. He left some gizmos, like the family TV remote, unusable. "As a kid, you don't really know where all the parts will go," he said.

But even though his mother and father asked him to stop, he couldn't help himself—he simply loved tinkering. By the time he was in Bowie High School in El Paso, Texas—across the border from Juarez— his physics teacher encouraged him to aim high in his career.

Along the way, he developed a passion for encouraging other Hispanic students to consider the sciences—and being of service to the cause of empowerment.

In January 2014, Ismael Mendoza served as an engineer at what is now the National Wind Technology Center on NREL's Flatirons Campus. *Photo by Dennis Schroeder, NREL 28828*

At one point, the director of the Minority Engineer Program at Colorado School of Mines visited Mendoza's high school. The teen was intrigued by the opportunity and, in 1998, arrived in Golden, Colorado, as a Mines freshman and immediately joined the Society of Hispanic Professional Engineers to establish a base.

After graduating in 2003, Mendoza worked in variety of engineering jobs but always kept his eye on NREL. A Science Bowl hosted by NREL planted the seed of his future work at the laboratory.

"I believe in the mission of what NREL does—focusing on our energy future—and wanted to be part of that," he said.

In 2010, following two years at an engineering firm designing substations for wind plants in Wyoming, Mendoza joined NREL as a field test engineer. His duties included helping test wind turbines at the laboratory's Flatirons Campus to ensure they comply with different International Electrotechnical Commission standards.

"We did all the instrumentation as a third party for power and wind measurement, from small all the way to utility-scale wind turbines," he said, adding that they often climbed 90 meters into the sky—where things can get tricky. "Sometimes we'd have gusts that would shake the turbine. You have to get your sea legs," he said.

Eventually, Mendoza began an effort at NREL's Energy Systems Integration Facility (ESIF), helping to establish virtual connections between NREL's test turbines and ESIF equipment. His experience is key in this research area, combining technical skills and understanding of how distributed energy resources can increase resilience and flexibility for the power grid. It also enables him to connect in other ways.

"We partner with different organizations," he said. "We run co-simulations with others from all over the world, including Colombia and Mexico." Mendoza also was part of an effort by NREL Project Leader **Riccardo Bracho** to help Mexico create a road map for energy reform.

Mendoza enjoys visiting his native country—and keeps Mexican traditions alive here in the United States. In his free time, he and his wife, Yuliana, whom he met at Mines and is also an engineer, dance with Semblanzas de Mexico ("Memories of Mexico"), performing authentic Mariachi-style dances.

As for his parents, they are proud of their son's accomplishments. "All my tinkering really paid off—and they're happy," he said. Additionally, over the years, Mendoza has volunteered to speak at middle schools, telling Hispanic students they have options in different types of engineering, including chemical, electrical, and mechanical.

"They say they want to be a mechanic or an electrician, and I tell them, 'You can become a mechanical engineer and design cars and engines instead of just fixing them,'" he said. "It opens up their perspectives."

Mendoza has since connected with several younger students who are now pursuing engineering studies, whereas before, the possibility had never crossed their minds, he said.

## Robertson—An Aspiring Astronaut Finds a New Passion

Two more of NREL's wind researchers started with dreams of space travel. Fortunately, their dreams got derailed—and they turned their passions to harnessing the wind.

Wind energy researcher Amy Robertson is a bit like Smokey Bear. When she gets a whiff of burning trees, she snaps into high alert.

"I can always smell when there are wildfires in the area," she said. "I immediately go to find out where."

That trigger remains more than 20 years after she and husband, former NRELian Greg Hayman, narrowly avoided being trapped in the disastrous Cerro Grande Fire that torched their home, along with hundreds of others, in Los Alamos, New Mexico.

The blaze began on May 4, 2000, as a controlled burn by the National Park Service at nearby Bandelier National Monument—but 60-mph wind gusts and drought soon created an inferno. While parts of the town were eventually evacuated, their neighborhood was not. By the time the blaze leaped over the protection lines, it was too late.

"They held the fire for three days and, on that last day, I decided to get out of the house and go for a hike elsewhere as I had been stuck inside for three days," she recalled. While she was out, the fire broke the boundary. The National Guard moved in and evacuated the town. "I couldn't get back to the house. Greg was still working in town and had five minutes to get what he could, so he grabbed some photo albums and his climbing gear and left in his 1971 Volkswagen bus." Somehow, their new Subaru Outback survived parked on the street—an older car of theirs wasn't so lucky.

According to Robertson, the firefighters didn't try to put out the fires in the neighborhoods, but rather focused on saving Los Alamos National Laboratory, where she was a technical worker. "They were protecting our national secrets and nuclear materials," she said. Parts of the laboratory were damaged, but there was no loss of life.

A shift in wind saved more homes from burning but, tragically, their house was a total loss along with its contents. "I definitely miss all of the things from my childhood and from my grandmother who has passed away—especially all of the letters she sent," she said.

Robertson truly knows the threat of climate change—as well as the power of wind, both for beneficial things and destruction.

### Growing Up in NASA-Town

In hindsight, the odds of Robertson becoming an engineer seem pretty overwhelming.

"I loved math," she said, and her father was a NASA engineer. Growing up in a suburb outside of Houston, she regularly met astronauts. For example, her soccer coach was Ellison Onizuka, who died on January 28, 1986, along with six other crew members when the Space Shuttle Challenger blew up after launch. Also, veteran astronaut Alan Shepherd gave a demonstration to her school about how the crew goes to the bathroom in space. That turned her off to becoming an astronaut.

The fact that her dad, who ran a gyroscopic flight simulator, once put 6-year-old Robertson on the machine for a spin also had an effect on her career decision. "I threw up everywhere," she said. "I thought, I'd be on the other side [of space exploration]. I won't be an astronaut."

### Discovering NREL and Offshore Wind

Though abandoning the idea of space travel, Robertson nevertheless turned out to love engineering as an adult. However, when her telecommuting option with Los Alamos National Laboratory proved no longer practical from Colorado, she looked around for another position. NREL was in view; a job opening as NREL's first dedicated offshore wind energy researcher was the perfect fit. She joined in 2010.

"I was always very passionate about renewables," she said. Initially, colleagues Walt Musial and Jason Jonkman provided guidance.

But truth be told, Robertson had never tackled offshore wind turbines or things that floated in the water. It didn't matter. "Amy is very humble, and at first she was openly questioning why we hired her over some of the other more experienced candidates," Musial said. "We had to break it to her that she was simply better than them."

She had to write a proposal her first week—despite the fact that Jonkman had left the day she started at NREL for a three-month research assignment in Denmark. Fortunately (or so it seems), he shared about a hundred papers he thought she should review. "They threw me in the deep end," she said, but added that it was all for the best.

## Floating Turbines on the Horizon

Robertson survived the initiation and has become a leader in offshore wind structural dynamics modeling, verification and validation, and data analysis.

Offshore options are still developing in the United States. Currently, Europe is where much of the offshore action is, with turbines fixed to the accessible sea bottom. The biggest hurdle in the United States is to get the infrastructure built to handle offshore wind—but Robertson is optimistic. NREL, in particular, is looking at the floating realm of the technology. This will be particularly valuable off the West Coast of the United States, where the seabed drops off abruptly.

But there are challenges in designs.

The task is to build a floating structure that deals with the complex forces of wind acting on the turbines up high while the base floats in the water. "We've had to develop a whole new design and modeling process to determine how this will work," she said. "That's where I've been spending most of my time."

While not yet happening at a commercial level globally, there is a small, five-turbine floating wind power plant off the coast of Scotland operated by Equinor, a Norwegian company. NREL performed some analysis for that installation. "Japan also is focusing on this technology," Robertson said—and she almost visited one site there—but, well, remember that gyroscopic flight simulator? There was rough water the date they attempted. Enough said.

Overall, the offshore option is compelling. "That's really where we're going," Robertson said, adding that it is an area in which she hopes the United States leads the industry. The University of Maine, for instance, may have a few floating turbines installed within the next couple of years. Bigger U.S. projects are floating about 10 years down the horizon from a 2020 milestone. "In 20 years, we'll be seeing large commercialization worldwide," she said.

These days, Robertson is focused on trying to understand how accurately the tools that Jonkman and others create reflect reality. So, she'll get data from some different projects and analyze it to see if the tool predictions reflect how the turbines actually behave. "This is called validating modeling tools," she said.

## Big Projects Keep Her Energized

Robertson focuses on two big projects. She leads OC6—short for Offshore Code Comparison Collaboration, Continued, with Correlation and unCertainty—an international research project run under the IEA Wind Task 3. OC6 brings together everyone from the global community developing offshore wind tools to verify and validate them. "Collaborating with an international team allows us to more quickly and broadly impact the industry," she said.

Robertson is also part of ATLANTIS, a U.S. Department of Energy Advanced Research Projects Agency-Energy (ARPA-E) project to advance floating offshore wind using controls in the design process to minimize mass and maximize productive rotor area for economical offshore wind power. The project officially kicked off in January 2020. NREL leads three of the 13 projects within ATLANTIS.

To maximize power on a wind turbine, you use control methods to change the rotor speed and the angles of the blade.

"Once you put that turbine on the water, those control methods can destabilize the system—potentially making the turbine tip over," Robertson said. "Integrating controls in the design process of the floating wind turbine can ensure that the system doesn't tip over, but also can help to improve the design and make it cheaper."

As part of the ATLANTIS program, Robertson has led a series of validation experiments at a wind and wave facility at the University of Maine. There are other ideas, too. Robertson and colleagues consulted with turbine inventor Henrik Stiesdal on a floating design that they can't even model yet.

Her peers are impressed with what Robertson has accomplished. "Amy is quick to learn topics that she was previously unaware of," Jonkman said, adding that Robertson knew nothing about wind energy and offshore wind when she started at NREL 10 years ago. "Now, she is an international leader when it comes to validation of engineering models for floating wind turbine design," Jonkman observed. He added, "She is very detail-oriented, kindhearted, wants her colleagues around her to succeed, and a joy to work with."

**Jennifer King atop the Siemens 2.3-MW wind turbine at the National Wind Technology Center in 2019. King engaged with autonomous energy grid modeling for wind turbines to work more efficiently and produce more energy.** *Photo by Dennis Schroeder, NREL 58260*

With her unquenchable desire to learn, Robertson's future is exciting. She is attuned to what is carried on the breeze—whether wildfire smoke or energy—and will stay focused on the power of wind.

## Jen King—An Early Love of Science Blooms

A girlhood in frosty White Bear Lake, Minnesota, about 20 minutes north of St. Paul, could have chilled any thoughts of becoming a scientist. But researcher Jen King's family defied stereotypes.

She and her sister experienced science museums and historical recreations with their parents—a father in computer science and a mother in finance.

"We were always exposed to numbers and science. Whatever we were learning in school, our parents would find a way to go see it in real life," King said. "Anything remotely related to what my sister and I were doing, like a dinosaur exhibit, we'd go check it out."

The list of educational outings—for instance, quirky trips to campsites of the voyageurs, the French trappers who explored the region—were as common to King and her sister as an afternoon slogging through a Chuck E. Cheese restaurant would be to other kids. "A lot more stuck that way," King recalled. "I was a science-y kid." Indeed, all those sessions in the Omnitheater of the Science Museum of Minnesota made her want to become an astronaut, and she even applied to become one.

The pull to science continued in college at the University of St. Thomas in St. Paul. The school allowed students to have internships, so for three years starting as a sophomore, she worked at an engineering firm. After a while, she began to lose her passion for the field, and wasn't sold on going to graduate school, until a mentor convinced her to give it a try. That led to the University of Minnesota—but for wind energy. Her advisor gave her experience with wind power plant controls and ways to control the wind.

"I became hooked on the research and the complexities surrounding wind farm controls from fluid dynamics to grid integration," she said. Additionally, she collaborated with NREL wind researchers by spending summers at NREL. "I fell in love with research and never looked back," she said.

## From Icy Minnesota to Windy NREL

After earning an Ph.D. in 2016, and with a connection already established at NREL, King started at the lab as a postdoctoral wind researcher.

"There are many challenges to wind energy research and renewable energy research, in general, and I love going to my job every day because of it," she said.

"Jen is an impossibly productive researcher," said **Paul Fleming**, one of her early mentors. "Drawing on her deep expertise, work ethic, and creativity, she has made countless vital contributions to wind energy." Fleming cited her range, from building up world-leading models of wind power plant control while inventing new multiturbine control techniques, to pioneering research to enable reliable large-scale deployment of wind energy onto the grid. "She is creating an immense track record of discovery."

Pete Johnson of Gemini Rope Access Solutions inspects the blade of a 3-MW Alstom wind turbine by rappelling down the blades in August 2013 at the National Wind Technology Center. *Photo by Dennis Schroeder, NREL 27196*

Indeed, King has found a way to incorporate her wind expertise into other cross-cutting technologies. Over time, her research has evolved from reduced-order modeling for wind power plant control to reduced-order modeling and distributed control and optimization of large-scale hybrid systems.

King developed algorithms to make wind power plants more efficient. She was part of a fiscal year 2020 Autonomous Energy Systems Transformational NREL Laboratory Directed Research and Development Program project that attempted to link thousands, even millions, of devices.

"We want to control a wind power plant, maximize the power it produces, and show it in simulations. But if we want to do it in the real world and online, it's really difficult," she said. "If we do it the way we were doing it offline, it takes tens of minutes for optimization centrally—with a central computer telling all of the turbines what to do. What we developed in this project was a way to get this down to real time, so that you could run it every second."

This is a fresh approach to wind power plant management. "You can have a turbine talking to its neighbor, but not all of its neighbors," King said. That's because wind power plants are spread out, and turbines can even be 10 miles apart, and weather can vary greatly in a single power plant. "We developed a distributed control strategy that applies to a local area of turbines. Conveniently enough, that also applies to the grid," she said.

## Surveying the Autonomous Energy System

As King said, her team is endeavoring "to find ways to better integrate wind into the autonomous energy system of the future. In this system, the grid, renewables, buildings, and vehicles will work together in a distributed fashion that takes advantage of the millions of controllable devices that are now online or coming online."

Phase two of that Autonomous Energy Systems Transformational LDRD began in October 2020, leveraging the Advanced Research on Integrated Energy Systems (ARIES) initiative—a link that expands capabilities at both NREL's ESIF and Flatirons Campus facilities. Her impact is clear.

“Jen has done a tremendous job as part of the Autonomous Energy Systems Transformational LDRD,” said project leader **Ben Kroposki**. “She was the key researcher developing advanced distributed controls for wind plants that are based on consensus algorithms and can solve optimization problems hundreds of times quicker than conventional algorithms.”

Kroposki said the team is putting the ideas into practice for use in controlling hundreds of millions of distributed generation devices, storage, and loads as part of ARIES. The first part involves massive simulations using the high-performance computing environment and then, eventually, demonstrating the concept at the Flatirons Campus.

“She’s been a superstar since day one,” said National Wind Technology Center Director **Daniel Laird**. “Starting with her work in wind power plant control and consensus control, she’s continued to make a really big impact on the wind plants of the future and, more recently, on ARIES and hybrid energy systems research.”

One focus of this effort is in the San Francisco Bay area in California. The idea is to demonstrate how to interconnect all of the photovoltaic devices, smart homes, and electric vehicles. “The only way we can do the Bay Area is if it has distributed optimization and control algorithms” King said, like those she and others are exploring.

“That possibility becomes millions of devices that you could potentially control. Right now, we’re not taking advantage of that at all,” King said. “However, the minute we do, we open up a whole world and are better able to integrate renewables with the grid. We can make the grid more resilient, more reliable, and even more economic.”

The first step, she said, is to control them, in general. “You can’t expect a utility to go to every house and say ‘We’re going to control this house and that house. This temperature.’ We, as researchers, need to come up with ways to do that in a distributed way, a hierarchical way,” she said.

If they can make it work, the chain of use would flow like a waterfall. “One way to think about it: A utility passes control down to a region, that region passes it to a neighborhood, in that neighborhood, individuals make decisions,” King said.

For example, someone in a house in Arvada, Colorado, could share electricity with a neighbor. “If we had solar, but we were producing too much, and our neighbor needed it—currently, they have to tell the utility that they need power and the utility provides it,” she said. In the future, a homeowner could just send the power directly. “It would be less costly, with no middleman,” King said.

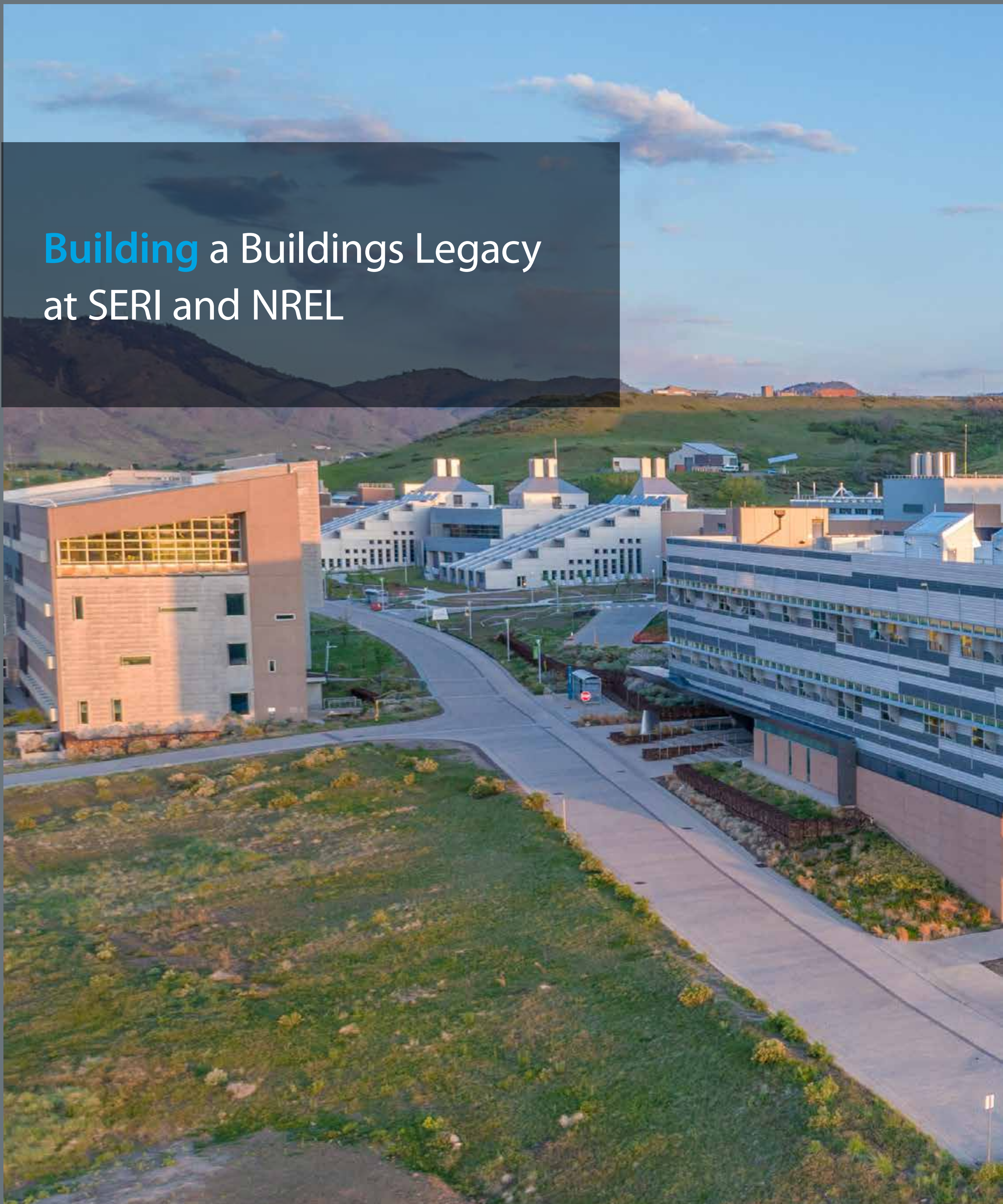
The LDRD goal is to also simulate millions of devices, with things talking to one another on a grand scale. There are options at NREL, too. “We can do it across campus. Flatirons down to ESIF. Theoretically, we could control a wind turbine based on the load profile of the RSF,” she said. While those capabilities don’t exist today, such connectivity is the goal. As for the Bay Area project, “We’re getting there.”

Regarding her own goals, King is clear: “I want to be a lab rat.”

That probably means breaking any siloed technologies and engaging in a suite of them. And so, the avid outdoorswoman—who enjoys hiking, biking, running, camping, and backpacking—loves what she does. In her own way, she continues—much like the voyageurs she once discovered—to make connections and explore.

Their stories may differ. But collectively, for these pioneers and other NRELians, the possibilities for the future of wind energy—and wind technology engineers—remain boundless.

# Building a Buildings Legacy at SERI and NREL



South Table Mountain Campus. *Photo by Josh Bauer, NREL 59215*


SERI building on Denver West campus circa 1985. *Photo by Warren Gretz, NREL 03361*

## SERI wasn't exactly a building mecca at the start.

Cables dangled from ceilings in the rented space of the unfinished Denver West office complex near South Table Mountain in Golden. Yet, across the country, there was budding realization among young idealists that architecture and structures mattered for energy conservation. Something attracted them to this world, although the path may not have been immediately apparent to most. Often there was an element of luck or serendipity that brought them to the threshold of investigating building sustainability.

NREL researchers and staff were no different.

For example, **Nancy Carlisle** wanted to teach physical education and the love of the outdoors to other women—but the staff at Colorado State University, in the mid-1970s, laughed at such a radical thought. Instead, she ended up choosing architecture and urban planning, including a concentration in environmental studies.

Around that time, **Chuck Kutscher** dreamed of space exploration attending college in Upstate New York.

And former folk singer **Ron Judkoff** served for three years as a Peace Corps volunteer in West Africa in the 1970s, helping to construct birthing clinics, dig water wells, and build sanitary facilities. Lessons learned proved to be lifelong. **Craig Christensen** developed a curiosity about solar energy aboard a National Oceanic and Atmospheric Administration (NOAA) ship in the Pacific Ocean and Gulf of Alaska in the early 1970s.

**Otto VanGeet**, a ski fanatic from Upstate New York, liked to "tinker with stuff" studying mechanical engineering at a local two-year college before ending up at Sandia National Laboratories in 1980. **Andy Walker**, a native of Colorado's high country, experienced the impact of sustainable housing while in the Peace Corps in Nepal in the mid-1980s. And, in 1986, **Sheila Hayter** joined the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) while an engineering undergraduate at Kansas State University. Thirty years later, she'd be elected to the ASHRAE board and, in 2018-2019, become one of the few females to lead the 57,000-member organization. **Roderick Jackson**, who joined NREL in 2017 as the buildings laboratory program manager for buildings, was honored a Black Engineer of the Year Award in 2022.

As these stories unfolded across the country, Carlisle was closest to SERI, physically.

When the federal government announced SERI's creation, Carlisle was in Colorado, employed in energy policy with the Western Governors' Energy Policy Office. The organization was seeking a contract for Western SUN, one of four regional solar centers proposed by the Energy Department (a relatively short-lived plan). Carlisle had gained expertise in solar incentives, laws, and passive solar design. And, not long after SERI's **Dana Moran** invited her to SERI during President Jimmy Carter's visit in 1978, she took her dream job at SERI. "I wanted to stay in Colorado and work for NREL," Carlisle said. From 1979 until she retired in 2017, she did just that, first at SERI, then NREL.

Nancy Carlisle, show in 2014, drafted the NREL General Development Vision Report, which outlined specific steps/plans for building a more sustainable campus. *Photo by Dennis Schroeder, NREL 29078*

Early on, Carlisle was an analyst, collaborating with passive-solar innovator and architect Greg Franta and others on federal buildings and their connection to the environment.

"Passive solar design was my first love," she said, combining architecture and engineering to reduce the building's energy load, with solar water heaters and photovoltaics to meet the balance of energy needs. SERI teamed with the Metro Denver Homebuilders to outfit 56 buildings with instruments in a study that found that a well-insulated building shell coupled with shaded south-facing windows and interior thermal mass could save between 40% and 60% on energy use. A parallel study of commercial buildings nationally determined passive solar design could cut energy use by 40%.

These findings were foundational when NREL's campus, which was originally open space with a few trailers, was built on the former site of the U.S. Army's Camp George West. In the 1980s, building experts began talking about creating a "net-zero" energy building, producing as much energy as it consumes, requiring a comprehensive approach to design and construction. SERI was part of the buzz.

Undeniably, things were more rudimentary back then. Carlisle said she was responsible for pulling together residential data and publishing the documents from housing studies. The data were stored on eight-track tapes. "I had to read the data into the software, and there was an algorithm that showed contributions from passive solar" to a building's energy efficiency. "I learned so much with the raw data," she said. The insights lasted her entire career.

## Kutscher Turns Up the Heat on Renewables

Adapting was the key early on. Chuck Kutscher, trained as a nuclear engineer (but from the heat transfer side), had taken a risk jumping from Rockwell to SERI in 1979. "I was looking to do something different, so I applied to SERI, and I also applied to [NASA's] Jet Propulsion Laboratory because—like many in my generation—I had a fascination with space exploration." After receiving offers from both laboratories, he weighed the two opportunities and chose Colorado. "I felt energy was a really important issue for the nation," Kutscher said. "And starting on the ground floor of a new institute sounded like an exciting opportunity."

Arriving at SERI, Kutscher found the laboratory chaotic. One colleague got a letter at home from the Human Resources Office saying that there were no openings—six months after he'd been

**Chuck Kutscher received the Governor's Excellence in Renewable Energy award in 2009.** *Photo from Sam Potts, NREL 16861*

hired. "It was an organization in its infancy. We had no badges," he said. Employee No. 482 would have to wait a while for that accessory. "During the first year, I admit I experienced some reservations about whether I had made the right decision. It just took a while for things to settle down."

His first big assignment was to design and build a solar desiccant cooling laboratory on the first floor of Building 16, one of the spaces the laboratory leased in the Denver West office complex. The now-large heating, ventilating, and air-conditioning laboratory in the Thermal Test Facility on the South Table Mountain Campus "has been through four incarnations," said Kutscher, all built up from a laboratory Kutscher assembled on a budget of $22,000. "I can go out there and see a few components I bought back in 1979 and 1980 that still work," he said in 2018, shortly before retiring.

Stability was not part of the operation. Kutscher related that it was a sad day when SERI's second director, Denis Hayes, gave a bitter farewell speech in the face of looming budget cuts. "We had no permanent office buildings back in the fall of 1981, and we came perilously close to being shut down," Kutscher said.

Still, in spite of threats of closure and some administrative disorder, the staff forged ahead with a shared passion. "We were all very young, motivated engineers and scientists, excited about the mission," he said.

## Judkoff Harmonizes with Solar Building

Ron Judkoff was a poster child for that shared built environment passion. The Long Island, New York, native, who spent time in the late 1960s as a protest folk singer, had absorbed vital lessons as a Peace Corps volunteer in Africa.

"Nothing makes you wish you knew some engineering more than when you're doing construction and somebody's life is going to be on the line," Judkoff related. He recalled his days in the field, saying, "The way I'd figure out whether a beam was strong enough was by putting it up on two rocks and then having a whole bunch of people jump on it." For the record, the beams always held.

But he knew his limits. Digging wells 100 feet into the ground—by hand—left him pondering how to ensure the walls didn't collapse. He thought, "Okay, how should the reinforcement rods connect?"

> "I suddenly had the chance to read something other than engineering textbooks. Solar energy was a brand-new thing. "
>
> —Craig Christensen

To find the answers, he wrote away for manuals, which would take a long time to arrive. "Sometimes they'd have the answers, sometimes they wouldn't, but they were helpful," Judkoff said. One manual taught him what the proper well support connection should look like. And from this exposure on the ground, he gained something greater. "I learned that I really liked building things and thinking about the technical aspects of building. I was especially fascinated by the thermal performance of indigenous architecture without heating or cooling systems." The modern buildings in Dakar would become uninhabitable during the frequent power failures, but his mud hut in Burkina Faso was comfortable with no energy source at all.

When Judkoff finally returned to the United States—after hitchhiking through the Sahara Desert—he set out to get a master's degree in architecture at Columbia University. He thrived there, though admitted, "I was more engineer than artist." Against the backdrop of the second oil crisis in 1978, he found his calling: building analysis.

After a short stint at Brookhaven National Laboratory in a building efficiency program that included solar power, Judkoff arrived at SERI as an "architect," which was duly noted in the March 22, 1978, edition of SERI News. There were challenges for the guy with badge number 199—no boss, nothing to do, and a bare cubicle in Denver West Building 2 with, yes, those cables dangling amidst unfinished walls.

"I used that lull to read up on solar energy and building efficiency," he recalled. When he began, the buildings group was considered to be part of the "passive" solar program. The so-called "active" solar work involved hot water, photovoltaics (PV), and what he termed "the sexy tech": concentrating solar power.

His first real project was in May 1978, helping launch the U.S. Department of Housing and Urban Development's Passive Solar Competition, a collaboration with the DOE aimed at architects who would submit plans. "Then, if some of those houses were built, we would monitor them and see how well they did," Judkoff said. He came up with the technical specs for the competition. "There were no computers, and we mimeographed stuff," he chuckled.

"A lot of what we copied came from Doug Balcomb's group at Los Alamos National Laboratory," Judkoff said. Balcomb had constructed his own passive home in Santa Fe, New Mexico, and was developing a quantified technique called the Solar Load Ratio method for designing passive solar houses.

"Doug, who came to SERI after he retired from LANL, can be considered the father of passive design science because he transformed what had been an art into something that could be calculated and incorporated into practice by any architect or engineer," Judkoff said. And, yes, the competition was a hit he said, with some 250 homes built and monitored, providing data for future passive design tools.

## Christensen Sails into Renewable Territory

Craig Christensen also found his way into the field during lulls.

As a science officer on a NOAA ship that sailed for 28-day survey missions, Christensen found he had free time. "I was at sea during the beginning of the environmental movement," he said. "After engineering school, I suddenly had the chance to read something other than engineering textbooks. Solar energy was a brand-new thing."

When the ship docked in port, he'd scour bookstores for information. He even went to the University of Washington

Craig Christensen found ways to improve building efficiency. *Photo by Warren Gretz, NREL 03399*

engineering library to see what they had on solar energy. "They had this much," he smiled during an interview, holding his hands about 30 inches apart. "One bookshelf. I perused everything there."

When his three-year stint at NOAA ended in 1973, Christensen—who had studied mechanical engineering at Brigham Young University—headed to Colorado with some shipmates returning to the NOAA laboratory in Boulder. He also was intrigued by the new field of passive solar building design, and even started on a master's degree in architecture at the University of Colorado, Boulder. "I soon decided that I was more interested in using my engineering in background and technical research," he remembered. After working as a solar consultant, individually and at a small mechanical engineering firm, he joined the fledgling SERI in the passive solar branch, which did buildings research. There, he met Judkoff. "He's a character," Christensen chuckled—and a future climbing buddy.

During that era, Judkoff said he and his colleagues were dreaming big—envisioning a time of zero-energy buildings, PV paint, and 3D software to optimize ultra-efficient buildings quickly and economically. Things that eventually became real. It wasn't PV pie in the sky, though. "That's why we were there [at NREL]. It wasn't that I was so prescient," Judkoff said. "Why set up this place unless that was the dream?"

## Walker Hears Solar's Call

To call Andy Walker a dreamer is probably accurate. After spending time climbing 14ers (mountain peaks standing 14,000 feet or higher in elevation), he enrolled at Colorado State University (CSU), then home to the CSU Solar Energy Applications Lab, a collection of solar-heated buildings. "It was one of three places in the country that you could get a good solar education," he said.

But it was in a paper he wrote for a composition class that he concluded nuclear and solar energy were two solutions to the energy crisis in the early 1980s. However, a nuclear energy class on risk changed his thinking. "We were quantifying risks, comparing them to the risk of dying in an airplane crash or an automobile accident. I think probably the point was the risks of dying in a nuclear accident were less than dying in an auto accident. But the takeaway for me was, why are we even talking about the risk of dying at all? This isn't coming up in my solar class," Walker laughed.

He dropped nuclear studies and continued with solar, majoring in energy conversion and bioengineering. During summers, he interned at SERI, once helping build a hybrid PV-wind water-pumping station for the United Nations. "There were no buildings here—just temporary trailers on this side of the highway," he said. Following graduation in 1984, Walker was finally able to pursue his high school dream—and decided on his desired destination: Nepal.

Andy Walker has collaborated with governments agencies as well as private industry to deploy energy efficiency and renewable technologies. *Photo by Dennis Schroeder, NREL 29088*


The Outstanding Team Award was presented to the NREL FEMP Project Development team of (from left) Chandra Shah, Karen Thomas, Deb Vasquez, Doug Dahle (in picture frame), and Tom Harris during the FY18 NREL Staff Awards. *Photo by Werner Slocum, NREL 55508*

Closer to home in 1994, Carlisle switched to a Buildings Program spin-off, the Federal Energy Management Program (FEMP). At NREL, she was part of the program, which helps federal agencies meet energy-related goals in buildings and facilitates public-private partnerships. She held that job for approximately 15 years, assisting federal agencies in meeting their goals for renewable energy use at their sites.

## Karen Thomas: Connecting Groups to Renewable Energy

That same year, **Karen Thomas** joined NREL's Washington, D.C., office and became a FEMP fixture. Years later, she won an NREL Staff Award for leading the FEMP Project Development and Finance Team, the procurement team responsible for supporting nearly $14 billion worth of upgrades to federal energy infrastructure projects.

"Everyone thinks I know everything—but it's just that I know everybody," Thomas quipped. Although she has broad knowledge, in Thomas' estimation, her role at NREL taps into something deeper. She is a product of a strong upbringing that emphasized connections with community.

She grew up in Fairfax County, Virginia, the fifth of six children. They lived in a house built by their father. "He only had a fifth-grade education and worked for over 50 years as a skycap [porter] at Washington National Airport (now called Reagan National Airport). But he and my mom raised the children and also rented out other homes father built on their property," she said. Her mother was a homemaker who fought in Virginia's courts for school integration and better opportunities for her family.

As a girl, Thomas said, "I loved to write and read as a kid. I would go to the library. I didn't realize that I was good at math until later."

It was during the 1960s that Thomas' school, Groveton High School, became integrated. In the early 1960s, her brother was the first African-American student to integrate the school. When Thomas entered the same school in 1969, she was selected as one of the first African-American cheerleaders. "We were sometimes cheering for a 0-10 football team," she said—but learned a fundamental lesson. "You still keep up the spirit. We're sticking together. We cheered a lot for first downs." She attended Morgan State University, a historically Black college (HBCU) in Baltimore, becoming the first in her family to earn a bachelor's degree. She also pursued an MBA at Howard University, another HBCU. She designed electrical distribution systems and was an energy and rate analyst at a utility before she came to NREL.

In Thomas' early days at NREL, when the path toward renewable energy wasn't always clear, she drew from her insight, experience, and even her cheerleading days to help inspire others. "We had to show them the way," Thomas said. Her communication skills proved invaluable to furthering the concept of building efficiency.

As she built relationships, she also helped steer discussions into innovation. If a potential client was short-sighted and proposed a project to install efficient lighting alone, Thomas would look

In 2013, Otto VanGeet explained the RSF to Jeremy Luselute and Shaun Tsabetsaye from the Zuni Pueblo Tribe, on a tour the RSF at NREL. Colton Heaps is on far right. *Photo by Dennis Schroeder, NREL 28133*

at ways to have a more comprehensive impact—suggesting including heating, ventilation, and air-conditioning (HVAC) upgrades or a chiller retrofit. “Let’s bundle technologies,” Thomas said. Further, she led the federal energy showcase program that highlighted projects such as a solar installation at a national park center. Typically, she asked, “What else?”

Indeed, that question was asked frequently among the buildings group.

## Constructing the Building Groups

Carlisle and VanGeet, for instance, served as founding and core members of the Laboratory for the 21st Century’s (Labs21) technical program. Labs21 was a joint DOE\Environmental Protection Agency (EPA) program with a mission to improve the energy and environmental performance of laboratory buildings. (It is now operating in the private sector as the International Institute for Sustainable Labs, I2SL).

In the Buildings Program office, Carlisle was surrounded by familiar pioneering faces: Kutscher, Judkoff, and Christensen—who started the same day as Carlisle did, one badge number apart from hers (672).

And 1994 was momentous for both Christensen and Kutscher: They shared an R&D 100 Award for a Transpired Solar Collector—which found permanent expression years later on NREL’s groundbreaking Research Support Facility (RSF). Building engineer **Paul Torcellini** also came aboard in September of that year.

NREL’s buildings program had come a long way. One measure was the willingness of staff to walk the talk.

In 1984, five years after starting work at SERI, Christensen (with SERI engineer **Cecile LeBoeuf**) designed and built a new house that was a radical experiment at the time: combining super-insulation with active/passive solar heating, technologies that were thought of as competing rather than complementary. The result was remarkably low energy consumption; such that, decades later, the house achieved zero net energy with the addition of less than 2 kW of PV.

Otto VanGeet was among the adopters after joining SERI in 1991. He had been considering putting what he had learned into practice by constructing an efficient home. By 1996, he was fine-tuning its features, using the SERI-RES computer simulation model (a tool previously developed by a Judkoff-led team that eventually resulted in a 2005 R&D 100 Award). VanGeet proceeded methodically, and the off-the-grid house he designed and built at 9,300-feet elevation in the Rocky Mountains was covered by network television; it’s also the subject of a 2004 NREL technical report, *The VanGeet Off-Grid Home: An Integrated Approach to Energy Savings*, co-authored by VanGeet and Torcellini.

VanGeet successfully integrated energy-conservation and renewable-energy features into his off-grid home. The design of the 3,176-square-foot house includes a tight, well-insulated, high-mass thermal envelope, passive solar heating (direct gain and Trombe wall), a wood-burning stove, natural ventilation cooling, active solar water heating, high-efficiency electrical appliances, and a PV hybrid electrical power system. It took some “lifestyle adjustments” by the occupants, but it truly was a real-world display of NREL building science.

Ron Judkoff gets a bird’s eye view of modular housing efficiency in 1995. *Photo by Warren Gretz, NREL 00962*

Craig Christensen and Chuck Kutscher pose next to the Research Support Facility, which uses their transpired solar air collector technology. *Photo by Dennis Schroeder, NREL 17659*

In 1994, Carlisle and her husband designed and built their own 3,000-square-foot passive home one mile from NREL. Christensen had just finished his passive solar home in Boulder as well. "We all used NREL software in the design of our homes and all compared notes as we designed and built. We all wanted to practice what we preach," Carlisle said. Torcellini built his own version years later.

For Judkoff, the early 1990s brought a new challenge. He volunteered to join a project evaluating mobile homes as part of the Federal Low-Income Weatherization Program. Overall, the program had been successful in determining how to perform energy retrofits of site-built homes; however, program leaders weren't seeing efficiency returns on mobile homes. "They were going to cut mobile homes from the program but wanted another set of eyes. I was that other set of eyes," Judkoff said.

Partnering with the Colorado Weatherization Program and its trainers, Judkoff endeavored to find out the most efficient ways to retrofit mobile homes. He developed the idea of testing the homes using calorimetry in a controlled environment. "I rented the gym of the Fairmount Bible Church four miles north of here," he said. "Mobile homes are bigger than you think and don't fit into an ordinary freight warehouse."

That space, 100 by 50 by 30 feet, upgraded with a bigger overhead door, became the test bed for about three years. Judkoff organized workshops, bringing hands-on experts from around the country to test methods to retrofit mobile homes for better efficiency. His approach worked. In the end, the Federal Weatherization Program kept mobile homes as a category, and another national laboratory found that these retrofits were among the most energy-efficient and cost-effective in the weatherization program.

## The RSF Takes Root on a Sustainable Campus

As NREL matured and grew, leadership sought to expand its footprint. That meant new construction.

Director **Hub Hubbard** allowed Judkoff to sit with the architects and engineers who were designing the Solar Energy Research Facility (SERF). "That started the tradition of people from the buildings group being involved in all the subsequent building," Judkoff said.

After the SERF was done, the same process was used for the Visitors Center, and then the Science and Technology Facility (S&TF). Torcellini said that, under Judkoff's direction, "we did lots of energy modeling on the building to really use the modeling to inform the design—this really changed the way that we thought about building design." Later came the Research Support Facility (RSF) and the Energy Systems Integration Facility (ESIF). "There's been someone, or several people at times, from buildings who have been involved in those projects," Judkoff said.

While Judkoff played a part, working in the background on these structures, he had become director of the Buildings and Thermal Systems Center (a post he held from 1996 to 2008) and was busy growing the buildings center of the future. Lacking the time to sit in on regular planning meetings, he asked **Shanti Pless** and Torcellini to take over.

It was a time of growth.

Carlisle, a senior project leader and group manager through 2009, led the development of NREL's General Development Vision in 2003 for the NREL campus (NREL's first 25-year sustainable Campus Master Plan). She also led the effort to obtain Leadership in Energy and Environmental Design (LEED) Platinum certification for the S&TF, which was the first federal building to receive this ultra-efficient designation.

"I had some ideas on the S&TF, which I brought to Director Richard Truly," said Carlisle. "I wanted to bring in panel experts to evaluate" the project. The director agreed, and this blue-ribbon group made a number of sustainability recommendations. "Truly and the [leadership] board decided it was worth letting go of the architect who had been hired. There was a solicitation nationally

The entrance to the Science & Technology Facility. *Photo by Marjorie Schott, NREL 15119*

for someone with more sustainability experience. We realized it would cost more to do the building right."

Her leadership drew engineer Pless into her orbit. Pless, who joined the laboratory in 2001, credited Carlisle with being "instrumental in NREL's campus buildings performance leadership from the beginning—ensuring long-term showcases for our campus for all of the federal government and industry to see that we know how to walk the talk." Pless was part of the group ensuring the S&TF secured the LEED Platinum facility certification. "That set the stage for all of the NREL campus projects over the next 15 years as well as provided leadership across the federal sector for adopting high-performance sustainability goals," he said.

Later, in 2009, Carlisle, VanGeet, and Pless authored an NREL report, *Definition of a 'Zero Net Energy' Community*. That report, said Pless proudly, is "still used today to support community- and district-scale energy planning goals and development approaches."

Named director of the Commercialization and Deployment Center in October 2009 (a position she held until June 2012), Carlisle was the logical person to help bring the vision of the RSF to reality. She was a natural choice because her work on the 2003 vision had distilled many facets of sustainability.

"We studied making the buildings more compact," she said. "That's why parking had to be stacked. We couldn't fit cars for 2,000 employees on land we had." That study also laid out a footprint for the RSF: narrow, bar-shaped wings only 55-feet wide, which maximize natural light and sustainability. She took the helm

NREL's Research Support Facilities (RSF) under construction. *Photo by Carl Cox, NREL 16282*

Front view of the Leadership in Energy and Environmental Design (LEED) Platinum certified Research Support Facility. *Photo by Dennis Schroeder, NREL 19350*

of the architectural programming for the RSF, a 1,350-person "net-zero" office building designed in two phases with a construction budget of approximately $120 million.

Kutscher's fingerprints are on the transpired metal solar-collecting facade on the south side of the RSF, which uses solar energy to preheat the building's ventilation air in cold weather. His Ph.D. thesis at the University of Colorado, Boulder, was on that technology—and he led the research group that did the early development of it. "I focused on the detailed heat transfer and fluid mechanics," he said. "Boundary layer suction prevents the wall from losing heat to the wind."

The 360,000-square-foot building benefits from other NREL innovations, such as electrochromatic window glazing, which employs low electrical current to adjust window tinting to control interior lighting and heat. To offset energy use, the RSF taps 2.5 megawatts of solar photovoltaics from its rooftop and nearby parking lot and garage.

It was fitting that, one spring day in 2018, Kutscher was admiring the RSF, completed in 2010, from the sunny deck of the NREL Café. Judkoff, who bumped into him that day, joked that Kutscher was the only person in history to have earned his doctorate for "holes drilled in sheet metal." In mock irritation, Kutscher replied, "Thanks a lot, Ron—although there's probably some truth in that." Offered Judkoff, "I was just admiring your resourcefulness."

Coming full circle, Judkoff said, "The RSF is really a passive solar building at heart."

These innovations reach beyond NREL's campus, in his opinion. "Because we did zero-energy buildings, a lot of other architects and engineers are taking the time to learn how to do it," he explained. "Because that happened, the State of California is now requiring zero-energy buildings in their upcoming [building] code. And other states are starting to follow suit."

Members of the Alliance to Save Energy tour the Energy Systems Integration Facility 2017 with Ron Judkoff. *Photo by Amy Griffin, NREL 46989*

Sheila Hayter is passionate about the energy efficient design of buildings.
*Photo by Warren Gretz, NREL 07154*

## Shining a Light on the Future

Not everything building-related was kept on campus. NREL staff played key roles in various competitions, including the U.S. Department of Energy Solar Decathlon, which allowed collegiate teams to design and build efficient housing.

Sheila Hayter, who has a particular interest in solar energy, led technical activities to assess energy efficiency and renewable energy opportunities for buildings belonging to multiple U.S. federal agencies. She also was the laboratory lead for DOE's Solar America Cities activities in Boston and New York City. In that capacity, she assisted these municipalities to incorporate strategies into policies, procedures, and specific projects for the adoption of solar technologies. Hayter served on the organizing committee and led the subjective judging component of the initial event in 2002, as well as for the 2005 and 2007 Energy Department Solar Decathlons.

Contributions keep on making a difference. Over long careers, these pioneers remained optimists.

Walker's patent on the Renewable Energy Optimization method of planning renewable energy projects across a portfolio of properties based on economic value was awarded the American Society of Mechanical Engineers' Thomas A. Edison Patent Award in 2015, based on innovation and impact. Walker is now an NREL fellow and still actively pushing boundaries. In his spare time, he has been featured on cable television for restoring his family's legacy cabin outside of Minturn, his Colorado hometown.

Christensen has a legacy, too. His first was the Building Energy Optimization Tool (BEopt), designed to optimize new and existing residential buildings and model accuracy. It's still in use today. "At NREL, we've had the opportunity to develop tools that really leverage our expertise and technical knowledge, so that users of those tools—practitioners—have the capability to make more efficient buildings," Christensen said. Later came ResStock, extending NREL's capabilities from BEopt analysis of individual buildings to large-scale simulations representing the entire stock of residential buildings in the country. "In each case, my initial conceptual ideas have been implemented, expanded, and enhanced by incredibly talented colleagues at NREL," he said.

Kutscher is also proud to have played a role in launching a modeling tool called Urban Renewable Building and Neighborhood optimization or URBANopt, a computer model for designing zero-energy districts.

So, as dire as things can appear on the planet, Kutscher has always been very focused on solutions. In his final years at NREL, Kutscher met with Brice Leconte—a developer of manufactured modular housing—which Kutscher said he sees as the building technology of the future. One of Leconte's modular iUnit apartments was brought to the Energy Systems Integration Facility for evaluation. Researchers used the ESIF's hardware-in-the-loop (or, in this case, apartment-in-the-loop) capabilities and energy modeling tools to improve the iUnit. There was some angst about the unit's delivery, however.

"I had this terrible thought," said Kutscher, "'What if that thing gets here and it doesn't fit through the overhead door?' I'll never live it down." So, he, Judkoff, Pless, and Leconte drove five hours to the factory in Nebraska where the modular housing unit was being built. Tape measures in hand, they quickly determined that it had an overhanging roof structure that was a bit too wide. Early the next morning, crews sawed off the extra wood trim; when the delivery truck finally backed the unit into the ESIF, the module just cleared—by less than two inches all around.

# Torcellini Sustains His Ancestral Home

Continuing to walk the talk, Torcellini always pondered sustainability, and these ideas came home to roost in his native state of Connecticut in 2013.

Eastford, where Torcellini's ancestors settled generations ago, has a long agrarian tradition. There's even a living history farm (Old Sturbridge Village) dating back to the 1830s from which Torcellini's family drew inspiration. When the family's house design process

**Paul Torcellini's Connecticut zero energy house in 2018.** *Photo by Dennis Schroeder, NREL 61158*

began in spring 2014, Torcellini was able to draw on his deep knowledge of efficient building—and wisdom from the past.

"Zero energy is a lifestyle choice," he said. "Our goal was to build a modest house with conventional styling using conventional framing techniques," including amenities, basement, and a garage.

The 1.5-story house was conceived as grid-connected and all-electric, using net metering to reduce costs. Torcellini notes that the house also cost less to build than a comparable structure—and they got just about everything they wanted. The conditioned envelope covers 3,597 square feet, which includes a root cellar and vegetable storage area—a nod to farming generations past. The home's 2,200 square feet of living space also has special elements.

Included in all this was plenty of modern innovation. The roof—made of metal so the family can collect rainwater without contamination from asphalt roofing material—is pitched at 27° to the south to accommodate a 9.4-kilowatt photovoltaic system.

> "Zero energy is a lifestyle choice."
>
> — Paul Torcellini

"You can build a house, or something like the Research Support Facility, and if you can cut energy consumption by 70%, you can usually put enough PV on the roof to power it," he said.

His award-winning structure continues to attract visitors. It, along with the impact of these NRELians, continues. Their footprints are visible.

"A big challenge in the world of building energy has been the gap that exists between building energy engineers and architects who often have trouble communicating with each other. There is no one better at bridging that gap than Ron," Kutscher said. He cited Judkoff's development of the international standard by which the accuracy of large building energy simulations is determined. NREL's reputation in the building space, Kutscher asserts, is due in large part to "a true Renaissance man of the building energy world." In 2020, Judkoff was named a fellow of ASHRAE for his many technical contributions to the efficiency field.

The accomplishments are tangible.

## Jackson Learns From the Ground Up

**Roderick Jackson** learned the building industry from the ground up. In fact, when he started, he was very close to the ground: a three-year-old picking up straight nails as part of his father's house framing crew in his hometown of Canton, Mississippi.

"Construction and building were always a part of my family history," said NREL's laboratory program manager for buildings, who came to NREL from Oak Ridge National Laboratory in July 2017. "Everyone knew my last name was synonymous with building houses."

And though many of his relatives were also involved in the trade, it wasn't easy fitting in.


Roderick Jackson (left) with the robotics team he mentored from Denver's High Tech Early College. *Photo by Roderick Jackson, NREL*

"I hated it," Jackson recalled. "I thought, 'This is something I'll never do.' Every day I wasn't in school from first grade forward, I was out on a job site."

His father, Louis Jackson, had a strong work ethic and held his family to the same standard. "All my summers I was working—winters, Christmas breaks too," Jackson said. This upbringing helped in one way: "It pushed me toward school, so I could stay away from the job," he laughs. "It really helped me excel in school."

In parallel, he was also a kid who enjoyed asking "why?" while trying to figure out how things functioned.

"I always had remote-control cars and would take them apart. I'd put the engine of one into the body of another. That never worked, but at least I had the good idea." Jackson paused during a 2019 interview. "I think that's still the case. I have ideas—as long as I surround myself with good people, we can get it done. That's the story of my life."

If that were true, this story could end now. But Jackson joked that his tale unspools like the narrative of Quentin Tarantino's multilayered film "Pulp Fiction." There are a few plot lines that overlap.

Jackson, who has coached a Denver high school in the FIRST Robotics Competition, has been "super-passionate" about the national FIRST Robotics Competitions since he became involved in 2002. Over the years, he has mentored inner-city kids in Mississippi—and then in Atlanta, Georgia—taking them to the regional finals. "It really makes an impact," he said. "I've seen kids go on to become engineers and doctors."

For Jackson, it's simply an expression of his core values. "It's good for them to see a normal person with a Ph.D.—at least I think I'm normal," he laughed.

Around the age of 16, Jackson had a change of heart on a job site. "I decided that I should pay attention out there. It was an opportunity," he said.

Still, he was happy to go to college, and went to Georgia Tech in Atlanta to study mechanical engineering. After graduation in 2000 (the same year he married his wife Nadriene), he returned to Mississippi to work for Delphi Technologies, an automotive parts manufacturer. But he didn't stop there.

"My father had retired, but he said that he could come out of retirement and build houses together as general contractors," Jackson said. "That sounded good."

Together, they constructed a few homes over the next three years. "It was great. I was getting paid to spend time with my dad. I was intentional about it."

And if that weren't enough, he pursued his master's degree in mechanical engineering through Georgia Tech's Distance Learning program. "I was too busy," he admitted. "I decided at some point that I should find something and excel in it and focus on it. I thought a Ph.D. would be easy—for some reason."

> "I have ideas—as long as I surround myself with good people, we can get it done."
>
> — Roderick Jackson

His plan was to pursue research linking three areas of personal interest: buildings, policy, and energy. Instead, he was steered into materials science research, focusing on carbon nanotubes. "It was good because I learned to take on something I'm not comfortable with," he said.

He also received a Graduate Education for Minority Students (GEM) Fellowship, which enabled him to intern at Oak Ridge. Through the fellowship, he met a mentor, Johney Green, who would later become his boss at the Tennessee laboratory as well as an associate laboratory director (ALD) at NREL.

When Jackson completed his doctorate in 2009, he was intent on teaching, and had a job lined up at a university. "Johney called and asked me to come and take a look around at Oak Ridge," he said. "I went, thinking I might want to do a partnership some time."

However, there was a job offer waiting in a familiar space: buildings, policy, and energy. "It was exactly what I had wanted," Jackson said. "I thought, 'OK, I can try this out.'"

His career at Oak Ridge was going smoothly—until one day when Johney told him that their boss, Martin Keller (who at the time was an ALD at Oak Ridge), wanted to see Jackson. The message Martin conveyed stunned him. "He said what I was doing wasn't why I got my Ph.D. or came to the lab," Jackson remembered. "He asked me how I would make the world different, challenging me to look for step-function impact in contrast to incremental impact. This wasn't what I was expecting."

Though he was taken aback at first, Jackson took up the challenge, and ended up presenting a stretch idea for a Laboratory Directed Research and Development (LDRD) proposal. The idea was accepted—but combined with three others to form one giant LDRD project linking transportation, building optimization, energy storage, and nanoscience. That was just the beginning.

He was informed that Martin wanted him to head a demonstration in which a car powers a house, and vice versa. When Jackson began to defer, Johney shared a truth: "Don't tell an ALD what you can't do. Just try." The kicker: The project had to be completed within nine months.

The result of the high-risk approach was a success. Marshaling resources, Jackson and his team, which included industry partners, used 3D printing to create the vehicle and the house, then connected them using wireless technology. He became the technical lead for the Additive Manufacturing Integrated Energy demonstration project.

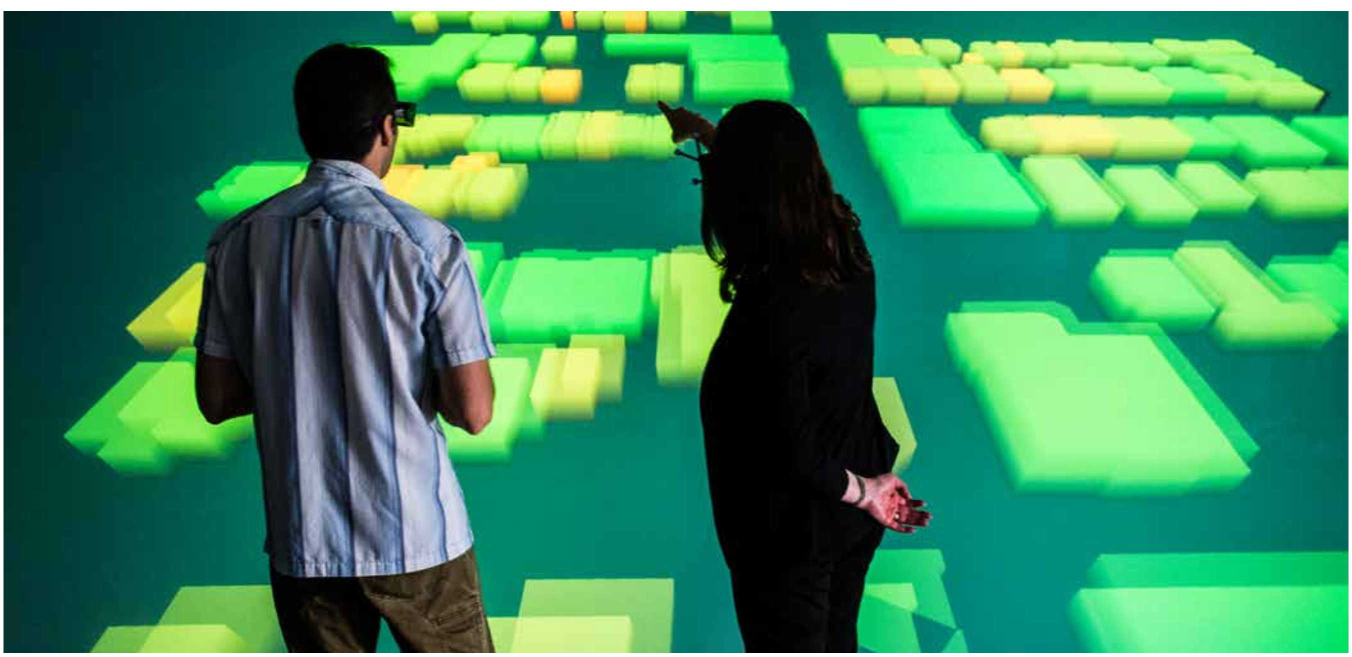
When Jackson arrived to work under him in NREL's Mechanical and Thermal Engineering Sciences directorate, Johney said that he's "seen firsthand how Roderick's leadership and expertise can transform projects and teams."

And that's exactly what he's trying to do. "I push the team," Jackson acknowledged. "We are one of the best, but I want us to be considered the premier buildings programs in the world."

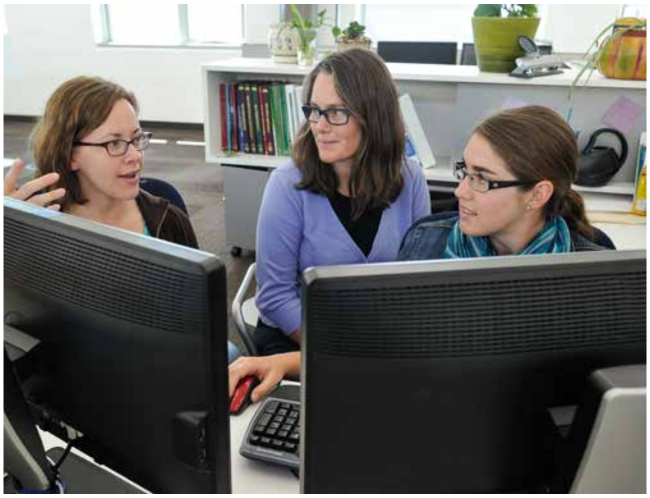
This goal of achievement is consistent with his own. "I want us to do big things."

## Envisioning the Buildings of the Future

NREL's engagement continues to pay dividends. "Being ASHRAE president taught me a great deal about leadership; in particular, how to motivate and inspire others to push boundaries," Hayter said. "The experience also gave me a heightened appreciation for how professionals in the buildings industry in the United States, and from around the world, understand and address challenges facing the industry."



**In 2016, Sheila Hayter reviewed models with Kenny Gruchalla of the Data Analysis and Visualization Group in the Insight Center Visualization Room in the Energy Systems Integration Facility.** *Photo by Dennis Schroeder, NREL 37224*



**Jennifer Daw and Rachel Romero discuss a project in 2014 as Shelia Hayter consults with them.** *Photo by Dennis Schroeder, NREL 31532*

Added Hayter in 2020, "Chairing the ASHRAE Vision 2030 committee is one of my current ASHRAE responsibilities. This role provides me the opportunity to continue the conversations that began during my presidential year about emerging challenges and opportunities with buildings industry leaders. It also allows me to bring insights from the work NREL researchers are engaged in doing related to grid-efficient buildings, cybersecurity, and resiliency into discussions that are defining ASHRAE's vision for the future of the built environment."

She noted that because ASHRAE is a global organization, she had the opportunity to visit with ASHRAE members and industry stakeholders around the world, which gave her an appreciation that we are all striving to make buildings more energy efficient, improve occupant health and comfort, and minimize the overall environmental impact of buildings.

The next generation is coming. **Rachel Romero** came to NREL in 2010, the same year she joined ASHRAE. Hayter, who became NREL's laboratory program manager for FEMP, encouraged the young engineer to become more involved in ASHRAE's Rocky Mountain Chapter. In 2019, Romero, who served on a variety of committees, was given the organization's Distinguished Service Award, an honor that made Hayter proud. For her part, Romero saw value in broadening her horizons.

"Professional involvement has kept me solid in my technical skills, even while I'm growing project leadership skills [at NREL]," Romero said. Involvement with an ASHRAE conference technical committee helped her support the DOE Better Buildings Smart Lab Accelerator. "[The committee] does a lot of work to move labs forward. By connecting ASHRAE and my work, I'm able to bring the tools to the federal government and share new developments coming from the program."

And, ultimately, there's the legacy of buildings.

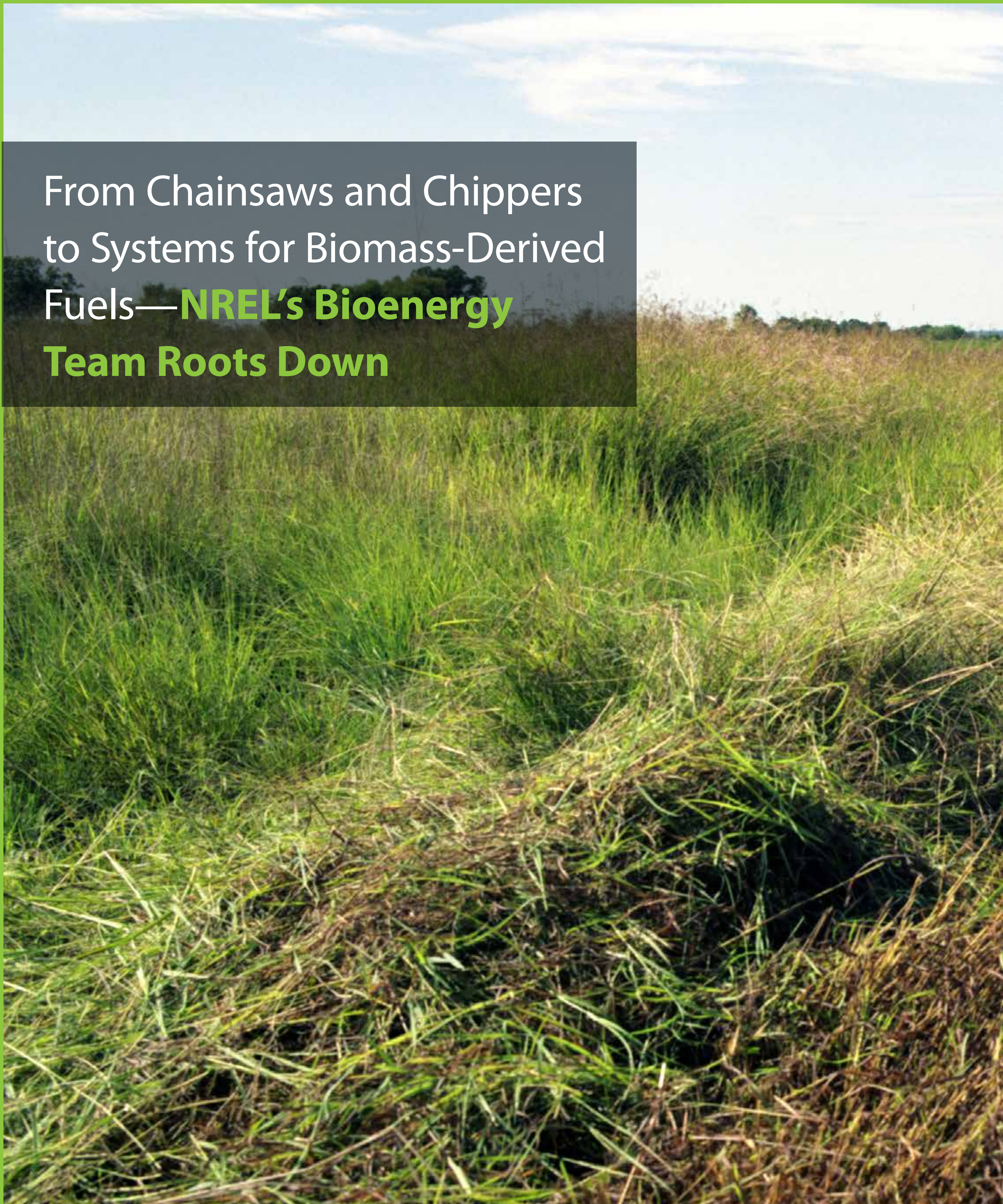
In 2020, a year before she retired in 2021, Thomas said of her role as national laboratory lead for FEMP's Utility Program that "I work to maximize collaboration between the federal sector and their serving regulated utilities to identify the best comprehensive energy solutions for federal facilities." Thomas said that such solutions ensure optimal performance of the installed energy conservation measures, manage energy use, and achieve persistent savings throughout the life of the utility energy service contract.

**Researchers Wale Odukomaiya (front) and Trinny Lai of the Building Energy Science Group investigating advanced phase change thermal energy storage composites for buildings.** *Photo by Dennis Schroeder, NREL 63294*

Kutscher noted that "one of the things I'm most known for around NREL is my work and presentations on climate change and solutions. NREL folks still bring me in to give presentations on this." He pointed to that topic as the theme of the national solar energy conference in 2006 that led to the study *Tackling Climate Change in the U.S.*, which he edited on behalf of the American Solar Energy Society.

Carlisle, who finished her career as director of the Integrated Applications Center, reflected on the legacy of NREL. "I just loved the RSF. The lighting, the operable windows," she said. "I was proud to be part of a team of NREL managers, buildings experts, and DOE who worked together to develop a beautiful world-class, zero-energy showcase that demonstrates an alternative, more sustainable way to design and build commercial buildings." It made her walk into the office each morning "something I looked forward to," she said. ■

# From Chainsaws and Chippers to Systems for Biomass-Derived Fuels—**NREL's Bioenergy Team Roots Down**



Switchgrass being harvested in 1991 at the Texas Agricultural Experiment Station at College Station, Texas. *Photo by Warren Gretz, NREL 00303*

In the early days of SERI, Mike Himmel collected cellulase-producing bacteria from a Yellowstone National Park hot springs. *Photo from Mike Himmel, NREL 03297*

One of the first things **Mike Himmel** bought for the Solar Energy Research Institute (SERI) in 1980 was a chain saw. The newly minted Ph.D. needed biomass specimens and had gotten permission to cut down some aspen trees in Rocky Mountain National Park. While sectioning the wood, he realized something: "There was no way to reduce it to a fine powder to study enzyme action," Himmel said.

He needed a special woodchipper. So, he borrowed a truck from the U.S. Department of Energy (DOE) motor pool and drove nearly 1,400 miles to Bandit Industries in Michigan's Upper Peninsula, where he bought a trailer-mounted chipper capable of digesting a grown aspen tree in eight seconds. "Those trees enabled our research for many years to come," said the NREL research fellow.

His initial shopping list grew quickly: fermenters, incubators, liquid and gas chromatography interfaced mass spectrometers, knife mills, fast protein liquid chromatographs—even steel walkways for the Field Test Laboratory Building (FTLB). "When I showed up for the job, there were a lot of good people with great ideas, but nothing here—so, it was time to grow and publish papers," Himmel said.

"I used the FTLB high bay because the original design for this big room was to house fermenters and, frankly, no one was around to tell me no. I bought large steel walkways to section out the room, and **Mel Tucker**, **John Baker**, and I assembled them on weekends," Himmel said.

Himmel, who had worked in a Greeley auto salvage yard in high school and was experienced driving big machinery, used a large forklift to help set up the walkways. Instead of Environment, Safety, and Health staff, there was "just one person worrying part time about safety," said Himmel. However, he didn't disregard caution altogether and noted, "I did qualify for, and receive, a SERI forklift driver's license!"

Things gradually took shape. In 1985, **Karel Grohmann**, his boss, came to Himmel's laboratory with a proposition. According to Himmel, "He said, 'Himmel, we have $30,000 [approximately $93,000 today] to get you moved to the FTLB. But, if you'd rather have that money to buy equipment, I'll make a deal with you. If you guys can move this stuff over there yourselves, you can have the money.'"

Again, Himmel, along with Tucker, Baker, and a handful of others, used rental trucks to shuttle every piece of equipment they had, and they employed a road-rated forklift to transfer centrifuges and other large equipment to the new site a mile away. They even hauled a large three-door refrigerator, which is still in the FTLB. With the money saved, Himmel bought much-needed instrumentation to conduct microbiological and biochemical research.

"We did everything ourselves: harvested, milled, and pretreated biomass for research," he said.

In the mid-1980s, Himmel designed a series of novel reactors for the pretreatment of biomass, including a 50-gallon paddle reactor and high-solids reactors for anaerobic digestion research. "That stainless paddle reactor is still in service today at the Integrated Biorefinery Research Facility," he stated.

The work culminated with the construction of a steel platform in the FTLB, which housed a surplus 50-gallon Pfaudler stirred tank, including a glass-lined reactor equipped with steam heating and conditioned cooling water systems. Himmel designed and built the entire system, which included a custom gantry crane to lift the 125-pound reactor lid. He even installed the piping, using a borrowed pipe-threading machine.

"I remember **Helena Chum** coming in and saying 'Himmel, you're a biochemist. You're standing here, threading pipe?' I said, 'You're right.' But there was nobody else to do it. There were only a few engineers on-site in those days," Himmel said. "Still, we generated our first pilot-scale batch of dilute-acid-treated wheat straw using that system and were able to show the U.S. Department of Energy that we could actually do biomass conversion research."

## An Institute Lures Improvisers and Searchers

In those days, SERI was a lot like a startup business and improvisation was key. That same spirit that fuels NREL's bioenergy program today had been sprouting for years across the country and the globe.

In São Paulo, Brazil, a young Helena Chum—the daughter of a Chinese father and Brazilian mother—had her interest in science stoked by a chemistry teacher in junior high school. In the same country, **Maria Ghirardi** gravitated to biology while growing up and applied to the Brazil's best medical school—but quit after four years because she said she became too emotionally involved with patients. **Pin-Ching Maness** pursued her love of botany, earning a bachelor's degree from National Taiwan University in 1974. And, in Beijing, **Ling Tao's** parents, both chemical engineers who worked on polymers, encouraged their daughter to follow in their footsteps; after all, her name in Chinese means "expectations as high as the clouds."

**Min Zhang**, who grew up in a town outside of Shanghai in China, was in high school in 1977, when the government launched China's National College Entrance Examination—known as the *gaokao* ("big test" in Mandarin). She took the second national college entrance exam, a grueling three-day affair administered nationwide, in July of 1978. And, a month later, a simple letter informed her that she was admitted to East China University of Science and Engineering to study biochemical engineering.

Meanwhile, **Jianping Yu's** fascination with genetics started as a boy, the result of his attraction to a neighborhood girl in his hometown of Zhengzhou—a provincial capital in east-central China—and her family's battle with hemophilia. **Violeta Sanchez i Nogue**, who grew up bilingual in a small town in Catalonia in northeast Spain, is among the newest generation of researchers, arriving at NREL in 2015 with a global perspective about science.

> "It was essentially a free-for-all."
>
> —Mike Himmel

The ground in the United States was just as fertile for future researchers, though the bent toward bioenergy may not have been as immediately obvious.

For **Kim Magrini**, sitting on her father's lap as a 3-year-old as he soared in his private plane over their home in Youngstown, Ohio, instilled in her a passion for flying. As for **Michael Crowley**, his upbringing put him way ahead of the curve in computing.

Bioenergy scored with a number of athletes. **Tom Foust** was raised in a small mill town in Pennsylvania and dreamed of playing football. **Adam Bratis** was a lanky kid from a Philadelphia suburb who aspired to play college basketball. **Michael Resch**, whose 6-foot-9-inch frame eventually led him to Europe as a professional basketball player, was in love with football while in high school in the 1990s in Wisconsin. **Gina Fioroni**, restless as an adolescent, found an outlet in marathons and ultradistance running while focusing with that same intensity on research.

Their starting points differed greatly, yet, somehow, all converged on Colorado, helping make NREL a biofuel and bioenergy trailblazer, supporting the DOE Bioenergy Technologies Office and the Office of Science.

### Taming the Early Bio-Jungle

In late 1979, Mike Himmel answered a SERI job advertisement for a biochemist. By the summer of 1980, armed with his Ph.D. in biochemistry, Himmel was a SERI postdoc. After two months, the laboratory hired him as a full-time employee, sporting badge number 1223.

A job in high school working in a large auto and truck salvage yard in Greeley paid dividends as an adult. "They didn't pay me much, but I probably would have worked there for free," he chuckled. "I learned everything I know about cars and trucks from that. There's nothing like taking parts off of things to learn how they work." He also drove heavy machinery, including Caterpillars and drag lines, which is why he was so handy with a SERI forklift.

At first, SERI folks had to invent themselves.

For several years, branch managers (as they were called) had large budgets not yet tied to milestones. "It was essentially a free-for-all," Himmel said. He was in the foundational biotechnology branch.

"I knew what we needed and what had to be done," Himmel said. One of the first things he did was to secure a permit from Yellowstone National Park to collect specimens. "We wanted to sample from the hot springs for microorganisms we could use to degrade biomass," he said. It was part of an effort to find more cost-effective ways to convert biomass to fermentable sugars for making fuels.

Not everyone shared his vision. Funding had dropped and, one by one, others in his branch departed. By the end of 1983, Himmel was the only one left out of 25 original employees.

He persevered—in part because of the mission, in part because he liked being near his family in Greeley. By the early 1990s, under the leadership of **Charlie Wyman**, funding started to grow for his group. A key moment came in the mid-1990s when Himmel wrote a white paper for DOE's Biofuels Office suggesting that it would be possible to improve cellulases—the enzymes that catalyze the breakdown of cellulose—by applying relatively new techniques in protein engineering.

" Maria was highly qualified for the position and, very quickly, she rose up the career ladder. "

—Pin-Ching Maness

"At the time, it was a novel idea," Himmel said—one that caught the attention of a large enzyme manufacturer, which opposed the innovation and argued to DOE that it wouldn't work. "Luckily, DOE didn't quite believe that," he said, "and we got our first funding" for that type of research. (This same company shared the stage with Himmel 15 years later to accept an R&D 100 Award for—you guessed it—novel cellulase research.)

This new concept spawned a whole new research and development (R&D) avenue, one that helped set NREL on its biomass conversion course. "Much of what you see here is the offshoot of those early days," Himmel said, sitting in his office.

Through the years, recognition of NREL's world-class abilities in protein purification and characterization has resulted in many partnerships and achievements.

With guidance and inspiration from then-Associate Laboratory Director **Ray Stults**, Himmel and his team furthered biomass conversion research at NREL by collaborating with Oak Ridge National Laboratory and Purdue University to launch the BioEnergy Science Center and the Center for Direct Catalytic Conversion of Biomass to Biofuels, respectively. (These centers are multi-institutional, DOE-funded research organizations performing basic and applied science to improve biofuels by understanding and eliminating biomass recalcitrance. That recalcitrance is the natural state of plant biomass that resists deconstruction to component chemicals and materials.)

## Ghirardi Trades a Doctor's Coat for a Lab Coat

Another path lured Maria Ghirardi. After rejecting studying humans or animals for humanistic reasons, she said, "I went into plants, particularly photosynthesis." Ghirardi traded dreams of a physician's coat for a scientist's lab coat to start an undergraduate program at the University of California–Berkeley called bioenergetics—the study of energy-producing and consuming reactions in plants. Her true career calling was unfolding.

Life in Berkeley was unsettled. "Things were crazy in the '70s and early '80s," Ghirardi laughed, yet sanity ruled in the laboratory. "In the bioenergetics program, I had three wonderful teachers who really raised my interest in that area of research. I talked to a professor who said I should get a master's or Ph.D. in that area."

She started with a master's program in comparative biochemistry, during which she researched different energy-producing pathways and microbes in plants. After publishing some papers, she decided to continue with a Ph.D. In 1988, she earned her doctorate—and was thinking about academia.

Instead, she took a postdoctoral appointment with the U.S. Department of Agriculture in Maryland. There, her research involved a particular protein in photosynthesis with fast turnover that was considered a regulatory mechanism for avoiding cell damage under high light. The experience shifted her focus away from teaching and onto research institutions.

When her three-year appointment ended in 1991, Ghirardi searched again for a postdoc researcher opening. That's when she saw an ad for NREL. "I had a friend who said, 'Come out here to Boulder—you'll love it,'" Ghirardi said. **Mike Seibert** (now an NREL research fellow emeritus) offered her a position. And Ghirardi, who


**Maria Ghirardi enjoyed more than two decades of algal hydrogen research at NREL.** *Photo by Warren Gretz, NREL 15589*

had become a single mother, decided Colorado was where she wanted to be and raise her son.

After finishing her postdoctoral training in another photosynthesis-related area, Ghirardi applied for and successfully received funds to work on DOE-funded research involving hydrogen production, a project related to her background in photosynthesis. “It wasn’t that much of a transition,” she said. “I learned quickly.” Following three years of learning about handling hydrogenases—proteins that produce hydrogen—she received funding for long-range and more basic research.

It didn’t take long for Ghirardi to impress her NREL colleagues. “I can still vividly remember her interview and presentation at NREL,” said Pin-Ching Maness. “She was highly qualified for the position and, very quickly, she rose up the career ladder and has been playing a key role ever since in developing renewable energy at NREL.”

Ghirardi’s impact was immediate. Maness cited the seminal discoveries Ghirardi and Seibert made in the maturation machineries of FeFe-hydrogenase (the enzymes that oxidize or produce hydrogen) in the green alga *Chlamydomonas*. This has become an emerging research topic probing the fundamental mechanism governing photobiological hydrogen production.

For her part, Ghirardi said, “My biggest contribution to NREL was the work that I initiated in collaboration with Tassios Melis, my Ph.D. adviser. We came up with a system, based on depriving algal cells of a major nutrient (sulfate), which induced photoproduction of hydrogen gas that lasted a total of three to five days.”

This groundbreaking effort led to expanded interest from the Energy Department’s Fuel Cell Technologies Office—and the rest of the world—in microbial hydrogen production. The research also resulted in 14 additional years of funding for Ghirardi’s research group at NREL. As she said, “Algal hydrogen photoproduction made my career.” Further funding received from two different Office of Science programs in the mid-2000s was initially focused on that same theme, although from a different point of view.

Ghirardi’s group also focused on the development of algal and cyanobacterial systems involving a study of fundamental regulations and biochemical processes that regulate the partitioning of electrons into metabolites and cellular bioenergetics. This research has led to several breakthroughs, one of which was the discovery of how hydrogenases are biosynthesized—a discovery that revolutionized the field of hydrogenase research. Ghirardi’s basic science research provided new insights and revelations on challenging bioenergetics and biosynthetic pathways.


Helena Chum in 1997, then Center Director in the Center for Renewable Chemical Technologies and Materials, is shown with pyrolysis oil, its products and its original state. *Photo by Warren Gretz, NREL 04804*

"Maria has left a large and impactful footprint in algal biohydrogen research with a renowned reputation internationally," Maness said. It wasn't a surprise that, in 2016, the American Association for the Advancement of Science named Ghirardi a fellow for her contributions to the field of photobiological hydrogen production in photosynthetic organisms.

## Chum's Career Flowers Organically

Helena Chum moved from Brazil to the United States after marrying Joseph H. Christie, an American scientist, in 1976. She had met her future husband at an electrochemistry conference in Santa Barbara, California, and then visited the laboratory at Colorado State University (CSU) where her husband worked with Bob Osteryoung and **John Turner**, another NREL pioneer.

In 1978, Chum joined CSU. Along with Osteryoung, she undertook the analyses of thermally regenerative systems and biomass electrochemistry under contract with SERI's **Tom Milne**, manager of the thermochemical branch. Chum was hired by SERI in late 1979.

"I was always very curious about all the objects that surround us," she said. While she felt things may have seemed a bit "wild" initially at SERI, it wasn't unruly. Instead, ideas flowed freely—the creative energy of change was in the air, and staff worked together across multiple areas.

For instance, while other national laboratories were already dominant in the high-temperature electrochemical area in the late 1970s, Chum and her colleagues in the SERI materials sciences group helped carve out an area of low-temperature research. Later, they explored some aspects of low-temperature fuel cells. However, facilities were limited, with one small laboratory for all their research. "For this kind of chemistry, you need space and [ventilation] hoods—and we didn't have them," she said.

Somehow, they adapted. Her group transferred to be under Milne, one of the first SERI employees, who came from Midwest Research Institute (MRI) as part of the first DOE contract with MRI (now MRIGlobal) to manage the laboratory.

Milne's major area was the development of molecular beam mass spectrometry, which sampled vapors of various reactors and enabled researchers to identify reactive intermediates and final products very quickly. "This instrument became integral to the research with multiple generations of spectrometers built and automated," Chum said, including portable versions that measured the performance of the laboratory's thermochemical gasification and pyrolysis research and that of industry collaborators, for small and large gasifiers.

"We had outstanding researchers throughout these 40 years; with them, we made impacts in various fields," Chum said. "Many left the lab over time to very successful careers in academia and industry. Many stayed, looking for ways to make multiple products from biomass, including energy."

One thing was clear to her early on: This biomass research needed a complete picture of the processes with multiple variables.

The interest of industry was in analyzing and predicting performance of products, such as pulp, paper, and feed. Because the laboratory's researchers were attempting to make biomass a source of chemicals, materials, and fuels, "We knew we had to drill down deeper into the workings of processes for all the intermediates," she said. "We had to be able to track everything, so I started from that point of view." That's how biomass chemical analysis began at NREL. The team pioneered the laboratory's analyses procedures and, together with international collaborators through the International Energy Agency, set up the National Institute of Standards and Technology Biomass Reference Materials, again under Milne. "This ethos continues today," she said, with ever more powerful instrumentation.

There were two investigative tracks unfolding then. As Chum recalled, "I started this biomass analytical line at the lab to collaborate globally. Wyman (director of the laboratory's Biotechnology Center for Fuels and Chemicals work from 1978–1997) spearheaded R&D to use a common feedstock in

**Helena Chum.** *Photo by Dennis Schroeder, NREL 19333*

pretreatment of lignocellulosic biomass, with Mike Himmel as the lead researcher in the enzymatic hydrolysis and pretreatment." The combination of these tracks produced a series of core papers, as identified by *Science Watch* in 2009, that highlighted key frontiers of research in biology, biochemistry, and biomass chemical analyses for ethanol fuels production.

Overall, Chum saw the process of developing the bioenergy field as gradual. "I had a lot of knowledge of the Brazilian system of ethanol in transportation—and how big were the problems bringing the fossil and renewable systems to operate in the automotive sector," she said. "But they were solved over decades for specific car lines."

Her multicultural background was useful to SERI and NREL. She was part of the international teams helping DOE set up a bilateral agreement with Brazil, an outcome of the first Rio de Janeiro United Nations Convention in 1992. It resulted in a major effort that brought photovoltaic lights and wind power to Brazilian rural areas. Another effort, in 2007, was to help DOE operationalize a memorandum of understanding between the two countries in the research and development of biofuels. NREL and partners had many such activities, including one with Petrobras, a Brazilian state-owned petroleum company, coprocessing petroleum processing streams with raw biomass pyrolysis liquids and its modeling.

"From my viewpoint, it would take longer than some expected to reach commercialization in lignocellulosic biofuels because we had to bring multiple industries together—or help create new ones," Chum said. "We had to have feedstocks and their supply chains developed so conversion facilities could have biomass to operate year-round, and products had to fit into the end uses or expand them. I thought scale-up was rushed in some areas, as did other experts in the area."

Chum said that research and development showed that in feedstocks and conversion processes, a key issue was the sustainability of the integrated systems in harmony with other land uses. Even after a decade, it remained a focal point at NREL in 2020—as well as at laboratories globally.

She cited multiple ways that NREL drove this forward: NREL was an active participant, and its researchers were authors, in the Intergovernmental Panel on Climate Change (IPCC), in assessing bioenergy; in renewables contributions, which led to a special report on mitigating greenhouse gas emissions to the atmosphere (2009–2011); and in feeding subsequent IPCC reports on mitigation and adaptation.

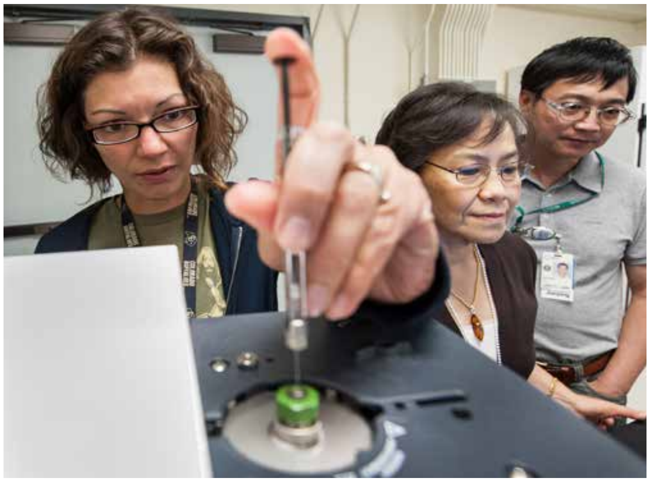
## Pin-Ching Maness Connects Her Girlhood to Bioenergy

As an 11-year-old, Pin-Ching Maness decided her career would be in biology. So, it was. As a junior at National Taiwan University, she took a microbiology class that inspired her with a series of experiments to identify various types of bacteria. "This class forged my path toward pursuing microbiology as a passion and topic of interest," she said. Simply put, she was hooked.

At Indiana State University, her master's thesis focused on how root nodule bacteria fixing nitrogen from the atmosphere could be converted into ammonia to promote symbiotic plant growth (e.g., in peas and soybeans). Next, she embarked on nearly five years of investigating nitrogen fixation reactions—first in cyanobacteria; later in photosynthetic bacteria, catalyzed by the nitrogenase enzyme—as a research associate at the University of California–Berkeley.

Her arrival at SERI was a long shot.

"I literally stumbled on the job at SERI in spring of 1981," she said, after her husband's geology job brought them to Golden, Colorado, that year. In January, her former boss, Professor Dan Arnon, pointed out to her that "there is a small biology group in an unknown place called SERI." With several contacts, she met Paul Weaver, who offered her a job on the spot after getting a one-year



In 2011, staff scientist Carrie Eckert (left) measured hydrogen production of an engineered microbe. Pin-Ching Maness (center) and scientist Jianping Yu (right) look on. *Photo by Dennis Schroeder, NREL 32726*

grant from the DOE Hydrogen Program to work on bacterial hydrogen production mediated by nitrogenase. "My very favorite enzyme," said Maness.

However, things were choppy at the laboratory. On her first day at the job, in April 1981, SERI laid off about half of its staff, going from nearly 800 employees to only 400. "Back then, very few folks had heard of renewable energy or SERI. It was a time of turmoil, chaos, and trial," she said. "But I was never discouraged. My one-year tenure turned into a regular assignment in 1982, which set the stage for a passionate pursuit for renewable technologies for the next 38 years."

In spring 2020, Maness retired but stayed on as an emeritus researcher, eager to extend her team's accomplishments.

"For the past three decades, I have achieved what I set out to do, above and beyond my wildest dreams, with the help of my colleagues inside and outside of NREL," she said. "I have always had a passion for developing various microbial platforms to yield biofuels from diverse feedstocks."

She added, "I am most proud of expanding and solidifying the biohydrogen portfolio for DOE, taking it to the next level of becoming a consortium of multiple national laboratories as a feasible route producing hydrogen via biomass fermentation, for which NREL is the lead."

For more than a decade, Maness' team cracked the genetic system of a very tough cellulose-degrading bacterium, *Clostridium thermocellum*, by manipulating its genome to increase hydrogen production and improve biomass use. "Along the way, we discovered this microbe can simultaneously fix carbon dioxide while degrading cellulose, a seminal discovery with ramifications in improving carbon-conversion efficiency," she said. All of it proves that an 11-year-old girl really can dream of a career and make it happen.

Her vision remains clear. "Our work is not done yet," she said. "We still need technological breakthroughs to enable a fuel economy based on bioenergy and biofuels."

## Zhang and Her "Super Bugs" Form a Hit Duo

Sometimes, breakthroughs come from a single platform. That's the case with Min Zhang—and her favorite bacterium.

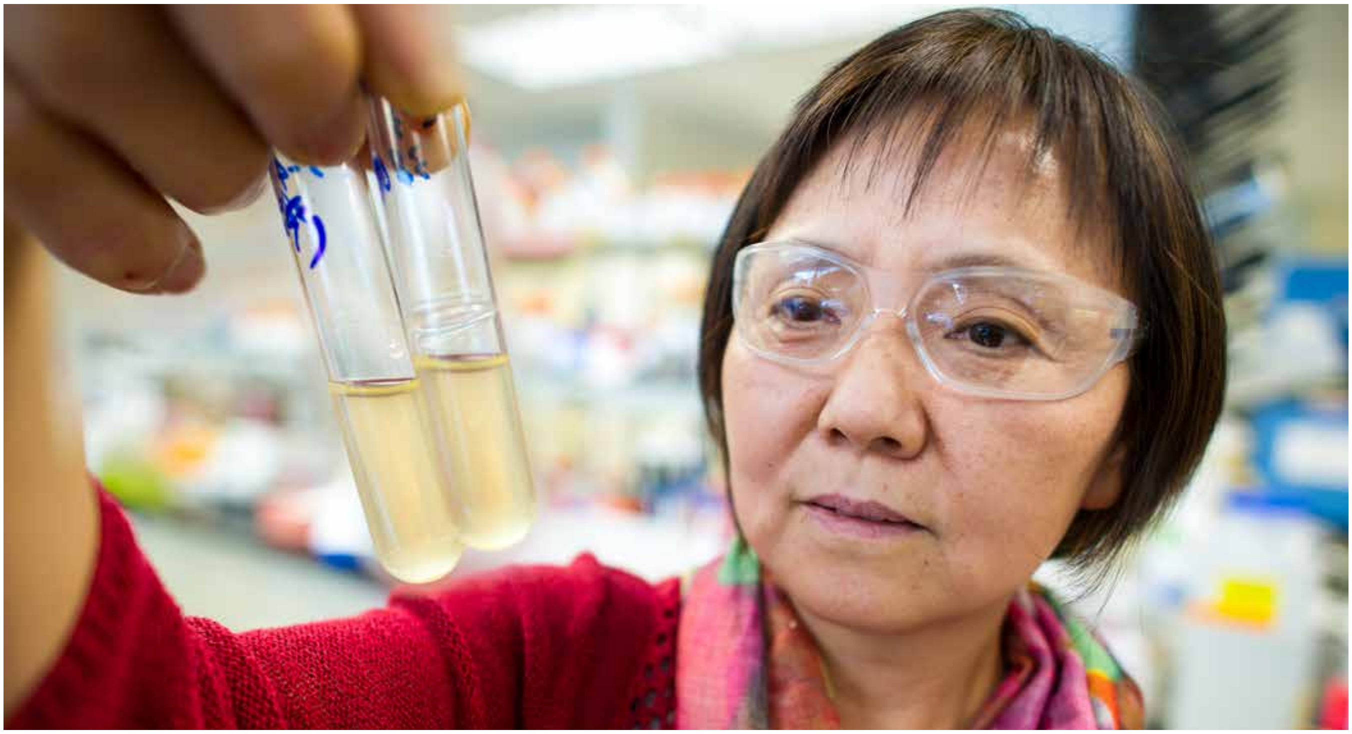
Zhang has a special relationship with *Zymomonas mobilis*, a rod-shaped bacterium that has bioethanol-producing capabilities. Of her many peer-reviewed papers and U.S. patents in the fields of biochemistry and biofuels, many reference this sugar-eating "bug."

Their fortuitous pairing began shortly after Zhang arrived at NREL in 1992. She came as part of a newly created team, by what was then the Energy Department's National Bioethanol Program, tasked with exploring a new path for ethanol conversion for biofuels. At the time, global researchers were focusing on using yeast for alcohol production.

"That [yeast] organism was the one people had studied for years. We at NREL decided to take a different approach," Zhang said. They chose the fermentative bacteria known to scientists as *Zymomonas mobilis*.

"We felt it could be very promising," she said, explaining that the organism could consume glucose very fast—three times faster than yeast—as well as produce ethanol at high yield, which would potentially improve fuel production costs. By tapping that hunger, researchers could use the bacterium to speed up the process of turning the sugars (such as those derived from the long-chain cellulose and hemicellulose found in feedstock) into usable fuels and products.

Next, the four-member NREL team successfully engineered the bug for pentose metabolism—pentoses are 5-carbon sugars that have been shown to be less appealing to organisms than 6-carbon sugars, such as glucose. Zhang and the team had more positive results. "We ended up with a breakthrough," she said, and their work garnered national attention. In 1995, Science magazine



In 2015, Min Zhang examines test tubes growing Zymomonas cells in the Molecular Biology Lab at NREL. *Photo by Dennis Schroeder, NREL 35204*

published "Metabolic Engineering of a Pentose Metabolism Pathway in Ethanologenic *Zymomonas mobilis*," and the editors of *R&D Magazine* honored the process with one of its prestigious R&D 100 Awards.

Three cooperative research and development agreements (CRADAs, or formal written agreements between a national laboratory and a non-Federal partner) followed, including a major commitment with DuPont, which built a plant in Iowa.

Although much of her time originally was spent doing foundational work with *Zymomonas mobilis*, Zhang didn't stop there—she pushed the frontiers of biofuel research even further. While observing a range of outcomes for various biofuels pretreatment processes, she focused on the problems of toxicity in breaking down cellulosic biomass for about four years beginning in 2008.

In 2012, with cellulosic ethanol maturing, DOE's Bioenergy Technologies Office was looking in fresh directions, including ways to create "drop-in" biofuels—fuels that could be mixed in directly with jet fuel and other products. "I started exploring new pathways to produce molecules that can be upgraded to drop-in fuels," she said.

And exploration is something she shares with others in her NREL cohort.

## Kim Magrini Takes Flight in the Lab and in the Skies

Although Kim Magrini earned a Ph.D. in physical chemistry at the University of Colorado–Boulder in 1989, the nearby Solar Energy Research Institute was not at the top of her wish list for postdoctoral positions. "I wanted to go to NASA," she admitted. But her husband, a radiologist, preferred staying in Colorado; so, they did. She came to SERI as a postdoc under **Greg Glatzmaier**, and then the lab hired her. "I'm so grateful that I've had a great career here at NREL, and many NREL-developed technologies are used at NASA, such as photovoltaics on the International Space Station," she reflected.

In 1990, Kim Magrini operates a device for measuring the output of high-intensity light sources. *NREL Photo by Warren Gretz, NREL 03944*

Pursuing her field of catalysis, using materials that speed up chemical reactions, Magrini made an impact quickly. "We were working in photocatalysis. There are inexpensive photocatalysts, like titanium dioxide, that when activated with light, rapidly transform harmful organic species in water and air to harmless compounds like carbon dioxide and water," she said. The investigation was successful. On the wall of her office in the FTLB is a plaque for a 1992 R&D 100 Award given for "Solar Detoxification of Hazardous Organic Materials in Groundwater."

Catalyst development also provided opportunities to work with industry. She developed with Yves Parent and CoorsTek Ceramics a fluidizable reforming catalyst that efficiently converted byproduct tars to syngas during production of biomass gasification ethanol. This work resulted in a patent licensed by industry. Currently, she works with Johnson Matthey, an industrial catalyst supplier, to modify zeolites for biomass conversion to fuels and products.

**The Steamboat Springs airport cat, Ted, with Kim and her plane.**
*Photo from Kim Magrini, NREL*

Another aspect of her life revved up, too. "After all the years of studying, I could afford to fly again," she said. Magrini went to the Boulder Municipal Airport and renewed her pilot's license with an instructor. She was aloft. But nothing could prepare her for being airborne on September 11, 2001, in her private plane. Being forced down by fighter jets seeking to clear the air space was the scariest moment in her life. Yet, it didn't discourage her.

Flying is not something alien to Magrini's scientific bent. She sees some similarities between her work at NREL and her time flying. "It's probably all the technical aspects of flying and research. A lot of studying goes on all the time with respect to staying current in flying. And you have to study and stay current in your field of research as well," she said. "To get good at it, you have to keep doing it."

One of the things Magrini helped take flight at the laboratory was NREL's Davison Circulating Riser system, an installation four years in the planning and execution that will help researchers and industry learn more about converting biomass to fuels intermediates, fuels, and, potentially, chemicals. She also developed a rapid screening method with the United States Forest Service that analyzed organic carbon content in soils that is used to measure soil health. One aspect of this work had Magrini and her colleagues taking soil cores in the Hayman, Colorado, burn area to determine how badly the soils had vitrified from the heat of the fire in 2002. The method is also used to assess how well bio-derived chars will function as natural soil amendments. This work was awarded an NREL Chairman's Award in 2006.

Throughout her career at NREL, Magrini has enjoyed working on research that spans materials development, significant industrial collaboration, and the ability to apply NREL research to industrial problems. As Magrini said, "It has been a wild flight."

## Yu Finds a Lifelong Love of Genetic Science

Jianping Yu was attracted to his future wife, Yali, at a young age.

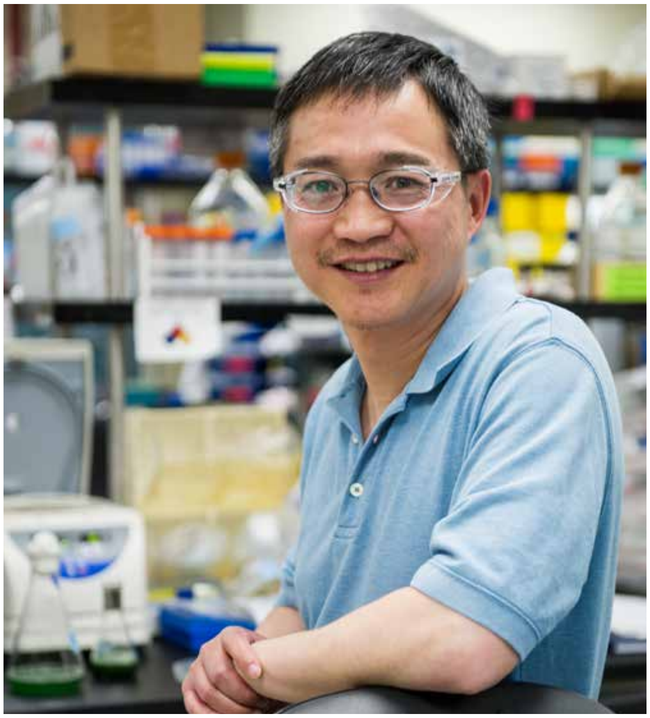
"It was like falling in love in first grade," he said. When they met, her family was afflicted with hemophilia, a mostly inherited genetic disorder that impairs the body's ability to form blood clots, causing the sufferer to bleed severely from even a slight injury—in extreme cases, it can prove fatal.

"I witnessed a lot of pain in her family," he said quietly. The greatest tragedy was the death of Yali's brother, who was about five years older than they were, in middle school. "When he was lost, I felt the loss as well," said Yu.

He explained it like this: "I thought that if hemophilia is a genetic disease, there's a genetic defect, and perhaps there will be a cure. That really motivated me to learn more about genetics; maybe I could help solve the problem of this genetic disease."

However, advances in medicine helped to ease the challenge of hemophilia and, as a result, Yu realized that he wouldn't need to devote time to this specific disease anymore. He began thinking about his future and decided he was interested in plants and photosynthesis.

"Plants do amazing things. They convert solar energy into food, fiber, materials, fuels, a lot of things," he said. So, the future NREL senior scientist began investigating biology in school—a passion he's never lost.



**Jianping Yu in his molecular biology lab in 2015, where he was examining various genetic strains to promote ethylene production.** *Photo by Dennis Schroeder, NREL 34221*

As for Yali, their bond grew, and the couple eventually married.

Yu played table tennis in high school and, later, attending Sichuan University as a biology major, he eventually become captain of the gymnastics club.

Like all athletes, he suffered some mishaps. "Any mistake is probably a mental mistake. Sometimes you cannot decide when to jump. If you've started running toward the obstacle and can't decide—you crash," he said. Such lessons linked with his education. "I was pretty disciplined, and that got reinforced by being in a team sport," he said. Teammates learned how to watch out for one another, which exercises to do, and how to improve. "A lot of things in my life are connected," Yu said.

Following graduation in 1985, Yu was pursuing a master's degree in China when his adviser went to the United States to spend a year at Michigan State University (MSU).

Yu was interested in the United States, and a number of his associates traveled there to study. "I could tell from reading books that science and technology were much more advanced in the West," he said. With political upheaval adding to uncertainties in China, Yu decided to try MSU.

He applied to the Plant Research Laboratory (PRL) and was accepted into this joint venture of the university and the U.S. Department of Energy. "PRL is very good in research and training," he said, and it also allowed him to choose cyanobacteria, his so-called "green bug." This group of photosynthetic bacteria lives in soils and in water and has proven ideal for genetic research. "The power to make specific changes to the genome and the power to change one step of metabolism lead to more precise understanding of metabolism and its regulation," Yu said.

After earning his Ph.D. in plant biology in 1996, Yu reached out to NREL in 2002. He had a good impression of the laboratory, but an immigration lawyer advised him not to switch jobs while pursuing his green card registration. It wasn't until 2005 that Yu again contacted the laboratory and accepted a position as a research associate.

Yu likes his green bugs. He chose them after earlier experimentation on animals as a biology student, dissecting frogs and chickens. "I just didn't like the smell and the blood, and I thought that plants and microbes would be easier to work with," he said. But those early sessions provided necessary training. "I learned about how the body system works," he said. "It helped me think about how plants work. Biology is interconnected."

> "He made a breakthrough and was able to engineer the same microbe to produce hydrocarbon-based biofuels, which led to a distinguished R&D 100 Award."
>
> —Pin-Ching Maness

It's not merely the green bugs that interest him with their "best genetic system." Throughout his career, he has valued genetic tools. "I felt that if we could apply genetic tools to study a process, we can really understand something in more depth," he said.

Yu has used those tools to delve into photosynthesis and organisms. "If you have the proper genetic tools, you can make specific changes [in genetic makeup, altering mechanisms]," he said. The application has allowed him to reverse the conventional process used to make plastics and other materials—which emits carbon dioxide. His work typically focuses on getting photosynthesis to take in carbon dioxide and then make organic compounds.

"He made a breakthrough and was able to engineer the same microbe to produce hydrocarbon-based biofuels, which led to a distinguished R&D 100 Award," team member Maness said. "He also conducted fundamental research probing how the carbon and electrons are being redirected when a novel pathway is expressed and its impact on improving photosynthesis," she said. She described the latter as "a holy grail" for harnessing solar energy.

His use of a strain of genetically modified cyanobacteria to produce bioethylene won not only the R&D 100 Award, but the even more prestigious Editor's Choice Award in 2015 from *R&D Magazine*. Yu's research demonstrated that ethylene could be made directly and continuously from a genetically modified cyanobacterium using sunlight and carbon dioxide.

Yu believes in another coming green revolution. "We're already in the next revolution using photosynthesis," he said. He thinks that with the use of advanced genetic tools, researchers can boost photosynthetic output without increasing the use of fossil resources. This step can slow down the release of greenhouse gas into the atmosphere, while producing more food, fuels, and materials.

According to Yu, photosynthetic energy-conversion efficiency is still extremely low. "We do photovoltaic studies at NREL, and we are one of the world leaders in energy-conversion efficiency," he said. "We demonstrate up to 40% energy-conversion efficiency in photovoltaics; whereas, in plant systems, the energy-conversion efficiency—calculating incoming solar energy and harvest—is far less than 1%, which means most of the energy is not used."

"I think there is huge room for improvement," he said. "It is quite obvious to me that the cyanobacterium is not performing at its potential."

Using genetic modifications and other genetic tools could provide a path forward. Even slight increases in efficiency could pay huge dividends in terms of producing food and materials. "Nowadays, there's added urgency for understanding photosynthesis and improving energy-conversion efficiency because of climate change," Yu said. "But I think NREL could be a world leader. We're making incremental advances all the time, but we'll need a lot of funding support."

The same spirit and discipline that carried him as a boy—and as a gymnast—carry him forward. "I think we have the technology pieces now that will enable this revolution," he said.

## Michael Crowley Finds Benefit in Sustainability, Computers, and a Yoga Mat

Maybe it was the jungle gym his father fashioned out of used pipes—or the merry-go-round built with a used dryer tumbler and a discarded car tire—that helped inspire Michael Crowley as a boy growing up on Long Island, New York.

With nine children to raise, Crowley's father, a statistics professor on a tight salary at Fordham University in New York City, had to be inventive. "He was very pragmatic and could do anything—all the plumbing, electricity, car repairs. Our backyard was just full of innovative things we made," Crowley said.

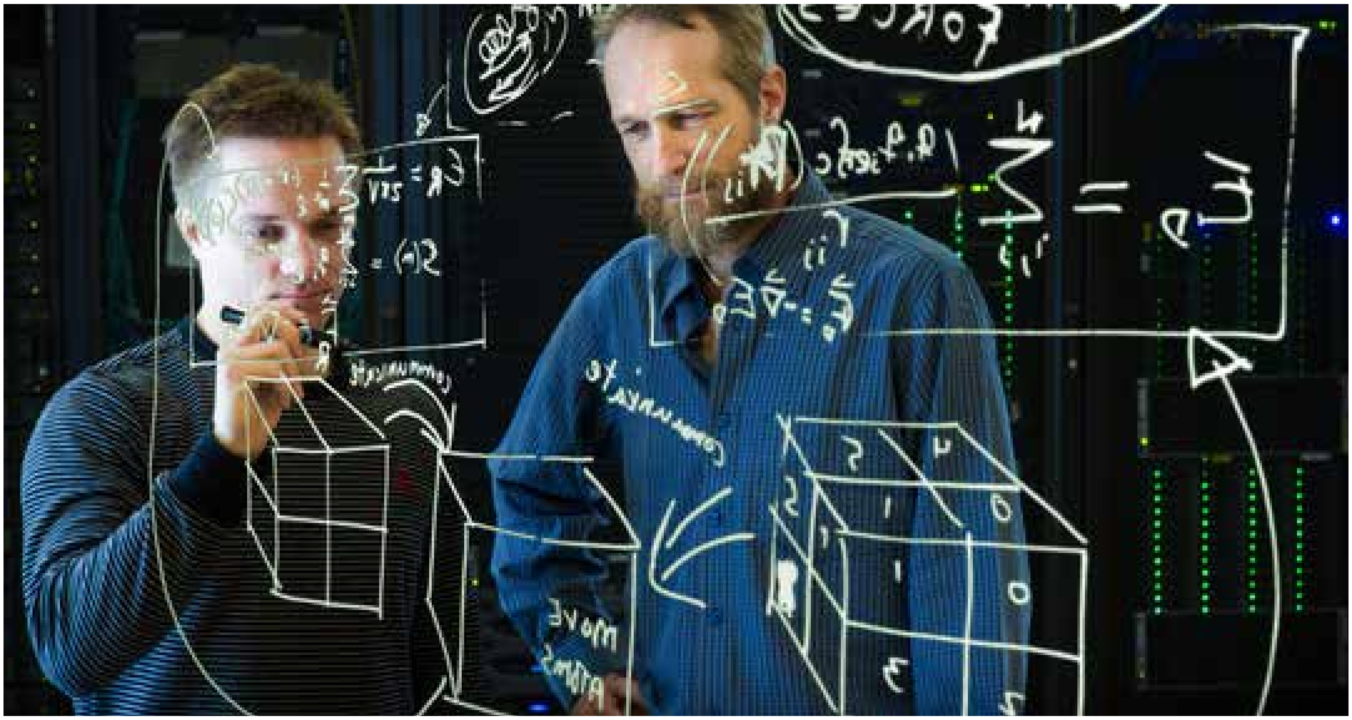
Once, when the telephone company was replacing a pole next to their house, his father asked for the old one. "We chopped it up with hatchets and saws, then painted it, making it into a totem pole," Crowley said. Sometimes, the boys would straighten bent nails so the reclaimed nails could be reused in home projects—early lessons in sustainability.

> "I'm very aware of how and why things can and should be more durable, more repairable."
>
> —Michael Crowley

"I'm very aware of how and why things can and should be more durable, more repairable. Another strong thing I saw from [my father] is that you could do anything. It's not like, well, you have to call the plumber or the electrician. You can do anything—anybody can. And to some extent, it should be that way," Crowley said.

As proof, when he was in eighth grade, Crowley bought an old Rambler for $10, then he and a younger brother took the car apart—and put it back together. "We found out everything there was to know. From then on, we could do anything," he said. In later years, he fixed his rusty 1980s Toyota pickup truck, only moving into the computerized world of cars when a virtually repair-free electric vehicle became available. Today, he does all of his own home repairs.

Self-sufficiency wasn't all Crowley and his siblings absorbed.



Former NREL scientist Antti-Pekka Hynninen and Michael Crowley (right) used the laboratory's supercomputer to simulate the motions of thousands of atoms, leading to greater understanding of how molecular models perform. *Photo by Dennis Schroeder, NREL 24348*

Growing up in an analytical home environment in the 1950s and 1960s, Crowley's family was exposed to various calculators, precursors of today's computers. "Our dad was a pioneer in getting computers going, especially at Fordham," he said.

Not only would the kids learn about slide rules (Crowley recalled a 6-foot model in his father's classroom that was used to demonstrate techniques), but they played with mechanical calculators the professor brought home. "There were hundreds of buttons—and if you've ever seen one of these things do division, it's an amazing thing to watch. You put in your number and move this carriage all the way over. It just starts figuring out how many times this number can go into that," he said.

The machine could get the remainder, shift the carriage over by one row—basically the way someone does long division—then crank away again with a steady sound: *Chucka-chucka-chuck. Chucka-chucka-chucka-chuck*. It left the number up on top, showing how many times a number went into it.

Crowley and his siblings—two girls, then five boys (Michael, the eldest), and two more girls—would try to beat the machines. Even when they couldn't, the attempts were fun. "To a large extent, I was exposed to [computing] so much, I knew how much you could do. That's one of my major tools for the science I do now," said the Renewable Resources and Enabling Sciences Center director.

Crowley said he wasn't trying to follow anybody in his career. "There wasn't a push to become an Einstein or to be better than anybody else. That was the natural intellectual environment we were in," he said, and noted, "That's why I do what I do."

Not surprisingly, Crowley attended nearby Fordham University. "I just loved math because it came so naturally to me," he said. He started his undergraduate years in biology, but eventually switched to chemistry. "I very quickly lost interest in biology because of how much memorization from physical principles there was and how little understanding was involved back then," he said. "I gravitated toward more physical sciences and mathematical things." Physical chemistry was a good fit. "It was always a challenge and interest to me. I like things that are challenging," he said.

Although he loved New York, Crowley needed to explore the West—and found his way to the University of Montana. He embraced the mountains and wilderness while pursuing both a master's degree and a Ph.D. in physical chemistry. Preparing for his thesis, he dove deeply into computerization. "I was very good at it, so it was a nice combination," he said. "I did plenty of experimental work, too." He experimentally discovered chaos in coupled chemical oscillators and proved the chaos computationally and theoretically.

Michael Crowley leads an NREL class in a yoga flow. *Photo by Dennis Schroeder, NREL 35265*

He also met his future wife, Gale, in Missoula. She was an artist with three young children—ages 2 through 6. “So, at 24, I essentially became their father,” Crowley said. It wasn’t that tough a transition. “I grew up in that environment,” he said, and the children loved him. There were complex times, too, but Crowley and his spouse worked to find balance—giving the children the best from work and life. Tragically, Gale died in 2011 following a short illness.

During their time together, there wasn’t a grand career strategy. But, after Crowley earned his doctorate in 1985, computation and modeling remained a thread running through his career. “I’m good at this, and if there’s a way to make a living with this, then go with it,” he reasoned. As a result, the family tried to “just keep moving and going with the flow wherever there looked like there were opportunities.”

Crowley had a postdoctoral fellowship at Brandeis University studying chemical chaos, which offered him the added bonus of swimming at Walden Pond. Then he was an assistant professor at Pennsylvania State University, studying semiconductor surfaces, followed by a stint at West Virginia University where he applied the nonlinear dynamical theories to controlling chaos in chemical oscillators and flame fronts. At Carnegie Mellon University and the Pittsburgh Supercomputing Center, and at the Scripps Research Institute, Crowley developed highly parallel methods for simulations of biomacromolecules in conjunction with two other researchers.

Also at Scripps, a shoes-optional workplace (at least for computational chemists) located near the beach in San Diego, there came another personal discovery—yoga.

In late 2006, there was one more change headed Crowley’s way: Funding for his area of theoretical research was drying up at Scripps. But a visit by NREL’s Mike Himmel opened a door to a new life. Himmel was at Scripps to determine whether some of the supercomputers affiliated with the institute could advance NREL’s research.

Crowley must have made an impression while he was confirming that there were some potential computer models that could boost NREL. He began doing part-time research for NREL in conjunction with **Mark Nimlos**. However, after six months, with things changing rapidly at Scripps, Crowley reached out to Himmel, an NREL research fellow who manages the Biomolecular Sciences Group in the Biosciences Center. Within 15 minutes, Crowley said, he received a very encouraging email.

In a matter of weeks, Crowley headed to NREL.

Joining the laboratory in 2007, Crowley began developing a simulation and theory group to lead the theory, modeling, and simulation efforts for biofuels research. “It was a really good move,” he said, “plus, I could be doing a mission that’s really important to me.” Additionally, he could teach yoga when time permitted, one of the practices he integrated in his life, and share his expertise.

His research is important to him. “I do like working in biofuels,” he said, and he’s been involved in upgrading some natural processes of things used in global energy sources. “One side of my world is to stay on top of, and push ahead, our computational and theoretical methods,” Crowley said. “But, at the same time, we’re looking for where the problems are, where the bottlenecks are, does the tool we have apply here? Can we actually help?” For example, his group has designed and implemented new methods and algorithms specifically for biomass- and biofuel-related questions.

“That’s where I like to be—where I’m looking to see what I can do, can predict, and make a difference in solving problems that appear unsolvable but are still fun and interesting,” he said.

Crowley takes the mission seriously. “I feel a strong mandate and ethical responsibility, to use taxpayers’ money, and the world’s investment in our lab, to solve the problems we’re being asked to solve. Not just those that are of academic interest,” he said. “That’s not to say that, in general, pure scientific questions don’t eventually make their way to being important. We have our toes in both camps: developing new methods, new theories; but on the other hand, always keeping an eye on where the methods apply to important problems and will make a difference in finding much-needed solutions.”

Crowley sees life as having come full circle. "It's interesting that I'm now back doing biology, but from a physical science direction," he said.

He remains curious, yet practical. "There are people who like to do these models of, say, a giant system on a giant computer. They'll say, 'Look, it holds together.' Okay, but what did we learn here—besides the fact that we can run this big problem on this big computer? Where is this useful to us?" he said.

Perhaps it comes back to the boyhood house on Long Island. "All those projects—we were trying to figure out how we can build what we want here," he said.

Crowley still has a clear childhood image of an airplane they assembled. "As a little kid of about 6, I remember we had a wagon, a fairly good-sized wagon. We set a big, 2-by-6 [board] across the driveway and had some old carriage wheels on the frame for propellers," he said.

The Crowley crew attempted to fly, using a long driveway as the runway. "We tried, I don't know how many times, taking turns driving. We were trying to get this thing off the ground. This was our airplane. We felt we weren't turning the propellers fast enough, or we weren't pushing fast enough," he said.

Of course, it never took flight. "But we believed we could do that. We kept looking for a solution. 'Okay, what's the problem here? And how are we going to solve this?'" Crowley recalled. "It wasn't enough that it looked like it was an airplane. This needed to get off the ground."

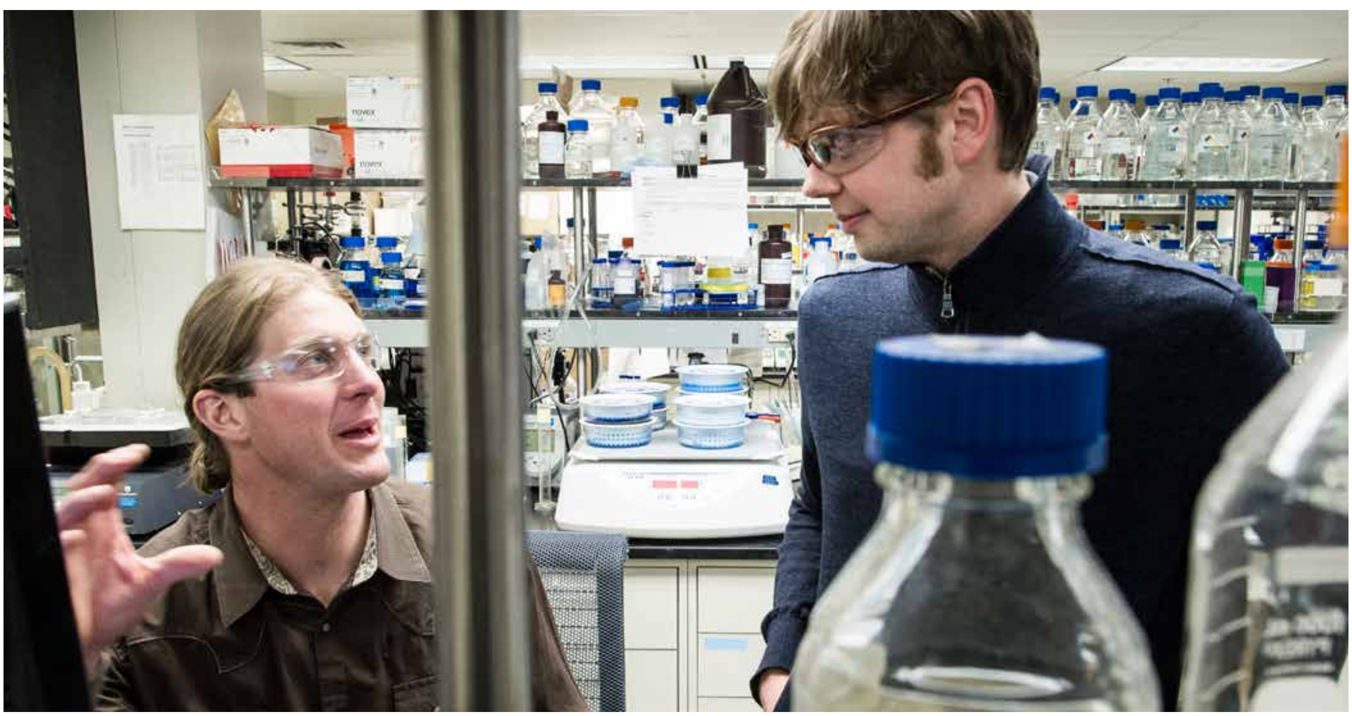
That spirit remains, as Crowley pushes ahead—on the yoga mat and in the lab. "Sometimes there's opportunity, and sometimes there isn't. You look for it, and try to stay the best you can be, and discover the things that really are worth pursuing," he said.

## Michael Resch Rebounds from Pro Basketball To Score in Biochemistry

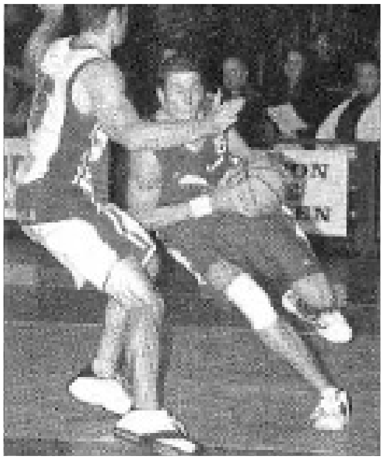
It's hard to miss Michael Resch.

The researcher in NREL's National Bioenergy Center stands 6-feet, 9-inches tall, and your first thought is, well, he *must* be a basketball player. True.

But growing up in Madison, Wisconsin, in the 1990s, Resch's main high school sport was football. He was on the gridiron every down, a tackle who was the biggest kid on the team. "I didn't get a lot of court time in basketball," he said. "We had three guys taller than me."



Michael Resch (left) and Senior Research Fellow Gregg Beckham discuss results found in vials containing an enzymatic digestion assay at the Field Test Laboratory Building. *Photo by Dennis Schroeder, NREL 28878*



A French newspaper pictured Michael on the court. *Photo from Michael Resch, NREL*

Resch thought of playing football at St. Cloud State. Yet, as the saying about hoops goes: "You can't coach height." And so, during a tournament with a competitive traveling team, he caught the eye of a recruiter from Lindsey Wilson College, a small liberal arts college in Kentucky. His path took a different bounce. "They flew me down to Kentucky and offered me a full ride," he said. "To me it was a free education."

Resch got good grades, but also burned out on basketball. He missed one season after hurting his knee; it required surgery. But, overall, he put up good numbers as a forward/center, averaging more than 20 points and 10 rebounds per game.

As a result, Resch was invited to a non-NBA players' showcase in Utah following his senior year in 2001. Separately, he had already taken his Graduate Record Examinations (GREs) and applied to Colorado State University for a master's degree program in biochemistry and molecular biology.

The following week, a team from a tiny town in the Bordeaux region of southwest France offered him an airplane ticket—in addition to a free apartment, car, and about $30,000 in untaxed salary for a 10-month season. With no knowledge of French, Resch folded his lanky frame onto a plane for his first-ever trip to Europe.

Meilhan-sur-Garonne was a touristy commune with one bakery, a post office, and city hall surrounded by vineyards and farmlands. Because there was no professional soccer team, all the local money poured into the basketball team.

Resch was a hired gun.

He was the lone American on the team, brought in so the club could win—and, thereby, move to a higher league in the French system. Each step up brought more prestige and sponsorship money. There was an adjustment for the big guy known as the "Ricain" (short for *Américain*). "Pretty much no one spoke English in the town or on the team," Resch said. One word made sense: *Allez!* Go! It was used to explain plays in combination with pointing. Eventually, the team hired a translator—whom they cut after six months when Resch mastered a smattering of the language.

His first day in France was Sept. 1, 2001. When the Sept. 11 attacks happened, Resch was in an information vacuum. "At that point, I had no cable TV. I had all the news from the Twin Towers in French. It was crazy. I thought it was a movie," he said. Already a local attraction, he became the focus of media attention. "I was getting interviewed by local newspapers, asking 'Are you ready to go to war?'"

Yet, despite his being a foreigner, he felt completely welcome. "Everyone was super nice. I was part of the family," he said.

The game was new, too. "I played forward, but their style of play is so much different than here. They grab and push, more like soccer. Very physical," he recalled.

With Resch, the team flourished.

The following year, with the help of an American agent, Resch doubled his salary and signed with a team in a higher league—a decision that would come back to haunt him.

"Things were shady there," he said. Playing for Cherbourg, located in Normandy, was completely different than Southwest France. For one thing, the team was owned by a bank, which meant a more business-like approach for the Seagull team. The squad would play in front of about a thousand fans, so it was a bigger event. More important, winning meant bonuses after each game. Losing meant trouble.

In the off-season, Resch had undergone microfracture surgery on his knee at one of the world's best clinics in Madison. To recover, he was supposed to be "nonweight-bearing" for six weeks. He wanted to do his rehab there in Wisconsin, but the team ordered him back to France. They wouldn't pay Resch until he signed an agreement to play. Worse, the first day he could walk was their first game.

"I was on crutches. I hadn't walked, let alone run," Resch said. He was young and felt trapped. The team could get another American easily, but it would have been hard for him to land on another team. "So, they had me. I was an idiot. I said, 'Okay, I'll sign it,'" he said.

The season was, to use a French concept, surreal. "I quickly realized that this was the last year I would play. My knee didn't feel good, and I had started back too early," he said. Plus, there was much more pressure, with more professional French players who were counting on bonuses for each win.

The locker-room atmosphere soured more quickly than brie left out in the sun. "When you win, it's a good team effort. When you lose, it's the American's fault. That's how it was. In the press, on the team. They fault you for not doing enough," he said.

Resch was singled out. Push came to shove. "I probably didn't handle it like I should have. I would get mad back," he said.

Then came one bit of luck. He got a call from Karolin Luger—an Austrian-born Colorado State University (CSU) professor known for her work with nucleosomes and discovery of the three-dimensional structure of chromatin—who was recruiting for CSU's doctoral program. The one week Resch had off was the week CSU was interviewing. He flew to Colorado. Although he hadn't been accepted, he was warmly received and encouraged to apply for a Ph.D. program with a stipend. "Serendipitously, my GRE scores were only good for three years; if I'd played for another year, there's no way I would have been able to take a biochemistry subject test after three years in France," he said. He was accepted at CSU—and nobody held his basketball adventure against him.

The season ended, his right knee barking. He took one farewell grand tour of the continent with friends, then headed to Colorado.

Resch got experience that led to his dissertation on the biophysical and structural properties of nucleosomes and chromatin—yet saw firsthand the struggles of an academic. He wanted something different. A posting for a postdoctoral researcher position at NREL caught his attention.

In 2008, he joined the Cellulase and Hemicellulase Enzyme Characterization team at NREL.

Ironically, in the same NREL class of postdocs was another former college basketballer—Adam Bratis. After a trip to the gym, Resch was back on the court for a recreation league team called the Biomass Ballers. "The league was terrible," he said, downplaying the fact that the NRELians won a championship. And T-shirts.

He does see links between basketball and science. "I think I learned more from science, actually," he said. "How to focus and stay prioritized. If only I could go back in my basketball career with what I know now."

Additionally, Resch was considered the leader on most teams that he played. "That taught me a lot about the advantages and pitfalls of leading," he said. "There is also an art to motivating a group of highly successful adults. I think the leadership aspect of playing sports has helped me as a section supervisor here at NREL."

His work has focused on "things that can be integrated into diesel fuel or gasoline, but not change the characteristics," he said. These can be used in drop-in fuels and plastic precursors. He is also involved in investigating biological lignin depolymerization with the goal of converting lignin into value-added fuels or chemicals.

Resch describes research into the realm of "biological deconstruction of lignin, feeding those monomers into microbes, which can be upgraded into other interesting chemicals."

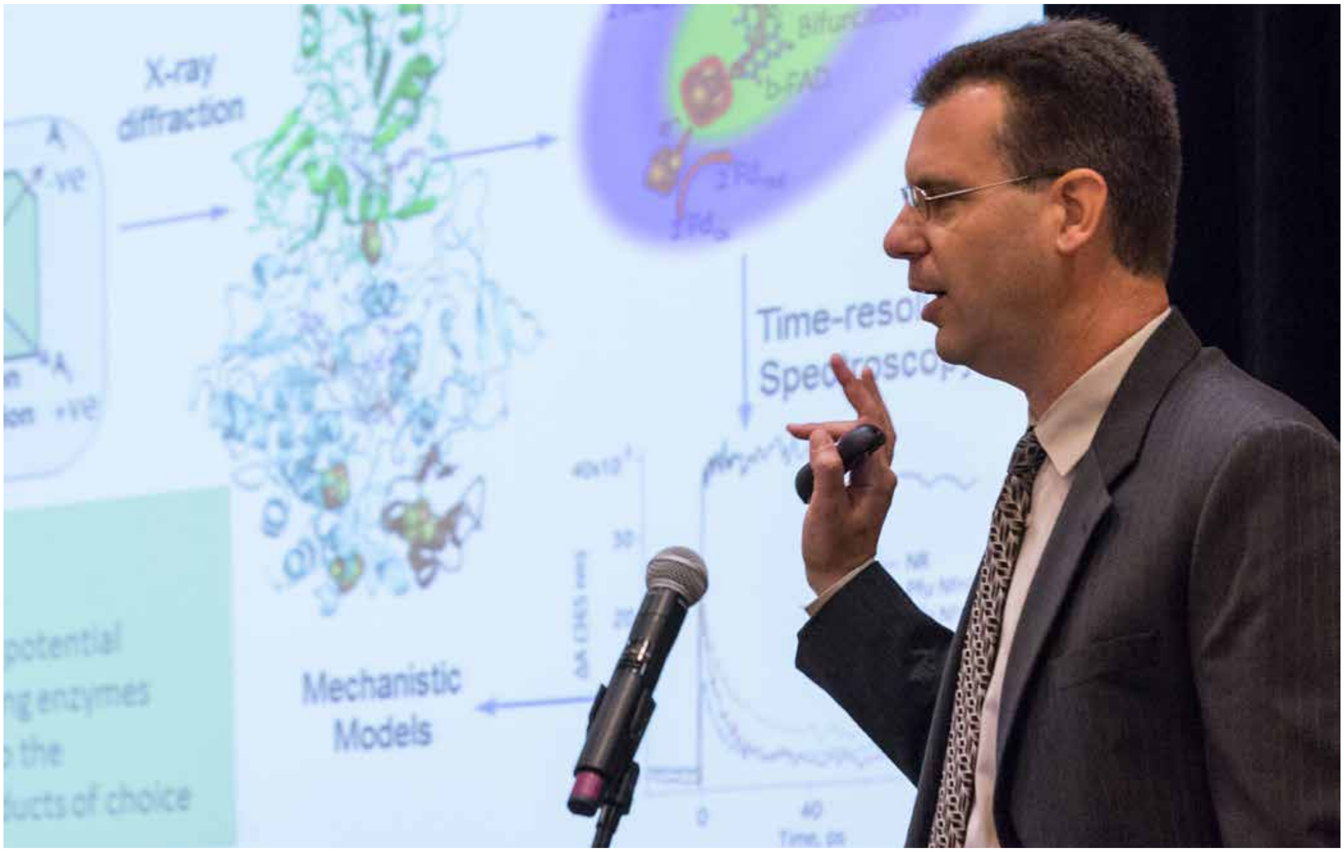
In 2016, when **Tom Foust**, his director in the National Bioenergy Center, suggested that working in the federal government could benefit both him and NREL, Resch jumped at the chance. After making inquiries, he found an opportunity at the DOE Energy Efficiency and Renewable Energy's Bioenergy Technology Office (BETO) in a management and operating (M&O) detail. This M&O practice, initiated during World War II, allows the federal government to tap outside experts for specific subjects.

> "There is also an art to motivating a group of highly successful adults. I think the leadership aspect of playing sports has helped me as a section supervisor here at NREL."
>
> —Michael Resch

With the details worked out, Resch and his wife, Laura, prepared to move at the start of Fiscal Year 2017. They packed, took their two young sons, and planned a two-year hitch in Washington, D.C. He worked on the conversion and algae platforms, as well as Area 6, which had crosscutting interactions with a variety of federal agencies in addition to the White House Office of Science and Technology.

When he returned to Colorado, he brought back new insights.

"I got lucky," he said—and despite the sore knees it took to land him, NREL did, too.




Adam Bratis speaks to attendees at the Inaugural DOE National Laboratory/USDA Research Collaboration Meeting on Bioenergy and Biobased Products in 2016.
*Photo by Werner Slocum, NREL 39554*

## ALD Adam Bratis Jumps for Science

Playing basketball for a private Quaker high school in Philadelphia, Adam Bratis, a 6-foot, 6-inch power forward, was a fierce competitor who caught the attention of college recruiters. "I hated to lose at anything," said the associate laboratory director (ALD) for Bioenergy Science and Technology with a smile. "It's okay to be competitive and still be a nice guy."

A self-described "science-y jock," he found what he calls his "happy place" on the basketball court. Once there, he could handle the ball and shoot. Still, the guy whose college coach told him he "couldn't jump over a grain of rice" was shooting for something more than hoops.

"Education was super important in our household. My dad was first in his family to go to college. Mom, too," he said. "It was ingrained in me from an early age: Do well in school, go to college, graduate school—and education was going to open up your life." Although "nerdy," Bratis and his sisters did well; their parents pushed hard. "My fear was that I didn't want basketball to be taken away. That's what I loved," he said.

Today, he grapples with the issue of parental expectations regarding his two sons but shrugs off any resentment of the past. "It is what it is," he said. "All that pushing helped me. I might not have been super motivated on my own."

Bratis rebelled in one area: biology. "I never took a single biology class in college," he chuckled. He majored in chemistry at Clarion University, earning a Ph.D. in organic chemistry at the University of Delaware (where he also earned an M.B.A.). He was clear-eyed about his future: "I always wanted to go into industry, pharmaceuticals," he said.

Because family members had suffered from both Parkinson's disease and Alzheimer's, Bratis focused his graduate research on finding an anti-Parkinson's drug. He admits he got tired of school and was getting job offers from major corporations. So, after earning his Ph.D., he took a job with Mobil. It launched an 11-year run with the energy company (which later merged with Exxon).

"I had a lot of jobs with Exxon—R&D, working in a refinery—and got lucky enough to have a gig at corporate headquarters," he said.

Once there, Bratis and some others were assigned to long-term strategic planning, looking 30 years out to foresee what the energy landscape of the world would look like. It was 2007; he was attending conferences, trying to understand the world of renewables, including wind and solar energy, biofuels, and electric vehicles. "I loved it and thought it was a direction we should be going in as a company—and we weren't moving that way fast enough," he said.

Meanwhile, ExxonMobil was putting him on a potential executive track requiring regular transfers. Bratis and his wife had had enough, moving to New Jersey and Texas. Around that time, he met an NRELian who told him about a job opening for a center director; he didn't get that position. And, because he knew he didn't want to be a professor, yet was unsure about where to go in industry, the concept of a national laboratory made sense.

> "When you can actually get a model to give great results—it reminds me of standing 15 yards behind the line of scrimmage, seeing the opponent line up, and thinking 'I know the play.'"
>
> —Tom Foust

"I saw NREL as a two-year stopgap," he said. "I said, 'Alright, if I don't know who I should work for in the industry, if I work with a place like NREL that partners with these energy companies, I'll be able to figure out which one I should go to next.'"

He arrived at NREL in 2008 for "a brief stay." As Bratis settled in, he discovered something about himself and the laboratory: "I fell in love with this place," he said. "I'm passionate about what we do and the people here. And we love Colorado." His stopgap move turned into a longer-term stayover. As an ALD, he gets to play coach to his scientific team—and it's a good fit.

As for the other bio-jock, Tom Foust had his own path to bioenergy.

Even though he labored in scorching steel mills as a teen, and later walked onto Penn State's football team as an undersized back, Foust described himself as a math nerd thrilled by pioneering computer arrays.

He recalled his amazement when entering a building at Los Alamos National Laboratory filled with big computer monitors in the early 1990s during an Energy Department tour. "When I first saw the darkrooms with glowing blue lights, I thought it was the coolest thing," Foust said. "There were people typing, looking at data, and simulating power plants. I thought, 'That's what I want to do—be the guy who sits in front of the computer screen and mathematically describes stuff.'"

After starting research reaction kinetics modeling as a Johns Hopkins University graduate student, Foust discovered that he loved mathematical models. "It's my passion in life," said the National Bioenergy Center director. "I've always liked math."

And while some may not see a connection between a defensive back and a modeler, Foust thinks differently. "When you can actually get a model to run and truly give great results—it reminds me of when I was standing there, 15 yards behind the line of scrimmage, seeing the opponent line up, and thinking 'I know the play.' The two are similar. It's a natural high," he laughed. "Maybe it's the nerd in me or the gratification I get from modeling."

## The Marathon Intensity of Gina Fioroni

When NREL Senior Scientist Gina Fioroni was a girl, she and some friends came up with a brilliant idea. At least they thought so. "Mom had a clothesline tied to a tree on an embankment," she said with a smile. "That rope ran to the house. I thought we could make a really cool sky ride if we'd attach a bucket to the line and cruise down."

After climbing up several feet in the tree and preparing to launch, the future scientist learned at least one important lesson. "Guess what doesn't hold the weight of a bucket and kid?" she laughed.

Knowing Fioroni, crashing was no big deal. "It wasn't the first time I'd fallen out of a tree," she said. She persisted with her action experiments. In another inspired moment, she used her pet as a sled dog. It worked—until they hurtled toward a tree. "He went this way; I went that way. There were some 6-year-old cuss words, and I got to eat some soap for that," she said.

But such experiences formed a lasting philosophy—one that has enabled her to navigate ultradistance runs, but it also can apply to her far-reaching chemistry research in fuels: "Nothing ever goes the way you planned," she said.

For instance, Fioroni was in sight of the 2013 Boston Marathon finish line, about to complete her 50th state marathon in her native Massachusetts, when runners suddenly stopped. In the

**Gina Fioroni in 2019 studying autoignition kinetics and soot precursor formation in the biofuels research lab at NREL.** *Photo by Dennis Schroeder, NREL 59634*

ensuing chaos, she learned that bombs had exploded, unleashing tragedy—shrapnel narrowly missing her waiting family. Shaken but unbowed, she finished the run the following year.

Her list of misadventures goes on.

In August 2015, Fioroni found herself struggling in her inaugural Leadville Trail Run, a rocky 100-mile route that crosses a 12,600-foot Colorado pass twice after climbing more than 3,000 feet to the summit.

"I spent the first 40 miles throwing up," she said. "I almost quit at mile 13 and was sure I was quitting at the 50-mile turnaround." Urged on by her pacer, Fioroni gutted it out, her headlamp bobbing in the darkness. Somehow, she moved up 227 slots en route to a 169th-place finish. She may have been toughened up for the ordeal by the ridiculous 314-mile Vol-State run she had completed over seven days in Tennessee's July mugginess, featuring hot, miserable weather and bad hotels.

Despite—or maybe because of this—Fioroni continued.

Twice she was thwarted on ultraruns in the Andorra region of Spain. In 2015, she said, "Sleep deprivation caught up with me at the 100-mile aid station," ending her bid. Three years later, she easily made progress through the first 100 kilometers when a freak hailstorm caused organizers to evacuate the course. In 2019, despite some personal challenges, she finally succeeded. Running with a teammate in the Colorado-like landscape, she became the first American woman to complete the Eufòria, a 233-kilometer trail. "It took us 106 hours and 31 minutes," she said—a span that included less than eight hours of sleep, a necessity because the cutoff for runners was 110 hours.

While Fioroni admits to being a bit crazy in pursuit of extreme races, she said there's a reason. "It's kind of fun to push yourself through the challenge," she said. "You also go through cycles—'I definitely can't do this.' 'I'm going to do it somehow.' It's always an adventure," she said.

And even though it takes a few weeks to recover from some epic trials, she rebounds and dives into research. Not surprisingly, the first day back at NREL after Eufòria, she was part of an NREL photo session with her co-authors to promote a paper published in the journal *Applied Energy*, titled "Impact of Ethanol Blending into Gasoline on Aromatic Compound Evaporation and Particle Emissions from a Gasoline Direct Injection Engine."

Her pursuits outside the laboratory overlap with her career track.

"Ultrarunning absolutely reflects and influences my day job—I can think of two examples," she said. "The first is tenacity, a necessary character trait for being able to slog through 100- or 200-mile races. It's not easy. I've wanted to quit, but my determination and passion for the sport keep me going," she said.

"The same holds true for some of the projects I work on at the lab. They can be challenging, seem to be never-ending, and full of setbacks, but I never give up. And I continue to develop solutions until I find one that solves the problem," she said. "One of the things I enjoy most about working at NREL is the variability of my work as well as the difficult problems that I want to solve—like a challenging puzzle. It wouldn't be so rewarding if it were easy, right?"

"Second, as a long-distance runner, I have a love and respect for the outdoors. And NREL, of course, is focused on improving the environment and sustaining it for generations to enjoy. I love that I have a small part in that," she said.

The combination is clicking. Fioroni's contributions earned her a promotion to NREL senior researcher in the Fuels and Combustion Sciences group.

“She demonstrates natural leadership qualities and is a future leader for the group,” said NREL Research Fellow **Bob McCormick**, her mentor.

McCormick cited her impact as the lead author on three of five major journal articles she published in 2019. She’s also often sought after for collaborations across NREL centers as well as for her leadership in the realm of fuel properties for the DOE Co-Optimization of Fuels and Engines (Co-Optima) project. Co-Optima is a DOE initiative investigating fuels and engines as dynamic design variables that can work together to boost efficiency and performance while minimizing emissions.

“I’ve been trying to increase the number of publications we’re putting out,” Fioroni said. In her new leadership role, she is in her laboratory less frequently, but is still involved in fuel combustion research. “We’re looking at different [fuel] blendstocks that could replace petroleum in gas or diesel,” she said. The goal is clear. “We want to understand their auto-ignition properties so we can find something that’s as good as, or better than, ethanol.” Additionally, her team is seeking blendstocks that might be cheaper to make or don’t come from a food-source grain.

Outside the lab, Fioroni’s motor keeps revving up. After five years of trying to gain lottery entrance into the iconic Western States 100 endurance run, she was accepted into the annual June event in 2019 that begins in Squaw Valley, California, and ends 100.2 miles later in Auburn. Fioroni was eager to test herself in the event.

“You start by going up the ski mountain as the sun is rising and fog is on the fields. It’s really amazing,” she said. And although she encountered a few logistical hiccups—once missing her support team for a handoff at an aid station—she reveled in the journey. At one point, a famed ultrarunning champion high-fived her as she passed, beaming.

But the true highlight for Fioroni may have come as she chugged up Devil’s Thumb, an aptly named landmark that few relish after passing through searing canyons. As she progressed, a race official shouted, “How’s it going?” Her response was instant: “I heard you have popsicles at the top.” The incentive proved correct. “All I wanted was that Otter Pop,” she recalled—and relished the frozen confection while heading toward the finish line. As she took the final lap on a high school track, with fans cheering and music playing, she became emotional. It had taken her 28 hours and 10 minutes—nowhere near the elite mark. But, for Fioroni, it was a personal high.

She has said that she will continue running. A frequent training partner is engineer **Stuart Cohen** of the laboratory’s Grid Planning and Analysis Center. He contacted her in 2014 after reading an NREL profile about her successes and realizing they both had completed the Run Rabbit Run 100 in Steamboat Springs. “He sent me an email saying that we both had been the last two finishers of the race,” she said smiling. Since then, they’ve both crewed for or paced one another on long events.

She is looking at the long haul, too. “There are people in their 60s running ultras. I think that would be cool,” she said.

“The good thing about running is that it’s time to be alone with yourself, to clear your head,” she said. “The rest of the day is stressful. I’m always on the move. I have lists of lists everywhere. If I’m free, I go to a list somewhere and find something that needs to be done.”

> “So just be prepared for anything. That makes it fun, too.”
>
> —Gina Fiorori

And, as she continues the quest for the best fuel, she wants to fuel others’ achievements. “I want to be an amazing mentor to the people who are on the projects that I oversee. I want them to enjoy the pursuit,” she said.

Fioroni will make lists for her tasks in the lab and lists for her runs. But she is aware of reality, something that stretches back to her girlhood: Nothing ever goes the way you think it will go.

“So just be prepared for anything,” she said. “That makes it fun, too. You never know what you’re going to come across.” Her approach will stay the same when life throws her a curve. “You have to get through, and you just find a way to do it. So, when other things happen in your life, you’re like ‘Oh. How do I deal with this? I’ll figure something out.’”

As for people who question her participation in extreme endurance events, Fioroni cited fellow ultra-athlete Cohen, who once answered an inquiry by responding, “We are all a little crazy in some way or another.” For her, that’s the truth. “I always have people saying what I do is crazy,” she said. But it is what she wants to do. It is all part of the plan one cannot plan for.

Of course, Fioroni is not the only one whose outside passions reflect her drive.

## Ling Tao Keeps Chinese Culture Alive through Dance and Schooling

Ling Tao, a senior engineer from the National Bioenergy Center (NBC), has taken part in the Chinese New Year halftime celebration for the Denver Nuggets as part of a dance troupe from the Denver Chinese School (DCS). Her troupe performed in traditional costumes with other local groups in front of 19,000 fans. It went well. "I do public presentations quite a bit—so I was not nervous," she said.

Tao had joined the dance troupe to make better use of time while she and other moms waited for their children to finish DCS classes. "This is better than chit-chat. We get exercise and have a very good teacher," she said.

While the dance is based on tradition, to keep pace with the times, their teacher modified some 2,000-year-old classical movements with more modern routines in a nod to current musical styles. Still, some standards prevail. "Certain moves are trying to show beauty, but are also conservative," she said. There's a more modest approach in Chinese dance than in some other dance styles. Overall, Tao likes the benefits of the practice, which help her keep a work-life balance. "In dance, you try to coordinate your body to flow with the music. That's difficult, yet beneficial," she said. "It trains the other portion of the brain."

Tao is mindful that this practice is outside of her comfort zone. "I'm an engineer, all about numbers and logic," she said with a smile. She's as passionate about dance as her work. "I would like to get other women engineers involved," she said. The dance builds on her past activities: She loved singing and swimming and, at one point growing up in China, excelled as a gifted track-and-field athlete at school. Now, juggling demands as a parent, it helps keep her work-life balance in check—and accomplishments as a researcher flowing.

## Violeta Sànchez i Nogué: Fluent in Three Tongues, Speaking a Universal Language

Researcher Violeta Sànchez i Nogué grew up bilingual—but not necessarily bicultural. Raised in a small town north of Barcelona (in Catalonia, a region in northeast Spain), she was fluent in her native Catalan as well as Spanish. "We learned both as kids," she said, which can be a plus. "Another Latin language is easy for us to learn. We can go to France, Italy, or Portugal and understand people there."

**Sànchez i Nogué (left) and her sister, Berta, playing in the garden of their family home as children.** *Photo from Violeta Sànchez i Nogué, NREL*

A Catalan poet once summed it up, writing "*Tot està per fer i tot és possible,*" which means "Everything remains to be done and everything is possible." Sanchez i Nogué understands the words as well as the spirit they evoke.

Maybe it was the pace of life growing up; or the location of her home, which was an hour's drive equally from the Pyrenees Mountains and epic beaches. Or, possibly, it was the tiny garden at the family home that yielded an abundance of fresh tomatoes, which she misses. Over time, her love of the outdoors and curiosity about nature grew.

"We would spend weekends and summer vacations outdoors," she said. Her father was a special education teacher, and her mother a banker. Sànchez i Nogué's last name reflects the typical Catalan blend of her father's and mother's surnames joined by "i" which stands for "and." The family had a trailer, and every summer they traveled around Europe and camped for two weeks.

"These trips built up my curiosity," she said. She enjoyed simply observing things in the natural environment. "My sister and I didn't collect things," she said. "We grew up not interfering as much as possible."

Later, Sanchez i Nogué experienced a different type of outdoorsy gathering—scientific camps organized by universities. During high school summer breaks, she joined other teens at these retreats, learning from experts. After being exposed to chemical engineering professors, she felt the pull toward that field—and when she went to university in Barcelona, that subject became

Sanchez i Nogué on a weekend in Sweden doing research for her Ph.D.
*Photo from Violeta Sànchez i Nogué, NREL*

her major. It also transformed the way she thinks. "Engineering programs shape your brain in a different manner. You need to learn how to be systematic," she said, a skill that offers advantages, in her opinion.

"I get excited about tiny things that make me happy. Science has this power," she explained. "You can operate on two different scales. You can have a super-big far-away aim; and you also know if you go step by step, you can reach that aim. This is a nice way to challenge yourself, but you also get the biggest reward in the end. Going step by step makes a lot of sense."

Although she was content with what she was doing, Sanchez i Nogué wanted to spend time away from her university. Through a European student-exchange program, she went to Lund University in Sweden. While there for nine months, working in a laboratory, she underwent another change. "This is where I diverged from more pure chemical engineering to the biotech world," she said.

After returning to Catalonia and graduating, Sanchez i Nogué began looking for work in chemical engineering. She didn't have to look long. Lund scientists contacted her and, with fresh funding, offered her a slot to work on her Ph.D. In 2008, she went back north. There, she worked on developing industrial yeast strains for the production of bioethanol from lignocellulosic feedstocks.

By this time, Sanchez i Nogué had added English to her arsenal of languages, but she claimed no mastery of Swedish. English was the common language among her group of principal investigators from France, Sweden, and the Netherlands.

"This had good and bad parts," she said. "We could talk with each other, so language was not a barrier. But when you want to learn Swedish, it is difficult. Swedish people are really good at English, so it's easier for them to switch rather than you make a huge effort to pronounce the right word."

Her focus was on Europe and even before she had defended her thesis, she was offered a job with a biotech startup in Sweden. She was happy to be there, but the startup faltered and, after two years, she returned to Barcelona, looking for work.

However, Sanchez i Nogué had made another discovery while in Lund—NREL.

"Honestly, the United States was not on my list," recalled Sanchez i Nogué. It wasn't until a colleague from Lund told her about a position in Golden, Colorado. After trying to find out about it, she emailed Gregg Beckham.

"I applied just because it was NREL. I would not have applied to any other U.S. company," she said.

Soon, she was on a flight headed west—but without any expectations. "I thought that they would say, 'Thank you, but we have three nice Americans nearby who fit.'" Still, she wanted the practice of pitching to potential employers.

After giving a one-hour presentation and meeting with Beckham and a number of other NRELians, Sanchez i Nogué learned, to her surprise, that she was the chosen one. She arrived at NREL in 2015 as a postdoctoral researcher, using her skills in biomass fermentation on a team producing renewable carbon fibers from biomass.

"I recruited Violeta for the Renewable Carbon Fiber Consortium (RCFC) project," Beckham said. "She did a huge amount of work to ensure the biological cultivation experiments in the RCFC project were done in a robust and efficient way to produce the key precursor, 3-hydroxypropionic acid (3-HP), for the downstream nitrilation chemistry."

The fully integrated projects gave Sanchez i Nogué a chance to collaborate with different people. "There was a tiny overlap among us; therefore, we were constantly learning from each other. This added a challenge," she said. "You need to know where they are coming from. In this case, it was me doing fermentations, Todd *Eaton* and *Eric Karp* doing separations and catalysis, and *Vassili Vorotnikov* doing the modeling. This was a really nice overlap among different disciplines and allowed us to pull the project together."

The team focused on production of acrylonitrile, a petroleum-derived platform chemical compound used in numerous materials, including resins, polymers, acrylics, and carbon fiber. The team presented an alternative process for renewable acrylonitrile production using 3-HP, which can be produced biologically from sugars. A big plus: This process avoids having hydrogen cyanide as a byproduct and also improves process safety and mitigates product handling requirements.

Sanchez i Nogué's role was key. As Beckham explained, "She was absolutely critical to the success of Phase I of the RCFC project. The 3-HP strain we had was not sufficient to meet the stage gate criteria, so Violeta found a lactic acid-producing strain that has turned out to be an incredible asset for the project." This interdisciplinary work was published in *Science* magazine in 2018, and the team received an NREL Staff Award in March of that year. The project, with Beckham and Karp as principal investigators, was named a finalist in the 2018 R&D 100 Awards and was selected for a Colorado Governor's Award for High-Impact Research.

Sanchez i Nogué found work on other projects that combine bioconversion and catalysis to produce biodiesel blendstock from biomass sugars. "It's with an amazing set of people," she said, adding that this is what she wants. "I need to keep learning and enjoying what I'm doing. If one piece doesn't work, it falls apart," she said. "For me, enjoying and learning go hand in hand."

Beckham said, "Violeta is an incredibly tenacious and talented researcher." Not surprisingly, she moved up from postdoctoral researcher to staff researcher.

And Sanchez i Nogué's NREL experience has been everything she hoped it would be after investing the time to earn a Ph.D. "The work opportunity I have here, I would not have it elsewhere," she said. She's pleased to be making a universal impact. "The projects we work on are so global—they supply the answers for global problems," she said. She knows that there may be different approaches to renewable energy challenges elsewhere, "but the essence and goal are common everywhere."

She can't predict her future. "I enjoy what I'm doing. The day I don't enjoy it, I will pack my things and go somewhere else," she said. When that happens, Sanchez i Nogué will heed the advice of the Catalonian poet, knowing that, indeed, everything remains to be done and everything is possible.

## Counting Growth Cycles Within Bioenergy Cycles

So, things change and remain the same. The dance goes on eternally. By his own count, Mike Himmel has already seen at least three major growth rounds in his department—similar to the life cycles of plants—sprouting, expanding, and withering away. "When you are in a place for this long, you are part of a lot of building cycles," he said.

Depending on gas prices, he's aware that national focus can shift from biofuels. He's seen it before. "You know this work will come back," he said. Still, he takes nothing for granted—and never has.

The whiteboard in his office is decorated with many different colors—numbers, lines, arrows, sketches—involving problems to be solved. "Scientists are actually artists, too. A lot of biochemistry is visualizing," he said.

A prime example of that took place in the early 2000s when Himmel worked with Pixel Kitchen, a Boulder computer graphics firm, to create animated versions of how cellulase enzymes might function. The animation did the trick and has been used widely throughout the world for educational purposes.

These days, his team is working more with bionanomaterials production and engineering. An example is the proposal to produce cellulose nanocrystals by enzyme action, the focus of a Laboratory Directed Research and Development project led by **Peter Ciesielski**.

Himmel stays passionate—seeking to keep the momentum going and avoid what he's seen at times in the past: loss of quality scientists. "You can always buy equipment again, but you cannot get the people back," he said.

Scientists (from left) Bryon Donohoe, Roman Brunecky, Mike Himmel, and Hui Wei stand in the greenhouse in the Field Test Laboratory Building in 2017 when they published a report on enhanced biomass digestibility. *Photo by Werner Slocum, NREL 47592*

## Watching Himmel's Spare Time

So, who is the burly ex-wrestler? Although he might not say it, Himmel has an h-index (an objective rating system for scientific citations) of 82. According to one expert's estimates, "After 20 years, a 'successful scientist' will have an h-index of 20, an 'outstanding scientist' an h-index of 40, and a 'truly unique' individual an h-index of 60."

Yet, even for someone in that realm, doing science can be challenging in the best of times—which may explain a few of this "truly unique" individual's ways to relieve the stress.

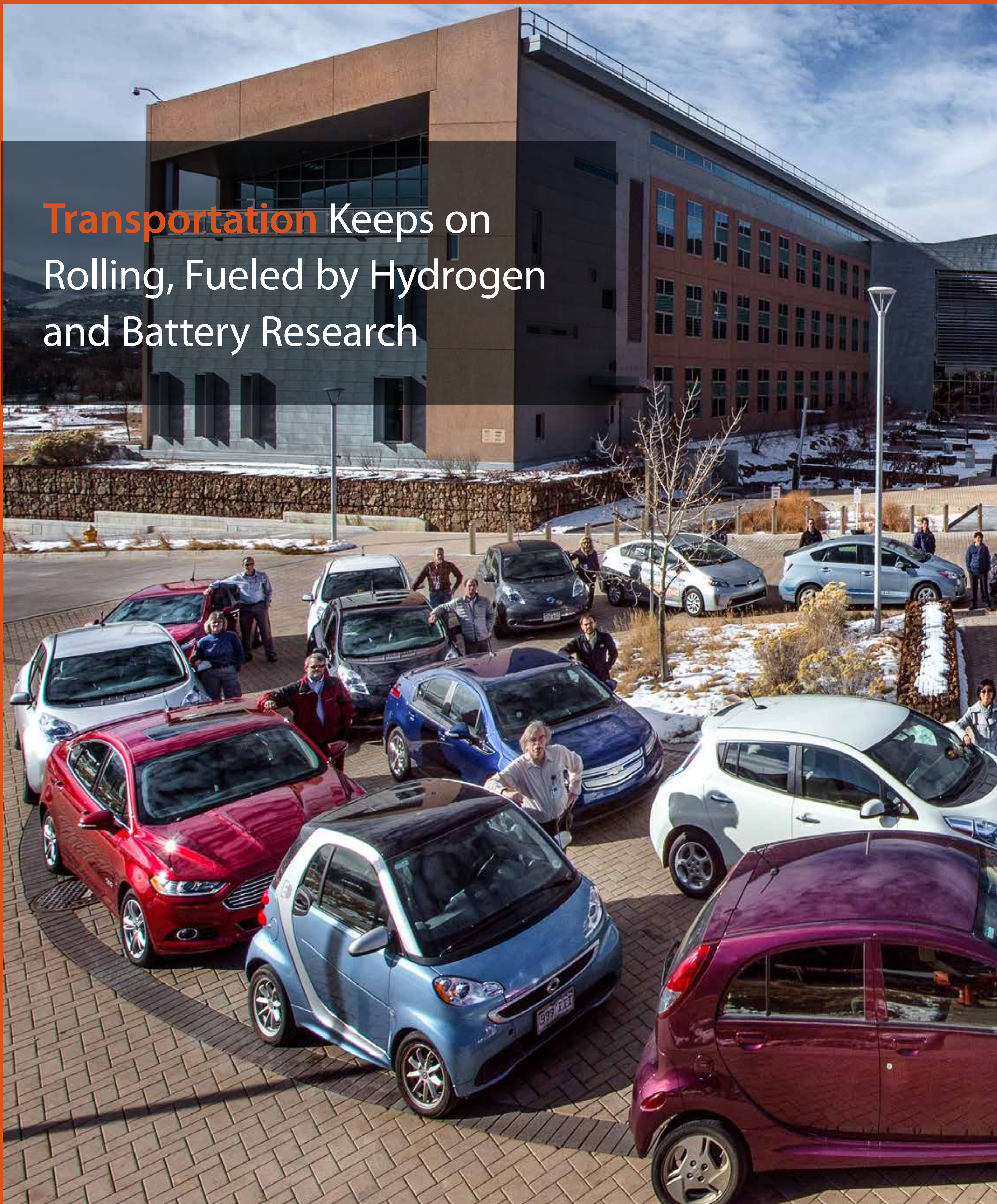
While Himmel no longer lifts weights (or wrestles—although he did move at hyperspeed once when a cougar showed up in his Roxborough Park backyard while the researcher was barbecuing), he is known for some unusual hobbies. Former Laboratory Director Richard Truly—a NASA astronaut who piloted the first night landing of the Space Shuttle—availed himself of one of Himmel's loves: watch repair.

"The admiral had a habit of taking what he called his 'space shuttle watches' on his flights," Himmel said. Each is inscribed with mission details and dates. However, after about a decade of performance, the watches began to fail.

The admiral asked around about repairs and learned of Himmel's skills. One day, **Garry Rumbles**, a colleague and friend, gave three of these watches to Himmel, asking if he'd attempt to repair them. "What a responsibility! This man is not only the boss, but also these are his pride and joy," Himmel recalled. Fortunately, he was able to fix them. Upon retiring from the laboratory, the admiral gave Himmel an antique watchmaker's kit, a family heirloom, as a gesture of thanks.

Himmel and others continue to pursue their passions—in the lab and outside. And, by doing so, they continue on the path of discovery, both personal and in the field of bioenergy. These days, woodchippers are no longer needed. Ideas flow through labs and computers.

# Transportation Keeps on Rolling, Fueled by Hydrogen and Battery Research



NREL employees drove their electric vehicles to the front of the Research Support Facility en masse in 2014, showing they drive the talk.
*Photo by Dennis Schroeder, NREL 32193*


MINI

The transportation sector in the United States has garnered frequent attention from numerous news outlets lately, as if someone had flicked the high-beam switch to put the focus on this rapidly evolving industry.

For example, it was big news when Ford Motor Company announced in March 2022 that the company was splitting into two distinctive product lines: one, Ford Model e, would focus on the delivery of breakthrough electric vehicles (EVs) at scale. Meanwhile, earlier in the year, General Motors Company said it would invest $7 billion in Michigan, much of that boosting production of full-size electric pickup trucks. And industry leader Tesla was preparing to open a $1.1 billion manufacturing facility in Austin, Texas, after delivering nearly 1 million vehicles to market in 2021.

Indeed, the novelty of talking about electric, hydrogen-powered, or autonomous vehicles has worn off well. The transportation sector had been changing for years and was evolving at full throttle.

However, it wasn't always that way with vehicles, hydrogen fuel cells and storage, or battery research. These overlapping fields had gained traction, but not always steadily. Truthfully, the topic is so vast that this overview can only touch on some high points.

These days, self-driving autos are sharing the limelight with self-driving trucks. Tesla is synonymous with status, and hydrogen cars are a reality in California. Currently, batteries are a holy grail. All are interrelated.

"In order to significantly increase adoption of EVs and make them on cost and performance parity with internal combustion engine vehicles, their batteries need to cost much less, be safer, last longer, have higher energy density, be fully recharged in about five minutes or less, use Earth-abundant and domestic materials, and be able to be recycled cost-effectively. Of course, consumer education and access to a widespread charging network are essential, too," said NREL Chief Energy Storage Engineer **Ahmad Pesaran** in a 2020 interview.

Clearly, we've come a long way from the era of gas-guzzling muscle cars churned out by Motor City. So have the NREL researchers who are changing the game. The paths that NREL researchers took to careers in the transportation sector were as varied as a New Jersey Turnpike interchange.

A nontraditional route was what **Ken Kelly** followed on his pathway to science. "As a high schooler, I was not very engaged in education—until I got involved with a vocational and technical high school alternative," Kelly said. "That led me to a vocational career in mechanical drafting. I eventually decided to pursue a degree in mechanical engineering at Ohio University."

**Keith Wipke** had a head start because his father was an organic chemistry professor. "I was always curious about how things worked. We built remote-controlled gliders with 5- to 6-foot wingspans, Boy Scout Pinewood Derby cars, took things apart and reassembled them, and did other things that helped me appreciate how physics and science, in general, described the world around us," he said. Everything came together when Wipke was a high school senior taking advanced-placement calculus. "I realized how this type of math could elegantly translate between distance, speed, and acceleration through performing derivatives and integrals; and I was hooked on a path of mechanical engineering after that," he said.

> "I realized how this type of math could elegantly translate between distance, speed, and acceleration through performing derivatives and integrals."
>
> — Keith Wipke

In Shiraz, Iran, Pesaran was intrigued during his 10th-grade chemistry labs to learn how mixing various chemicals can create new materials that could be more useful. "I was fascinated by the science of how mixing chemicals can result in changes of color, precipitation, smoke, or foam," he said. Pesaran, whose high school was affiliated with Pahlavi University, went on to earn a bachelor's degree at Pahlavi in chemical engineering and a Ph.D. in heat and mass transfer sciences from the University of California, Los Angeles (UCLA).

Although **Bob McCormick's** father was a banker, he had a keen interest in technology, which he imparted to his three sons. McCormick started in biology and biochemistry in college but switched to physical chemistry because it grabbed his attention. "Chemistry and math together—what's not to like?" he queried. Eventually, he chose chemical engineering. "I'm really more of an applied chemist than a chemical engineer today," he said. "Knowing some things about engineering is helpful from time to time." For his master's degree, he headed to Iowa State University to study chemical engineering, particularly oxidation catalysis.

**Huyen Dinh's** journey was an upheaval. She was 9 years old when she fled Vietnam in 1979 with her mother and two younger sisters. Their father had already left for the United States five years earlier when U.S. troops evacuated the country. With only the clothes on their backs, they escaped—surviving hunger, a perilous sea journey threatened by pirate attacks, and a refugee camp in Malaysia. Eventually, they settled in Canada, with no job, no community, and no knowledge of the language or the culture of their new home.

"My mother did not want us to grow up in a communist country," Dinh said. "She wanted us to have freedom and opportunities so that we could pursue anything we wanted to do. My mother and father made lots of sacrifices for us so that we could have a better life." Her route to fuel cell research—specifically, direct methanol fuel cells—began in 1998 as a postdoctoral researcher at the Los Alamos National Laboratory (LANL), doing research on electrocatalysis for methanol oxidation. She chose LANL because it was the premier place to do fuel cell research and development (R&D) at the time.

In Mexico, NREL Behavioral Scientist **Paty Romero-Lankao** steered her career in a novel direction. Romero-Lankao remembers the moment when she decided to pursue environmental research. She had just told her respected undergraduate adviser in her hometown of Mexico City that she wanted to write a thesis on the sociology of the state—a heady topic for a young student to tackle. "She said, 'Don't be stupid—work in environmental sociology,'" Romero-Lankao laughed. "That got me started with environmental issues."

Since 1985, when she received her bachelor's degree in sociology from the Universidad Nacional Autónoma de México in Mexico City, Romero-Lankao has focused on the interactions among people, mobility, the built environment, and energy systems. Along the way, she completed two doctorate degrees in sociology: one in 1997 from Universidad Nacional and the other a year later from the University of Bonn in Germany.

As a Wisconsin high schooler, **Bryan Pivovar** won a statewide competition in marketing. "I never thought those skills would be particularly important in science," said Pivovar. "But much of my recent success professionally may have more to do with marketing than it does with science." Not that his science is lacking, but the NREL senior research fellow believes his marketing ability helped him clarify and sell the benefits of hydrogen.

For **Jen Kurtz**, in high school, it was a tale of love at first sight with physics. "Physics provides a foundation for understanding things around me. And I started what is, hopefully, a lifelong pursuit of continual learning," she said. "I realized that science and engineering were simply natural fits and the foundation for my career."

Likewise, **Margo Melendez** cited high school science teachers in Waukesha, Wisconsin, as priming her for a love of science. "I still remember Miss Kraft, my high school chemistry teacher, and all of the amazing experiments she did to demonstrate science," said Melendez. "But, even more, she got us thinking about how what we learned could impact the world."

**Donal Finegan** grew up on a small family farm in the town of Carrickmacross, about an hour's drive north of Dublin, Ireland. And while he knew he wasn't going to raise pigs, cattle, and sheep forever, the upbringing influenced him to become an engineer. "We had to build things, plan things," Finegan said. "I constructed sheds with my father, fixed and repaired equipment. It definitely set me on a more practical path."

But if anyone's early days foreshadowed a four-decades-long future in transportation—the ability to move long distances—it was probably **Rob Farrington**.

In 1974, his parents drove their 17-year-old son from the family's Arkansas home to New York City, dropping him off at Columbia University to study nuclear engineering.

Based on his standardized test scores, Farrington had been accepted to Columbia after finishing his junior year of high school.


**Rob Farrington in 1996 testing cutting-edge battery technologies.** *Photo by Warren Gretz, NREL 06029*

He took a correspondence course in English to meet the state's four-year requirement to get his high school diploma—just in case college didn't work out.

"Neither of my parents attended college, so they weren't able to provide any insight into what college was about," he said. "I didn't know where Columbia was." Indeed, the Massachusetts Institute of Technology had also contacted him—but he recalled that his high school counselor scoffed, saying, "That's a vocational school—you learn to fix cars."

Born in Tripoli, Libya, and educated for five years in England, Farrington adjusted to being uprooted and becoming independent, too. "A lot of it was trying to figure things out on my own," he said.

Because he was advised not to specialize too soon, Farrington enrolled in mechanical engineering at Columbia—taking a course, by chance, in renewable energy. "I loved it," Farrington said. He went on to complete his master's thesis at Columbia on solar heating in 1979 while writing a renewable energy computer program.

Around that time, Farrington heard about SERI and interviewed for a position on a Friday. "They called back on Monday and offered me a job as an engineer," he said. On June 4, 1979 (a snowy day in Golden, he recalled), Farrington picked up SERI badge number 727. "My first lab was in a trailer where the Outdoor Test Facility is now," he said. "There were rats. It was miserable. But we were excited. We were working on renewable energy. It was good for everyone, we thought."

They were positive that photovoltaics (PV), wind power, and solar thermal technology would eventually win the day. Vehicles, hydrogen storage, and batteries? Not on the radar.

## Matt Keyser—Using a Blowtorch and Coffee Can

There were battery believers. Take **Matt Keyser**. Growing up, he was always good at math and science, so studying mechanical engineering at the University of Colorado (CU)–Boulder came naturally. It just so happened that, while at CU, he also spent a summer interning at SERI.

After graduation in 1991, Keyser's first job was with a Boulder company that made power supply equipment, primarily used in military jets and rockets. But there was a systemic flaw. "The Tomahawk cruise missile was falling out of the sky because its power supply was sending intermittent power to the guidance

In this 2016 photo, Matt Keyser uses the slot die system in the Process Development and Integration Laboratory to coat components used in the battery internal short circuit device. *Photo by Dennis Schroeder, NREL 36179* system," Keyser said. "They gave me the issue to solve—which was a bit odd because the problem had existed for about 10 years, and I was the newest junior engineer at the company." Still, he figured it out. "To be honest, it wasn't a hard solution," he said with a shrug.

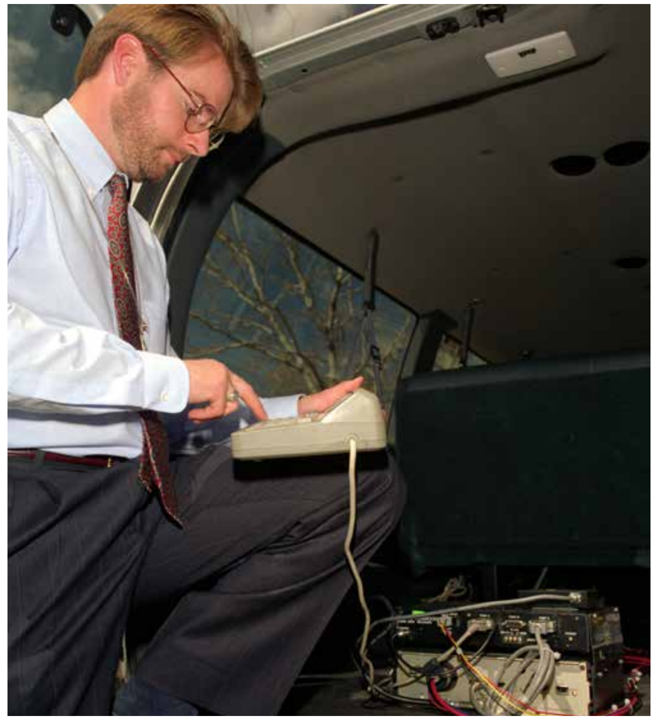
As part of this solution, Keyser needed to heat treat some of the copper parts for the power supply unit. However, his small company didn't have the funds for an oven to do that. So, he improvised. "I took a coffee can and wrapped it in insulation. Then I got a blowtorch and heated up the coffee can to the annealing temperature I wanted," he said.

His unorthodox approach attracted the attention of the president of the company. Keyser said, "As I was walking with the blowtorch and improvised oven, I passed the president in the hallway. He asked, 'Do I want to know what you're doing?' I said 'no' and kept walking." Keyser used his makeshift oven to anneal the copper parts so that they could be swaged into place without fracturing. The fix worked, and the military retrofitted the Tomahawks based on his design.

"I'm proud of what I did," he said. But he decided to try something different. "I wanted the focus of my work to be something that enables a renewable society: energy, solar, and efficient transportation," he said. "That's when I called people I knew at SERI to see whether there were any jobs open."

There was one and, in 1992, Keyser joined the laboratory in the area of battery system research. "Essentially, I was designing a vacuum insulation for sodium sulfur batteries used in electric vehicles, which started my career in the battery field," he said.

Eventually, laboratory leadership decided to start an energy storage lab, and Keyser was tasked with setting it up. "Our first lab only had two pieces of equipment: a calorimeter and a battery-cycler. That was it," he said. It was indicative of the startup level. "We really didn't know a lot," he said. For example, the laboratory bought a battery-cycler that was made for battery packs, when they actually needed one for cells or modules. "We took our lumps, but then gained experience," Keyser said. The lab's reputation grew with the U.S. Department of Energy (DOE) and industry, a standing that NREL innovators of all stripes helped burnish—even those who didn't start initially on the transportation track.



Keith Wipke installing transmitters and small computers on the shuttle vans in 1996 to streamline van pickups and deliveries via satellite relay. *Photo by Warren Gretz, NREL 02292*

## Keith Wipke Takes the Routes Less Traveled

Again, there are many byways into transportation. Keith Wipke demonstrates how turns can lead to unexpected destinations. Wipke took a renewable energy class as an undergraduate at the University of California, Santa Barbara, during which they toured Siemens Solar in Camarillo, California. "I became convinced that solar energy would be the future energy source for our country," he said. "But I was a mechanical engineer, not a materials scientist or physicist, so I became interested in concentrating solar power (CSP) and the thermal/fluids knowledge you would need to apply that."

Wipke spent summers at SERI/NREL in 1991 and 1992. When he graduated later with a master's degree from Stanford University, he wanted to work at NREL in CSP. Instead, he learned that his former boss had shifted over to hybrid electric vehicles (HEVs) and was helping DOE launch its HEV program as part of the new Partnership for a New Generation of Vehicles. Hired at NREL in 1993, Wipke became involved in gathering data from experimental and student HEVs, which transitioned into modeling advanced vehicles. "Ultimately, that exposed me to the benefits of hydrogen fuel cells for efficiency and zero emissions, which led to my current role as the lab program manager for the Fuel Cell and Hydrogen Technologies Program," Wipke said.

In 2016, Matt Keyser and Ahmad Pesaran worked on the battery internal short circuit device. *Photo by Dennis Schroeder, NREL 36181*

## Ahmad Pesaran Swaps Cooling for Cool Cars

Ahmad Pesaran wrote his Ph.D. dissertation at UCLA on heat-activated air dehumidification using desiccant materials to enable use of evaporative cooling in humid areas, such as Florida. "At the time, I didn't know that SERI was funding my research," said Pesaran. "But when I was looking for job opportunities before graduating in 1983, my adviser suggested I contact the SERI project manager, Terry Penney, who was funding my Ph.D. adviser as part of a DOE-funded solar cooling program." Pesaran talked with Penney and was hired as a postdoctoral researcher to explore solar cooling and desiccant dehumidification R&D projects.

"I flew to Denver in May 1983, and Terry was kind enough to pick me up from the airport and drive me to SERI the next day," Pesaran recalled. That kind of community support and camaraderie that existed at SERI, as well as the mission of renewable energy and energy efficiency, hooked Pesaran to make SERI/NREL home for the rest of his career. When the Hybrid Electric Vehicle Program was launched at NREL, Penney asked him to join the program to investigate and address potential thermal issues with batteries. "Working with GM, Ford, and Chrysler automotive engineers to electrify vehicles was exciting and fun," Pesaran said.

## Ken Kelly Merges into Transportation's On-Ramp

Merging into the transportation on-ramp also guided Ken Kelly, who was initially attracted to solar power. After getting his bachelor's degree, he was working as a manufacturing engineer when he received a newsletter from his alma mater, Ohio University, about a new curriculum for graduate studies focused on the Stirling engine (a heat engine operated by the cyclic compression and expansion of air or other gas). "That really piqued my interest," he said. "So, I applied and was accepted." The program was affiliated with Sun Power, Inc. and focused on using Stirling engine technology in energy-efficient applications, such as a Stirling solar concentrator or village power generator, to improve the world.

Added Kelly, "I came to NREL in 1991 by way of SERI. As I was wrapping up my graduate studies, I was looking for an opportunity to stay in the area of energy efficiency/technology. Combing through newspaper ads at the university library, I found one in the Denver Post for a quality control engineer," he said. "I applied and the rest is history. I started at SERI in August 1991 and, about a month later, SERI transitioned to NREL."

While there wasn't actually a Transportation Center at the time, laboratory leadership soon formed one, combining research in HEVs with more conventional component and fuels research. Kelly, who had begun his career as a quality assurance engineer, was part of a small group launching the Alternative Fuels Data Center. "We were trying to figure out how these vehicles performed in the field," he said. In those days, before the World Wide Web, they collected paper forms that drivers filled out and fed them to the laboratory's data processing system that entered into an Oracle database. "We were supposed to make sense of it and get the word out to Congress and the public," Kelly said.

From there, he helped launch a national program of alternative fuel vehicle emissions testing, and joined with Farrington, Wipke, and Pesaran to build up NREL's core capabilities in the battery program, vehicle systems analysis, vehicle thermal testing, and computer-aided virtual car design. But it was his "once in a lifetime assignment" in Hawaii from 2010–2012 that was a true highlight.

Hawaii had launched the Hawaii Clean Energy Initiative (HCEI) with DOE in January 2008, setting a long-term goal of achieving 70% clean energy by 2030. The need was clear, and NREL provided technical support to help guide the way. By July of that year, the price of oil in Hawaii soared to nearly $150 a barrel, and gas prices first surpassed $4 per gallon—painful for a state that imported all its oil.

"I went from focused laboratory research to big-picture transformational planning across energy sectors," Kelly said, serving as co-chair of the HCEI Transportation Working Group. The group sought to make the Aloha State a testbed for EVs and pitched manufacturers, such as GM and Nissan, with the island's receptivity.

By 2011, approximately 1% of vehicles sold in Hawaii were EVs, which greatly surpassed the national average of approximately 0.1%. As Kelly noted, within a year, Hawaii led the nation in available EV charging infrastructure per capita, positioning the state at the forefront of an evolving U.S. auto market. The effort paid off. According to the Hawaii State Energy Office, electric vehicle ownership in the state soared to 12,716 vehicles in October 2020 from 161 vehicles in October 2010.

Kelly also engaged with Hawaiian utilities, local stakeholders, and international industries to promote the smart grid. For example, by connecting Hawaii with NREL innovators, such as **Ben Kroposki** and **Dave Corbus**, he expanded the scope of work. NREL partnered in deploying and testing prototypes of EVs (and accompanying charging equipment) that could enable vehicle-to-grid power exchange.

He returned to NREL, applying his island expertise to the Integrated Applications Center's Sustainable Energy for Remote Indonesian Grids, before rejoining the transportation team to research electrification of buses and trucks. For Kelly, the ability to experience such broad projects in his more than 30-year career "is one of the things that makes NREL so great."

## Rob Farrington Kept It Simple

Rob Farrington's aspirations were simple regarding his career. "My goal after college was to stick with my first job for five years—I think I've exceeded it," he said.

"During all of the ups and downs of funding, there were many, many times I thought, 'This is it.' Fortunately, no one else would employ me," he laughed. "So, I stayed." The former principal researcher and group manager eventually became the strategic planning and business development manager for NREL's Center for Integrated Mobility Sciences.

Farrington also remained at NREL because his opportunities were so varied. "I've worked in solar hot water, solar heating, PV reliability, building airflow, hybrid vehicle research, and now strategic planning," he said. He began in systems analysis, examining solar domestic hot water for houses. "I expected every house to have solar water heating," he said. That expectation hasn't come true, he noted in 2020, because natural gas has remained inexpensive.

After a stint in buildings, Farrington was offered a chance to join a new research group focusing on HEVs. "Technology moves fast. There's a pretty rapid turnover. A lot of the research we did was proprietary, and we couldn't publish. I was fine with that because we were making an impact," he said.

For Farrington, the move to HEVs enabled his biggest NREL accomplishment: leading the U.S. Department of Energy/Ford Hybrid Electric Vehicle Propulsion Systems Project, a five-year, $114 million endeavor in the 1990s. The partnership helped the automaker build its first HEV.

"It was a terrific experience, and I learned a great deal from the Ford research staff," he said. "Working with cutting-edge researchers at Ford's Scientific Research Lab (nicknamed the "Sci-Fi Lab") in Dearborn, Michigan, was wonderful."

He even drove a vehicle powered by a gas turbine engine. "It sounded like sitting in a jet," he recalled. "It vented the exhaust up overhead—and could've done serious damage to pedestrians. Ford realized it had no future."

The shift to vehicles also led to Farrington's most nerve-wracking experience: testifying before the U.S. Senate Finance Committee on advanced vehicle technologies. During this time, he also completed a Ph.D. in mechanical engineering from CU-Boulder.

## Revving Up with the Help of "Mom"

During the 1990s, one of the key players in NREL's transportation research was **Barb Goodman** (profiled in Chapter 8), who managed an ethanol group and, after a merger, formed the laboratory's Transportation Center. The best part, Goodman said, "was really building a team. We had maybe 15 or 20 people. It was a rule that nobody got hired without coming through 'mom'" (a term of endearment by which Goodman was known).

Margo Melendez knows that bond well. In the late 1990s, she was employed at Ford, and one of her assignments as a new engineer was to support the FutureCar Challenge, a DOE program. Among the researchers she connected with were some from NREL. When a DOE program manager suggested she join the national laboratory system, she reached out to Barb Goodman and NRELian Cindy

**Margo Melendez.** *Photo by Dennis Schroeder, NREL 38991*

Riley. It was shortly after the Columbine High School shooting, and the people skills of NREL management won her over.

"How Barb and the laboratory responded [after Columbine], letting parents bring their kids to work with them that week or working nontraditional schedules, checking in on families, offering support in general—I thought, 'This is the kind of place and culture I want to be surrounded by in the rest of my work life.'" Melendez joined NREL in June 1999 and eventually became a group manager in what she called "an amazing place."

Another person Goodman hired was Senior Research Fellow Bob McCormick. "I interviewed for a job at NREL in early 2001," McCormick said. "Barb asked what aspect of my work I was most proud of. And I said that some of the results we had produced had been used by the Environmental Protection Agency in a rule-making that had really made a difference in how we protect the environment in this country. I have always admired Barb's commitment to trying to make a difference, doing work motivated by changing the way things are done to something better."

McCormick and others were part of the expanding family. "We were growing something special, creating these new avenues and paths for the lab around battery research, analysis, power electronics," Goodman said. She teamed with then-NRELian Terry Penney, a transportation researcher who was "as opposite as night and day from me," she said. "He was a grand visionary. I was the one who could implement. We really, early on, recognized and played to each other's strengths."

## Bob McCormick Makes a Big Impact

Future Senior Research Fellow Bob McCormick wasn't destined to work in transportation.

He describes himself as a scrawny kid growing up in Stillwater, Oklahoma. "I had really skinny arms," he recalled. "I think my dad wanted to beef me up a little bit." To that end, the senior McCormick signed up 8-year-old Bob for wrestling. "I wasn't great," he said, but he enjoyed the sport, and continued until he was 18. More important, it began a lifelong pursuit of martial arts.

Grappling is not the only obsession that drew him in. Despite growing up in Oklahoma, McCormick sought higher ground than the surrounding Tornado Alley. "Oklahoma was way too hot for me. I needed a colder climate," he said. He ventured out of the college town, becoming a skilled rock climber and ski mountaineer. Even while an Oklahoma State undergraduate in his hometown, he managed road trips to more challenging sites, including Boulder. "I moved to Wyoming when I was 25, largely to pursue my interests in climbing and skiing," he said. "The fact that I could get a research assistantship and go to grad school was an added bonus."

For McCormick, work-life integration is not a theory. It's what makes him tick—and truly keeps his equilibrium intact as much as when he's "skinning" uphill on backcountry skis. "I really love being in the mountains. Hiking and skiing," he said. "And it pays dividends because, if I didn't, I'd find my work to be pretty stressful."

McCormick brought that attitude to NREL, which he said had a job opening that "looked like my resume." He quickly applied but, to his surprise, he wasn't hired. The setback was only temporary. Several months later in 2001, he got word that a fuels performance engineer position had basically been created for him. He was tasked with tackling problems related to displacing petroleum with lower-carbon biofuels. The challenges were immediate, in part because many of the test methods were set up for petroleum, which has different chemistry from biofuels.

"Under Bob's leadership, we established several new laboratories in Building 16 for analytic chemistry of fuel properties and expanded our experimental capabilities at ReFUEL," Goodman said, referring to the Renewable Fuels and Lubricants Laboratory, a state-of-the art facility for vehicle testing.

Robert McCormick and Teresa Alleman sorted a variety of chilled biodiesel samples in 2012 to be introduced to a mass spectrometer for analysis in the Fuels Performance Lab. *Photo by Dennis Schroeder, NREL 21940*

McCormick is known as a major player and leader within the Co-Optimization of Fuels and Engines (Co-Optima) initiative, which includes nine national laboratories and research that cuts across two NREL directorates. His expertise in both light-duty and heavy-duty engine technology, coupled with his breadth of fuels expertise, has been cited as instrumental in expanding NREL's work with both DOE and industry.

McCormick credits Vehicles Laboratory Program Manager **John Farrell** with launching Co-Optima. "It was kind of our idea," he said. And McCormick is proud of the ongoing research that this initiative continues to pioneer, pursuing ways to get fuel and engines to work together in various vehicles.

As is a tendency at NREL, McCormick is quick to spotlight his varied team of a dozen researchers for his many successes. The team comes from a broad range of backgrounds, including pharmacological and food chemistry research. "It's interesting to see what they come up with when I give them a problem," he said. "They think differently than I do." But that diversity is a plus. "I'm nothing without them," he said. "They are really creative, smart, and quite willing to tell me I'm completely full of it," he said. "There are times I've said something can't possibly work. Six months of experiments later, the person is back in my office, gloating."

Even as his research gained recognition over the years, McCormick's role changed. "I don't get my hands dirty anymore in the lab, but I help my team with analysis and writing," he said. His mentorship remains. And that quality of being a mentor was a key reason he was surprised when named a Senior Research Fellow in 2018.

This expansion of responsibilities magnifies the potential for stress. "I'm kind of responsible for keeping my group funded," he said. "And I don't know if anyone's told you the great secret about research: It's an exercise in enjoying failure. Because it's just one failure for something to work the way you thought it was going to work, after another. But the way you enjoy failure is that you learn as much as possible from that—and maybe even turn failure into success."

## Creating ADAM

Although Farrington was happy doing the research, Goodman saw his leadership potential. She convinced him to become a principal research engineer and group manager of the Advanced Vehicle System group in 2002. He acquiesced on the condition that she mentor him, and she agreed. Farrington held that role until 2017.

"She was a terrific people manager," Farrington said about Goodman. "The most important thing I learned: It's about the people, stupid. It's always about the people. There is no close second. If you don't treat people well, you will not meet your milestones. The work we do here is all about people using it."

ADAM, shown in 2004, with an actual human researcher, was designed to evaluate human physiological response to thermal conditions. Sensors measure skin temperature and core temperature changes. *Photo by Warren Gretz, NREL 13206*

As Farrington saw it, “My job was helping people live better lives.” He did this, in part, by helping oversee the development of the ADvanced Automotive Manikin (ADAM), a mannequin controlled by a model of the human thermoregulatory system.

“We used ADAM to evaluate vehicle climate control, U.S. and Russian liquid-cooling garments for extravehicular activities (also called space walks), and emergency procedures for evacuation of wounded soldiers on Army helicopters,” Farrington said. “We obtained very valuable information from him. Not only was he self-contained, articulated, and remotely controlled with heated and sweating segments, but he also breathed.”

There were amusing moments, including the time Farrington and his team realized they needed additional equipment for ADAM. “I wrote a simple program,” he said. “And when I brought Barb to see ADAM, I suggested she ask him how he’s feeling.” When she did, ADAM responded, “I’m a bit warm, but I’d feel a lot better if I had a new computer.”

A veteran of automotive research, Farrington is realistic about the future of vehicles. “I think cars will remain for quite a while, although ownership may change drastically—from individual ownership to shared ownership,” he said. “Or people may simply use alternatives—autonomous vehicles or, hopefully, mass transit.”

Some landscapes may not change much. “In rural areas, individual ownership will continue and probably in many suburban areas as well,” Farrington added.

The NREL veteran also thinks drivetrains will be electric, progressing from hybrids to plug-in hybrids to fully electric, possibly fueled by hydrogen. He’s happy to have played a role in this evolution. “It’s been a great career,” he said.

## Batteries Make a Connection

Just as the Energizer bunny hammers home the worth of long-lasting batteries for consumers, that concept could be equally valid in promoting the key role that batteries play in sustaining mobility and providing the “juice” for engines.

If others downplay the importance of batteries, Ahmad Pesaran doesn’t— which has led to a powerful career. As he noted in 2020, he has been at NREL for nearly 40 years with achievements in solar and heat-activated air conditioning, ocean thermal energy conversion, and battery research. His honors include winning three R&D 100 Awards (for technologies from algorithms for extending life of lead acid batteries, isothermal battery calorimeters, and a battery internal-short device), NREL’s H. M. Hubbard Award, DOE’s Office of Energy Efficiency and Renewable Energy (EERE) Outstanding Impact Award, and becoming an SAE Fellow (formerly the Society of Automotive Engineers).

“But my favorite accomplishment was building the NREL battery program,” he said. “I started with $200,000 for an HEV battery thermal modeling project with a couple of part-time staff in 1996 and evolved it into an annual $5 million battery R&D program with more than 16 full-time staff in 2017.” He was the manager of the Energy Storage Group doing research on various aspects of battery developments and improvements. Some of the areas that were becoming ever-more important were the Pesaran team’s focus on microstructure electrode modeling, computer-aided engineering of batteries, lithium-ion science of safety, battery life


Bryan Pivovar explains the research being done in the Hydrogen Fuel Cell Lab in 2017 during a tour of the ESIF. *Photo by Dennis Schroeder, NREL 45921*

and degradation modeling and testing, second use of EV batteries, and battery recycling.

All of this required building multiple labs and developing experimental capabilities as well as bringing more than $100 million to NREL from DOE and various private and government entities. "While building this, I had the privilege of mentoring and leading more than 100 dedicated and competent engineers, scientists, postdocs, Ph.D. students, undergraduate interns, and visiting professionals over two decades," Pesaran said. That's a lot of juice.

Pesaran—who has owned multiple HEVs since their introduction and now drives an electric vehicle—believes NREL's research and collaborations with industry, universities, and national laboratories contributes to achieving DOE's battery targets, which will enable widespread adoption of EVs.

## An Early Fuel Cell Researcher

Today, people may be generally familiar with the concept of hydrogen fuel cells—devices that convert chemical potential energy (energy stored in molecular bonds) into electrical energy. The technology is becoming more marketable. California began selling hydrogen fuel in 2015 and has more than 40 hydrogen fueling stations for more than 8,000 fuel cell cars so far.

But when Bryan Pivovar began his doctoral research in 1994 at the University of Minnesota, fuel cell technology was largely unknown—even to him. "When I started my Ph.D., I wanted to work on either catalysts or polymers," he said—tracks that could have led to working with companies such as ExxonMobil. "And that would be great," he said. "I didn't expect to be a renewable energy scientist." However, an unexpected twist led him in a different direction.

A thesis adviser alerted him to the fact that there was going to be funding for fuel cell research starting the following year, a topic that needed both catalyst and polymer research. Pivovar, who had a fellowship for his first year of graduate school, got a one-year head start on the project because he had independent funding in hand. The adviser sagely told him, "You can have first choice of which direction you want to go."

"At the time, fuel cells were a giant white space," Pivovar said. And because his advisers weren't established fuel cell experts, "we were all learning together." In reality, he said, this meant that "I got to do fuel cell work before anybody else knew what fuel cells were."

In part, he was often more educated in the area than his advisers because he could dedicate 100% of his time to learning about the topic from the literature. As a result, the junior students would often come to him for advice. "While it extended my time in graduate school, it served as great training and almost certainly accelerated my career," he said.

Still, the technology was largely unheralded. "When I got my Ph.D. in fuel cells in 2000, I always had to explain to people what a fuel cell was," he said. "That isn't the case anymore."

### Bryan Pivovar Becomes Mr. H2@Scale

"He is a tireless advocate of integrating hydrogen into the entire energy system," said Jao van de Lagemaat, director of NREL's Chemistry and Nanoscience Center.

So, it was natural that Sunita Satyapal, then director of DOE's Fuel Cell Technologies Office, in Pivovar's words, "voluntold" him to lead a "big idea" focusing on hydrogen across the national laboratory system. Pivovar reluctantly agreed.

"I knew it was important that NREL take the lead in this area, but it wasn't until we were a few months into putting the story together that I began to realize how much benefit hydrogen has to offer," he said.

He also learned how low the marginal costs of implementing hydrogen could be with the proper research and infrastructure investments. "Now, I see it as the most important professional effort of my career," he said.

The initiative, which began in 2015, took major steps forward in 2016 as several dozen staff members from across 14 DOE national laboratories worked together to evaluate the potential of hydrogen across the U.S. energy system. The group also engaged industry, regulatory bodies, utilities, and other stakeholders.

This effort became known as DOE's H2@Scale (hydrogen at scale) initiative. DOE gave two Fuel Cell Technologies Office recognition awards (in 2016 and 2018) to Pivovar and other national laboratory contributors, citing analysis and scoping of the initial vision.

A major focus of H2@Scale is to enable affordable and reliable large-scale hydrogen generation, transport, storage, and use in the United States across multiple sectors.

This research and development feeds into existing commercial hydrogen products and different applications, such as the production of hydrogen for fuel cell vehicles. NREL's work also aims to decrease the cost of electrolyzers with an eye toward producing hydrogen at scale. An overarching goal is to reduce carbon emissions.

The goal of the H2@Scale initiative is to use the unique attributes of hydrogen to address critical challenges facing our energy system, Pivovar said. Notably, hydrogen can be made efficiently and intermittently from low-cost (renewable) electricity, while enabling clean, efficient end use (grid, transportation, buildings, and industry).

Additionally, hydrogen allows for grid-scale energy to be shifted across time, distance, and energy sectors, empowering society to service all its needs cleanly, efficiently, reliably, and economically.

"Hydrogen and renewable energy have the ability to leverage each other, allowing each to make the other more economically viable and competitive," he said.

In Pivovar's opinion, this is one of the main factors that makes NREL such an exciting place to do hydrogen research.

"What I've seen in the past few years is incredible," Pivovar said. "The ways industry and investors are embracing hydrogen make it seem that, as much as the past decade has been the decade of wind and solar, the 2020s are looking to be the decade of hydrogen."

## Huyen Dinh Settles into the World of Hydrogen

Huyen Dinh feels at home in the world that Pivovar and others inhabit.

Her route was long, but her family's sacrifices paid off, as Dinh wound up earning a Ph.D. in electrochemistry in 1998.

She was employed by three different startup companies in California for the next 10 years, developing commercial direct methanol fuel cells and methanol fuel cartridges for portable electronic applications, such as laptops and cell phones.

**John Turner**, who became an NREL emeritus researcher, hired Dinh in 2007. There was not a fuel cell program at NREL yet, which was one of the reasons he brought her aboard, she explained. His funding was in photoelectrochemical (PEC) research—a path to split water to make renewable hydrogen. "My initial research at NREL was learning PEC, a new technology for me," Dinh said. "Although I was not a PEC expert, I had experience working on codes and standards, and this resulted in me leading an international working group to develop standard PEC testing protocols for DOE's hydrogen production program." The result of the five-year effort was a document widely cited and downloaded.

As a senior scientist and hydrogen production lead at NREL, Dinh acted as the liaison between DOE and NREL on hydrogen production research projects.

**In 2014, Huyen Dinh was at home in the Electrochemical Characterization Lab in the Energy Systems Integration Facility at NREL.** *Photo by Dennis Schroeder, NREL 31430*

Her team used wind energy and solar power to "split water," yielding renewable hydrogen that powers fuel cell cars, which then convert the hydrogen back into water. "We split water by using renewable electricity to make sustainable hydrogen," she explained. "We're working on four different water-splitting technologies: low- and high-temperature advanced electrolysis, solar thermochemical water splitting, and photoelectrochemical water splitting. We're working hard to make low-cost, renewable, and sustainable hydrogen for energy storage, transportation, and the grid."

Dinh served as director of HydroGEN, an NREL-led consortium with representatives from five other national laboratories. HydroGEN supports collaborations among federal laboratories, academia, and industry. As part of her work, Dinh connects NREL experts and helps coordinate approximately 30 different HydroGEN projects with universities, industry partners, and other national laboratories.

In 2018, DOE's Fuel Cell Technologies Office honored Dinh for outstanding dedication and organizational excellence in leading HydroGEN. In 2019, the laboratory gave Dinh an NREL Staff Award for her "extremely successful and timely development of HydroGEN and enhancing hydrogen production research at NREL."

Just as Dinh found an NREL home in hydrogen, Donal Finegan did, too.

At the age of 20, Finegan came from Ireland to the Colorado School of Mines for three months in a summer research program for undergrads. At Mines, he said, "I investigated synthesis of membranes for separation of hydrogen from other gases."

As part of weekly lectures and workshops, he also got a taste of photovoltaic and other renewable energy research topics. In a coincidental bonus, participants toured NREL. Still, the laboratory was not in his plans. Did he think he'd ever work at NREL? "Never," he said.

Early on in academia, he didn't know his next steps. "I wasn't sure what topic I wanted to pursue, but then I figured that most alternative energy sources would require some form of energy storage," he said. "That's why I ended up focusing on energy storage—because it was a foundation for all the technologies that captured my interest."

He returned to Europe, where he pursued a Ph.D. at the University College London. Finegan's doctoral research relied on a synchrotron: a cyclic electron accelerator in which the accelerating electron beam travels around a fixed, closed-loop path and generates high-intensity X-rays for research. He applied high-speed X-ray imaging to evaluate how an internal short and thermal runaway propagates in commercial Li-ion batteries.

Finegan had started working with both NREL and the National Aeronautics and Space Administration (NASA) during his Ph.D. studies and, by the time he earned his doctorate in 2016, he was already harvesting the beginnings of what would become a bumper crop of awards for his promising research. That year, the Royal Society of Chemistry gave him the Sheelagh Campbell Award, an honor for a student working toward a Ph.D. in electrochemical science at a university or research institute in the United Kingdom or Ireland.

NREL and NASA worked out an arrangement in which the laboratory appointed Finegan as a postdoctoral researcher in April 2017, and NASA shared his time probing the failure analysis of Li-ion battery cells at the Johnson Space Center. Finegan spent about a week each month in Houston, Texas, as part of his assignment.

In 2018, Finegan won an NREL Director's Award for his achievements in the field of battery safety science.

Finegan also represented NREL in London—with partners at the University College London, NASA, the European Synchrotron, and the UK National Physical Laboratory—to receive the Engineer Collaborate-to-Innovate Award. The honor, which is similar to an R&D 100 Award in the United States, was for Li-ion battery safety research using NREL's patented, R&D 100 Award-winning battery internal short circuit (ISC) device. He also went on to win the Young Researcher of

Jen Kurtz (right) talks with colleagues Kazunori Nagasawa and Rishabh Jain in October 2019 while looking at an electrolyzer in the Energy Systems Integration Lab at the ESIF. *Photo by Dennis Schroeder, NREL 60020*

the Year from both the Institute of Chemical Engineers and the European Synchrotron.

Finegan is not only attracted to the laboratory's mission, although he enjoys flying the banner of renewable energy. In response to a question about the benefits of being here, he paused, "I like the work environment. There is always something interesting happening, and I find a tremendous sense of purpose working under the umbrella of NREL, particularly with the challenges we face today. NREL is also very encouraging of having a good work-life balance, which is not something every university or national lab has," he said.

Jen Kurtz found the world of fuel cells quickly. "In college, I realized that my desire for purpose could be satisfied by studying energy, and I found a great fit in grad school studying a hybrid power plant with fuel cells. This set me on a path to work at a fuel cell company as a design engineer," she said.

In 2007, she jumped when a position at NREL opened that was well aligned with her experience. "NREL was a dream workplace for me," she said, adding that it was Keith Wipke, Sam Sprik, and Leslie Eudy who gave her a chance to join their team.

She excelled and, in fall 2020, was selected as director of the newly created Energy Conversion and Storage Systems Center. She manages a team of about 100 researchers focused on advancing NREL's integrated research impact on energy conversion and storage solutions.

"My activities are closely aligned with our Integrated Energy Pathways critical objective [one of three long-term NREL objectives adopted in 2020]. I expect that research platforms like ARIES [Advanced Research on Integrated Energy Systems] will be a key enabler for the innovations needed to realize big energy system goals over the next couple of decades," Kurtz said. "I also expect integration across technologies and sectors will grow as the boundaries of our traditional energy systems are dissolved for new energy system configurations and operations."

## Batteries Grow Up

Things have changed from the humble beginnings of battery research. As Matt Keyser, a group manager, pointed out, NREL has multiple battery labs with nearly 9,000 square feet of space, covering a range of capabilities.

Such progress didn't come by accident—and it certainly didn't hurt that Keyser was on the team. He hasn't been idling. His efforts on battery thermal management and safety have earned him a DOE Vehicle Technologies Office Distinguished Achievement Award, four R&D 100 Awards, and seven patents—three of which have been licensed.

Keyser and colleagues licensed the Isothermal Battery Calorimeter. The NETZSCH Group has sold it commercially to test large-format Li-ion cells and batteries that are used in electric vehicles, aircraft, stationary power backup, storage applications, and space applications.

Finegan was part of that team. "Donal is an innovator and key contributor in the field of battery safety science," said Keyser. "In his short career, he has already developed a national and international reputation for researching the safety of Li-ion cells." He added that Finegan has "made an impact with many of our outside partners, such as NASA, LG, and Tesla. Donal has only started, but he will continue to push the knowledge of battery safety for years to come," said Keyser.

Keyser also played a part in the first-of-its kind ISC device that he produced in collaboration with NASA to better understand failure modes, particularly overheating, in Li-ion batteries. Little did he know that this research would almost bring him into the orbit of cosmetics-maker Revlon before that of the space agency.

As he tells it, his team started looking into the ISC concept around 2007, but "our success was initially limited. We tried low-temperature-melting alloys," he said, such as indium alloy—but that had flaws. "After two years, we decided to pursue a different direction. I thought, 'How are we going to make this work?'"

The answer: wax.

The ISC device, Keyser said, is "basically a bunch of metal separated by wax." But all waxes are not the same. He tried using paraffin (candle wax) at first, but the material's properties weren't quite right. For example, when candle wax melts and spills on a surface, it becomes brittle. "Well, what direction should we pursue now?" he thought.

He did some research on microcrystalline wax, which has two primary uses: as old-fashioned "sealing" wax for letters and, more commonly now, in cosmetics, such as hair spray and makeup. That's when he called Revlon. "But they said, 'Ah, no. You're on your own.'" Fortunately, Keyser was able to find other suppliers.

He eventually decided on a combination of paraffin and microcrystalline waxes. While neither material on its own was adequate, together there was magic. "You need to put on your 'mad chemistry hat' and combine them," he explained. He did, gaining the best properties of the microcrystalline but keeping the rigidity of paraffin.

## Paty Romero-Lankao Forges a Different Type of Movement

As a girl, Paty Romero-Lankao was a disappointment to her mother. "My mom was expecting me to get married as soon as possible," she said.

Growing up in a poor neighborhood of Mexico City, the youngest of six had other ideas. Marriage could wait. And when her father, who had studied engineering and worked as a designer, asked the teenager what she'd like to do for a living, Romero-Lankao had a ready answer: "I didn't know what I wanted to do with my life," she said.

After finishing an advanced degree in Germany, Romero-Lankao returned to Mexico as a university lecturer. Although on a tenure track, she eventually felt constrained by the institution. Looking abroad again, she discovered an opportunity at the National Center for Atmospheric Research (NCAR) in Boulder. She moved to Colorado in 2006 to start anew.

"It was all new," she said. "I learned to work with modelers. There were climatologists, hydrologists, a lot of the physical sciences," she said. Yet Romero-Lankao came from a different perspective.

**Paty Romero-Lankao, shown outside of Union Station in Denver, in 2018, focuses on understanding the behavioral aspects of the interactions among mobility systems, the built environment, and energy systems.** *Photo by Dennis Schroeder, NREL 53238*

"I wanted to understand—and was obsessed with—the factors that empower people to deal with threats and take advantage of environmental opportunities," she said.

To her, a noticeable shift in weather patterns, along with increases in the severity of floods and storms, are a new reality. "They are extremes that are affecting what we care about: our families, homes, communities," she said.

As such, her research at NCAR was interdisciplinary. She examined the intersections between urbanization and risks associated with food, energy, and water systems. "I worked a lot at NCAR to understand what makes people change—and what factors prevent them from changing," she said.

She learned, for example, that most people don't like it when you tell them there's a looming problem and they only have minutes to react. Change requires a different approach.

In July 2018, she joined NREL's Transportation and Hydrogen Systems Center as a senior research scientist. She also holds a joint appointment with the University of Chicago's Mansueto Institute for Urban Innovation, where she is a research fellow.

"Behavioral science is an integral part of our strategy to transform energy," said Associate Laboratory Director for Mechanical and Thermal Engineering Sciences Johney Green (profiled in Chapter 8). "Paty's domain expertise in this area is a tremendous asset in our efforts to execute NREL's mission."

There's a clear thread between Romero-Lankao's research at NCAR and NREL, and she is optimistic that her insights can be shared. "If we focus on how energy is translated to humans, we see it is electricity and gas—what we need to eat, sleep, heat our houses," she said. "If we can provide this in more sustainable and equitable ways, maybe that will help people understand things are changing," allowing them to make important connections in their lives.

She's facilitating the spread of these ideas. For instance, Romero-Lankao led a workshop that attracted a range of talent with diverse scientific backgrounds—from engineering and applied mathematics to the social sciences. The group looked at ways to integrate end-use electricity generation and consumption technologies from electric vehicles, buildings, solar, and wind technologies with other analytical capabilities.

"Expanding our center's research to include the human element has long been a part of our strategy; so, I was very excited when I first met Paty and learned about her work."

— Chris Gearhart

She is clear that the issues are complicated. For example, she said electric vehicles are presented as a transformational solution to decarbonize transportation, "but true transformation takes more than technological innovations. Understanding how mobility opportunity plays out across socio-spatial differences is an important step in enacting transformative change."

Fortunately, she is well positioned. "NREL is on top of a huge energy transition," she said. "We're already working on the technologies and simulations. Guess what? People use those things," she said, citing the way people are increasingly embracing solar energy and EVs. "How people behave and make decisions—what drives fear and culture—are social science questions, not technical ones," she said.

Transportation and Hydrogen Systems Center Director Chris Gearhart said, "Expanding our center's research to include the human element has long been a part of our strategy; so, I was very excited when I first met Paty and learned about her work," he said. "Since bringing her to NREL, she has been a dynamic and innovative force for integrating the social sciences into our more traditional engineering approach to mobility research. I am really looking forward to seeing where she takes our research going forward."

Romero-Lankao is eager—yet realistic. "We are trying to resolve some puzzles. Energy ones are challenging," she said. Answers aren't obvious. "I wish you could create a formula, make some algorithms, and voilà—that's it." She sighed and shook her head. But she's not discouraged.

## The Road Ahead

The road signs may still be a bit muddled for transportation. For instance, regarding the adoption of hydrogen fuel, one of the biggest barriers is the cost of building an infrastructure. But Bryan Pivovar is optimistic about progress in the near term, especially because of the support of industry-led groups like the Hydrogen Council, which includes many members of the oil and gas industries.

One ingredient is key: "You need to be able to envision a future that doesn't exist today," he said.

Pivovar said the support of those around him—in research, analysis, and management—are helping him refine and spread the message. Now that he's an NREL research fellow, his pronouncements will carry greater weight.

Through it all, it comes back to making his case for hydrogen. That draws on a lifelong skill.

"The ability to convey information clearly and succinctly has a lot of value," he said. "Having the technical depth behind it is useful, of course." But for him, the equation is simple: "How do you make your viewpoint clear and sell it?"

Pivovar knows. It's what he does daily.

That's why he believes, despite challenges, the future is wide open for hydrogen deployment. "We need to provide energy services, and it comes down to the best way to provide them," he said.

Pivovar credited NREL and its researchers with having much to do with, as he put it, "making renewable energy electrons among the cheapest electrons on the planet." Now, by advocating for hydrogen technologies, "Mr. Hydrogen @ Scale" (as his colleagues nicknamed him) said that he sees the next target.

"We can help reform the entire system, not just the grid," he said.

For Donal Finegan, one focus is on overcoming the challenges associated with fast-charging Li-ion batteries. "We are trying to understand the degradation that comes along with fast charging," he said. "Of course, we all recognize that the current inability of electric vehicles to charge quickly is a major impediment for their widespread adoption."

When asked several years ago if he will continue to research Li-ion batteries longer term, he said, "In the automotive sector, Li-ion may not be the final or only solution. I am also open to exploring hydrogen fuel cells and tackling some of the material and infrastructural challenges they face."

Additionally, as Paty Romero-Lankao attested, the future of transportation is fraught with societal challenges. Among them are user perceptions and culture—as manifested in lack of familiarity with EVs, cultural and status expectations of comfort, continued anxiety and distrust, or just lack of knowledge—which can become crucial sources of social barriers to adoption.

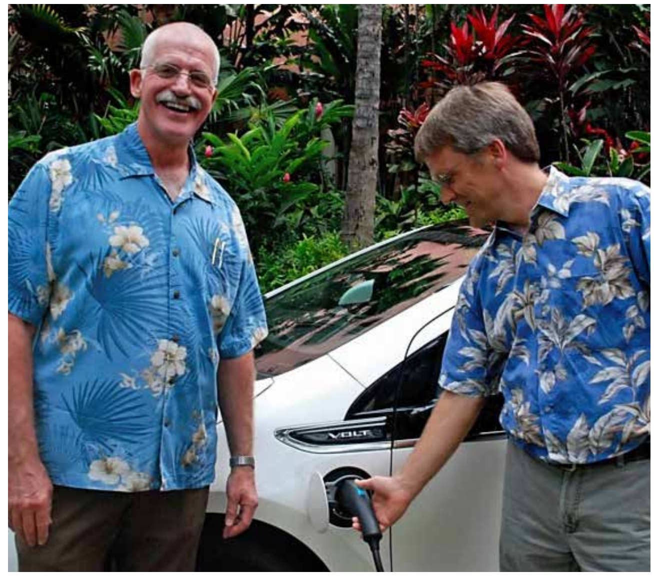
## A View of Vehicular Convergence

In Keith Wipke's view, the arc of accomplishment in the transportation field is clear. During 29 years at NREL, two achievements stand out.

The first was the development and ultimate licensing of a vehicle modeling tool called ADVISOR (ADvanced VehIcle SimulatOR). "Before we licensed the tool to AVL, we gave it away for free on the newly developed World Wide Web—and had more than 8,000 people from all over the world download it and use it," Wipke said. "At its peak, we had more than 10 people developing and using the tool for DOE and the auto industry."

A second major accomplishment was analyzing second-by-second data from 185 hydrogen fuel cell vehicles over a nine-year period and publishing the composite data product results online. This effort helped demonstrate the current state of the art and show where additional research was needed. "It was very satisfying to ultimately see retail consumer hydrogen fuel stations come online in California," he said. "Additionally, carmakers such as Toyota, Honda, and Hyundai, rolled out their small-volume production fuel cell EVs commercially."

The future is also coming into view. "I am very excited about how hydrogen can couple multiple sectors of the economy together through Hydrogen @ Scale," Wipke said. For example, he said hydrogen can help couple the renewable power utility sector



**DOE's Steve Lindenberg (left) and NREL's Ken Kelly charge-up a Chevy Volt in Hawaii in 2021.** *Photo by Ken Kelly, NREL 24520*

with the transportation sector and, with industries such as steel manufacturing and ammonia production for fertilizer, in a way that is impossible with only storing renewable power in batteries. "We are now [in 2020] making major investments in hydrogen at the Flatirons Campus that are going to usher in a whole new set of exciting grid-connected research for hydrogen at the megawatt power scale," he said.

Ken Kelly, who began in a nonconventional manner and was, in 2020, promoted to chief engineer of Commercial Vehicle Electrification, has traced the climb of diverse transportation innovations. "I was involved in the early days of passenger car electrification—starting with vehicle systems research evaluating all the different powertrain options that might take hold—series hybrid, parallel hybrid, plug-in hybrid, and range extenders," he said.

Kelly transitioned to assist with development of power electronics and electric machines for electrified passenger cars. The unthinkable happened. "HEVs are now fairly commonplace," he said. "Now, commercial trucks and buses are poised to go through that same evolution: finding the optimal powertrains for the different applications, developing the component technologies— batteries, motors, power electronics—then transitioning the technology."

Progress is coming, so that zero-emission vehicles such as trucks, buses, and school buses become commonplace. All along, NREL and its researchers have helped steer the progress, with batteries, hydrogen fuel cells, more efficient engines, and new theories about how all of this fits together.

# NREL Family Members Express Themselves Through Their Passions

NRELians on Team Ireland celebrate winning the first NREL Charitable Giving Kickball Championship in 2018, with the victors donating $500 to the Foothills Animal Shelter. *Photo by Dennis Schroeder, NREL 53222*

Imogene Manuelito was born in Gallup, New Mexico, a member of the Navajo Nation. *Photo by Dennis Schroeder, NREL 32751*

NREL's family, and their journeys, have been incredibly diverse, shaping their accomplishments.

Many have added to the laboratory's legacy while also excelling in pursuits beyond their professional capacities—competing in the Olympics or pursuing a passion for the Old West by traveling back in time via mapmaking. Some have amazing backgrounds: One NRELian grew up on a yacht in the South Pacific, another behind the Iron Curtain, and a third on a Native American reservation. Others expressed the spirit of the laboratory by volunteering in an African orphanage, donating a kidney to a brother in Venezuela, or simply playing kickball for charity.

Their stories display a kaleidoscope of excellence.

All are part of the bond that has helped set NREL apart as both a beacon of research and a pillar of the community. It seems fitting, then, to begin with the tale of a Native American, a representative of people who long practiced values of sustainability.

## Imogene Manuelito Weaves Influences of Navajo Ancestors into Her Path

"I grew up on the Navajo Reservation in northern New Mexico," said **Imogene Manuelito**. Yet, unlike many contemporaries in her tribe, Manuelito's saga didn't end there.

"At an early age, my grandparents and great-grandparents groomed me to leave the reservation," she said. "They told me that there were better ways to live—and not to live as they did. They had a hard life [living without electricity or running water]. And, as I learn about their history, the times they lived in—I agree with them," she said.

Her grandparents told her stories of the "Long Walk to Bosque Redondo" in 1863 and 1864 when the U.S. government forced the tribe to leave its native land. "It's a miracle they survived," she said. She understands some of their struggles, having grown up without electricity and running water. Still, that experience allowed her plenty of time to listen and learn in her community of Newcomb, New Mexico, outside of Farmington.

As she played string games with her great-grandfathers and grandfathers, they taught little Imo about her ancestor, the renowned Chief Manuelito and the leadership he provided for the Navajo people during a critical time for their tribe. Chief Manuelito's values and beliefs were expressed in stories her grandfathers told her about how to care for animals, her family, the environment, and herself.

She watched as her great-grandmother, Gladys Manuelito—a famous Navajo rug weaver whose tapestries now hang in museums—carded wool spun by her husband, Sam, and wove complicated designs from memory.

Despite the closeness, family members envisioned alternatives for the first grandchild on either side of her family.

"My grandpa said there was an American man on the moon—and asked, 'How did they do that? Maybe you'll go there someday,'" Manuelito recalled. "He'd say, 'When you meet us again, you can tell us all these stories. You can tell us if you ever got to the moon or not.'" He was always fascinated by, interested in, and supported the sciences.

Pursuit of learning was the key, an almost sacred quest. "My great-grandpa would tell me—in words passed on to him by his father, Chief Manuelito—that education was critical to balancing the two diverse cultures. 'You, my child, are expected to learn and educate yourself. You must leave our land, increase your knowledge and skills to survive,'" Manuelito said.

She absorbed the message.

"In kindergarten, I said I knew I was going to college—which amazed my mother," she said. Encouraged by her family, she looked at horizons beyond set boundaries—and, as a teen, discovered a talent for communicating. Manuelito gained an appreciation, too, of the importance of writing, which led to understanding and negotiating contracts.

Those skills would one day lead her to NREL and a position as senior subcontract administrator in the Acquisition Services group. As part of the Office of the Chief Financial Officer, she is responsible for negotiating and awarding subcontracts. Prior to that position, she was a program administrator in the Procurement Office, where she managed the policies, procedures, and compliance function for subcontracts and purchase orders.

## Understanding the Language of Contracts: Windows to the Past and Future

When she was a girl, Manuelito couldn't have known where her path would lead. She was merely seeking a fresh avenue. "When I was 14, I was looking at a college application form and there was a space for outside activities that would support my educational goals. I thought, 'I have four years to fill that space in,'" she said.

While searching for work after school, Manuelito went to an office run by a man who sold and leased horse trailers. "I asked him if he needed any help, and he sort of looked at me. Then he asked, 'Can you type? I need all these contracts typed up because the banks can't read my writing.'" A stack of four- to five-page contracts lay waiting in a pile. "I thought, 'Oh boy. Hope I don't mess them up,'" she laughed.

She didn't. Instead, she absorbed the topic. "That's where I learned terms in banking and finance and loans." Beyond the terms, she began to understand the philosophy and bigger picture of contracts. During her career, Manuelito has encountered a range of agreements spanning health care, the court systems, tribal governments, and municipalities. Sometimes, there's more than meets the eye.

"Working in contracts is also about negotiations and compromise," she said. At home, both grandparents had asked her how she was going to negotiate. Manuelito remembers, "They'd say, 'You can't get everything you want. Is it candy, a toy, jewelry? What can you live with? What do you need? And how will you pay for it?'"

She heeded their wisdom. "You've got to figure out how to get what you need—what's the best for the people and your family— and be satisfied," she said.

"I learned how to grasp negotiations pretty easily. I understood how the process worked in the non-Indian environment and on paper," she explains. "So, when I started reading tribal treaties and doing historical research with different tribes, I was amazed with what my ancestor negotiated." Her ancestor, Chief Manuelito, negotiated a pivotal treaty for the Navajo Nation with the federal government in the middle of the 19th century.

"To this day, things he sought are referenced, and the U.S. government is held accountable to this treaty," she said. Today, the Navajo Nation is the largest federally recognized American Indian tribe in the United States and has the largest reservation, extending into Arizona, New Mexico, and Utah.

## Heading North to a New Home in Denver, by Way of D.C.

Manuelito's college preparation paid off, and she enrolled in Grand Canyon University in Arizona. While there, she was drawn to leadership activities, an attraction that continues. "When I take leadership classes, I think about my own family, about what leadership is, and what it means. Is it inherited, learned, or acquired? I'm still trying to answer that question," she said.

To explore that path, she went to Washington, D.C., where she worked with the Department of the Interior at the Bureau of Indian Affairs. As part of the first Clinton administration, she helped provide testimony to Congress on issues related to Indian affairs. Because she was only in her mid-20s, she felt overwhelmed at times—and uncomfortable being called on to provide insights into the lives and needs of Native Americans across the country.

"Just because I lived on an Indian reservation and I'm Native, doesn't mean all native lands are the same. There are more than 550 distinct cultures (tribes) with different needs and priorities," she reflected.

Eventually, she decided to return to her New Mexico roots to get more experience and research her history. However, when her job in Albuquerque faced budget cuts, she opted to transfer to a position in Denver—and more than two decades ago, Colorado became her new home.

She first learned about NREL while employed at the Council of Energy Resource Tribes, because the nonprofit had contracts with the laboratory. However, when her organization was considering moving to D.C., Manuelito learned of an opening at NREL in communications, handling business subcontracts. In 1999, then-Communications Director Bob Noun hired her.

## Completing a Sustainable Circle at NREL

NREL was a great fit and completed a circle of sustainability for Manuelito.

"Sustainability is woven into our culture. The mission of NREL reminds me a lot about where I grew up and stories my grandparents told me about reusing things, not wasting water, and not to pollute. Keeping your environment 'pure and organic' is always best, as my great-grandparents, grandparents, and parents would teach," she said.

**A photograph of Manuelito's great-great-grandfather, Daháana Badiane, Navajo war chief and statesman. The head chief of the Navajo Nation from 1870-1884 and war leader during the seizure of Fort Defiance, Arizona, Chief Manuelito was the last to surrender during the Bosque Redondo strife in New Mexico.** *Photo by C.M. Bell, Washington, D.C., 1874*

Manuelito thinks her grandparents would be fascinated that she is part of NREL and would be curious about the types of research that comes out of the laboratory. Her great-grandfather Sam, who worked as a dental assistant in World War I, was always advocating science. "He would be particularly proud," she said.

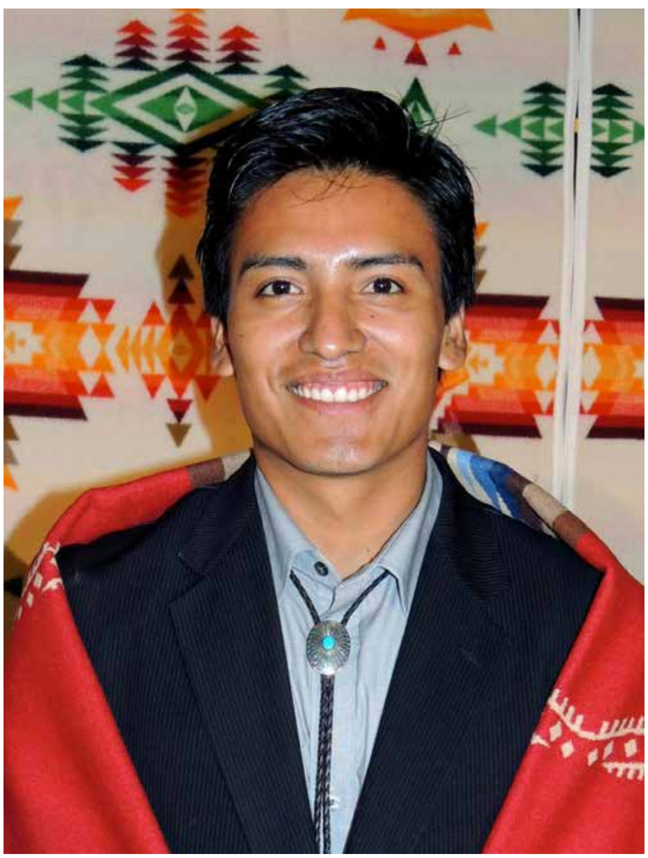
She's happy in Denver and at NREL. "There's a balance here for me, which is important in our culture: spirit, mind, body, and Earth. I stay close to my values, as stated in our traditional Navajo Beauty Way prayer, which states (as translated from Navajo) that I walk with joy, peace, confidence, and harmony before me, behind me, below me, and above me. This is the trail that I follow, that my relatives and ancestors paved for me."

"Certain things I feel responsible for: being an ambassador for my tribe and my race. Even explaining to my own race how they should look at things—there's no room for self-pity or entitlement," she said. "One of my goals is to articulate all the stories I was told, how I got introduced to two cultures. How I succeeded."

Manuelito said that as she looks into the future, she realizes the importance of staying connected to her family, especially since she has lost several close family members over the years. She expects to encounter her relatives again (in her next journey) and tell her great-grandparents and grandparents of all her adventures. Of course, she plans to thank her elders, reminding them that all her journeys happened because they inspired a little girl to shoot for the moon.

## Kevin McCabe Crosses Over a Cultural Bridge

**Kevin McCabe's** name sounds ideal for a combatant in the ancient Gaelic and Irish sport of hurling. Indeed, McCabe is dedicated to the team game, which he describes as a blend of lacrosse, baseball, and field hockey. And, before COVID, he often played three times a week as a midfielder with the Denver Gaels team. However, unlike many of his teammates, "I don't have any connection to Ireland," he said. Instead, McCabe is seven-eighths Native American—half Navajo (Diné), one-quarter Sioux (Sisseton Wahpeton Oyate), and one-eighth Seneca (Haudenosaunee)—with only a pinch of Scottish ancestry. McCabe's Native American lineage is "my true identity," he said. His ancestors are now at his core, although he only fully realized his heritage when he went to college at Stanford University—the same place where he was exposed to hurling.



Kevin McCabe celebrated his Native American heritage at his Stanford graduation in 2013. *Photo by Kevin McCabe, NREL*

As for his family's name, McCabe said it likely comes from the era when Irish railroad foremen assigned more pronounceable names to Navajo workers building the western rails. His name is a veneer; his deeper legacy is the one he wants to share with his people by connecting a range of renewable energy technologies, particularly geothermal, with tribal communities. That is his calling.

McCabe's father (a petroleum engineer) and mother taught McCabe and his three siblings about their roots. Still, McCabe said he felt distant from that legacy growing up in Littleton, Colorado. "It was hard," he said. "We never grew up near pockets of Native culture or people." Although they would visit relatives in areas with heavy concentrations of Native Americans in Arizona or New Mexico, and even went to the Navajo reservation, McCabe said, "I never felt part of the history growing up."

Everything changed when McCabe arrived at Stanford University, which has a robust and active Native American community. "There were many tribes from all over—even the Pacific Islands—as part of the mix," he said. "Seeing that as a community, and finally being around my people, it started clicking. I got really involved."

During that time, he joined the American Indian Science and Engineering Society, serving as an officer in the group. He also was engaged with the Stanford Powwow for two years. "It's the largest student-run powwow in the country," he said proudly. For McCabe, the view became clear, linking past to present. "I was finally around that culture and around my people," he said.

McCabe purposefully started steering his life toward the plight of Native Americans in the United States. "Conditions on some reservations could be called extreme poverty," he said. He witnessed communities that lacked running water or electricity. He saw the toll of major social issues: substance abuse, suicide, and joblessness. "I was trying to understand what those issues were," he said. "Having them contextualized by friends at Stanford started to hit home to me."

He began to pivot in his studies from mechanical engineering, eventually earning a master's degree in petroleum engineering in 2015. He knew that tribal lands had great natural resources, both mineral and renewable. "I wanted to get involved to develop those resources effectively, but also respectfully. And without waste," he said.

But as he was graduating, there was an economic dip in the oil and gas industry. "That led me to branch out," McCabe said. "The focus for my degree was subsurface reservoir engineering, and geothermal has that as a major component, understanding and simulating the subsurface." Although he had heard about NREL growing up, McCabe said, “I never really knew what they did.” Still, he reached out to NREL and found an internship with the geothermal program in February 2016.

McCabe began working on a county-level, thermal-demand assessment for the Geothermal Vision Study, a large U.S. Department of Energy initiative. He was then hired as a primary modeler on the Distributed Geothermal Market Demand model (dGeo). He used other modules of the dGen suite of tools, including dSolar (distributed photovoltaics) and dWind (distributed wind). In 2021, McCabe was part of the team that won an R&D 100 Award for NREL’s dGen, which is an open-source software that simulates customer adoption of distributed energy resources through 2050.

McCabe was part of a winning effort for a Laboratory Directed Research and Development (LDRD) project, getting seed funding for a new techno-economic analysis for geothermal simulations. There’s no shortage of work, it seems.

“Renewables were a welcome change of pace for me after two years developing oil and gas projects,” he said.

For now, McCabe said, “I enjoy the work every day. The main thing is to try to learn from all the experiences I’m having and to apply them effectively in the future as well.” He knows he’s changed greatly. Although he once loathed writing, that is past. “It’s come full circle now with all the publications required for the projects here and career advancement requiring adept technical writing skills,” he said. “Being able to marry those two has been challenging, really rewarding work.”

McCabe is able to take stock of his evolution. “It’s not as dramatic as I make it out to be,” he said. “I’ve transformed throughout the years. I went from someone who didn’t know what he wanted to major in as an undergrad, to finding my way as a mechanical engineer, to completely switching to petroleum engineering, and now working in the renewable sector. I feel that there’s so much to learn here, and I’m still getting up to speed. My ultimate goal is to work in the tribal energy side of things as well. I hope I’m setting myself up for that field.”

McCabe has traveled far and will continue his journey. “I have a lot to learn and am still learning,” he said. And that’s a good place to be for someone grounded in his heritage—and eager to help his people on their journey.

## Billy Roberts Charts a Home in the Old West

Journeys are something that **Billy Roberts** knows intimately—although his journeys may involve leaps of centuries.

“Sometimes I feel like I was born in the wrong century,” said NREL’s chief cartographer.

He believes in sustainability, raising or hunting his own food, and being connected to nature. “I’ve always been obsessed with food, ranching, farms, and self-sufficiency,” he said. His youthful fantasy was to come to Colorado and start a mountain ranch. “That won’t happen unless I win the lottery,” he said.

Instead, he settled on a 10-acre farmstead north of Boulder and, for a number of years, lived there with five Alpine dairy goats; a couple of horses; and an assortment of chickens, ducks, turkeys, geese, and bees—not to mention an array of vegetables, such as strawberries, which, if not eaten by humans, help feed the brood. Waste was composted.

“I’d do all my own everything,” he said, which meant adhering to a rigid schedule of getting up at 6 a.m. daily for ranch and household chores, highlighted by a 7 a.m. appointment in the milking shed with two goats. There’s no other option: Start slacking and their milk quickly dries up. At times, his land’s bounty reached NREL, and he brought in eggs and goat cheese to share.

### Wrong Time, Wrong Place?

While Roberts may be a man out of his era, he certainly was in the wrong place as a boy growing up in the East Texas countryside, a few hours’ drive from Houston. His town had two stoplights, one gas station, a Dairy Queen—and no western mystique. His relatives saw no need to travel or move.

“I always felt like the black sheep, like I didn’t belong,” he said matter-of-factly. “I was so very different from everyone else.”

Roberts knew something was missing, in part because he grew up watching Marty Stouffer’s “Wild America” documentary-style TV series about wild animals. “My memory of his show was that it was always set out west somewhere. There were mountain lions, bears, mountains, snow—all the things we don’t have in Southeast Texas,” he said. “I was always amazed by it. I remember asking my parents, “Where are these places? And why don’t I live there? Why do we send Christmas cards with pictures of snow on them, and it never snows here?”

Billy Roberts found a home in the West, embracing traditions and caring for livestock such as Clover. *Photo by Billy Roberts, NREL*

His passion for the West never left. “I always felt in my heart that’s where I belonged,” Roberts said. He finally reached his promised land on the family’s first and only vacation outside of Texas when he was 18. His clan flew to Denver and drove to San Jose, California, in seven days via the Grand Canyon—stopping for snapshots, then hitting the highway again. They rolled through Rocky Mountain National Park in record time. “We didn’t take a hike. We took pictures.”

Despite 12-hour, carsick days, he was close to bliss. “I saw mountains for the first time in Denver and was overwhelmed. I was absolutely in awe, all the way through Utah, through Arizona, parts of California. Everywhere I went, I felt this was home; the West was where I was supposed to be.”

“I never forgot Colorado and the West,” he said. After trying college and a few different paths, he returned to college. “I’d drawn maps as a kid of fantasy places,” he said. So, upon a counselor’s recommendation, he enrolled to study geographic information systems (GIS). He began with cartography 101 and loved it, eventually graduating from Texas State University, San Marcos with a bachelor’s degree in GIS and cartography. Roberts completed part of his dream in 2007, arriving in Colorado and starting work at NREL.

Mapmaking had helped Roberts reach his destination and fill the empty space in his heart.

Along the way, he studied Native American lore and experimented with skills they knew well once upon a time. He tanned the hide of a deer, soaking it in ash water and working in the animal’s organs to create supple buckskin. “It takes trial and error,” he said, with people and archaeologists trying to figure out how people lived. But now, some of those traditions are recovered; along with them, a measure of independence.

In 2018, Roberts liquidated the farm—it had become too much to juggle with his job—but soon embarked on a new adventure.

“I make renewable energy maps, but my hobby and my passion are the history of the Old West—and also maps,” Roberts said. “I’m fascinated with Billy the Kid, in particular. One day, I decided to try and find every place he ever went and map it out.” He designed a wall map, taking inspiration from real maps of the Old West made in the 19th century and earlier, and took it to Lincoln, New Mexico, the heart of Billy the Kid country. He found Lincoln was still nearly complete. It’s the best-preserved Old West town left in existence. “If you were to drop Billy the Kid into Lincoln’s single street today, he’d still recognize it, because most of those old adobe buildings are still

Anne Miller accepting the Van Morriss Award during the 2018 NREL Staff Awards gathering in 2019. *Photo by Werner Slocum, NREL 55590*

standing," he said. He created a map that was a huge hit with local residents, so he started selling it at local shows.

Billy Roberts is now pursuing other ways to explore the life of the more infamous Billy.

## Anne Miller's Origins for Her Trek to NREL

While NREL has attracted people from all over the world, some of its innovators have come from the laboratory's own backyard. Colorado has shaped the worldview of NREL's 2018 Van Morriss Award winner, Technology Transfer Office (TTO) Director **Anne Miller**.

"I grew up hiking, camping, and skiing in Colorado and developed a real appreciation of the natural beauty of the state," Miller said. "It certainly made the opportunity to contribute to NREL's mission that much more compelling."

Evergreen, Colorado, especially cast a spell after Miller's family moved to the then-remote area before Interstate 70 was completed. "I remember being carsick driving up from Denver on the old U.S. 40," she said. But once the family arrived in north Evergreen, an idyllic life unfolded, filled with meadows, trees, and adventures. For example, her neighbors held annual Christmas yule log parties—where kids would go into the woods to find a hidden log with a ribbon tied on it, and the discoverer would be carried triumphantly back to celebrate at a meadow bonfire. "It makes your hair stand on end, but that was before the fire danger we have now," she said.

As a teen, Miller's summers were spent working on a now-defunct Evergreen dude ranch. "I was the biggest dude there," she said. "The wrangler would take me on rides just for laughs because I was so uneasy on a horse."

Still, that sense of wonder for the outdoors stayed with her—even as she ventured out of state to Colgate University in New York. Of course, there were adjustments. "I clearly didn't realize what the winter there would be like," she said.

Although she considered becoming an attorney like her father (her mother was an occupational therapist), she ended up getting an MBA from Wake Forest University in North Carolina.

Miller returned to Colorado with her school-teacher husband, Ken, whom she met in college. She was hired by an engineering firm in Broomfield. "I was basically working on contracts and doing software licensing," she said. "That was a great chance to get exposure to the technical world of big water projects."

But in the back of her mind, she always wondered about working at NREL. And, in 2005, she happened to spot a classified ad in a Denver newspaper. "It was serendipitous," she said. "I already had a job, but this was really my dream job." She was pulled to NREL. "The chance to contribute to the mission was powerful," she said. "I still feel that way some days. I'll just be walking up to a building from the parking garage, thinking, 'Wow, I get to work here and be a part of this.'"

She started in Procurement as one of a handful of employees focused on agreements—such as cooperative research and development agreements with partners on joint research and development projects—but, within three months, a reorganization brought her into the TTO. She had found her second home.

For the record, Miller has helped close more than 30 Agreements for Commercializing Technology (ACTs)—mission-related, reimbursable work—including the laboratory's administration of the Wells Fargo Innovation Incubator program and Shell's GameChanger Powered by NREL. She also helped secure partnerships with ExxonMobil and the Los Angeles Department of Water and Power.

But it's not just about metrics. This rich environment nourishes NREL's research.

"There's a lot of value that the laboratory gets out of partnership agreements," Miller said. "Not only do they diversify our funding sources, but they provide insight into real-world problems."

She notes that partnerships offer researchers the opportunity to help companies develop solutions that enable technologies to be deployed and have an impact for both the company and consumers. "There's also a beneficial feedback loop from this type of engagement," she said. "We understand where we need to be in the future to be relevant to industry."

As she said while accepting the Van Morriss honor at the 2018 Staff Awards ceremony, "This should be a team award"— but the annual recognition can only go to an NREL technical or administrative staff member who is a leader through major improvements in productivity, capability, or efficiency. Nevertheless, Miller was quick to recognize TTO for being highly regarded as one of the best TTOs in the national laboratory system, according to Miller.

In her remarks, she cited the "tremendous amount of people across the lab that give us the support we need to be successful, including finance, legal, contracts, DOE, communications, and management—and most importantly, the principal investigators and technical staff who have the skills to bring partners here to work with us and who produce the technologies that our partners are interested in."

## Vahan Gevorgian Embraces Science Around the Globe

While Miller was absorbing her surroundings, some 6,600 miles away from Armenia—a nation of about 2.5 million people located on the eastern flank of Turkey—**Vahan Gevorgian** wasn't bothered by the fact that his country was part of the Soviet Union.

"No complaints. It was a good childhood. Of course, it was during the Soviet times, but I was too young to understand that it was an oppressive regime," the NREL principal engineer said. Instead, he worked hard in school, traveled a few times in Eastern Europe with his parents, who were both chemical engineers, and enjoyed the sport of soccer.

"I spent a lot of time playing with friends. Soccer was everything there—you just grow up with it," he said. There was another passion, too: "In childhood, I was pretty interested in technical stuff—how an airplane flies, how a car runs and, before computers, how TVs and radios work," he said.

Out of curiosity, Gevorgian took toys apart. In that pre-Legos era, he had Russian-made Konstruktor kits. "They were much fancier than Erector Sets. You assembled different things, with little screws, wrenches, and drawings. Cranes, cars. You added pulleys, brakes—once you got bored, you'd take it apart and build something new," he said. This, combined with the time he spent in laboratories—particularly his father's chemistry lab after school—probably ensured his path to science.

At the time, Russian was the language of engineering in the Soviet Union, so he learned that in addition to his native Armenian. In fifth grade, he started to learn English. But it wasn't until he arrived in the United States years later that he discovered the key to fluency with the help of Jerry Seinfeld and other TV sitcoms.

After graduating from high school, Gevorgian joined the ranks of hopefuls seeking to pass a grueling, multiday entry test for the university, which was theoretically based on achievement instead of financial assets. Like all schooling under the Communist system, the university was tuition free.

"I probably was nervous—but it was like 30 or 35 years ago, so I'm not sure," he said. He took the math and physics portions, but was excused from nonscience subjects because of his high grades in school. He did well and was admitted to the National Polytechnic Institute of Armenia, a top school, to study electrical engineering. While there, he was hired to help others with experiments in their laboratories.

Later, Gevorgian pursued a Ph.D. in electrical engineering from State Engineering University of Armenia, although his future path was already unfolding. Wind energy was growing, and he wanted to play a role in the field. "I was interested in renewables," he said, and the university was developing a renewable energy test site.

In 1991, the same memorable year the Soviet Union officially dissolved, he was part of a university group visiting the United States to learn about utility-scale wind power generators. "We spent a few weeks with a company near Los Angeles and brought back a couple of early wind turbine generators," he said. The visit made a big impression, and seeing large wind power plants near Palm Springs "was a good learning experience," he said.

Gevorgian began making computer models of wind turbines. He earned his Ph.D. in 1993, receiving a notice by mail several months after he completed his work. That same year, he met then-NRELians Larry Flowers and Ken Touryan when they visited the university as part of an international project. The meeting with Flowers and Touryan was "a happy coincidence," said Gevorgian. "We spent some time talking and looking at my computer models of wind turbines and stuff like that." Flowers asked him if he'd be interested in coming to NREL in the Village Power program that looked at places where the cost of power was already high—places such as remote villages that were used to importing diesel fuel—as a post-doctoral researcher. A few months later, in 1994, with strong support from Touryan, the formal offer arrived. Gevorgian was headed to the West of the West.

Gevorgian, then unmarried and without kids, arrived at the National Wind Technology Center (NWTC) on a two- to three-year assignment, helping with modeling and testing projects of hybrid wind/diesel power systems. "I really enjoyed what I was doing," he said. And, without family obligations, "all day long, I was working, working, working." He was proud, too. "The team collectively achieved worldwide recognition in the areas of small wind hybrid systems," he said. The group had projects in the United States and all over the world.

While at the NWTC, Gevorgian was part of a team operating the 2.5-MW dynamometer and conducting advanced wind turbine drivetrain tests. He became a test engineer in charge of power quality tests for wind turbines and also was responsible for testing

**Vahan Gevorgian metering a peak power dynamometer setup with a 10-kW alternator in 1997.** *Photo by Warren Gretz, NREL 04759*

and instrumentation of the dynamometer. Yet, he realized that testing takes a lot of time and energy. "At some point, I thought that maybe I'd be more useful to NREL switching gears a bit and starting to use my modeling skills again in the area of grid integration of renewables," he said.

Still, it wasn't all work. His free time in the 1990s was spent in front of the television.

"I was watching many sitcoms on TV and repeating the phrases out loud. Because, believe it or not, a sitcom is the best way to learn conversational English—*Seinfeld*, *Married with Children*, you name it," he said. "Sitcoms, I tell everyone, use real language; it's real slang, what people say every day. That helped me a lot. Watching the news, I didn't learn anything."

Gevorgian moved up steadily, from postdoctoral researcher to temporary employee, until he was hired permanently in January 2001. One thing remains constant—he always looks to engage in the next level. He contributed technical knowledge, including the development of advanced control algorithms for variable-speed wind turbines and grid support capability for both wind and solar power plants.

Eventually, a position in the grid integration group fascinated him, and Gevorgian saw it as a chance to move beyond simply proving new technology. "When you test things for clients, they listen to your ideas, but that's about it," he said. Instead, he had lots of ideas about grid integration that he wanted to help implement.

Even after being selected to work on grid integration, Gevorgian maintained close ties with NREL's testing folks. "I also do a lot of theoretical work with my present team," he said. "I realized you could test mechanical things, but how about simulating events that happen in the grid?" he said. There was no apparatus back then to do that. He helped shape that idea—and DOE eventually funded it. Out of that work came the Controllable Grid Interface, a one-of-a-kind power system simulator at the multimegawatt scale. As a result of his work, NREL owns one of the largest power system simulators in the world.

Gevorgian is working to connect all of the facilities at the NWTC and the Energy Systems Integration Facility—maintaining offices in both locations. With this work, the laboratory can demonstrate real-time operation between the two sites and will be able to run dynamic power system simulations using power hardware at both locations. This effort was another first-of-its-kind achievement cited for Gevorgian's Hubbard Award, given to an NREL researcher who has made sustained high-level research contributions and who has shown true leadership and initiative. The man referred to as an "engineer's engineer" is still puzzled by the award. "Everything they mentioned was a contribution from so many people—I had part of it," he said. "It still remains a mystery. I'm glad to accept it but, without false modesty, there were many others who deserved it."

Perhaps drawing on his sitcom mentors, Gevorgian joked during his Hubbard Award acceptance speech that he was thankful to those at NREL who hired a young postdoctoral researcher "with a strange accent and a fear of public speaking," noting, "20 years later, the accent is still there. The fear is there, too."

Gevorgian said he'll keep trying to take his work "to the next level and adding functionality. I'm not after any prizes; I'd just like to continue engineering." His equation to stay integrated at NREL is simple. "As long as the lab likes me, and I feel the same way, I'll stay," he said.

## Sakshi Mishra Gains Traction in Engineering

Although engineering was long considered a male occupation (check out Bobi Garrett's experience in Chapter 8), that perception is changing. And female NRELians are at the vanguard of that transformation.

Mishra enjoys taking part in Bollywood dancing as one of her cultural outlets.
*Photo from Sakshi Mishra, NREL*

Researcher **Sakshi Mishra** faced a choice heading into college: whether to pursue computer science or electrical engineering. "I was strongly advised by my community in central India against studying electrical engineering," she said. "They said, 'It isn't for girls. You are not going to be able to work with machines.'"

She thought differently. "I went into electrical engineering because they said I could not do it," she said, adding that there was also an interest. Growing up in Mandsaur, India, Mishra had helped her father fix the family Fiat, continually asking questions about how the car's systems operated. Later, during power outages, she closely examined her home's power inverter to understand ways of generating electricity without relying on the utility grid's power. She felt comfortable in the world of engineering.

The pursuit wasn't easy—starting with a 1,000-mile train journey that took 32 hours to get to the Vellore Institute of Technology (VIT). It was her first time on the campus in southern India. "My mom was worried. She said I wouldn't understand the language. I said, 'They speak English, Mom. Take it easy.'"

The courses were intense, and there were challenges being one of only 17 females out of 90 VIT electrical engineering majors. Still, she excelled and also developed a passion for energy systems. In her final semester, she and another VIT classmate qualified for scholarships to study in Australia. Again, her parents were nervous about the transition.

"That was my first culture shock—it was so Westernized," she said, "but it was wonderful." She also gained hands-on experience with renewable energy experiments.

After graduating in 2014, Mishra looked at graduate programs in the United States and, despite her parents' hesitation, began pursuing a master's degree at the University of Michigan, Dearborn. Seeking more focus, she switched to Carnegie Mellon University, enrolling in the Energy Science Technology and Policy master's degree program. There, she gained exposure to machine learning and artificial intelligence (AI).

Mishra studied breakthroughs in deep learning based on machine-learning algorithms. "I wanted to find out how it could be used for renewable energy applications to help solve climate change problems," she said.

A class on data-driven building energy management further whet her appetite for the budding research area.

> "I was strongly advised by my community in central India against studying electrical engineering."
>
> —Sakshi Mishra

Additionally, an internship at Black & Veatch gave her experience "in the real world of energy" issues, she said. While at the consulting firm, she contributed to studies about the feasibility of fuel cell plants and the photovoltaic adoption rates among consumers.

When she completed her master's degree in 2015, Mishra contemplated whether she should pursue a Ph.D. Instead, she took a job as a grid planning engineer with American Electric Power. Seeing the energy landscape up close required a steep learning curve, she recalled.

Although she relished the challenge, something else was in the back of her mind. "I wanted to be somewhere where I could have a direct impact on accelerating a clean energy transition," she said. "I knew about NREL as the place to go for renewable energy research". And research was something she missed in the industry. "It made sense for me to come here," she said.

In August 2018, Mishra joined the Integrated Applications Center. "I believe it is vital to bridge the gap between clean energy's state-of-the-art research and industry deployment," she said.

She engaged at the nexus of energy systems and artificial intelligence, in her words, "actively exploring AI-based methodologies for accelerating the transition to clean and resilient energy infrastructure, through renewable integration and sustainable and smart energy systems design." Additionally, she is leading the predictive analytics effort for NREL's Intelligent Campus group. She also helped to develop REopt Lite, an optimization tool aimed at studying the techno-economic feasibility of behind-the-meter distributed energy resources. In August 2020, Mishra, along with **Nick Laws** and **Ted Kwasnik**, received the NREL Chairman's Team Award for Exceptional Performance in recognition of the team's release of the open-source REopt Lite model that is driving solar and storage deployment and building new research collaborations.

For all the intensity of engineers, Mishra dismisses the idea that science types must be "nerdy" or overly focused. "They can flex their creative muscles, too," she said. Her own life is proof.

In the past, as a hobby, Mishra sketched during vacations. "Though today, deep-learning algorithms are capable of generating sophisticated pencil sketches with minimal directions, I still think that the joy of creating art by hand is somehow more fulfilling," she said.

She also remains steeped in her cultural traditions, making henna art tattoos for Indian festivals and enjoying the jubilant "Bollywood" dance tradition. Then there's her love of motorcycle riding—something she hasn't pursued in the United States, but fully intends to when she has a chance. "I'd love to travel from coast to coast on a motorcycle," she said, smiling.

Mishra is glad she didn't allow herself to be diverted from her choice in science, technology, engineering, and math subjects and is grateful for those who encouraged her. "I was fortunate to have great mentors and advisers on the way," she said. "I wasn't held back from pursuing any opportunity because of my gender."

The Sky family (with Haiku, far right) on its catamaran, Imagine, during a journey to the Great Barrier Reef in 1994. His father, little sister and younger brother, are there with two family friends. His mother took the picture. *Photo from Haiku Sky, NREL*

## Haiku Sky's Unusual Experience Helps Him Survey the World

*Born in a tepee*
*Sailing reefs, skiing, surfing*
*Wants to fly sky-high*

If you hope to get a sense of who geospatial science researcher **Haiku Sky** is, you have to know about his parents—particularly his father: a true long-haired child of the '60s. "He liked walking his own path," Sky said.

Sky's dad was an engineering student in college when he was drafted as a pilot and stationed in Japan during the Vietnam War. After the service, he remained in Southeast Asia, flying DC-3s into Indonesian airstrips. Locals—many of whom had never seen an aircraft—called him Orang langit, which translates to "Skyman."

Eventually, he changed his last name to Sky, married a pilot from Singapore, and began raising a family unconventionally—to say the least. "I can't make this up," Sky chuckled. Life was different from the start. "I was born in a tepee," he said, referring to the small farm his father owned near Ashland, Oregon.

The elder Sky, who had a deep love of Japanese culture, chose his eldest's son's first name in honor of the haiku form of poetry (consisting of a single, unrhymed verse comprised of three lines containing five, seven, and five syllables, respectively). The younger Sky is aware of his heritage but claims no special advantage in the art form as a birthright. His parents, who took what he called an "organic approach" to learning, didn't pressure the young boy into mastery. "I feel like I'm a decent writer," Sky said. "I've written some haikus, but they weren't very good. Maybe that's the irony of my life—I wasn't gifted with the poetic ability of my namesake."

The tribute to Japan didn't stop there. Sky has a younger brother, Shinku (for a more obscure form of poetry), and a sister, Issa (the first name of a poet who wrote both haiku and shinku).

Early on, the family lived half the year in Oregon and the other half in Indonesia, mostly in Bali, while the father worked six-month contracts as a pilot. Sky learned a smattering of Indonesian during this time. When asked if he still speaks the language, he replied, "sedikit-sedikit" (meaning "a little").

When Sky turned 10, his father moved everyone to Brisbane, Australia. For the next seven years, they lived aboard "Imagine," a 37-foot catamaran sailboat that they built themselves and named for the song by John Lennon (not surprisingly, the elders were Beatles fans). Every year, the family sailed from Brisbane to the Great Barrier Reef.

Sky's mom, Anne, who had a teaching degree, was able to homeschool the kids. "A large part of our curriculum was integrating the natural environment into our daily studies," Sky said. "My mom emphasized the marine and terrestrial biology, geology, geography, and history of each location we visited."

Many nights were spent identifying constellations, planets, and other cosmic objects. "We also utilized astronomy to learn rudimentary navigation using a sextant, despite having a GPS to get us from place to place," he said.

## Countercultural Connection to the United States

Clearly, this upbringing was not typical for American kids. Sky wasn't in Little League or Boy Scouts. "I felt a gap," he said. "In some ways, when you aren't raised in an environment, you may be more curious."

From an early age, he developed an interest in soccer, which fulfilled a need to belong to a team. In later years, he gained an appreciation for standard American sports; however, the family focus had always been on individual activities. They surfed on the east coast of Australia and skied in the winter.

At Christmastime, when back in Oregon, they'd all climb into the family's Volkswagen bus (yes, it's true) and head to a nearby mountain. The younger Sky, who had lived in Colorado as a boy, was passionate about skiing. "We'd go there, camp out, wake up, and try to get first tracks," he said.

Countercultural influences shaped his and his siblings' characters. "I think our rebellion was to be pretty good kids," he said. "Education was important. We strove to go to college. I think that, in teenage years, you want what you don't have."

When he turned 17, the family made "this weird, deep decision," according to Sky. "Maybe it was time to sell the boat and return to the United States." To help with the move, his parents bid on a government contract for airborne mapping at the old Lowry Air Force Base east of Denver. However, it took ingenuity to land it from halfway around the world.

It was 1998. The elder Sky had a blocky cell phone, and Anne had an ancient laptop. The boat had no cell service, so Sky rigged a cable up the mast—and received one bar of cell service. Anne faxed in the contract for the job—which they won. So, Sky Research, which his parents had started in the 1970s, pulled up anchor and headed back to the United States.

## College as a Global Discovery

Haiku Sky was planning to attend Southern Oregon University near the family home. However, he had a Plan B.

"There was a joke in my family that the kids had to get our pilot's licenses before we got our driver's licenses," he recalled. It didn't work out that way, but reality wasn't far off. He was a pilot at 18, before his freshman year of college. "I felt like there was an obligation. And I was testing the waters of a career path as well," he said. (Seven years later, he earned an instrument rating, which means he can fly without visual assistance. "I won't lie. It's a bit creepy," he said.)

But he didn't need to climb into the professional pilot's seat. School was fascinating to him. "They had a great geography program. I developed a deep love for studying something that encompassed the natural world—the physical and cultural worlds combined," he said.

This led Sky to focus on geographic information systems, which essentially was digital mapping. "Part of the reason I embraced the geospatial side of things was that it allowed a unique view of the world," he said. "You could, without taking a step away from your desk, zoom in and look at something very minute, and zoom out to expand. I loved it from an aviation experience."

He also learned about NREL from one class—and began wondering about the laboratory.

However, following graduation, Sky joined the family business. Then he moved to Denver for a project that was supposed to last six to nine months. He met his wife, Nichole, here—and the project lasted for nine years.

"I always had my eye on NREL," Sky said. "I knew it had a lot of smart, talented engineers. In admiring the lab, I wasn't sure if it was necessarily where my skill set fit."

After working at several small aviation firms, Sky applied to NREL. And, in August 2018, he landed a job in the Strategic Energy Analysis Center as a geospatial data science product manager.

Sky said working at NREL has been a wonderful experience. "Every single day I'm more impressed and amazed. Then, when you expand outside the team, to the department or lab as a whole, it is incredible—the vibrance, scope, and depth of the work conducted here," he said. He cites the people and the mission as his favorite aspects of the laboratory.

This place—more than 8,000 miles from Australia and Indonesia, which held a mystique for him for years—has made him feel at home. "I feel incredibly honored to work with such a great group of people," he said. "The enthusiasm and passion everyone has is contagious. It's hard not to feel very passionate myself."

And while he misses the ocean—"If there were an ocean on the other side of the mountains, I'd never leave," he mused—Sky does have his GIS portal that allows him to zoom to any corner of the planet.

Perhaps there's even a haiku in there somewhere:

*He follows his path*
*Settling in at NREL*
*Maybe he can soar*

## Judith Vidal Sees Giving as Part of NREL Life

While a majority of NREL staff gives in a variety of ways—through the laboratory's annual charity campaign or by donating time to various causes—some have gone even beyond those avenues.

Building Energy Science Group Manager **Judith Vidal** was shocked by the appearance of her "baby" brother, Omar, during his visit to Colorado in 2015. Twelve years of dialysis in the siblings' native Venezuela had taken a severe toll on him.

"His body was really bad," Vidal said. "He'd shrunken two inches, he was hunched over, and all of his fingers were deformed. I was angry, sad, desperate. I started yelling at him that he didn't care about himself—not even about his daughter."

Eight years his senior, Vidal had tried for years, along with others, to convince Omar to get a kidney transplant—but he continued to refuse. He'd already suffered through many major surgeries. She was aware of this, of course, and did what she could to help. She gladly paid $420 each for his three dialysis sessions during his visit.

But the treatment to remove waste from the bloodstream wasn't the answer for a young man in his thirties. It interfered with his calcium absorption, twisting his frame and affecting his pallor. And that wasn't the worst of it. "He was dying," Vidal said.

Known for her bubbly personality, Vidal was blunt. Tearfully, she told him that she would donate a kidney, but he had to decide to get the operation. "I'm the oldest, and he's always listened to me," she said. Finally, he agreed. "He told me—'I promise I'll do this. I'm in pain.'"

Omar returned home and began the long process of qualifying for the operation against the backdrop of an economically stressed country. After multiple delays, including recovery from a parathyroid surgery, he got word in 2018 that it was his time. Meanwhile, Vidal saved $20,000 for the tests and operation to help ease the financial burden. "The situation is so bad there that insurance like my brother's won't even cover a pill for a headache," she said. Her mind was made up.

> "This gave me the opportunity to feel the sensation of giving life back."
>
> —Judith Vidal

Others were nervous about the procedure, which was taking place in Venezuela. "Everybody, especially here, was worried that I was going alone," she said. Her husband, Edgar, an American citizen, was not allowed to enter the country. Vidal was okay to do so because she had dual citizenship.

Assured by Omar in mid-June that all of the medicines were available for the surgery and everything was squared away, Vidal said goodbye to Edgar and her two children and flew to Venezuela.

She was at peace.

### A Long Wait Overcome in Venezuela

Vidal had come to the United States in 2005, bringing her two young children from a failing marriage. She pursued her Ph.D. at Colorado School of Mines, settling on metallurgical and materials engineering. While she enjoyed the challenge, life was anything but easy as she struggled to get her footing in a new country.

"It was a difficult time, but I was like, 'I'm a fighter,'" she said. "Having these opportunities—I'm following my dreams."

Because of her studies, Vidal didn't have time to return to her homeland. Her sister also lived in the United States and, together, they flew their brother, his daughter, and their father, Omar Sr., here for visits to stay connected. Her brother's health, damaged when he was 18 as a result of complications from an autoimmune disease, gradually worsened. Complaining of headaches, he went to an emergency room in 2006, waiting three hours before he fainted. Doctors found that his blood pressure was extremely high. Dialysis became the norm as he endeavored to maintain his employment as an accountant in Venezuela.

Back in Colorado, life wasn't slowing down for Vidal. After earning her Ph.D., she joined NREL's solar program in 2010. "I wanted to make an impact here," she said, so she dove into her work—saying yes to new challenges. Finally, in June 2018, with both of her children settled into college, Vidal was able to make the trip back to Venezuela for the surgery.

When she checked into Santa Sofia Clinic, a hospital that performs two kidney transplants a week, she underwent one more test to confirm that her blood was compatible with her brother's. A day later, the results came back—a perfect match.

"We got the green light," she said. "I was so happy and excited." On June 17, the night before her operation, she met her surgeon, Dr. Genaro Rosito. "He was so peaceful. I knew our lives were in his hands. I was feeling confident," she said. "Since day one, I wasn't scared at all. Never. I'd made my decision. My brother was the one scared about me—that it was going to be painful."

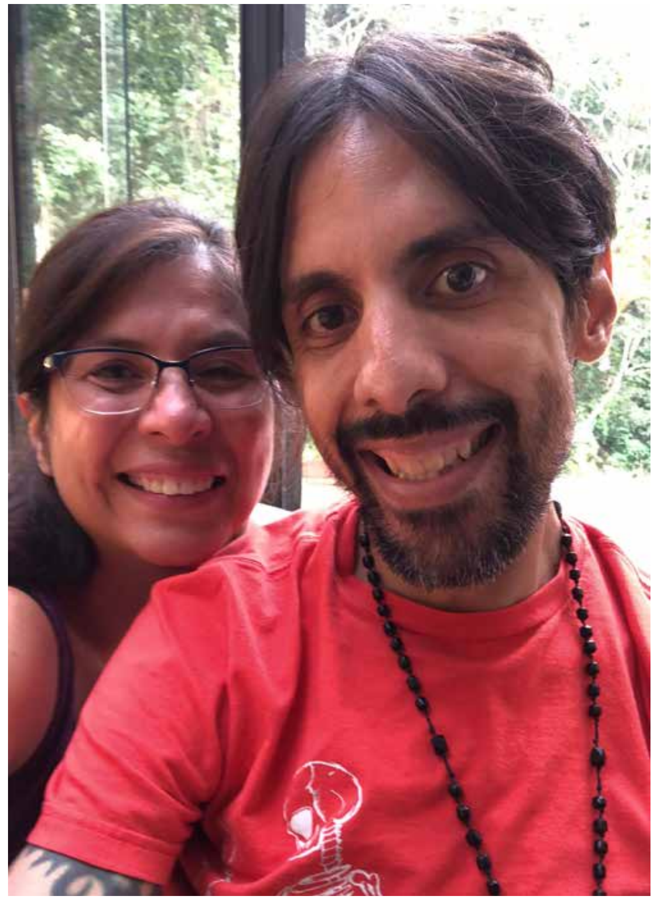
## Tense Moments in a Life-Changing Day

At 7 a.m., Vidal was prepped for what she expected would be a three-hour operation. She spoke to her brother. "I told him: 'I'm here. Everything is going to be perfect. Don't worry. I'll see you tonight.' And I gave him my smile."

The doctors had said that if they received no word during the procedure, her family should assume all was well. So, Judith's husband and children stood by for any updates relayed by Judith and Omar's father.

During the operation, the doctor found the procedure required more time. Although Vidal wasn't in any danger, the additional anesthesia kept her asleep longer than expected in the recovery room. Her family nervously waited for news and, finally, at 3 p.m., they heard the procedure was successful.

Omar was already awake when Vidal regained consciousness—worried that his sister was in pain. She was, but not from the operation. "I was in pain because of my back," she said. "I had been on that very hard bed for too many hours. I asked the nurse to please put a pillow under my back."



**Siblings Judith and Omar Vidal are all smiles a week after the transplant.**
*Photo by Judith Vidal, NREL*

She walked that evening, her healing already beginning. Vidal was able to leave the hospital after five days and went back when her brother was released a couple of days later. She gave a hug to a completely revitalized man—reborn at 41 with the help of his new kidney.

"When you see pictures of him before, his skin was literally green—he was undernourished," Vidal said. "Now, he's already gained 20 pounds. And within just 24 hours after surgery, he had a normal skin tone."

The new kidney started functioning almost immediately, removing the toxins from Omar's blood. He was invigorated. "I couldn't keep up with him walking," Vidal said. "He said that he wanted to stay awake—he had so many things to do. He received his life back after so many years."

According to Vidal, so much good has come from her decision. Not only is her brother regaining his health but, in her mind, she has benefited as well. "I was the lucky one," she said. "This gave me the opportunity to feel the sensation of giving life back. After giving birth, this is the most amazing thing in my life," she explained, saying, "a mother doesn't think about the pain, but about the new life."

Since the surgery, the two siblings have grown closer than ever. "Before, we talked once a month. Now we FaceTime three times a week," she said, smiling. "We have the connection with the organ that was mine—now it's his. And because of our blood compatibility, I joke with him that I wasn't always certain we were related. But now, I'm sure he's my baby brother," she beamed.

Vidal carries a 12-inch scar as a reminder of her transformation. "It changed my life," she said. "I'm more relaxed. I know what is important."

Weeks before the surgery, Associate Laboratory Director Johney Green had asked Vidal if she would consider becoming a manager in the Buildings and Thermal Sciences Center. She agreed, with one condition: that the transition from her solar work be gradual. "I have more on my plate," she said. "I like to say yes." Overall, research is part of her passion. "I love to mentor and, here, I have the opportunity to bring in bright Ph.D.s and help launch their careers," Vidal said.

She is enjoying life more than ever—and hopes her example can inspire others. "You shouldn't be scared going through that type of surgery," she said. The results can be beautiful. As Vidal looks at her life—family, work, and her donation—she said, "I am so lucky." She is living the power of yes.

## Lisa Fedorka Has a Beak Experience Rescuing Wild Birds

Most wild-bird rescues don't take place in the media glare that Administrative Associate **Lisa Fedorka** experienced. It happened when her team relocated a duck and her brood from behind the KUSA studio in 2006. While it was memorable to help an expert from Wild B.I.R.D. (Wild Bird Information and Rehabilitation of Denver) move Nina (who had become a local web-footed TV celeb) before the mother duck attempted to march the hatchlings across traffic to open water, it was an unusual day for a volunteer. Back then, Fedorka and several dozen others spent countless hours at the bird shelter on South Quebec Way on more routine tasks, such as feeding, cleaning, and caring for as many as 3,000 sick, injured, or orphaned birds each year.

**Judith Vidal works with a Differential Scanning Calorimeter in 2017 to characterize thermal fluids at high temperatures for corrosion-resistant metal coatings.** *Photo by Dennis Schroeder, NREL 45090*

"The days were long, particularly in the summer," said Fedorka, as tiny survivors in incubators must be fed by hand every 15 or 30 minutes from early morning to late at night. The numbers grow as birds with broken wings or the West Nile virus arrive in carrying cases.

Luckily, she had learned some bird-care basics on her own while keeping cockatiels. From those pets, she knew that adult birds often ignored their own offspring, forcing humans to hand-feed the babies. "There's no DVD for them to watch, so sometimes it takes several clutches [of eggs] to learn," said Fedorka.

In 2002, Fedorka decided to volunteer at Wild B.I.R.D., but hadn't yet been trained when a friend called frantically seeking help with two baby blue jays she'd found. "I was a pretty poor option, but I was the best she had. I didn't know what to do, but I knew who did," Fedorka recalled, so she dialed the shelter. It was the beginning of an intensive education that continues to this day. But, on that day, and by intuition, Fedorka had done one vital thing correctly—not feeding the birds herself, an often fatal mistake some well-meaning folks make.

As she came to learn, each species of bird has different food requirements. Some eat seeds, others sip nectar, and a few— such as crows—chow down on protein. In some cases, rescued chicks are too cold to learn to eat, and attempting to give them nourishment would be their doom. Then there are subtleties in bird behavior.

"All birds are good birds—and some are very tough. Yet, they are emotional and can get depressed," Fedorka observed. In those instances, birds can will themselves to die, she said. So, caregivers must be sensitive and give them time to get used to being in a shelter. Yet, some victims can mend quickly, and Fedorka has seen a broken leg repaired in a week.

### Training To Help a Broken Bird

Fedorka's formal training began with the shelter basics: cleaning cages, washing dishes, and preparing food. Gradually, as she gained experience, she learned how to use feeding tubes or syringes to get food into a beak or a bird's crop (a stomach-like part of the digestive system). Starting with older, healthier birds that are easier to feed, Fedorka eventually gained the skills needed to handle the most fragile avians. A typical session might include monitoring three different incubators, each with between 10 and 30 hatchlings of Front Range species. Whether robins, sparrows, finches, or flickers, they all need sustenance repeatedly. When a young bird willingly gapes—opens its beak—it's saying, "I want food," Fedorka noted. Their tones can range from a sweet trill to the raucous scream of a young woodpecker.

> "It is particularly thrilling when a bird is well enough or old enough to be released."
>
> —Lisa Fedorka

Fedorka, who joined NREL in 2007 in administrative support for the Advanced Vehicle Systems group, said the process "delights me"—even when a healthy hatchling digestive system means the constant need for a clean nest. At one point, she would spend her lunch hours, and even some time waiting in her car commuting, fashioning thousands of toilet-paper nests so that volunteers would have a ready supply. It was one efficiency that helped the process. "You cannot stop. You're always on the move because there's always another mouth to feed or nest to clean," she said.

Unlike many shelters, Wild B.I.R.D. didn't reject the most common types of birds, like pigeons. It gradually prepared them for release. The big moment was release day, when the licensed rehab expert deems it's time to get recovered birds back into nature. This is not some random cage opening. Rather, the shelter team tries to ensure that the birds are able to join others of its species. Sometimes, the moment is magical, like "seeing an American pelican take off and join more of its kind on a sand bar in a lake," Fedorka said.

The shelter closed around 2017, so now Fedorka helps whenever she can. "When people find orphaned, injured, or sick birds and can't take them to the rehabbers in communities like Centennial or Louisville, they will bring them to me, if I'm able to take them," she said. Also, some veterinarians have her contact information and refer individuals to her when they get calls about grounded wild birds.

Her passion continues. "It is particularly thrilling when a bird is well enough or old enough to be released," she said.

## Kate Young Sees Africa through Children's Eyes

Watching the sun rise on Mount Kilimanjaro after a night of hiking was awe inspiring. But it probably wasn't the highlight of Laboratory Program Manager for Research Project Management **Kate Young's** African venture in May 2009. That came later when she and her husband, Randy, helped give a party at the orphanage where they were volunteering.

"They sing a great birthday song, 'Jambo Bwana,'" Young said, which means "Hello, hello, sir," and speaks of welcoming foreigners, ending with "hakuna matata" (there is no problem), a phrase now familiar from "The Lion King." Guests and residents shared the traditional African "Jambo" food, just as they all helped in the garden to grow vegetables to sustain themselves. The Malaika Children's Home—Malaika means "angel" in Swahili—was founded in 2004 by Francesca Jutta and "Mama" Jutta. The founders saw an urgent need for refuge in Arusha, the Tanzanian capital and gateway to Mount Kilimanjaro's 19,341-foot peak. Arusha was also a community ravaged by disease, and Young was able to commit to a week's work through one of Arusha's many Denver connections.

Young collected about $450 in donations (including some from NREL donors after joining the laboratory in 2008). She also took suitcases of donated school supplies and clothing so that some of the 15 boys and girls in the children's home could have decent uniform shoes and mattresses. "One of the things I like most is immersing myself in the culture. If we just had done Kilimanjaro or a safari, they both would have been amazing," Young said. But the Golden couple would have experienced Tanzania as tourists. Instead, they had deeper insights and saw life through local eyes. They relied on their hosts, especially Mama, to give them that perspective.

"We asked her 'What do you need?' Their hostess said, 'So-and-so doesn't have a mattress and has been sleeping on this cot. This one needs school shoes.'" Mama Jutta took them into town to help with the shopping, because the Coloradans didn't know how to buy mattresses in the town.

The experience helped her understand the people. "You see how locals shop, do business, take the bus, and get by on a day-to-day experience. It really opens your eyes to what's going on in other parts of the world and how privileged we are here," Young said.

At other times, she and Randy played with the kids, sorted clothes, or helped in the garden. Their setting included a cow purchased through the Aurora Rotary Club. Other projects, such as an outdoor shelter, a rainwater collection system, and solar panels to provide some an hour or two of electricity each day, were all supported by Denver-area groups. The groups also backed projects beyond the children's home, helping to build a local hospital and set up its computer system.

If the week at Malaika was moving, the trek up to the dormant volcano was nearly as compelling. The Youngs followed the eastern Marangu Route, a five-day round-trip excursion. Two guides led the way, along with porters, as the trail snaked through the four vegetation zones: the dense forests, the low alpine, the highland desert, and the summit alpine.

"You hike all day every day, staying in little huts located along the way,"Young said. While the porters carried the food, the couple was responsible for their own equipment. On the third day, the trekkers went to bed early and were awakened by guides at 11 p.m. Their night summit began.

"We reached the rim of the crater at about 6 a.m. the following morning and hiked along that to the other side to the peak, just as the sun was coming up over the horizon. It's amazing. There are glaciers up there, and features along the way they have marked," she said. "It was nothing like climbing a 14er around here. It was noticeably thinner air." As a result, things proved difficult, because Randy was still recovering from Lyme disease. "He made it to the rim, but couldn't make it to the peak," Young said. Instead, he went down with one guide, while she summited with the other, reaching the peak at 19,341 feet above sea level. By the time she returned to the hut, Randy was sleeping, and there was concern he was getting altitude sickness. Typically, the adventurers make it down by 10 a.m., and then can have food and a nap.

"Because of his altitude sickness, we had to keep going," she said. They finally arrived at the lower-elevation camp around 3 p.m., her only food for 16 hours being some Clif Energy Bloks she brought with her. "I was running on adrenaline by then," she recalled. Finally, she could rest—and her husband was able to recover with the increased oxygen.

> "You realize what a big impact you can have and how a little money can make such a huge difference."
>
> —Kate Young

Despite the difficulties, summitting Kilimanjaro was an amazing experience, and Young is encouraging about such a trip, as long as adventurers have a trusted travel coordinator like the one they used.

"Afterward, take the time and get to know the culture," she reiterated. Don't be shy about finding ways to help, she counseled. "You realize what a big impact you can have and how a little money can make such a huge difference," she said. And Young plans to return someday—though for now she and her husband are busy with their own two sons, born after the return from Tanzania. "There's a fantastic relationship between Arusha and the Denver area," she said. "We were like family the whole time we were there."

## Ian Baring-Gould and the Far Reach of NREL

Among NRELians, the idea of traveling the globe to spread knowledge is one of the things that makes the laboratory so impactful. Just as people traveled from around the world to join the ranks of NREL, so too have researchers and engineers scattered to the four corners of the globe to engage in problem-solving. **Ian Baring-Gould** is one of those engaging in the power of widespread communities.

If you played a real-world version of the TV show *Where in the World Is Carmen Sandiego?* based on Ian Baring-Gould's deployment travels for NREL, the result would consume much of a world map.

"I've been on every continent, over 70 countries now, largely for the laboratory," said Baring-Gould.

His journeys coincide with the expansion of renewable energy technologies globally. Baring-Gould is amazed at the progress of renewables, particularly wind, during the past few decades. He's seen it firsthand. As a program manager at the National Wind Technology

**Baring-Gould at a remote polar station operated by the National Science Foundation.** *Photo by Ian Baring-Gould, NREL*

Center at the Flatirons Campus, he has served as manager of the laboratory's distributed wind research and testing portfolio.

"It's just staggering, the explosion of the wind industry, and how we've gone from a technology (when I got here) of 80 cents per kilowatt hour, and now dropping to the point where wind is arguably the cheapest electron you can put on the grid," Baring-Gould said. He added that "solar technologies have also seen significant reductions in cost—and with DOE and industry, we are working hard to provide similar cost reductions in distributed wind, providing more energy options across the United States and around the world."

Baring-Gould concentrates on deployment, which, he said, "is about how you articulate those positive impacts and benefits of wind development." That's where his background comes to the fore. "We don't have to sell the idea of renewables," he said. "We're there to educate and tell people about renewable energy, and that includes the warts. We talk about the positive and negative impacts and let people make up their own minds."

Baring-Gould's arrival at NREL was "complete luck," he said. "When I was at the University of Massachusetts, Amherst (UMass), I was in a renewable energy program focusing on wind energy"—a pioneering program more than four decades old. Because of that, there were strong links between NREL and the university professors. "The research we were doing at UMass was for NREL," Baring-Gould said. "As a grad student, I was part of a contract to develop computer software for isolated power systems, including microgrids and control strategies."

Baring-Gould also helped install the then-largest wind turbine on the East Coast before coming to NREL in 1995 as a student intern to finish out the code development, which was sponsored by DOE and the laboratory. Once at NREL, he joined the Village Power Program in which laboratory staff were exploring ways to provide power to off-grid communities.

At that time, the thinking was that renewable energy technologies were too expensive for the main grid. Early on, Baring-Gould and colleagues searched for the best ways to reach those communities through renewable technology scale-up. According to Baring-Gould, such analysis "continues to play a role in my career today."

His engagement in rural electrification has been a thread throughout his career and reflects his desire for rewarding community work. "NREL is a community—the researchers, the teams I'm part of," he said, adding that, similarly, "The work I do is community power." These ideas of community power and how to scale up their development that were initiated by NREL researchers back in the 1990s have expanded into research on highly resilient microgrids for resiliency and disaster management. "From that early work, we are now at a point where minigrid and microgrid power systems are seen as a core element of providing clean, sustainable, and highly reliable energy services to hundreds of millions of people across the globe," he said. "NREL's work in this space has been critical to the development of the wider industry, and concepts such as the Quality Assurance Framework for Mini-Grid Power Systems have become a standard that are being deployed around the world."

His field is different from a lot of what NREL does. "It's really bringing power to people who don't have it—or lowering the cost of power to improve lives," he said. "One of the reasons I was really drawn to this challenge is that it touches communities in Alaska, Africa, and other places," he said.

Not only does Baring-Gould have the capacity to make physically arduous journeys, but he pushes the envelope mentally, too. "Ian has the amazing ability to keep the global picture in mind while also memorizing detailed budget numbers," said **Suzanne Tegen**, a former NREL colleague who now serves as assistant director of Colorado State University's Center for the New Energy Economy. "Some of my favorite memories at NREL are the brainstorming sessions Ian and I had," Tegen said. "We would walk around the NWTC talking through potential projects and pushing ourselves to think new thoughts. Sometimes my brain hurt afterward. But there were always good outcomes, and both NREL and our team benefited from Ian's vision and ideas."

His colleagues noted that Baring-Gould communicates easily with industry stakeholders, high-ranking government officials, the general public, engineers and scientists, and the next generation of the energy workforce: K–12 and university students.

Away from the laboratory, Baring-Gould is active outdoors. In particular, his volunteer work with the Rocky Mountain Rescue Group (RMRG) provides a personal complement to his tasks at NREL. He sees his commitment to the Boulder rescue group as community based—the same as his assignment at NREL. "It all kind of revolves around community engagement," he said.

Just as he discovered the sport of crew by chance in college, Baring-Gould also stumbled into the rescue world in 1995. "I wandered into a store and saw a table with folks looking for volunteers," he said. RMRG filled his desire for an outdoor connection. "It provides a contrast to work at NREL," he said. "Here, we spend a lot of time behind a computer screen. The stuff in the rescue world is a lot of the same problem-solving—using engineering skills. Yet every situation is new, and every problem is different, and it's all in the spur of the moment."

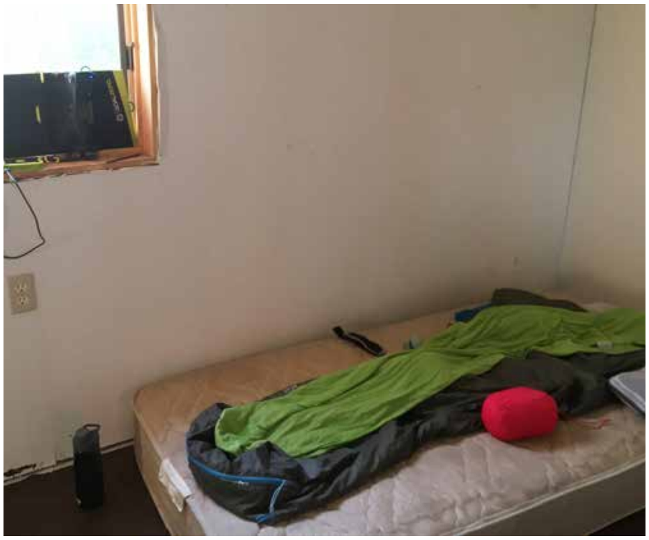
Baring-Gould believes the next 20 years will be exciting. "There's going to be a huge reimagining of the grid and changes in the way things are done," he said. "Renewable energy is a major part of the solution—cost-effective, domestic, clean—all of these things critically important to every country." This has been proven by the International Energy Agency with analysis, such as the 2020 Energy Outlook, which calls for huge investments in renewable energy technology during the next 20 years, even under scenarios that do not focus on global decarbonization. "Distributed energy sources, such as wind and solar, will also allow us to change how we think about how we get all of our energy, not just electrons," continued Baring-Gould. "In the parts of the world with extensive grid networks, the optimal solution to get large renewable contributions requires central station renewable development and more distributed generation close to loads. When you look to the large parts of the world that do not have advanced transmission systems, the role of distributed generation will only increase."

> "The work we do at NREL doesn't just impact people in the United States," he said. "It impacts everybody."
>
> —Ian Baring-Gould

Baring-Gould noted that given the advancements in the control of distributed renewables and storage, much of which can be traced back to NREL research, the cost of distributed generation can be significantly lower than the transmission upgrades that will be needed to support large-scale central station renewable projects. He added, "How NREL can use expertise to apply knowledge to the world is going to be amazing to be part of."

And it all comes back to the art of problem-solving. "Whether taking someone off a cliff," he explained, "or setting up a rural microgrid, or helping a government figure out how to rapidly expand the use of renewable energy, or pulling together in a boat, it's all equal. If you've done it right, it looks beautiful, has symmetry, and seems easy," he said—and he sees that beauty spreading.

"The work we do at NREL doesn't just impact people in the United States," he said. "It impacts everybody—the family in Kenya, folks in Pakistan, or China, or India, or wherever. Huge ripple impacts across the world," he said. "I have faith. I am an optimist. Even though there are bumps in the road, we'll get there. And what continues to be clear to me is that the NREL community will have a key and expanding role in helping others not only develop new



Sherry Stout's accommodations in the field are rarely four-star. *Photo by Sherry Stout, NREL*

technologies, as we have done for the last almost 50 years, but helping other communities deploy these technologies in a way that maximizes the benefits for them and the planet."

## Sherry Stout's Excellent Adventure Representing NREL Remotely

When going to remote locations is a necessary component of your job, a sleeping bag is often just as essential as a laptop for State, Local, and Tribal Program laboratory program manager **Sherry Stout**. She's slept on the floor of a post office in Rampart, Alaska; a tribal closet; and even a storage room in Diomede, Alaska. For the record, the closet was nice—and Stout's not complaining.

"Camping doesn't bother me a bit," she said. "I'd rather do that than stay at a [chain] hotel. It's more fun to be in the villages and live life with people." It's a life she's familiar with, having grown up in a rural community in New Mexico (about 20 miles from Albuquerque) that relied on an electric co-op for power.

"I grew up hauling water during summer water shortages—and using a septic system," Stout said. "Growing up, I didn't understand that daily flickers and possible weekly outages weren't normal."

That's what drives her to these remote locations: stopping the flickering lights for good—and, in some cases, bringing light for the first time. It's what helped her persevere when, during an energy conference in Alaska, she was thrown to the ground by a magnitude 7.0 earthquake. And it's why she got back up to help carry tribal elders out of the building between aftershocks. "You learn a lot about yourself and how you respond to different things," she said.

Since Stout joined NREL as a full-time engineer in 2013, she's visited upward of 60 American Indian tribes and Alaska Native villages, the "Lower 48" states, and abroad.

"I work with communities to meet their energy goals," she said. "One of my favorite things is when I get a cold call from a tribe because another tribe has given them my cell phone number." At times, though, it can seem a bit overwhelming. "I question my sanity sometimes for giving out that number," she laughed.

That's because the need is critical. Many tribes and rural Native areas, as well as developing nations, are faced with high energy costs. Stout is part of NREL's efforts, in support of U.S. federal agencies and foundations, to find solutions.

The challenge is that there's no one-size-fits-all answer. Power costs in Alaska are different than those of the Lower 48. So, different problems require different solutions.

For instance, energy costs in Alaska Native villages stem from their significant use of diesel fuel, most of which is brought in by barges or planes. So, Stout's work with such villages often involves reducing their reliance (and resulting expenditure) on diesel.

Meanwhile, tribes in the Lower 48 either struggle to pay their on-grid energy costs or lack access to the grid entirely. More than 15,000 tribal homes have no electricity.

"Many tribal communities are more economically depressed, making bills difficult to pay," Stout explained. "Tribes can take the funds they save from energy bills and put that toward other programs. Health and language programs tend to be at the top of the priority list."

But to really transform the relationship Native areas have with energy, Stout and others are working to turn energy generation into a potential source of profit.

"Some tribes are using large-scale energy projects to generate additional revenue, as they have fantastic renewable energy resources and few other economic opportunities," she said.

According to a 2018 NREL study, American tribal lands make up approximately 5.8% of the United States but represent an estimated 6.5% of total U.S. utility-scale renewable energy potential. In other words, a larger percentage of tribal land is suitable for renewable energy projects than is typical in the rest of the country.

Ultimately, Stout wants tribes and communities to become energy self-sufficient—but that goal is a long way off. There are 573 federally recognized tribes and, so far, NREL has worked with about 240 of them. A key component of reaching the others is building trust.

Sherry Stout (left) travels to remote areas of the United States—including Alaska, as shown here—and developing countries to help communities develop energy resources. *Photo by Sherry Stout, NREL*

"A lot of rural communities, in general, and definitely tribes, are really relationship focused," Stout said. "When you build those relationships with communities, a lot of these programs take longer to unfold than in better-financed cities or states."

These projects need to be nurtured, she explained. While that takes longer, the solutions tend to be more lasting as a result. "You built those relationships taking a long-range view," she said. "Lasting projects done this way are going to make an impact."

Stout's reputation for quality assistance is spreading beyond the United States. She was in Colombia, helping develop policy and regulatory frameworks to make sustainable rural electrification possible.

"Colombia is a bit of a blend of the U.S. situation," she said. "There are about 117 communities that are designated to receive renewable-energy-based microgrid power. Some of these will get electricity for the first time, like our Lower 48 tribes, and some will be offsetting diesel use, as in Alaska. The challenges related to energy production are most like Alaska, as these communities tend to be fairly remote. However, the goal of the project is to spur economic opportunity, so that is a bit more like the Lower 48."

During her time at the laboratory, Stout learned her goal is to help bring the benefits of energy innovation to the communities she assists. And, like them, she takes the long view. As tribes' energy needs evolve, she—and NREL—will be there to assist.

But she feels the benefits are mutual. "The best part of the job is what I learn from the community members," she said. "NREL staffers go into communities as technical experts, but we are really the students. It's incredibly humbling, and I'm incredibly grateful to be able to do this work."

## Sheila Terry Hits Homeruns for NREL's LDRD Program

LDRD Program Administrator **Sheila Terry** knows about teamwork and dedication—both at NREL and on the softball diamond.

A self-described athlete, Terry has been on championship co-ed softball teams for years. Called "Next," the team gathers on the pitcher's mound after a win and chants "Whooooo's next?" She also joined the Crazy Bats. But she doesn't attribute their success to hyper-competitiveness; quite the opposite.

"What I like about our teams is the level of respect we have for each other. We don't get down on anyone having a bad day, maybe dropping a lot of balls, or striking out—it happens to us all. It even happens to professionals. None of us out there is getting paid to play," she said. "We're supposed to be having fun. And if we're not having fun, we shouldn't be doing it." The players show the same positivity and respect toward their opponents. Next team hosts a barbeque after every game; and, win or lose, the opposing team is always invited.

That same spirit prevails at NREL. Since the fall of 1999, Terry has been with the LDRD (and its predecessor) program, which supports the development of innovative science and technical research intended to elevate NREL as a leader and to develop distinctive capabilities.

"One thing I like about NREL is that everyone loves their job and puts 100% into what they're doing," she said. "When I need project data, I reach out to principal investigators, and they give me all the information I require. It's important to me to demonstrate respect in these interactions."

She added, "I truly respect each person I interact with because of the knowledge and skills they bring to each individual or team effort. When I send out report reminders or a request for data, I completely understand that everyone is busy. If there's a deadline, I try to work with people to get the information in a timely manner without impacting their ability to get their job done."

Terry joined the laboratory in 1997 as a contract employee, encouraged by her sister who had worked at the laboratory. Still, Terry came close to leaving after a year. “I was one day from my temp contract expiring. My boss [in Communications], **Marguerite Kelly**, told me they wanted me to stay but that they didn’t have a spot,” Terry said. Fortunately for NREL, an administrative assistant quit that same afternoon. “They offered me that job,” she said.

“A few months later, I filled an administrative assistant position with Bob Noun in Government Affairs,” she said. Several years later, she was hired as an executive assistant for one of the associate laboratory directors. Part of her duties was administrative support for the person who was managing the Director’s Discretionary Research and Development Program. “That is how I got on this path,” she said.

As a high schooler in Denver, Terry not only participated in track but became the first female athletic trainer at Thomas Jefferson High School, helping various squads. “I thought about a career in athletic training, but no one encouraged me to go in that direction at the time. I was told that a woman would never be allowed in an NFL locker room,” she said. Still, her experience in assessing problems, and being responsive in a timely way, found an application at NREL.

When she began, the process of submitting an LDRD proposal required a mountain of paperwork. Up to 200 pre-proposals were submitted to her by email; each had to be printed, logged in, categorized, and copied. A Friday deadline meant Terry would work through the weekend to ensure that pre-proposals were ready for review by close-of- business Monday. Deadline day for full proposals was particularly hectic.

“I had to put up ‘traffic signs’ to direct people to my desk, because everybody coming to that floor was saying ‘How can I find Sheila’s desk?’” she chuckled. Seventy or 80 full proposals would come in, each requiring original signatures from center directors of every team member on the proposals. Once the 5 p.m. final cutoff hit, her Herculean task started in the cold of January and February.

“About two months after the weekend preparing pre-proposals, I spent another weekend doing the same thing for full proposals—as many as 10 members could be on a given panel at a time,” she said. Until about 11 p.m. Friday, then early morning to late at night both Saturday and Sunday, Terry labored. She’d drive to her home in southeast Aurora at night, often on snowy or icy roads. Nothing deterred her. “I’d barely get everything done by Monday morning, so all the panels had everything they needed,” she explained. Still, she said with satisfaction, “I never missed a deadline.”

Eventually, Terry used the NREL Copy Center to bind proposals, making them easier to distribute. Unfortunately, it also created another step in distributing proposals for review. “At that point, I knew I needed an automated process. As the program grew, the time commitment on top of the amount of paper being used for the process was alarming,” she said.

As an alternative, Terry researched submission processes at other laboratories, then made a recommendation to her supervisor. She couldn’t get the financial support to build a full database. “I had to move on to other options, which is how we got to the current site,” Terry said. She has developed a rhythm (with space baked in for last-minute requests from the NREL Leadership Team) for the cycle that is year-round.

Through the years, one of the opportunities that Terry appreciated most was the chance to interact with NREL’s leadership. “I truly valued the opportunity to work closely with Bobi Garrett, my primary LDRD mentor, over the years and all of NREL’s leaders,” she said. “I was included in planning meetings with our leadership that provided information on NREL’s direction. Leadership changes often highlighted positive changes in direction for the lab, which I have witnessed firsthand.”

“Deputy Laboratory Director Peter Green put his own personal touch on the program, which I appreciate,” Terry said. “He shares his logic for making LDRD changes in policy with me, which is very beneficial to the enforcement of the guidelines.”

There’s a mountain of work in sifting through the sea of proposals. The NREL Leadership Team, center directors, and research fellows used to review projects using a poster session format until Terry submitted an alternative proposal to leadership. Prior to the 2010 call for submissions, she recommended a panel review and selection process that was adopted and that NREL continues to use. “Panel reviews are much more interactive,” she said. Gone, too, are the marathon preparation weekends.

There is, of course, plenty keeping her busy outside of NREL. When she joined NREL, she hadn’t completed college. But, in 2016, she earned a bachelor’s degree in communications from Regis University.

One thing that didn’t take up her time during the COVID summers was softball when games were cancelled. But if you think her dedication will flag, you don’t know Terry. In 2018, she broke a fibula in her leg by sliding into third base; she was safe, but had to be taken off the field. “I needed a substitute runner,” she said, adding that the sub scored a run. Despite the setback, she rallied. “I managed to play the last two games of the season, against my doctor’s wishes—we were short of females and faced forfeiting the


Sheila Terry (in a Regis University sweatshirt) is a member of the Crazy Bats, who lived up to their name once by winning a title on a 27-degree day.
*Photo by Sheila Terry, NREL*

games," she said. "I used my athletic training skills to wrap my leg and was able to play ball. We didn't have to forfeit any games, and the team ended that season in second place."

So just like the rhythm of LDRD, the Next player who is versatile enough to play right field, second base, or catcher is looking forward. Whether at NREL or in an Aurora softball league, Terry is ready to help her team.

## Tim Tetreault Soars with the Olympic Spirit

Project Manager **Tim Tetreault** felt a connection with the Summer Olympics athletes as they paraded into London's stadium in 2012. He was entitled to because he had worn the United States uniform at the Winter Olympics three times: In 1992 at Albertville, France; in 1994 at Lillehammer, Norway; and, finally, in 1998 at Nagano, Japan. His specialty, Nordic Combined Skiing (ski jumping and cross-country skiing), pairs the challenge of soaring off a ramp at 55 miles per hour with a gut-busting, 45-minute race on cross-country skis. And while his event is different than anything that unfolded during the London venues, the overall experience of participating was familiar.

"You might have some preconceived notions about what it would be like," he said. However, he felt "blindsided" by the spectacle as he marched in the opening ceremonies in his first Olympic appearance during the XVI Olympic Winter Games. "It's like you're part of a performance," he said. It was hard to take everything in, surrounded by hundreds of world-class athletes and colorful uniforms from scores of countries. The opening ceremony was "very energizing," Tetreault said. "Everybody's there, full of hope and anticipation for their upcoming competitions."

Unlike some Olympic stars, Tetreault said that he "just kind of happened into the Olympics—it's not like I had been dreaming of this for years." He simply enjoyed skiing and ski jumping. Maybe it was something in the frosty New England air of his hometown of Norwich, Vermont, located in an area along the Connecticut River called the Upper Valley. Tetreault was the sixth person from his town of 2,500 to compete in the Winter Olympics; two other men from the hamlet went with him his first year. A rugged area traversed by the Appalachian Trail, the Upper Valley is the site of nearby Dartmouth College's ski jumps. Over time, skiing and ski jumping spawned local heroes who inspired younger kids to follow. While the world stage wasn't his goal as a boy, Tetreault said, world-class competition "was a real possibility from a young age. But it wasn't something that I focused on. I didn't start thinking about it until a few years before the Olympics."

Tim Tetreault has soared in three Olympic competitions. *Photo by Tim Tetreault, NREL*

Instead, there were endless joyful rides on the J-bar lift during weekend ski trips as a 9-year-old. This interest led to a membership in a ski club to learn ski jumping, first on a small ski jump the size of a mogul and then on progressively larger jumps used for competition at his Hanover, New Hampshire, high school where ski jumping was a sport. (He said Hanover classmate and NRELian Dan Bilello was also a member of the high school ski team, where he competed in ski jumping and alpine racing. Bilello partly credits Tetreault for his own lifelong interest in skiing.) In 1988, Tetreault was one of four American ski jumpers selected to compete in the Junior World Championships in Austria.

Obviously, ski jumping can be dangerous. During one practice jump, Tetreault landed on the side of a hill in softer snow, falling and suffering a broken collar bone and minor concussion. "Crashing is part of learning," he said simply. "Some people have a bad crash, and how they come back can make or break their success." It took him almost a year and a half to get his confidence back. Some never do, he noted. The popular image of ski jumpers, fueled by memorable televised wipeouts, is of jumpers as daredevils—but Tetreault said that's not accurate. Just as a sane person would never attempt to go into a gym and attempt a backflip dismount off parallel bars without practice, nobody in his right mind would climb to the top of a ski jump tower and shove off without years of prep.

Veterans know how to handle long, lightweight skis, to head down a straight track, to smoothly take off, and to hold their skis in a V-shape for better lift (a technique that revolutionized the sport during Tetreault's career, replacing the previous style of jumpers holding skis parallel in flight). "If you're in balance in the air, there's really not much that can happen—unless a gust of wind comes along," he said. And the feeling? Exhilarating, as if flying, for the three to five seconds jumpers are airborne.

Despite his best efforts, Tetreault found trying to mix training and engineering classes at the University of Vermont too difficult. He dropped out of school, eventually moving to Steamboat Springs, Colorado, to train with the best ski jumpers in the United States. He shared a studio apartment with two other hopefuls, worked in a ski shop, and pursued his side passion on the slopes.

In 1990, at the urging of the U.S. Ski Team coach, he transitioned from focusing solely on ski jumping to the two-sport discipline of Nordic Combined. Practice was a constant battle between the quick-twitch muscles needed for liftoff and the endurance training for the cross-country race. "It made training more fun," he said. "You don't get bored." The group would prepare all summer, then travel in winter throughout North America, Europe, and Japan, competing every weekend on the World Cup circuit.

Bolstered by success, he got his Olympic shot. Tetreault had no real hope of winning a medal for the first two Olympics he participated in. He did, however, win a bit of notoriety when he slipped and broke his leg after running to catch a bus on an icy street in Lillehammer. Returning home in a cast, he listened as CBS commentator Andy Rooney mentioned his injury as the most embarrassing incident in the games. Tetreault chuckled and said, "I had a sense of humor about it. It didn't bother me at all."

In 1997, after he finished third in a World Cup event in Finland, podium prospects brightened for the coming year. He was among the elites, as evidenced by the three individual national championships he captured during his career. For his third Olympics in Japan, among 2,176 participants in 72 events, he felt there was a chance for a medal. His event required two jumps off a 90-meter platform and a 15-kilometer cross-country ski race. However, the veteran came up short of Olympic hardware. "I wish I could have done better," he said. "I don't feel I performed as well as I could have." The joy of jumping is foremost, yet he readily concedes he has been a competitor as long as he can remember, trying to keep up with an older brother. Tetreault quit jumping in 1999—and, except for one brief two-weekend return four years later—hasn't jumped since.

He returned to school, studying at the University of Colorado. In 2008, he joined NREL in the Integrated Applications Center. Tetreault was deployed off-site in 2014, first with the Army Office of Energy Initiatives and then with the Environmental Security Technology Certification Program in the Office of the Secretary of Defense. He manages the Installation Energy and Water technology demonstration program.

Still, Tetreault has vivid Olympic memories, as well as a bag of Olympic schwag/trash—pins and the like—which he will share some day with his kids. But every time the Olympics rolls around, he has a bond. "I certainly feel a connection," he said. "Unfortunately, I don't know what somebody feels like when winning a medal— when you watch a majority of the Olympic athletes, that's the story of me: getting by, I wasn't a professional athlete. The Olympics are kind of like the reward you get, this big celebration and party, in competition with the world watching. It was exciting. The majority don't win medals and aren't contenders, but they're still representing their best. That I can relate to."

## Dan Bilello Snaps a Ski Streak

Strategic Energy Analysis Center Director **Dan Bilello** said the words calmly and without hesitation: "I'm an addict."

However, Bilello, who coordinates work for the State Department and U.S. Agency for International Development, does not appear ashamed. "I'm a sick man," he deadpaned. Bilello's "sickness" is that he is hooked on the mountains—more specifically, telemark skiing (also known as free-heel skiing), in which the ski boot is attached only at the toe. He also may be, in his own words, a touch obsessive-compulsive about this back-country sport.

He skied more than 200 consecutive months. (It wasn't his only extracurricular activity: He helped form the Table Mountain Boys, now the Table Mountain Gang, in 2000, playing bluegrass music during NREL lunch breaks and at various laboratory events.)

The ski streak began innocently enough in 2000 during Thanksgiving break in Snowmass, Colorado—and, well, snowballed from there. It now continues as a motivator. "It's an excuse for a hike and to spend time in the mountains above tree line," Bilello said.

Doing anything each month for many consecutive years is tough— and Bilello's snow run was in serious jeopardy several times. In October 2002, he returned from an NREL trip to India with a serious bacterial infection and ended up in a hospital emergency room. "I still hadn't gotten my turns [ski turns down the mountain] in for the month," Bilello recalled. But, because he felt his antibiotics kicking in and realized the number of trick-or-treaters was dwindling at his Denver house, he came up with a last-minute plan. "I was thinking, 'Man, I'm going to miss my October month, but I'm not feeling that bad,'" he said.

An early snowfall had covered the Front Range, so Bilello made a choice. "I grabbed my old gear, leather boots and skinny tele skis, went up to the schoolyard where they've got a little bit of a hill, and I lapped a couple of turns," he said. Another time, a few days before Christmas 2005, Bilello was with Tim Tetreault in Keystone, Colorado, and they had hiked up to some in-bounds terrain and untouched snow in the trees. They skied down without incident. But, when they funneled into an area where a lot of trails converged, disaster struck. Bilello stopped hard to avoid running into a careless skier—and broke an ankle.

"I'm sitting at the hospital, thinking, 'Aw shoot. I am not going to get January in,'" he said. But, by the time January came around, he was in a walking cast. "I figured if I could get out of a walking cast, I can get into a ski boot," he recalled. Once again, because there was snow on the nearby Green Mountain neighborhood, he was able to find an outlet. He convinced his wife, Elena, to go with him. "I did a lap, making safety turns," he said.

Lest someone objects, one thing should be clear: There's no sanctioning body for this record. Bilello is The Commissioner. "Part of the reason I love this [streak] is you can kind of make your own rules," he observed. Official ruling: That gimpy January 2006 lap he took near Green Mountain was added to the Excel spreadsheet he uses to track his streak.

### New Hampshire—Getting Hooked on the Outdoors

Hanover, New Hampshire, is a place famed for its outdoorsy orientation, offering all forms of skiing, including ski jumping. It was there that Bilello grew up, and where he met Tetreault. Bilello tried ski jumping, going as far as the 20-meter jump—but, unlike Tetreault, Bilello preferred alpine-style skiing.

That was his sport—until he saw someone using telemark skis in 1986. "I thought that was super cool," he said, so he bought his first pair of teles, then skinny skis, which looked like cross-country skis. While equipment has evolved over time, with gear getting bigger—even spawning AT, or "Alpine Touring" bindings with heels that now lock down (and which Bilello shuns)—back then, telemarking was a balancing act on the hill.

"There's a fair amount of skill, which is part of what I like," he said. Smitten, he left traditional downhill skiing. "It's the difference between fly casting and spin reel [fishing]. Fly casting involves so much finesse, balance, and rhythm—the same thing with tele skiing," he said.

Ski enthusiast Dan Bilello skied every month for more than 17 years. *Photo from Dan Bilello, NREL*

And it's not strictly true to say that Bilello only cares about tele skiing. He also runs and rides bikes—lesser cravings, perhaps, but still intense. He has completed the grueling 120-mile Evergreen-to-Avon Triple Bypass bike ride over three mountain passes with Tetreault. The two of them also plowed ahead on the annual Imogene Pass Run, continuing even though race organizers were turning competitors back from the snow-covered, 13,000-foot pass. Bilello also has been a pacer for ultra-marathon runners such as **Jimmy Salasovich**, **Jerry Davis**, and **John Barnett**.

Bilello sees a clear connection to his time on the slopes and at NREL. "When you are doing something you love; even the most challenging days are fun and meaningful," he said.

But telemarking is in his blood.

"There's the art of it, the flow," said Bilello. Not only does it allow him to get away from the crowds—at least a third of his trips take him to areas outside of ski resorts—but it gives him what he calls a "magical feeling."

"It's the interface of momentum, gravity, resistance from the snow, and quality of the light and snow," he said. "Combine all of that. Feeling the pressure and arc into a turn, that weightlessness as you transition out of a turn, then drop into your next turn. Working with gravity to bend and turn that ski to initiate that turn."

His words came fast; but, ultimately, words fail. "You have to feel it," he said. "It's addictive." He used that word again: addictive, but clearly a passion with a purpose.

## A Streak that Exists Because of Colorado

Bilello has always loved skiing. But there were barriers at times in his life. Attending Lewis and Clark College in Portland, Oregon, he skied once in a while, but was often too financially strapped for lift tickets, and he couldn't afford a car. Likewise, in graduate school or while living abroad, there was neither much time nor money.

When he arrived in Colorado (and NREL) in 2000, he said he was bitten hard by the ski bug. "I wanted to make up for lost time—and make up for all the skiing I wasn't able to do. The snow first hit;

I just got after it," he said. For a number of years, he would ski close to 50 days each season. More recently, that frequency has dropped in favor of quality over quantity.

Still, if you are going to ski at least once a month, you have to be prepared for some less-than-ideal conditions. It helped that, for 10 years, his dog, Cheyenne—whom he describes as a "bundle of muscle"—loved getting out into the mountains as his ski buddy. Both sought snow as their element and playground.

"It's a whole state of mind. A lot of friends say I have an optimistic sense when it comes to snow quality. By far, my favorite type of skiing is midwinter, deep powder skiing," he said. Yet, especially in Colorado, in a good snow year, he believes there's access to great-skiing high-alpine through mid- to late-July. However, August and September are always a bit rough.

Bilello employed different strategies to preserve the streak.

"August is usually a question of 'Do I hike really far for better snow, or do I go up to St. Mary's Glacier [in the foothills] and knock out some reasonable turns?' Same thing for September. 'Do I wait for the end of the month when there might be a storm that rolls through and drops new snow on dirty snow, or do I grind it out on the first week of September?'" he said.

Bilello joked that it seemed like in truly bad months or a drought, he might have to fly to Canada or Chile to keep things going—but he managed every month in Colorado. Because of the nature of his work at NREL—which deals intimately with threats of climate change—he doesn't take skiing, or the environment that produces such lush conditions, for granted. In fact, he's worried, knowing that future generations may not have the same opportunities.

Perhaps that's partly why he embraces his mountain moments.

The streak, he said, evolved over time. He didn't set out to build a record, yet discovered he's not alone. A few years ago, he found a website dedicated to such strings of consecutive ski months, mostly with people in the Pacific Northwest, which has proximity to volcanoes and permanent snow fields. To his amazement, he learned there are skiers who have done this for 30 years or longer.

For the record, Bilello ended his streak at 213 months on July 4, 2018. "A good run!" he remarked.

And, if the streak had to end, well, the ski aficionado's six pairs of skis stand at the ready, from his original late-1980s XCD GTs to locally built powder skis for the deep days.

He said he feels grateful for both NREL and the mountains that surround it. Engaging in the drive is one example, he said, of ways in which NRELians stay refreshed. "The passions of people here at the lab are amazing," he said. "When you're out doing something you love, you come back here energized and ready to take on the work. It's one of the real strengths of this lab."

These achievements are just a sample of the accomplishments of the NREL family, whose passions in the laboratory are matched by their fervor on slopes, in orphanages, remote villages, and beyond. ■

# Directors Pursue a Renewable Pot of Gold

Former NREL directors Richard Truly, Charlie Gay, Denis Hayes, and Dan Arvizu, plus current director Martin Keller (second from left), join in a Lab Directors roundtable at the NREL 40th Anniversary Celebration in July 2017. *Photo by Dennis Schroeder, NREL 45643*

In October 2012, NREL recognized (from left) Larry Kazmerski, Judith Hulstrom, Roland Hulstrom, and Sylvia Motazedi for 35 years of service.
*Photo by Dennis Schroeder, NREL 23013*

A cigar smoker from Philadelphia who had worked in solar research for years in Princeton, New Jersey. A political activist instrumental in launching Earth Day. An astronaut admiral. The son of an illegal Mexican immigrant. These are some of the directors who have taken the aspirational ideal of a renewable energy institute and made it a reality.

As **Sylvia Motazedi**, NREL's prime contract coordinator in the Office of the General Counsel, observed, "Different visions, but all great." She would know. In June 2022, she marked her 45th anniversary at the lab—a month ahead of NREL's official 45th anniversary.

All of these leaders, along with countless others, helped steer NREL from a handful of staff in an unfinished office building in the Denver West business complex to a global leader in research and commercialization of alternative energy. When the Solar Energy Research Institute (SERI) officially began on July 5, 1977, it was anyone's guess what would happen—or how the journey would unfold.

## Employee No. 14 Saw It from the Beginning

Sylvia Motazedi was flustered as she parked her car in the Denver West office park on June 1, 1977. It was supposed to be her first day at the fledgling SERI, but there was no sign anywhere of such a sunny place.

"All I had as an address was 'Denver West,' which was under construction with only a couple of buildings surrounded by horse pastures," said Motazedi. "I was completely lost, panicked that I would be late." She had made the drive for the first time from her southeast Denver home—having interviewed elsewhere for the job as executive assistant to Laboratory Director Paul Rappaport.

As a young man rode up on his bicycle, Motazedi got out of her car and asked, "Do you know where the Solar Energy Research Institute is?" The man replied, "Oh, yes. That's where I'm going." The rider—bearded and wearing a cycling outfit—turned out to be a scientist. He led her to the shell of Building 3.

When they stepped inside, she encountered a structure with no interior walls or ceiling panels. About 10 mismatched government-issued desks stood in a row, telephone cords hung from the ceiling, and a lone copy machine sat forlornly on the floor. "I thought, 'Oh my! What have I gotten myself into?'" That's how Employee No. 14 started her career at the laboratory—even before the laboratory director and others arrived. "I had no idea what a startup was," said Motazedi.

A couple of days later, Motazedi and the procurement manager drove to the Federal Center to buy copy paper and supplies. "We brought it back and realized we didn't have a filing cabinet to put this in, so he found parts of one, and we assembled the first filing cabinet," she said. Welcome to the can-do spirit of SERI.

## Paul Rappaport—Blazed Trails as the First Director

**Paul Rappaport** had joined the RCA Corporation in 1949, working as a researcher studying energy conversion and developing solar photovoltaic cells. When the Carter administration was looking for a director for the new solar lab, his name surfaced prominently.

As solar pioneer Larry "Kaz" Kazmerski said, "Rappaport was the god of photovoltaics."

According to Kaz, the backstory of SERI's location was tied directly to solar, in a way. In 1975, the federal government issued a call for proposals for a national solar institute and, after sorting through 22 bids, the Ford administration narrowed it down to two options: one in Arizona and one in Colorado. "I was told a story by Rose Rappaport (Paul Rappaport's wife)," Kaz recalled. "The story is probably fairly accurate. She said that in July, they were making the decision [between Arizona and Colorado], and Paul was the designated director on both proposals."

The Rappaports visited Colorado and, several weeks later, flew to Phoenix. "They stepped out from the airplane into 119-degree temperatures, and Rose whispered to Paul, 'Colorado,'" said Kaz.

According to Kaz, Rappaport didn't regret the decision and began building the SERI family in his new state.

"If I really had to characterize the lab at its inception, we were like family," Motazedi said. "It didn't matter what your position was. We were all here to start up an organization," she said. "We kept bringing people on. It didn't really matter if you were a scientist or had some other position, we were like family."

With a comparatively small group, many just out of college and recent arrivals to Colorado, social activities rolled. "People had to live in apartments in Golden temporarily. So, maybe they would reserve a rec room, have a potluck, dance, and have fun. There were barbeques and marshmallow roasts in the mountains. Everybody came and brought their families. It's not that we were best friends—we were acquainted," she said. Over time, ski and golf clubs sprang up.

> "We were like family. It didn't matter what your position was. We were all here to start up an organization."
>
> —Sylvia Motazedi

The motto, "work hard, play hard," was commonplace, Motazedi said. And the work got done by "people pulling together and making it happen," she said. "Initially it was one foot after another, then getting established, and developing relationships with DOE, which was new as well."

There was an informal tone, inspired in part by Rappaport, who was outgoing and insisted on being called "Paul" by staff. "Paul was a character," she said. The thing that most excited him initially about living in Colorado was the blue sky. Coming from RCA in New Jersey, Rappaport almost never saw a clear sky. "He couldn't believe that the sky could be blue for days at a time. One day, he came into the office after a cold night and said he stepped outside of his home in Evergreen and couldn't stand up on the ice. That really tickled him," she said.

The director was excited that he could get license plates that read "SERI I." Still, there were some old-school behaviors. For example, he smoked cigars—in the office. And he expected Motazedi to bring a pitcher of water into his office every morning. "I was glad to do it," she said. Yet, he was constantly engaged in exploration and "always had a twinkle in his eye. He was a very special person," Motazedi said.

When the director held staff meetings, they were often around one of the outdoor ponds in the expanding Denver West complex. It was during that time that the staff jokingly took to calling one of the ponds *Lake Ty-D-Bol*, after a brand of blue toilet cleaner, because the property manager used an algaecide that turned the pond water vivid blue.

Still, there's no mistaking the seriousness of the purpose. "Everyone was here because of the mission. It was a collection of people strongly focused on a mission," Motazedi said. "Within a year, there was talk of everybody moving here on the site. So, that was always part of a master plan. The 'when' and 'how' and 'what' the South Table Mountain site would look like wasn't articulated," she said.

Of course, the laboratory had to grow to survive. "As any organization matures, it's necessary to have more prescribed processes. Those processes and procedures evolved to support the mission," Motazedi said. "Everything grows and matures. I would characterize us as being a tight-knit community as compared to today. Now, the lab is a large organization, and it is much more compartmentalized."

## President Carter Visits on a Rainy Sun Day

If there's one date that announced SERI's coming of age, it's probably May 3, 1978. President Jimmy Carter visited the laboratory on what he had proclaimed as "Sun Day"—and Motazedi was seated in the front row with her husband for the gathering on South Table Mountain. Rain pelted and the wind gusted as the president spoke around 4 p.m. Motazedi's boss had been worriedly phoning for weather updates prior to the presidential arrival—but it came off without a hitch.

Carter joked that the administration hadn't made a final decision on where to locate the laboratory—and was considering a site where the sun actually shone. "It was a great day," Motazedi said. "I'd never been face to face with a president." Motazedi had signed up for seats, and she and her husband were separated from the podium only by a rope. "There was security and the Secret Service, but it wasn't like today," she said. As Carter walked past, her

Director Paul Rappaport (behind the lectern) greets President Jimmy Carter during his visit to the Solar Energy Research Institute on May 3, 1978.
*Photo by Dana Moran, NREL 14618*

husband stuck out his hand and shook the president's hand. "The president was very friendly and interested in what we were doing," she said, "including inspecting some solar panels. I was in awe."

Motazedi didn't know Paul Rappaport before she started working for him. She had moved to Denver in 1974 to work for a rural electric association, after having traveled to Wyoming to work at a similar organization. She had casually dropped off a resume at an employment agency—but SERI wasn't on her mind.

"SERI was being discussed on the news, and I was paying absolutely no attention to it. I thought that it was going to be located in Boulder and wasn't interested," she said. Then, one night, the personnel director of SERI's operator, Midwest Research Institute (MRI was the predecessor of MRIGlobal, which is part of NREL's current operator, the Alliance for Sustainable Energy), called. MRI was doing a labor market survey to assess the talent in the Denver metropolitan area for recruiting purposes. "I said 'I'm not interested,'" she laughed. But they persisted. Eventually, Motazedi found herself meeting twice with Rappaport at the old Stapleton Airport when he flew in from New Jersey to interview her. He was clear: He wanted someone dedicated. She was impressed—as were they. Motazedi got the job.

Helping start the laboratory matched her skills, and she bonded deeply with Rappaport, who would invite Motazedi and her husband to his Evergreen home for dinner. "That's how things were back then." Sadly, early in his tenure, Rappaport became ill with cancer. "I did what I could to support him," Motazedi said. That same year, Rappaport received the William R. Cherry Award from the photovoltaic (PV) industry in recognition of his work in the field; in April, he died at age 58.

Motazedi stayed in her position for the next two directors—Denis Hayes and Hub Hubbard—two very different visionaries.

## Denis Hayes—The Earth Day Guy Lands at NREL

In Motazedi's words, "**Denis Hayes** was a grassroots individual and, in working for him, I was interfacing with presidents of companies like General Motors. I was communicating with the White House. I was communicating with people of high influence, including Robert Redford."

Indeed, his arrival at SERI was unorthodox. Hayes was not a scientist; rather, he was closely associated with the first Earth Day in 1970.

**Denis Hayes.** *Photo by Warren Gretz, NREL 04976*

Denis Hayes knows firsthand how Earth Day blossomed in 1970, having served as the national organizer of the April 22 event. The second director of SERI, who served from 1979 through July 1981, also understands how devastating it was when much of SERI, including himself, was uprooted in 1981.

Hayes, most recently president of Seattle's Bullitt Foundation that funded environmental organizations in the Pacific Northwest, said that his involvement in both Earth Day and SERI was part of a series of "fortuitous things that have occurred" in his life.

Hayes was part of NREL's Earth Week in 2015, helping to emphasize the laboratory's connection to the time many consider the birth of the environmental movement. Former Laboratory Director Dan Arvizu said that Hayes "helped put this laboratory on the trajectory we are enjoying today."

During his 2015 visit, Hayes explained that the original Earth Day "came out of the 1960s—a decade unlike any other in American history." The turmoil of the Civil Rights movement, antiwar protests, and growing ecology concerns were all strands that "we wove … into one fabric," he said.

It wasn't all fun and done.

## SERI Becomes Home Sweet Home

Hayes recalled that in the wake of renewed environmental activism and several oil crises in the 1970s, funding for renewable energy research began to increase rapidly. In May 1978, Hayes chaired a national event called "Sun Day," modeled on Earth Day, that helped catalyze a constituency for solar and renewable energy. First Lady Rosalynn Carter served as honorary chair. Actor Robert Redford and his then wife were, Hayes said, "huge solar and renewable energy enthusiasts, and they saw SERI as an important element." President Jimmy Carter used the occasion to break ground with Rappaport for SERI, and SERI took the national lead on PV, innovative wind technologies, passive solar buildings, and biofuels, among other things.

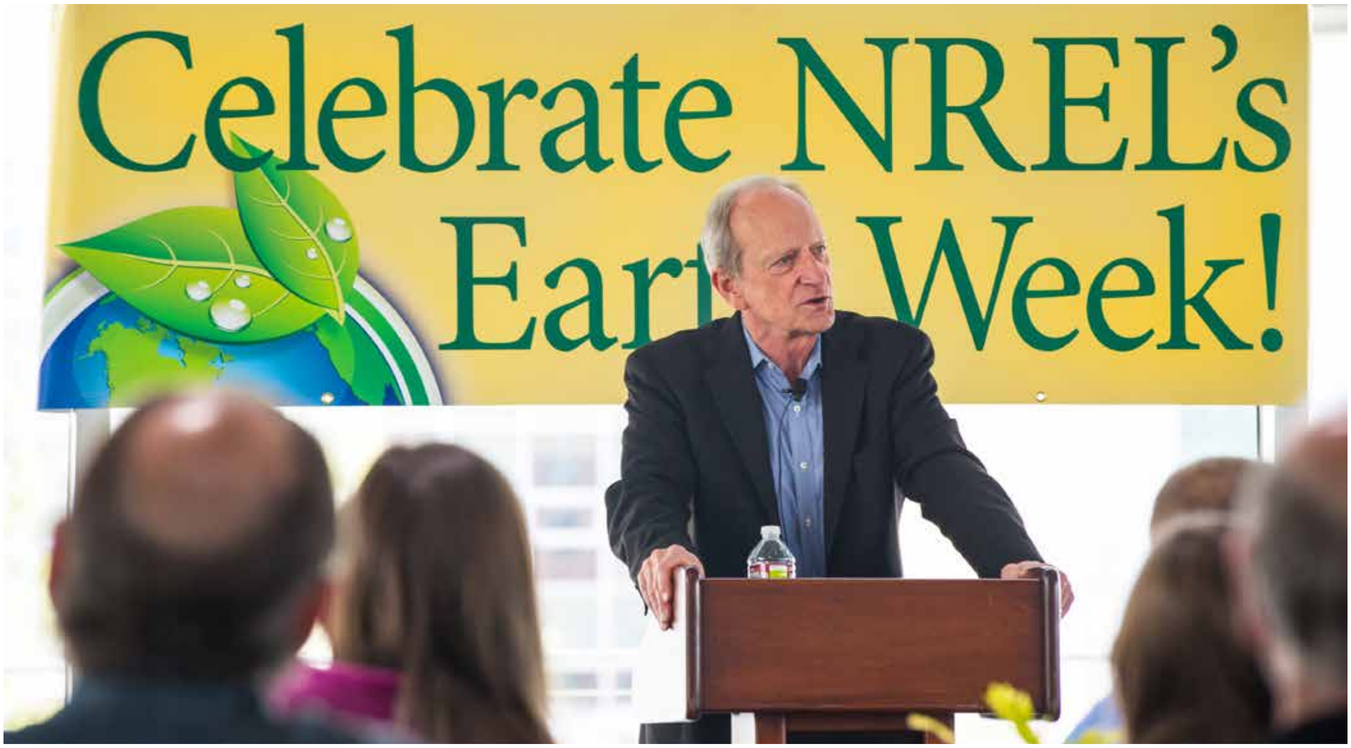
Again, as part of the fortuitous happenings in his life, Hayes found himself offered the SERI director's job in July 1979 by President Carter. Hayes was 35—the youngest director in the federal laboratory system. Moreover, as noted, he was not a research scientist.

"There certainly were people at SERI who knew far more than I did about PV, biofuels, innovative wind, passive solar architecture, and even solar law," commented Hayes. "But I possibly had a deeper overview of how all of these fields fit together and could be matched against the quantity and quality of energy needed throughout the economy. My comparative advantage was in knowing where the best opportunities could be found. I was a generalist, surrounded by a world-class team of specialists."

> "That was the worst day of my life. I would have cut off my left arm to stay at SERI."
>
> —Denis Hayes

Hayes recalled that, just prior to his unexpected appointment, he had done an interview with *60 Minutes* in which he referred to the Energy Department's Barstow Project—a large solar "power tower" in the Mojave Desert—as "a gold-plated turkey." Hayes chuckled at his outspoken comment. "That caused consternation when suddenly I had a role in the decision-making process. Nevertheless, from the perspective of 2020, my criticism was probably understated. That ill-conceived boondoggle did not deserve the huge fraction of the federal solar budget that it was receiving."

Arriving in Golden, Hayes found the campus was "the nerve center for a great many things." SERI's budget in 1979 was about $130 million (which, after adjusting for inflation, equals $380 million




Earth Week 2015 kicked off with former NREL Director Denis Hayes speaking in the cafe. *Photo by Dennis Schroeder, NREL 33271*

today, he said in 2020). "Although not a huge sum in absolute terms, it was nevertheless as much as the entire rest of the world was spending on renewable energy research. SERI was a very important institution," he said.

Hayes noticed that the media attention paid to SERI, coupled with the volume of solid research papers coming out of the laboratory, were making an impact. To further exploration, he persuaded the U.S. Department of Energy (DOE) to establish a director's discretionary fund to support novel research.

"I tried to be evenhanded across technologies," Hayes said, but admitted that "my true love, throughout it all, was photovoltaics."

As he explained, "Thermal technologies had dominated the energy space since the Industrial Revolution. But, by the end of the 20th century, in any contest between thermal technologies and quantum technologies, the smart bet was on the latter. I watched what was happening as computer chips and other semiconductor technologies flourished, and I knew intuitively that, with mass production, photovoltaics could ride a similar learning curve."

Hayes commanded a degree of visibility that was unusual in the buttoned-down world of national laboratory directors—and he proudly admits he used it to aggressively promote renewable energy. He believed this advocacy role was appropriate because "solar and wind didn't have much of an industry then. Ninety percent of the solar industry consisted of solar water heater manufacturers."

His guru was Kaz and, overall, the SERI staff was capable and eager. Hayes fit the mold and mood of those freewheeling times. For example, he often rode his bicycle to work from his house on Lookout Mountain. "The ride home was always tougher," he smiled.

He admired President Carter who, although being a politician first, also was a strong proponent of renewable energy. Under Carter, SERI was tasked with finding ways to implement a goal that the president had set, to achieve 20% of the nation's energy (not just electricity, but 20% of all *energy*, Hayes noted) from renewable resources by the year 2000. Hayes was given a $2-million budget to assemble working groups and drew from other national laboratories and major universities to figure out how to achieve that goal. The resulting report published commercially in 1981 fell on an unreceptive political landscape.

## Cloudy after a Change in Presidential Leadership

Even after Ronald Reagan defeated Jimmy Carter in 1980, Hayes said he was hopeful that things might stay about the same at SERI—in part, because Reagan had given some positive speeches about solar power on the radio programs he hosted during the five years after he left the governor's mansion in California and before being elected president. That proved to be wishful thinking.

Hayes arranged for the 20% report to be read into the Congressional Record and published commercially. But, by doing so, Hayes said, "I had crossed my Rubicon." His relationship with the new Secretary of Energy worsened, and the ax fell in June 1981 when word came from Washington that SERI's annual budget would be slashed—from about $130 million to less than $30 million, Hayes said. About a third of the staff and all contractors were to be terminated immediately, with two weeks' notice and no severance pay.

Expecting to be personally called to account, but furious that SERI was undercut, Hayes called an all-hands staff meeting on June 20, 1981, in a room at the Jefferson County Fairgrounds. "It was probably a bit of a tirade," he said, noting that he was desperately trying to make an impact on an uninterested Congress while rallying "the troops"—both those about to be terminated and those who remained. In his speech, he referred to the Energy Department as "a bunch of dull gray men in dull gray suits roaming a dull gray building thinking dull gray thoughts—destroying the world's best hope for a solar future."


**Harold "Hub" Hubbard addresses staff and media at the groundbreaking ceremony for the Field Test Laboratory Building (FTLB) in 1982.** *Photo by Warren Gretz, NREL 04432*

Looking back, he concedes that his words were "intemperate. But accurate."

Immediately after his talk, Hayes resigned.

"That was the worst day of my life," Hayes said. "I would have cut off my left arm to stay at SERI."

Even as the events pained him, Hayes praised his successor, Hub Hubbard, as "a great calming influence," a man remarkably skilled in finding a way to get things done within constraints.

## Hub Hubbard Shines the Spotlight on NREL's People

**H. M. Hubbard**, an executive at MRI, wanted to be called "Hub" when he joined the lab in 1982 as its third director. "He loved people and started having all-hands meetings," Motazedi said. This had not been done before as a standard practice, which subsequent directors followed. A scientist who had established his credibility during his work at DuPont, Hubbard had returned from a trip to China to be told he was headed to Colorado rather than returning to Kansas City, Missouri.

Hubbard's tenure saw a large reduction in SERI's workforce because of federal budget cuts. "That took its toll on Hub, because he loved the people so much," Motazedi said. A lasting personal touch was that Hubbard, in collaboration with MRI, established the Staff Awards Program. Since 1990, when he left the laboratory, management has given an annual award in Hubbard's honor to a member of the research staff. The award recognizes someone who has made high-level research contributions as well as demonstrated leadership in furthering NREL as the foremost renewable energy laboratory in the United States. "That is a testament to his love for people and his need to recognize their achievements and accomplishments," Motazedi said.


Charlie Gay waves a flag to start a competitor in Sunrayce 1995. *Photo by Mike Linenberger, NREL 02707*


Charlie Gay starts the 100-kilometer Solar Bike Rayce for high school students in 1996. *Photo by Anna Duda, NREL 02113*

## Charlie Gay Boosts Solar

**Charlie Gay**, who spent most of his career in private industry and is an internationally recognized PV pioneer, led NREL from 1994–1997. According to the omnipresent Kaz, "Charlie's strength was his ability to motivate his colleagues with his extraordinary vision and technology innovation. He continued to instill these values in our U.S. solar energy programs."

Fascinated by science and solar energy since he was a boy, Gay earned a Ph.D. in physical chemistry from the University of California–Riverside. In 1974, he began his career when he saw an advertisement in the *Los Angeles Times* for a metallurgist at Spectrolab, Inc. There, his assignments included designing solar power system components for communications satellites. Later, he joined ARCO Solar, where he established a research and development program and led the commercialization of crystalline silicon and thin-film technologies.

In 1990, Gay became president and chief operating officer of Siemens Solar Industries and served in that role until moving to Colorado, where he was recruited to replace retiring NREL Director Duane Sunderman.

Gay cited the launch of the Enterprise Growth Forum as a main accomplishment during his tenure in Colorado. The annual event, which continues today as the Industry Growth Forum, is a "way that a lab researcher or one of our industrial partners has a chance to present their business model to a panel of business and finance experts," he said, adding that this allowed "diverse stakeholders, who might not otherwise see what was coming out of the labs" the opportunity to turn a cleantech concept into a commercial reality.

Following his role at NREL, Gay returned to the private sector, serving in executive positions for a range of solar manufacturing businesses. In 1998, he helped start the Greenstar Foundation, a nongovernmental organization focused on building a solar-powered community center to deliver electricity, pure water, health and education information, and wireless internet connections to villages in developing countries.

In 2016, Gay said he decided to join DOE's Solar Energy Technologies Office (SETO) as its director because, "I could bring some of the perspective of what is happening in the industry to help DOE time the rhythm of its work to match the accelerated speed of change in clean energy technologies—so our research is not obsolete before it leaves the lab." Gay retired from DOE in 2019.

**Richard Truly in 2000.** *Photo by Warren Gretz, NREL 09084*

## Richard Truly—Fighter Pilot, Astronaut, and Admiral Advocates for Renewable Energy

**Richard Truly**, a retired vice admiral in the United States Navy, received the nonprofit Space Foundation's General James E. Hill Lifetime Space Achievement Award in Colorado Springs in 2016. During the ceremony, he focused on a group near the rear of the banquet room at the Broadmoor Hotel. The audience included top military brass, the head of the National Aeronautics and Space Administration (NASA), astronauts, space industry friends, and four generations of his family—but the retired Navy admiral, space shuttle commander, and former NASA administrator made sure to give a shout out to NREL.

"There's a table of folks there from the National Renewable Energy Lab, which was my last day job," Truly quipped. As strongly as he feels about his aviation career, Truly is clear that the bonds to NREL—which he led from 1997 to 2005—remain vital, linked to an important chapter in his life. "NREL was a thoroughly enjoyable experience, which is why I stayed there," Truly recalled later.

Of course, whatever his accomplishments at the laboratory, it is hard to beat his military service reord, as spelled out that day: leadership of military space endeavors, such as the Manned Orbiting Lab program and Naval Space Command; missions as pilot and test pilot, including on the early space shuttle flights; and leading NASA back to flight after the loss of the space shuttle Challenger.

For Truly, though, NREL was a perfect fit. He knew about scientific institutions from his time at the Georgia Tech Research Institute (1992–1997). "Although they had different research missions, the cultures were similar. As I got to know NREL, I got to recognize some of the things I had learned at Georgia Tech," he said.

Still, it was an adjustment. "I arrived at NREL not knowing much about the energy business or about NREL itself. It was a steep learning curve," he said. "I brought all of the previous experiences I had with me. I knew how to run big organizations and, for me, it was a lot of fun."

Truly shared a leadership philosophy that seemed simple and effective.

"NREL was different than NASA, which was very large. But organizations are all about people. Whether it's a big organization like NASA, or a somewhat smaller one, it's still about the people who work directly for you, making sure they and you get on the same team—then every day involving all the people," he said. Among the people he brought to the laboratory was Dale Gardner, who had flown under Truly's command in 1983 on the space shuttle Challenger.

Despite his successes at NREL, Truly remains humble about his abilities as a leader or how he became a good one. "It's hard for an individual to know where they learned a certain lesson. I can't really point to any specific things," he said. "You just do things that need to be done."

And that's how he, along with what he called "lots and lots of friends at the lab," accomplished their mission.

## Dan Arvizu Sells Renewable Energy

For his 61st birthday on August 23, 2011, **Dan Arvizu** decided to do a tandem skydive in Hawaii.

This adventure wasn't a spur-of-the moment decision for the man who led the laboratory the longest, from 2005 to 2015. It was part of his core being. "I'm a risk-taker. There's no question about that," Arvizu said with a grin. "I like to think that these are calculated, very deliberate, and well-thought-out risks—measured risk/reward kinds of things."

His family also took risks. Arvizu is of Mexican descent, the son of immigrants.

"My dad was born in Chihuahua, Mexico, and only had a third-grade education," said Arvizu. "He joined the Army, becoming a U.S. citizen on board a ship heading to the Philippines, and got his GED while in the service. My mother's family comes from another city in Mexico: Hermosillo," he said. But she was born in the United States, unlike most of her older siblings.

After World War II, Arvizu's father took a job selling shoes for a large chain that was expanding in the U.S. West. The family moved frequently—Arizona, New Mexico, the Texas panhandle—so his father could open new stores for the company.

"Because my dad was a salesman, he knew no strangers. He was very gregarious. Everybody was his friend," he said. "I kind of picked up some of those characteristics."

As a youngster, Arvizu spoke only Spanish. "When my older brother, Eli, was about to enter first grade in Odessa, Texas, local school officials visited us and told my parents they should use English," he said. Arvizu can still mimic a Texas drawl if he wants, because that is where he first learned to speak English.

The family's move to Alamogordo, New Mexico, felt comfortable to Arvizu and became the place he says he's from.

If anyone suspects that Alamogordo is out in the boondocks—and, therefore, lacking in educational opportunities—think again. It actually offered an educational bonus. It was the nearest town to Holloman Air Force Base, which today serves as a North Atlantic Treaty Organization base with a German air wing stationed there. Because military offspring went to the public schools, the armed forces paid for the schools—offering unexpected opportunities.

Arvizu was ready to soak up knowledge. "I was intrigued and very interested in science at an early age. I had fifth and sixth grade teachers who encouraged math and science," he said. "I got excited about those subjects and had a propensity for them." That provided a foundation that the public schools built on.

"I took calculus in high school," he said. Many of what are now called STEM courses—science, technology, engineering, and math—were taught by professors hired from New Mexico State University (NMSU), which was 60 miles away in Las Cruces.

"I put all of my energies into band," he said, noting that left-brain-dominant people, like him, often excel at both math and music.

"I started playing the trumpet in fifth grade. I just begged my dad, and he bought me a $20 trumpet, which I used for a couple of years. Then my band director came to my folks and said that I needed a new trumpet," Arvizu said. "I ended up playing trumpet every day for the next 15 years," he said. Eventually, his musicianship earned him a scholarship to NMSU.

In all, he moved 17 times and had 22 roommates from the time he left home at 18 until he graduated from NMSU in 1973. Due to an unusual schedule (which included summer work), he took five years to complete his degree—but it was worth it. Not only did he pay for all of his expenses, but he had enough money to pay cash for a 1970 Pontiac Firebird. His self-described muscle car was Castilian bronze with a white vinyl top.

If Arvizu had some things figured out, he was clueless about his future back then. That's when one of his mechanical engineering teachers asked the top student in the class of '73 if he knew where he was going to work. Arvizu didn't, despite his 3.8 grade point average.

"My teacher said, 'Have you heard about Sandia?' 'Not really,'" Arvizu said he answered.

He was about to find out about it—along with Bell Labs and other national laboratories.

"I'm the poster child for the American Dream," Arvizu said. "I can say without reservation that I've been blessed with great opportunities."

## Getting Educated at Bell Labs

"I had a knack for math. It was easy to do," Arvizu said.

His skill with numbers, among other things, added up to Arvizu graduating in the Top 10 of his class at NMSU. Knowing that, a mentor was eager to introduce the prize student to Sandia National Laboratories in Albuquerque. However, as Arvizu was approaching graduation in 1973, an oil embargo hurt the economy—and the federal government shifted research priorities. Undeterred, his mentor offered, "But Bell Labs is hiring."

At that time, AT&T ran both Bell Labs and Sandia. As a result, Arvizu's first recruitment trip was also his first airplane ride.

On March 30, 2013, U.S. Senator Mark Udall (left) got the overview from Director Dan Arvizu from the nacelle of a Siemens 2.3-MW, 80-meter wind turbine at NREL's National Wind Technology Center. *Photo by Dennis Schroeder, NREL 24569*

Previously, he'd never been further east than Dallas, or reached the West Coast, staying instead in a slice of the Southwest.

Bell Labs didn't hire at the bachelor's degree level, so they offered promising candidates such as Arvizu a chance to get a master's degree for free, no obligation. Despite some other higher-paying options, Arvizu jumped at the chance.

"It seemed pretty obvious," he said. "I was single and debt-free." Arvizu was given the choice of four of the best engineering programs in the country: MIT, University of Illinois, Purdue University, and Stanford. Not caring to go to unknown turf in the Midwest or East, he chose Stanford.

Arvizu was one of 400 recruits to pursue Bell's master's offer—90 of those at Stanford. After completing his degree, Arvizu returned to Bell and, as was the custom, became a recruiter at his alma mater.

But the recruiter soon became the recruited.

## Starting in Solar at Sandia

While on a trip to New Mexico State as part of an AT&T team, a fellow recruiter asked Arvizu if he would join Sandia.

"He said, 'We're going to start a solar energy program. Would you like to be in on the ground floor?'" Arvizu recalled. "I said, 'Yeah. That sounds really interesting.'" So, the mechanical engineer went to Sandia in 1975 to start its solar program in an era when SERI, NREL, and even the U.S. Department of Energy didn't yet exist.

"I designed the heliostats for the National Solar Thermal Test Facility power tower," he said, referring to the field of mirrors that reflect concentrated sunlight onto a central receiver on the top of a 200-foot tower.

But he didn't stay too long. Sandia wanted researchers with doctorate degrees—something Arvizu lacked. To meet their requirements, the lab started a doctoral support track. Only two of its 8,000 employees were selected at a time for the program—one was Arvizu. There was a caveat: Sandia required that the degree be completed in two-and-a-half years.

"That's ridiculous," said Arvizu, explaining that he again chose Stanford, where the average engineering doctoral candidate took five years to complete a degree.

To succeed, he figured out a strategy. First, he studied remotely for a year, taking videotaped courses and proctored exams. Then he went back to Palo Alto, California, on a full ride, plus relocation expenses, and two-thirds of his salary.

"I was the richest grad student you've ever seen," he laughed.

Stanford's so-called "entrance exams" were a huge barrier to successfully earning an engineering Ph.D. These exams were a grueling two-day session of orals covering a massive amount of information on four topics. The outcomes were simple: a clear pass, a provisional pass (meaning one more attempt was allowed), or failure and a farewell to Stanford.

"I knew I had to pass my orals," he said. To prepare, he cleared the deck of any distractions. "You needed to really gut it up and not think of doing anything else," he said.

Even so, Arvizu looks back on that time as "the most intense two years of my entire life," he said. He saw the stack of books given candidates for each topic and understood the mandate: Know everything in these tomes.

> "I was a salesman of the work that NREL did, of the value that it brings, of the mission objective."
>
> —Dan Arvizu

Yet, when the tests finally came, there were three clear passes and one provisional out of 40 candidates who were tested. Arvizu was one of the clear passes. He was awarded his degree in 1981, returning to Sandia as Dr. Arvizu, Stanford-approved expert on fluid flow, thermodynamics, and heat and mass transfer.

At Sandia, he was a researcher moving up the ranks, proud of technical accomplishments, and supervising a small team. It was 1989, and he was thinking that he was already on a path for technical management.

"My bosses came to me and asked if I would be interested in taking over the technology transfer function at Sandia," he said.

Technology transfer was hot, then the focus of powerful interests in government (such as those of New Mexico senators Pete Domenici and Jeff Bingaman). "They really wanted to put it on steroids," he said. Surprised, Arvizu demurred. "I said, 'No. I have no interest. Is that a technical job?' They said, 'No, not exactly. It's related to technical stuff.'"

He had his reasons. Then 38 years old, he considered such a shift "a fairly significant risk because, in technical ranks, you grow on the technical foundation you've built. But to change directions like this, and get out of the mainstream, was a career move that was quite a departure from what I had envisioned," he said. Again, they asked.

Arvizu refused politely—but, finally, his determined bosses prevailed. He took over a backwater office with one employee—and five years later had built it into a powerhouse. Eventually, he asked to return to the research ranks.

His second big risk came a few years later, when he left Sandia. "Sandia had plans for me, but then CH2M Hill came and recruited me, and they had a big carrot," Arvizu said.

The uncertainty of moving to Denver to join the international civil engineering firm was coupled with a second concern.

"I was moving out of a national lab and into a private-sector company—quite a departure from what I had been doing," he said. Yet the risk-taker prevailed. "It was enough of an adventure and a broadening experience—and it got me valuable exposure to the private sector," he said.

## Arvizu Lands on Familiar Turf at NREL

After all he had done, coming to NREL wasn't a major shift.

"I had been meeting with the folks from SERI since 1981, so I knew Larry Kazmerski, Jack Stone, John Benner, Bob Noun, and Roland Hulstrom. At that time, the three national labs with solar programs—the Jet Propulsion Laboratory, Sandia, and SERI—would come together. The solar research community was an itty-bitty group, so we all knew one another," he said.

Arriving at NREL in 2005 in his new role as laboratory director, Arvizu felt at ease. "I was familiar with what was going on here, and the people. I was not a new commodity when I came. It was an easy integration," he said.

One thing he didn't have was the pressure of former laboratory directors looking over his shoulder.

"When I get together with [former lab directors] Richard Truly or Charlie Gay, there's a connection, as there was when I used to

Director Dan Arvizu in 2015 at the entrance to NREL's South Table Mountain Campus. *Photo by Dennis Schroeder, NREL 34341*

get together with Hub Hubbard. The secret handshake is still very much active in a metaphoric sort of sense. We all know what it feels like to sit in chair number one—and what it's like to deal with some of the things that are both pleasant and not pleasant. A little bit of being part of the club, but nothing formal," he said.

Someone once asked Arvizu what the biggest surprise was in running the laboratory. "I'd say how different the years were from year to year. Every cycle has the same components, but they are very, very different," he said.

He saw ups and downs during his tenure. Big budgets and expansions—including the Energy Systems Integration Facility, the Research Support Facility, and other parts of the South Table Mountain Campus—as well as threats of federal government shutdowns. It was neither predictable nor easy.

"I had so many roles—everyone's just-in-time deadlines. I've tried to balance the best I could and still achieve all I wanted to achieve—that made me a very focused person," he said.

## Promoting NREL with Well-Honed Skills

One of Arvizu's favorite parts of the job was "representing the lab in a broad context, with broad audiences, who are astounded and mesmerized by what we do and how valuable an asset we are. Getting a chance to rep the collective NREL is incredibly fun. That's stimulating," said Arvizu.

It comes back to those years in his father's shoe store.

"When I was still working with my dad, we'd deal with tough customers—and the customer is always right—all these things you do as a salesman. I said, 'Dad, I hate being a salesman. I will never be a salesman.' And you know, as I reflect back on my career, that's exactly what I was," said Arvizu, who became chancellor of his alma mater, NMSU, after leaving NREL.

He continues to keep tabs on the lab from his home state and, from time to time, meets with NREL leaders. "I was a salesman of the work that NREL did, of the value that it brings, of the mission objective. I did this to try to convince the unpersuaded. I hope I was a good representative because, frankly, the work that NREL does is just exemplary," he said.

# Martin Keller and the Leaders Who Helped Build NREL's Family

Martin Keller (right) and the leadership team discuss the laboratory s long-term strategy with staff in 2018 an all-hands meeting in the NREL cafe.
*Photo by Dennis Schroeder, NREL 52788*


elements missing?

President Joe Biden walks with Martin Keller during a visit to NREL's Flatirons Campus in 2021. *Photo by Werner Slocum, NREL 65478*

**Martin Keller**, NREL's ninth director, started his tenure in November 2015. To understand his passion, it helps to have a sense of his family history.

Keller's father grew up in Regensburg, Germany, a picturesque city in Bavaria with its medieval center intact, spared from destruction in World War II. His mother was a lifelong "social bee," constantly making cakes and taking part in local politics. "That's why everyone loved her," he said. His father was pressed into military service during the war when he was only 16—but later fled the German forces and was picked up by the U.S. Army. "The best thing that ever happened to him," Keller said—because his father was able to learn English while tending bar at an American Officers' Club.

The family spent all its time in the Alps, hiking and skiing, which proved invaluable during the younger Keller's later military service in Germany's elite mountain division. It was in that environment that young Keller credits a family friend, a painter, with stirring his early passion for nature and science.

"My uncle (that's what I called him) also loved nature. One time, he gave me this little butterfly net. We were out there to catch butterflies," Keller said.

There were plenty of mentors.

"My physics skills were not the best; not bad, not good," Keller said. So, one day in 1983 when he was in 11th grade, a biology teacher took him aside and said, "Martin, you need to become a biotechnologist." Keller recalled thinking, "Biotechnologist? What is that?" But he started researching the field. He found an expert in a nearby city and called him to ask about the discipline. The expert offered to have his students meet the novice, so Keller drove two hours and learned about this new world.

For Keller, this was a lesson in self-advocacy that would repeat itself soon, when he had to decide about college. "I really didn't want to stay in Regensburg, but I realized there was a very famous professor, [Dr. Rainer] Jaenicke, who lived here. I called him up and talked with his assistant, who said, 'The professor is very busy, but always does his experiments in the evening. This is the best time to catch him.'"

Keller walked to the distinguished man's office, knocked on the door, and was greeted by a somewhat surprised elderly man in a white lab coat. "Prof. Jaenicke, I really would like to talk to you about biology or chemistry because I'm debating about coming to the university here," Keller said then. The professor was gracious, saying, "If you don't mind sitting here during my experiment, while I get up and do my measurements, I'm happy to talk to you."

They spent two hours together and, toward the end of their session, the professor presented Keller with a biochemistry book. "I was really excited. I decided that's my place, and I went to the University of Regensburg," Keller said. As an added bonus, the professor mentored him through school, helping guide his way.

## An Outdoorsman Weathers a Stint in the Army

During the 1980s, military service was mandatory in Germany. Keller was determined to win a spot in the 23rd Brigade stationed in Berchtesgaden, Germany.

When the time came for the grueling physical test, the young man with a knack for skiing tricky chutes was ready. Applicants had to scramble up a mountain in leather boots while carrying a heavy pack with skis. They climbed rock walls and were judged on their ability to schuss down the mountain. Finally, they all ran a 5K footrace at a fast pace. Keller made the brigade.

"My time in the military was awesome," he said of his group that, during the Cold War, trained to protect the French Alps in case of an invasion. "We went heli-skiing to practice avalanche rescue. We were climbing and skiing every day—strapping guys in toboggans."

Still, it was among this skilled unit, whose members also happened to be highly educated, that he came to realize he was not made for the German military.

Once, an officer barked at him for rolling up the sleeves of his winter uniform during a sunny day. "But it's hot, sir," he countered. The officer wouldn't budge, so Keller rolled the sleeves down—only to roll them up again once out of the officer's site. The biggest reason he didn't fit in the military? "I asked too many questions," he said.

## Making a Name at the University

Keller said he soon realized Regensburg was famous for "hotshots" in biology, attracting students from all over Germany. He decided to move ahead more quickly than everybody else—directly to industry. He pursued a then-little-used practice in Germany: summer internships.

A big chemical company offered him a stint; however, only doing chemistry. "I had no idea about chemistry. So, I said, 'That's interesting,' and accepted," he said. For the next three months, he worked on a complicated antibiotic structure. "We discovered a couple of very nice chemical reactions," he remembered, which led to his first publication.

Years later, Keller asked the man who hired him (and who had become a good friend) why he chose young Keller despite his obvious lack of chemistry background. "My friend had a big smile and said, 'I had three organic chemists working on this project, and they could not do anything. You came in and had no fricking clue what you were doing. You tried things a chemist would never try because they listen to everybody who said something would not work,'" Keller said. That approach led to a breakthrough.

Happily, Keller stayed in his hometown and became one of those earning a Ph.D. (summa cum laude). He was on a safe track in German academia, spending several years on that trajectory. Then, in 1996, another Regensburg mentor, renowned microbe expert Karl Stetter, contacted him about joining Diversa, a California-based biotech startup. Keller, who described himself as a "calculated risk-taker," considered the offer. With little money, a young son, and roots in Germany, he and his wife weighed their options.

The Kellers decided to relocate to San Diego for a new adventure. He went on ahead but, soon after arriving, Keller got some unexpected news from the company's chief technology officer (CTO), who took him aside and told him there was a problem: The fledgling company only had cash for three more days. The CTO felt, however, that things would work out. "I called my wife, Sibylle, and said: 'There's good news and bad news. The good news—I found a wonderful home. The bad—I may be out of a job in three days,'" Keller said. They trusted things would improve. And they did—Diversa found new investments and continued.

Keller was in on the ground floor of a new enterprise, which started with about seven people and grew to nearly 400.

"From day one, I was a consultant—there when the first equipment was unpacked at Diversa," he said.

At Diversa, he learned a lot, including that his self-described German directness needed some toning down (a lesson he learned when asking the company president why he had only concluded one deal when the target was five).

But the biotech industry was volatile and, after nearly 10 years and three rounds of layoffs at Diversa, Keller had had enough. The end came when a new leader informed Keller that he might not be part of the company's future. Keller immediately gave three-month's notice—with no job prospects.

After he left Diversa in 2006, a friend called to tell him that Oak Ridge National Laboratory (ORNL) was looking for a microbiologist. "I thought, 'Where is Oak Ridge? Tennessee?' So, I looked at the map," he said, and the southern German saw it was in the south. He was won over when the ORNL leadership team backed him with close to $1 million through a Laboratory Directed Research and Development (LDRD) project. This funding provided him with the opportunity to buy a large piece of research equipment for his budding team. "I realized I really don't want to do management anymore," Keller said. He was ready to go back to science.

But why is Keller so passionate about science?

"Science is a form of art," he said. "When you talk about science and art, they are not so different. Science is a way to express yourself, to learn about nature, engineering, about technology."

His passion was obvious, and ORNL asked him to take over the Biosciences Division. "I want to do science," he protested, but then relented.

Next came the discussions about forming DOE's BioEnergy Science Center (BESC). Keller was in the room where it happened and was not shy. "I was sitting there and watching this discussion. New to the lab," he said. And he did what he tends to do: He spoke up. "I said, 'What you guys are proposing will not work.'" Suddenly, he recalled, they responded that he was going to be the director. Again, he protested, "I want to do science," he said but, in the end, acceded.

As founding director, Keller set up the BESC, which included NREL among 18 partners, as a virtual biotech company, pursuing DOE-funded basic and applied science to improve biofuel yields.

## Enjoying Family Life Down on the Farm

The Kellers bought a 25-acre farm with an idea to raise livestock, including alpacas. The initial acquisition was part of a bigger plan.

"When we moved to this country in 1996, we saw it as our opportunity to combine great things in the United States—its openness and politeness—with the good things from Germany—our traditions and food—and bring them into our family," Keller said.

With the farm, the couple decided to "constantly have our three kids and their friends at our place, instead of having them hang out where we couldn't see them," he said. The couple also introduced their neighbors to the concept of *Gemütlichkeit*, a German word that signifies a warmth and coziness. "For that, it is important to have a sit-down dinner at our long table, which seats 12," he said.

Despite his longing to do research, Keller became ALD of ORNL's Energy and Environmental Sciences directorate, responsible for the energy, biological, and environmental research programs. Keller and others had the concept to create a car using 3D printing, including about 20% of parts made from carbon fiber. Overcoming doubters, the team persevered and created a replica of a vintage 1965 Shelby Cobra sports car, which was unveiled at the 2015 North American International Auto Show in Detroit.

> "When you talk about science and art, they are not so different. Science is a way to express yourself, to learn about nature, engineering, about technology."
>
> —Martin Keller

On the heels of that success, ORNL and its partners unveiled the Additive Manufacturing Integrated Energy project, a demonstration in which additive manufacturing connected a natural-gas-powered hybrid electric vehicle to a high-performance building designed to produce, consume, and store renewable energy.

With projects rolling at ORNL, why would Keller be the first to submit his resume to NREL for the open laboratory director position? As then Deputy Laboratory Director Bobi Garrett said at an early all-hands meeting, his resume was in the hat "even before we had the website up."

"It sounds like I was desperate by sending my resume in," Keller quipped.

Yet, he's clear: Laboratory director at NREL is his "dream job." Having been raised near the Alps, Keller said, "For me, looking out the windows and seeing the mountains is like coming home."

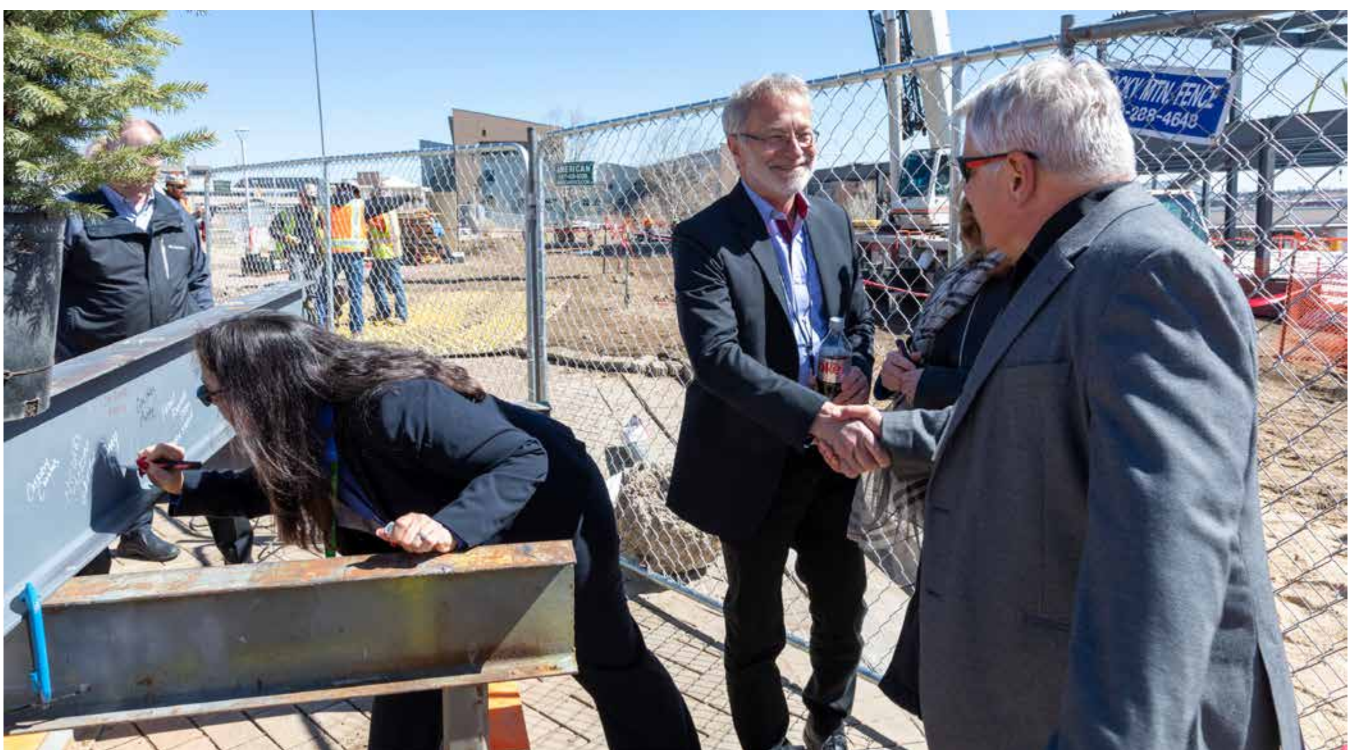
"Part of the reason I'm here is to see if I can be a part of creating a conscious and sustainable environment. I want to give our kids and our children's kids the same freedom that we have," he said.

He knows change is hard. "Sometimes, you have to make tough decisions," he said. "When I'm 95 years old and look back at my life, I hope that I've made some important changes. I want to tell my grandchildren, 'I was part of this. I was a tiny part of what you see.'"

## Keller Reflects on His Years at NREL

On Nov. 30, 2021, Keller marked his sixth anniversary at NREL. Among his proudest accomplishments, he noted that:

- After hundreds of interviews with NRELians across the organization, scores of informational sessions, and weeks of debate among the laboratory's leadership team, NREL established its long-term vision. This science and technology strategy is meant to guide the laboratory during a period of upheaval in the world of energy. Notably, the Energy Department endorsed this plan and the focus on its three critical objectives: Integrated Energy Pathways, Electrons to Molecules, and Circular Economy for Energy Materials—which together will transform the energy future.
- In Fiscal Year (FY) 2017, Keller challenged the greater Business Development Team and other NREL leaders to shoot for $100 million annually in new partnership work. At the end of FY 2020, NREL hit an all-time high in new Technology Partnership Project (TPP) agreements, surpassing that lofty $100 million goal. This funding will support the equivalent of more than 200 full-time employees. NREL's TPP work includes Eaton, Shell, and ExxonMobil. And because of these and other relationships, NREL's global reputation and impact continue to expand.
- The laboratory continued to develop capabilities through other focused initiatives. The arrival of the Eagle high-performance computer multiplied computing power for numerous programs. The expansion of the Flatirons Campus is taking NREL's research capabilities to a whole new level. And, in summer 2020, while mindful of COVID-19 precautions, NREL broke ground on the new Research and Innovation Laboratory (RAIL). Keller and others signed a steel beam in March 2022 in a RAIL topping-off ceremony as the building headed to completion. During this period, NREL also launched the new Advanced Research on Integrated Energy Systems research platform.
- In December 2021, Keller and the leadership team shared the news that NREL had earned a 97 positive score—an "A" grade—from leadership at the Office of Energy Efficiency and Renewable Energy (EERE) for the laboratory's performance. This tied the lab's highest score ever, recorded in 2020. That mark exceeded the lab's previous top grade—a 96—tallied in both FY 2018 and FY 2019. EERE recognized



Martin Keller (center) greets Associate Lab Director for Materials, Chemical, and Computational Sciences Bill Tumas, in March 2022, while Amy Read (left) of the U.S. Department of Energy's Golden Field Office signs the final beam during the topping-out celebration for the Research And Innovation Laboratory (RAIL) on NREL's South Table Mountain campus. *Photo by Werner Slocum, NREL 66777* that NREL's FY 2021 achievements had met—or exceeded—expectations in both mission and operations.

- NREL continues to be a world leader in credible and objective analysis. The groundbreaking Los Angeles 100% Renewable Energy Study (LA100) has become a standard for integrated engineering-economic analysis that can be replicated worldwide. Another example is NREL's Mexico Clean Energy Report. Released in April 2022, it concludes that, in light of the potential for and the low cost of renewable energy generation, Mexico is ideally poised to become a clean energy powerhouse.

Of course, due to the COVID-19 pandemic, 2020 and 2021 tested the NREL leadership team and NRELians in ways that required new approaches to the laboratory's mission. Still, Keller was pleased to point out that researchers continued to exceed expectations, winning six R&D 100 Awards across two pandemic years in the annual national competition, with two additional projects cited for Special Recognition Awards. Those brought NREL's total to 71 R&D 100 Awards since 1982—an impressive number for a laboratory of NREL's size.

### Leaders Past and Present

While the directors have been in the spotlight, they undoubtedly rely on a range of supporters; notably, members of the leadership team. And while there isn't space enough to highlight all of those, some examples are worthwhile, starting with "NREL's true mother," **Barb Goodman**, as well as her friend, **Bobi Garrett**.

## Barb Goodman—Known as NREL's Mother

As Barb Goodman stood nearby at the NREL Service Awards ceremony in 2018, Chemistry and Nanoscience Center Director Jao Van de Lagemaat referred to her as the person "better known as NREL's real mother." Everyone seemed to immediately understand. After all, she had been at the laboratory since 1984, helping launch careers, expanding NREL's technical capabilities, and ensuring that anyone in need of a hand could always count on her and NREL. She retired in 2018.

However, should anyone question the political correctness of the nickname, Goodman was clear that she was completely

**Barb Goodman applauds at an NREL Service Awards ceremony in 2017.**
*Photo by Dennis Schroeder, NREL 48778*

comfortable with it. "I take it as a compliment. It feels kind of natural," she said with a laugh. "I have been a mother for a long time."

NREL's former executive director for Institutional Planning, Integration, and Development can list a lifetime of experiences, both professional and personal, during her tenure at NREL. "I got married for the second time; had my daughter, Carlie; went through another divorce; and suffered the deaths of family members—I've had a lot of big life experiences," she said, then paused. "I've had the good and bad, the ups and downs of life we all go through. I feel like the people of NREL have been my family, supporting me through it all."

Goodman was quick to reflect on the blessing of working with "so many really wonderful, kind-hearted people" and being able to, in her words, "share all those experiences with them and to share similar events in their lives. We used to joke that people come to check in with me when they get married and before they have kids. I became their work mom."

And while she accomplished an array of professional achievements—serving as ALD for Mechanical and Thermal Systems Engineering and director of the Center for Transportation Technologies and Systems for 16 years—she never forgot the human element of her job. "A lot of the people I was hiring in the earlier days were the ages of my sons. Now they are more like my grandkids' ages, practically," she said, shortly before retiring.

"She's the unifying spirit of the lab, its soul," Keller said. Fortunately, with his support, Goodman stayed connected, helping to launch an NREL alumni association.

That a girl from a small Minnesota town—the 14th of 15 children, who was married at age 17 and once considered becoming a lawyer—would end up as the matriarch of a national laboratory is a testimony to Goodman's drive.

## Goodman Leaves the Twin Cities for the Big Apple

Growing up with nine brothers and five sisters encouraged creativity. "We found and created our own entertainment," Goodman said. "We played 'pioneers' out in the yard—gathering and cooking things. We'd make TV sets out of cardboard boxes or create our own movies. I never felt I was missing something growing up. We had a lot of love and closeness in the family."

Her father, who worked as a legal liaison between the liquor industry and the government, had a range of law books. "I'd sneak into his study and read them, because we didn't have many books," she said. "I even thought of becoming a lawyer." However, the family's idyllic world was upended when they moved to New York City before settling on Long Island; Goodman was in junior high. "It was complete culture shock," she said of going from a Catholic school, where she knew everyone, to a public school with a diverse student body. "It took me a few years, but I adapted and became a very good student," she said.

Goodman also worked after school in a grocery store. "Our family had a strong work ethic," she said. It was there that she met her first husband, who was eventually drafted into the Army. Because of the uncertainties surrounding the Vietnam War, the young man decided he wanted to get married. "He called me one day and proposed," Goodman said, adding tongue in cheek, "Very romantic." The couple wed the day before Goodman graduated from high school. Her parents had extracted a promise that she attend her graduation, and she did.

A year later, having moved first to Texas, then to Fort Carson in Colorado, as her husband was transferred by the military, Goodman had their first child, Jason. A few years later, a second son, Kris, was born but died after just a few months of life; then a daughter, Jessie, came along in the fifth year of marriage. Life was hard, and things weren't going well in the relationship, so the couple divorced. "It was traumatic," she said. "I thought, 'Where the heck was I headed when I started this and my life was derailed?'"

Goodman had been set to go to college and loved math and science, so she enrolled in Front Range Community College in Westminster. "I kind of figured that I was going to be a math teacher at that point," she said.

A mentor who encouraged Goodman to teach classes, asked about her plans and then suggested applying to the Colorado School of Mines. "I didn't even know it existed," she said. But, after an encouraging meeting, she decided to go there. She worked as a waitress and tutor. "We did homework together at night," she said of her children, as she pursued a degree in chemical and petroleum refining engineering. "I didn't think where I would work. I just started taking classes in the courses that seemed interesting," she said. Among her professors was **Bob Baldwin**, who later became an NREL principal scientist.

"I first met Barb Goodman when she was a student in my senior-level chemical reaction engineering course," Baldwin said. "She was what is often called a 'nontraditional' student because she was not following the normal pathway from high school directly to college. She was, accordingly, much more mature and savvier about the way the world works. She was an excellent student, a 'front-row sitter' by choice."

After graduation, Goodman had many choices. Conoco flew her to Texas to discuss an accelerated management position. "I cried the whole way home," she said. "I didn't want to go back to Texas." She was able to work at the former Mines Research Institute in Colorado, which was closing and had to dispose of about 50 years' worth of chemicals. Mines then offered her a full-time job working on pyrolysis of biomass. At the same time, she got an offer for a temporary job at SERI and chose SERI. She said, "I've taken a few risks—they've paid off well, I'd say."

## Fueling SERI and NREL

Goodman started at the laboratory in July 1984, working in the Field Test Laboratory Building (FTLB) for Dan Schell doing biomass research and performing acid hydrolysis of wood chips to convert them into ethanol. Schell later became a manager at NREL's National Bioenergy Center. He recalled that "doing the work outdoors was probably the most exciting part. I think we were able to work on our tans when it was sunny." There were other thrills. "At that time, we had just moved into the FTLB," Goodman said. "Often, rattlesnakes made their way into the building. There was one on my desk one day but, fortunately, I was out of the lab."


Goodman test drives a hydrogen vehicle in 2008. *Photo by Pat Corkery, NREL 15858*

She learned to cope with other uncertainties. She credits her managers at the time—**Stan Bull**, **Bill Hoagland**, and **Charlie Wyman**—with finding a place for her. Her first big assignment was to do the techno-economic analysis as to whether a program focusing on anaerobic digestion should be cut by EERE. Under a tight deadline, Goodman surveyed members of the industrial waste industry and found they supported the work. She flew to Washington, D.C., and delivered her findings to the program director, arguing that, not only shouldn't the program be shut down, but it should be expanded to municipal and industrial waste. "At the end, I was told that was the best presentation from SERI—and that we'd get $4.5 million for the expansion," she said.

Goodman managed that program and later authored a book chapter on biomass. NREL leadership noted her abilities with people and asked her to take on some problematic programs, beginning with one in fuels utilization. Goodman managed an ethanol group and, after a merger, formed the laboratory's Transportation Center. The best part, Goodman said, "was really building a team. We had maybe 15 or 20 people. It was a rule nobody got hired without coming through 'mom.'"

One of the people she hired was Senior Research Fellow Bob McCormick. "I interviewed for a job at NREL in early 2001," McCormick said. "Barb asked what aspect of my work I was most proud of, and I said that some of the results we had produced had been used by the Environmental Protection Agency in a rulemaking and had really made a difference in how we protect the environment in this country. I have always admired Barb's commitment to trying to make a difference, doing work motivated by changing the way things are done to something better."

McCormick and others were part of the expanding family. "We were growing something special, creating these new avenues and paths for the lab around battery research, analysis, power electronics," Goodman said. She teamed with then-NRELian Terry Penney, a transportation researcher who was "as opposite as night and day from me. He was a grand visionary; I was the one who could implement. We really, early on, recognized and played to each other's strengths," she said.

Goodman was ready for new challenges. "Opportunities came up. I said, 'Okay, I'll try that.' I never got tied to a specific career path. I could be on the lookout for something new. Maybe that's the risk-taking," she said. "Different roles sort of came naturally. I worked hard and tried to do a good job. I was willing to attempt different things, and I enjoyed them all."

Goodman advocated for NREL staff and spoke her mind. "I do feel I've brought forth a lot of the nurturing, caring, and concern to management during my career," she said. "As chair of Staff Council, there was a period when I'd meet with the director and say, 'You know, the staff feels like this …' [The director would reply] 'Okay, Goodman, what do I do about it?' I've had a close relationship with every lab director since I came here. I've been able to speak frankly to each, and I think that they've appreciated that perspective. Also, I think the staff appreciated that I could take their messages forward. The messages weren't always listened to, though," she said, smiling.

"Barb built an enduring legacy at NREL," said **Wendy Dafoe**, program manager in Vehicle Technology Integration. "As a leader, mentor, visionary, and friend, she influenced NREL's future and impacted the lives and careers of countless employees."

Among the rewards for Goodman's efforts was receiving the Van Morriss Award for leadership. "Because this award is selected by the lab director's office, I was a part of that discussion with Director Richard Truly," said former Deputy Laboratory Director and Chief Operating Officer Bobi Garrett. Goodman's nomination "recognized her many accomplishments, but spoke specifically to her leadership impact on people," Garrett said. "She was widely acknowledged as providing tough love when needed, but bringing a strong and enduring focus to nurturing and developing staff."

Goodman and Garrett grew close while serving on the leadership team. Garrett clearly recalled that during a stretch in 2016, when they were preparing a proposal to extend the contract to manage the laboratory, "What touched my heart was that every day during that campaign, Barb showed up at my office at noon with a fabulous homemade lunch. I have never eaten so well in my entire life," Garrett said. Garrett joked that she and Goodman are twins separated at birth because "we have the same initials." Indeed, the BGs performed well together on a variety of stages.

## Charity Is Part of the Whole Person

As Goodman noted, charity and sharing were key parts of her life, both in and out of the laboratory. "Having been a single mom, I know how much even a little help can mean," she said.

Early on, she joined the laboratory-wide charitable giving efforts—and had the typical Goodman effect. "I guess I didn't like the way it was run, so I volunteered," she said. "I brought different aspects—such as getting people out to see what organizations do—to drive home the reality of how great the need is. If you haven't walked in their shoes, you don't know what they are going through. Once you've seen that, it's hard not to want to help."

And it wasn't only in formal organizations that her touch was clear. As McCormick noted, "I cannot tell you how many times Barb asked me about my children. And when one of them went through a rough period as a teenager, she was there for me and understood that I was distracted; she checked in on us often. Having her unwavering support and understanding on the work side of my life during this time is something I will never forget," he said. "Her example of how a manager, a leader, should treat people is, I think, her most important legacy at NREL—and I see it informing the culture all over the lab."

"I've been so blessed in my personal life and in my professional life. I couldn't have envisioned a career or life that was any better than what I've had," Goodman said. She paused, then laughed, "With a few minor glitches."

> Barb "was widely acknowledged as providing tough love when needed, but bringing a strong and enduring focus to nurturing and developing staff."
>
> —Bobi Garrett

# Bobi Garrett—A Pioneering Engineer

Bobi Garrett was always something of a pioneer in the realm of engineering and renewable energy.

When she earned a chemical engineering degree in 1976 from Montana State University (MSU), she was one of seven women in a class of 30 chemical engineers—which may seem small, but it was said to be the largest number of females in a graduating chemical engineering class at that time. Throughout her career, Garrett accepted challenges in fields ranging from national security to health care at a time when there were few women mentors. And she earned a master's degree in business administration (MBA) degree just before the birth of her first child.

So, it's not surprising that Garrett was selected by the *Denver Business Journal* as one of the "Top Women in Energy" in 2015. And, in December 2020, she was given a Lifetime Achievement award by the U.S. Clean Energy Education & Empowerment (C3E) Initiative, led by DOE in collaboration with the MIT Energy Initiative, Stanford Energy, and the Texas A&M Energy Institute.

As DOE noted, "During her tenure at NREL, Garrett integrated and implemented the lab's strategy across research and operations and ensured business and operating systems enabled high-quality, impactful research."

Although her professional accomplishments are widely known, the foundation of her path may not be as familiar.

It starts with a hammer.

## A Montana Childhood Sets a Foundation

When Garrett was almost 2 years old, her family moved to an old farmhouse on the edge of Missoula, Montana. After that, for years, they lived in what she calls a "construction zone," as the house was transformed from a 1930s design to a modern, split-level home of the mid-1960s.

"It was my playground," she said. "Imagine all the scrap wood, bent nails, wire remnants, and other materials that were there to use to build things. I constructed countless forts, trains, airplanes, and cities over the years."

The experience shaped her early thinking and, indeed, her outlook on life. "The process of seeing the larger house come together from the pieces, and the hands-on experience of getting to build my own models, shaped me," she said. "It was the foundation for what became a passion for systems thinking later in my career."

When she was about 5 years old, her favorite toy was a small hammer. "It was my teddy bear," Garrett said. "It's true what they say that when you have a hammer, the whole world looks like a nail," she said. "I was often in trouble for hammering on the furniture or walls."

## A Math Fan Finds Engineering Adds Up

Arithmetic was easy for Garrett in elementary school. "I really, really liked math," she said, and gravitated toward the subject.

She said both of her parents were very intelligent people who could have completed college if they'd had the opportunity. Instead, they had to make a living to support Garrett and her two older sisters. "They made it clear to all of us: 'You WILL go to college.' There never was a question," she said.

Her mom worked as a midlevel supervisor at AT&T, while her father was entrepreneurial, holding a lot of different jobs, including one as an electronics technician for the City of Missoula, calibrating the city's police radar guns and ensuring that stoplights were synchronized.

"Going through high school, I loved math and science and had great teachers," Garrett said. "I thought I was going to go to the University of Montana in Missoula and become a math teacher. That was my line of sight."

But that changed when she got a call from the head of the MSU chemical engineering department in Bozeman. "He said, 'I want you to come visit and consider going to MSU in chemical engineering.' I had no idea what he was talking about, but I agreed because there was a scholarship involved. And I'm always someone to leap into new experiences. That's how I got set on the path of engineering," she said.

The pitch for chemical engineering was strong: Chemical engineers can do anything—in part because each must learn mechanical engineering as well as something about electrical engineering and economics—whereas other engineering students don't have to learn anything about chemistry. It was also considered a portal to many career paths, such as medical school, law, or business, in addition to engineering.

Still, it was unfamiliar turf. "Relatives cautioned me that you don't want to get in too narrow of a field because you might have trouble finding employment," Garrett said.

While the rhetoric surrounding the subject was about opening doors, the practical reality was the coursework strongly focused on preparing students to work in refineries. "That was the dominant career path for many of my colleagues, and it didn't appeal to me," she said.

However, a summer internship in 1975 at the Atlantic Richfield Hanford Operations in Richland, Washington, allowed her to veer off that track. "I had never heard of the Hanford site, but I wanted to go because I didn't know anything about it," she said. The trip from Montana to eastern Washington felt like going "to a big city—but it really wasn't." At Hanford, she worked on projects involving analyzing and developing new processes for nuclear waste management.

"I learned a lot, met a lot of interesting people," she said. When she graduated, she got a job offer there and returned for two years as a process engineer.

## A Career Change from Nukes to Renewables

Garrett's career started at a large company of 12,000 people—with exactly three female engineers. "We were unusual, kind of under the spotlight," she said. "There is nothing that prepares you for that."

It was during this time that she started seeing the topic of "renewable energy" show up in various professional meetings, and so badgered her Hanford manager to let her attend a conference in Portland, Oregon, where she heard a young engineer/architect named Ed Mazria speak (he is now considered one of the fathers of passive solar design buildings). "It opened up a whole new world, and it fascinated me," Garrett said.

One other thing happened that would have a major effect. While at Hanford, Garrett worked on a project with researchers from what was then known as the Battelle Lab and later became the Pacific Northwest National Laboratory (PNNL). When she heard about the things they were doing, she decided to apply to PNNL.

That's how she embraced her renewable energy future—and met her husband.

Arriving for her first day of work at Battelle/PNNL in June 1978 was memorable. The manager she was supposed to report to was out of the country. Instead, a peer-level manager named Tony Garrett signed her in.

About two weeks later, Garrett got an invitation to go to breakfast. "I was telling a colleague of mine, 'Hey, I just got invited to my new employee breakfast.' She said to me, 'What are you talking about?' And that's when I realized it was a date," she said laughing.

It was a good breakfast, and the couple started dating. Tony left the laboratory not long afterward to start a nuclear and ceramic engineering consultancy, and then an electrical design and construction company. "That's what I did on the weekends: helped him wire houses," she said. She learned enough to earn a journeyman electrician's license—and burned through a couple of pairs of wire cutters along the way when she clamped them down on lines she thought had been turned off but still had juice. "That taught me the importance of safety and not to make any assumptions; walk down the job before you do it," she said.

She joked, "I accused him once of trying to get rid of me."

Early in her 20-year run at PNNL, Garrett was part of a rotating assignment for newer graduates. Her second rotation in renewables was all she needed. "I called Human Resources and told them this is where I wanted to be," she said. She had the opportunity to work on solar, wind, and geothermal research projects that were launched as part of President Carter's focus on alternative energy.

Also, her manager encouraged employees like Garrett to pursue MBAs, setting them up to be in an area similar to NREL's Strategic Energy Analysis Center. She leapt at the chance, earning an MBA from the University of Washington in 1984. "I crashed to finish by taking three classes the last quarter while working full time," she said, to graduate right before the first of her three children was born.

At PNNL, which had more women in the ranks than her previous employer, Garrett held a succession of line management and program management positions with increasing levels of responsibility. "I was very fortunate to have had the diversity of roles that I had," she said. Often, when faced with a new opportunity, "My first reaction was: You want me to do what? Next reaction: That sounds interesting, sure," she said. "When you get out of your comfort zone, you learn and develop the most."

> Often, when faced with a new opportunity, "My first reaction was: You want me to do what? Next reaction: That sounds interesting, sure."
>
> —Bobi Garrett

"Everything's an opportunity to learn something," she said, sounding a bit like the teacher she originally intended to become.

Significantly, during the early 1990s, PNNL launched an energy initiative, which Garrett led. In addition to setting an energy research strategy, PNNL hired its first energy ALD, Jack White, who had led the New York State Energy Research and Development Authority, and Garrett served as his deputy. She also began working with folks from NREL, including Tom Bath and Walter Short, as well as others from Sandia National Laboratories, on an EERE strategic plan. Because NREL was located in the geographical center of the three laboratories, the group would often meet in Colorado.

"I would go home and say to my husband, 'You know, it's the funniest thing. As soon as I pull into Golden and NREL, I get the feeling of being home. I guess it must be because it's kind of like Montana or something,'" she said.

And home was calling.


Martin Keller (left) and Bobi Garrett (center) listen to Caroline McGregor (right) talk during a poster session at the U.S. Clean Energy Education and Empowerment (C3E) Initiative ambassadors retreat at NREL in 2016. *Photo by Dennis Schroeder, NREL 36273*

## NREL Welcomes Garrett

The pull to NREL wasn't just about its location.

"You know what? It was the people," Garrett said.

While helping prepare a management and operating contract for NREL in 1998, Garrett's work proved to be an unintended bridge. Eventually, she was invited to come to the laboratory in November 1998 as part of the executive team, comprising Midwest Research Institute and Battelle, to manage the laboratory. Garrett arrived as the associate director for Strategic Development and Analysis, responsible for laboratory strategic and annual planning, among other things.

"Within a couple of weeks of getting here, a few things struck me as being really unique about NREL, relative to my prior experience," she said. "When you talked to researchers here, they tended to talk first about the problem that exists in the world and why the work that they're doing is a response to that problem. Then they tell you about the details of their work."

"That was mind-blowing to me. At the lab I came from, the conversation started in the other direction. The researchers would talk about the work they were doing in great detail and then get to how it might be used. Sometimes they didn't know because the mission was advancing basic science knowledge," she said.

"The other uniqueness was how ubiquitous analysis was in all the research work at NREL," she said. It was informing the research direction and was part and parcel of the research guiding it toward reducing the cost of new technologies.

"I'm really proud of the lab's analysis capability—it's a high-impact core competency. It's unique in the national lab system," she said. Analysis was elevated to be on par with research in the strategy that Garrett helped create in 2008 to win the bid to continue to operate the lab. The DOE request for proposal challenged bidders to identify how to increase NREL's impact. Garrett recognized that, ultimately, our energy future is created through thousands of decisions made by governments, institutions, and individuals over multiple decades. The vision was to establish NREL as a global thought leader on the forefront of important analyses, grounded by credible and objective data and modeling tools, that could inform these decisions. Garrett championed investments to strengthen NREL's capabilities, connect the capabilities to leading institutions globally, and conduct critical analyses that could inform the global energy dialogue.

Bobi Garrett celebrates a double during the Inaugural World Cup Kickball Tournament in July 2018. *Photo by Dennis Schroeder, NREL 52061*

She created the concept for the Joint Institute for Strategic Energy Analysis and worked with a team of founding members to launch the new institute. Garrett said that although she's championed the focus on analysis, the impact was achieved through "leaders such as **Doug Arent**, **Walter Short**, **Robin Newmark**, **Dave Mooney**, **Maggie Mann**, and countless others who did the hard work to take this research capability to the next level. It's one thing to have a vision, but to implement it, you have to have people like those folks and more," she said.

Garrett, who loves change, never felt stagnant at NREL. "This role that I've had kept me engaged and focused on building the institution," she said.

An innovator, Garrett said she enjoys being able to think and create the first steps in a new direction for initiatives, such as developing the systems integration research area. As with analysis, this involved attracting key talent to NREL and investing in emerging leaders, such as Ben Kroposki. And when the concepts mature and move on to their next step, that's very rewarding," she said.

Garrett, who served as senior vice president of the Alliance for Sustainable Energy, led the search committee to select Dan Arvizu's replacement as NREL laboratory director when Arvizu retired in 2015. "Delivering the slate of candidates to the Alliance board, which included current director Martin Keller, was likely one of my most important contributions to increasing NREL's impact," she said.

"It was delightful working with all three of the directors I had the opportunity to support at NREL," Garrett said, "Richard Truly, Dan Arvizu, and Martin Keller. They're all, in their own ways, national treasures; they're statesmen, thought leaders, game changers."

## Connecting the Dots at NREL

"My bent in life is to try to connect the dots on everything. It's about integration," Garrett said. And she's able, by nature or nurture, to look at things and see patterns and processes. Being able to see the big picture as well as the details helps to create and carry out impactful strategies. The times she had the most fun were when she made the biggest jumps, she said.

"I took some big career leaps and often felt a fair amount of stress in the front end of taking on a new role, which is part of why I like to mentor people now," she said. "I always felt that when I went into a new job, I had to know everything on day one. I was like an obsessive maniac, trying to read everything I could possibly read to know everything. After a while, I realized that making a transition is a replicable process of letting go and taking on, and I gave myself permission to relax and follow the process."

"You don't have to know everything. You just have to know who to ask. Once I recognized that, it made all the subsequent transitions much easier," she said.

Garrett wants to pass that wisdom along. "There were long periods of my career when there were no mentors, and I had to learn on my own to figure things out," she said. "Then there were periods of time with mentors, sounding boards, and it was such a vast difference. One of the things I am most proud of was launching NREL's Women's Network. As its first executive champion, I sponsored its initial charter and served as convenor. The next generation of leaders took the reins and has created a network and programs that have permanently changed the laboratory for the better."

"Clearly, for me, my passion and legacy are around the people. Can I help people get to be on the path they want? Over the years, people have asked for advice, and some of the most delightful conversations are with those mentees. You learn something from everybody you talk to. So, I get as much, maybe more, than they do," she said.

Before she retired in 2019, Garrett typically parked in the furthest part of the garage so her walk to the Research Support Facility would take longer—and she could view the campus. "I was proud to come here every day, to make a difference," she said.

"NREL is creating a better future for the next generations. I'm proud to be able to say that I've enabled others to have a big impact. It feels good," she said. "It felt good to go home every day and know you've contributed to the greater good. Not just at the lab, but for the world."

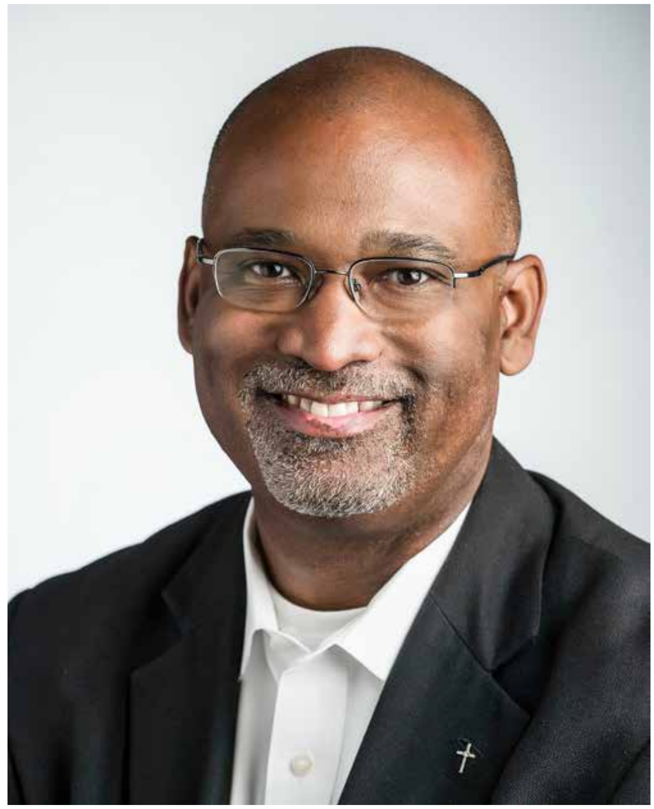
## Johney Green—<br>Science Groundbreaker

According to Associate Laboratory Director for Mechanical and Thermal Engineering Sciences (MTES) **Johney Green**, Jr., he's "been a trailblazer in many ways during my life." Among Green's personal accomplishments: He was the first in his extended family to earn a Ph.D.; in 2008, he became the first African American appointed as a research division director at ORNL; when he came to NREL, he became the first African American ALD for a research directorate at NREL. "That's Black history," Green said.

But he's not focused on himself. Instead, he credited his parents for showing him the path forward.

His father, Johney Green, Sr. was a trailblazer. "He grew up in Baton Rouge, Louisiana, and was the first in his family to go to college— despite the fact that his father's family did not embrace higher education," the younger Green said. "They just didn't see why anyone would go to college." However, a scholarship allowed the elder Green to attend Southern University in Baton Rouge, a historically Black university. The elder Green would steadfastly study at the kitchen table of his family's tiny house as guests and relatives noisily swirled around him. Nevertheless, he persevered. "When he graduated, nobody in the family came to the ceremony," Green said.

After working as a teacher, the elder Green took the test required to get into the Memphis, Tennessee, police academy at the request of civil rights leader Rev. Samuel Billy Kyles. "Rev. Kyles wanted him because my father had gone to college and could pass the test," Green said. His father did pass and, following training, was the only African American in his graduating class of 11 rookie



**Johney Green.** *Photo by Dennis Schroeder, NREL 39633*

officers. Progress was incremental and, in the 1960s, Memphis still had institutional racial barriers. Green recalled that "my father was not allowed to arrest a white person if he saw someone commit a crime." Instead, his father had to telephone a police station to get a white officer to respond.

Green's mother, Emma, who taught first grade, helped her son keep a positive perspective in the face of incidents of bigotry, encouraging him to stay positive. Her message to Johney Jr.: "Anything you put your mind to, you can do," Green recalled.

It was in that same spirit that his father eventually returned to teaching while in Memphis. In the early 1970s, he was selected as one of the outstanding Black teachers chosen to work at a previously all-white school (Snowden) during a court-ordered school integration. He encountered many challenging situations. "But, even with all of that stuff, he's not bitter," Green said. Because his father was a positive role model, one of the white students who attended Snowden later praised the elder Green. Green Jr. became friends with this student when they were classmates at the University of Memphis. His friend's words "made me proud," Green said.

That is why growing up in Memphis, Tennessee, and Baton Rouge, Louisiana, as the only child of two teachers, the younger Green knew that a college education was important. What he didn't know was what his major would be.

"I picked mechanical engineering because I was good at assembling furniture or other things at the house for my mother," he said. "I didn't know what a mechanical engineer did, but I thought, 'I'm good at math and science, and I can put stuff together'—so I decided to be a mechanical engineer." Once Green settled on a major, his plans were simple: get a bachelor's degree and a job. "I had no desire to pursue a Ph.D. and do science at the highest level. That was not in my thought process at all," he said.

He dreamed of going to Georgia Tech and was accepted as an undergraduate, but he didn't get any scholarship money. The cost of a Tech education would have been a hardship on the family, so instead he chose the University of Memphis, where he was offered a full ride. He was comfortable there, one of his two hometowns, as he calls them. "We lived in Memphis during the school year, but spent most of the summer in Baton Rouge," Green said.

He excelled at the University of Memphis—and Georgia Tech paid attention. In January 1992, the latter invited Green to attend its first Focus Program, a gathering held over Martin Luther King Jr. Day weekend, designed to introduce underrepresented minority students to graduate programs. The Focus Program "changed my life," he said simply.

## On Track at Georgia Tech and Oak Ridge

Green's life was now on a new trajectory: exploring the academic universe. "The first step was being exposed to grad school options at Georgia Tech," he said. "Once I decided to go, I received a national GEM Consortium fellowship with ORNL as my sponsor company." The Graduate Education for Minority Students (GEM) network includes corporations, laboratories, and research institutions and enables qualified students from underrepresented communities to pursue graduate degrees in applied science and engineering. Through GEM, Green interned at ORNL for two summers, an experience that resulted in another turning point.

"That's when I realized I wanted to do research; I didn't want to just turn the crank at a repetitive job. I didn't want to plateau," he said. "I wanted new challenges, new concepts—to continue learning." As his interests deepened, Green learned that he enjoyed the areas of heat transfer and thermodynamics the most. And, as he once told an interviewer, he and some friends were well-known as the mechanical engineering posse across campus.

Green's life shifted in several ways during his time in grad school. While interning at ORNL in 1993, he met his future wife, Tonya. "She was working in the graphic design department at the laboratory. I was doing engine research," he said. They began their life together. Sadly, also around that time, Green's mother died of breast cancer; she was only 50 and had been his inspiration. "That's why I wear this little pink wristband" he said, holding out his right wrist. "She was my hero."

"That's when I realized I wanted to do research; I didn't want to just turn the crank at a repetitive job. I didn't want to plateau. I wanted new challenges, new concepts—to continue learning."

—Johney Green

Green pushed forward with his studies. As he was finishing up his master's program, Oak Ridge offered him a research job and Tech offered a stipend to work on his Ph.D. Green negotiated an arrangement to complete his coursework, take the laboratory job, and write his doctoral thesis remotely. "I used chaos theory for my Ph.D. research on stabilizing engine combustion, which was a little bit of a departure. It comes in handy now," he laughed.

In June 1995, Green started as a full-time researcher at ORNL in the Fuels, Engines, and Emissions research group. Three years later, his managers asked him to go to Ford's Research and Innovation Center in Dearborn, Michigan. "For a year, I worked side-by-side with the Ford team as a visiting scientist," he said. His runway seemed clear in research. And, after completing his Ph.D. in 2000, Green recalled, "I was beginning to hit my stride as a researcher, looking at advanced low-temperature combustion modes for diesel engines. It was a new research area for DOE's national labs."

Everything was working out just fine for the rising researcher. But just as chaos theory can be unpredictable, so can the life of a scientist. His managers came to him in 2002 with a new proposal: They wanted Green to head to DOE headquarters to work for a year with the Vehicle Technologies Program on the 21st Century Truck Partnership, a research collaboration focused on truck

**Johney Green (left) and Juan Torres (right) host a tour of the ESIF for University of Colorado president, Todd Saliman (center) in March 2022. Peter Green is in the background.** *Photo by Werner Slocum, NREL 67004*

efficiency, safety, and emissions. “I said, ‘I’ll go if I can do research when I come back.’ They said, ‘Well, Johney, if that’s what you want to do—when your assignment is up, you can do that,’” he said.

He was unaware that, upon his return, he would move into management. “When my assignment was over, my group manager retired,” he said. “And since I had worked with industry, with our sponsors at DOE, and had done some decent research at the lab—and normally didn’t offend too many people when I interacted with them—management said, ‘You’re management material.’ That’s how I got on this track.” He doesn’t say it with regret, despite his love of research. “You can do much more through others than just yourself as an individual contributor,” he said. “You can have a much larger impact.”

After doing that job for five years, Green bid on the new job of division director for the Energy and Transportation Science Division, taking on that role in 2008. A few years later, Keller became his ALD. While Green flourished at Oak Ridge, he stayed in contact with Keller after Keller became NREL’s laboratory director in 2015.

In 2016, a tempting opportunity for Green opened at NREL. “All of my Oak Ridge experience was with DOE Office of Energy Efficiency and Renewable Energy programs. It was a natural fit to come here,” he said. On Aug. 15, 2016, NREL’s new ALD for Mechanical and Thermal Systems Engineering started work. His plate was full, leading the laboratory’s transportation, buildings, wind, water, manufacturing, and geothermal research. Early on, Green circulated to meet as many staff as possible, but adds “there’s never enough time.”

His impressions were generally positive: “The greatest strength is the passion for the mission,” he said. The same might be said of its greatest weakness. “The fact that the staff at NREL clearly understands the mission of the organization and is passionate about it is a strength. Passion about a topic usually produces meaningful outcomes,” he said. “However, an overused strength can be a weakness. If we are too passionate about something, we may miss another valid perspective that could help us to advance our mission in a different way. That is how it can be a weakness in some instances.”

His vision is clear. Green said, “I would love for us to be recognized externally by DOE and our collaborators as an organization that enables the development of advanced energy technologies. We’re doing fantastic science and engineering that is pushing innovations.” Also, he wants the NREL family to feel engaged. “I hope that this is seen as a great place to work and to have an impact on developing those technologies,” he said.

An area that truly excites him is the laboratory's high-performance computing (HPC) work and how it can tie in to so many areas of the laboratory to achieve technology innovations. As for projects, he likes the Exascale Computing Project that focuses on how HPC can aid in the development of wind power plants. "I would love to do more things like that," he said.

Green is a man on the go, so there isn't a lot of time to relax in the family's Highlands Ranch home. Although he has heard race-based comments everywhere from higher education to daily life, he said he strives to stay upbeat. "If you can form relationships with people from different backgrounds, it helps break down barriers. The more that people can spend time with one another, the better it is," Green said. Ultimately, he said, "you find out people are people. There are good white people and good Black people as well as examples of the opposite." He summed it up, saying, "Different cultures have different perspectives. We all need understanding."

Just as his father and mother did, Green believes strongly in education. He remains a strong backer of the GEM fellowship as well as other avenues that can help minorities gain access to opportunities. "The world isn't perfect," he said, "but there is progress." Green finds NREL a great example of working in harmony, and he sees the collaboration in his Mechanical and Thermal Engineering Sciences (MTES) directorate invigorating. "The great thing is that everyone's here for the same reason—for the mission," he said.

## Juan Torres—Cybersecurity and Hard Work

"I'm living the American Dream," said **Juan Torres**, NREL's ALD for Energy Systems Integration.

Born in León, Mexico, he emigrated with his family in 1971 as a 4-year-old to La Junta, a small town in southeast Colorado. Torres' parents were "essentially uneducated" but eventually found work at a pickle and relish canning factory to support their family. As the eldest of four children, "Everything was the first for me," he said. His parents enrolled him in school and, after learning some English, Torres said he soon had "lots of responsibilities as the family interpreter."

Although not formally educated, his parents and grandparents had deep convictions about education. His grandmother, who arrived earlier in the United States, believed that many of life's hardships could be overcome through study. He recalls her saying, *"Estudia y un dia te bendicira Dios y tus manos estaran llenas de dinero."* (Go to school and someday God will bless you, and your hands will overflow with money.)

That philosophy came naturally to Torres, who loved school—and he took as much math and science as he could. He benefited from the practical wisdom of his elders. "Where I came from, we didn't have a lot of money. So, I learned to understand how things worked out of necessity so I could fix them," he said. "If the car broke down, I'd be there with my dad to help. I developed that knack of understanding how things work." His father had apprenticed in electronics in Mexico, continuing to expand his knowledge by taking correspondence courses after arriving in the United States. He repaired TVs in his spare time. "I remember playing with vacuum tubes. I always wondered, 'How do these electronic things work?'"

Still, Torres said, "I didn't have much career guidance, and no inkling as to what an engineer was. I loved drawing, so I thought I would be an artist." While attending La Junta High School, he recalls opening an old physics textbook that described the various types of careers in science. "I read that electrical engineers designed stereos. At the time I thought, 'I like stereos,'" he laughed. Personal computers were just coming out, too, and Torres felt a pull toward the nascent field.

A deeper calling was developing simultaneously. "I grew up watching Star Wars and Star Trek and wondering what could be and what the future might look like," he said. Without realizing it, Torres always had a systems-thinking approach. "That's just the way I think. I didn't realize how much differently I saw the world than most people until others brought it to my attention. Over time, I've understood it better," he said. Eventually, he'd come to consider himself more of a systems engineer than an electrical engineer, but that realization was still in his future.

As the athletic young man prepared to graduate from high school (where he'd played tight end and defensive end for the La Junta Tigers football team, forward on the basketball team, and had run 200 and 400 meters in track) two things were clear: School was important—and so was work.

### An Architect Makes His Way to Electrical Engineering

Seeking employment comes naturally to Torres. From the age of 12, he worked in the cucumber fields in the summer with his uncle to make money. During high school summer break, he pulled 13-hour shifts, earning $3.35 an hour by stacking pallets of tomato juice and doing other manual work at the local canning factory.

The experience didn't sour him on the products. "I love tomato juice and tomato soup, and I actually acquired a taste for tomato juice in my beer during that time," he said. "Now, the pickled relish is another story—especially after what I heard about the kinds of things that fell into the relish grinder."

Although Torres had been accepted at the University of Colorado Boulder to study architecture, he instead followed a friend to the DeVry Institute in Phoenix to study electronics engineering technology. While there, he found a 35-hour-a-week job stocking shelves, watering plants, and loading bags of concrete at a home supply store.

After a year, he decided Phoenix was not for him and returned to La Junta, where he enrolled in a community college and took a position as a jack-of-all-trades at a local store. Among his duties, Torres was a salesclerk, stocked shelves, ran the fireworks stand in the summer, and sold Christmas trees in the winter. Eventually, he enrolled at the University of Southern Colorado (USC)–Pueblo, continuing the same applied engineering studies he had started in Phoenix.

He reconnected with his grade school classmate and future wife, Michelle, and they were married in 1988 while working on their undergraduate degrees.

> "I found even in designing circuits, I'd take an artistic approach to it. My design would work, but I wanted it to look good."
> —Juan Torres

His college experience wasn't typical. Every weekend, Torres drove 60 miles back to La Junta (from Pueblo) after classes ended on Friday and clocked a weekend of work in addition to working as a math tutor during the week. He wasn't slacking in school. Torres also carried a full load of courses in electronics engineering technology, which is an applied engineering program. "I took a lot of computer programming, microprocessor, and circuit design courses. I also essentially had enough credits for a math minor," he said, which later prepared him for graduate school.

There was one other momentous thing he undertook at that time.

"Had my parents become U.S. citizens before I turned 18, I would have automatically become a citizen. I began to realize my limited rights, especially when I found out I couldn't vote. Around my junior year of college, I started to see that many of the job openings from recruiters visiting USC required U.S. citizenship. It was then that I applied for citizenship," he said. He became an American citizen, complete with what he calls "all of the precious rights."

It also helped Torres that he had shown some vision in his studies. "When you start in school, your world is based on what you just studied. I thought I wanted to do circuit design," he said. Indeed, he had completed a senior independent study course, using what was new technology then—field-programmable gate arrays (FPGA). An FPGA is an integrated circuit that can be programmed in the field after manufacture. "I found even in designing circuits, I'd take an artistic approach to it. My design would work, but I wanted it to look good," he said. "I would apply an artist's eye to include balance in the design. My eye naturally will go toward those types of things. Does it make sense at a systems level—does it balance?" His FPGA research led to a second-place paper at a national engineering student competition as well as a job offer from Sandia National Laboratories in 1990.

## Leveraging Sandia as a Career Base

Sandia hired Torres as a lab technologist. "As I was exposed to more and more aspects of real-world engineering, I began to find other things, along with seeing the bigger picture," he said. His systems views were coming to the forefront. Over time, he supported the design of mobile command-and-control systems for the U.S. Air Force.

He realized that to advance in his career at Sandia, he needed a graduate degree. He decided to attend the University of New Mexico and earned a Master of Science degree in electrical engineering with a concentration in signal processing and communications. "For two years, I took two graduate courses per semester while working full time. It was a full load, but I was determined to get that degree," Torres said. "Eventually I got into Sandia's University Part-Time program and was able to work 20 hours per week while attending school full time. That was the fewest hours I'd ever worked while going to school." Graduate degree in hand, Torres was promoted to technical staff, a move that opened new doors in his career.

In 1993, Torres became the engineering liaison for design of a mobile command-and-control system at Peterson Air Force Base in Colorado Springs. He designed systems for national security missions. "I designed technologies and systems for novel computer network control in secure environments," he said. "The knowledge I gained on this program was foundational to work I did later in cyber vulnerability assessments for utilities and other critical infrastructure owners."

Torres was later accepted into a Ph.D. program in electrical engineering at Stanford University. He completed most of the coursework, but eventually withdrew from the program to spend more time with his children and pursue a career in management. "I had to make a choice to spend time doing homework or spend time with my kids; it was an easy decision at that time in my life," he said.

He still found time to be actively engaged with the Hispanic Leadership Outreach Committee at Sandia, serving as chair and volunteering as a computer workshop instructor for middle school students in at-risk schools and as a College Bowl coach for the nonprofit Hispanic Engineer National Achievement Awards Conference. During the latter part of his 27 years at Sandia, Torres became familiar with NREL, and he also spent about 6 years managing Sandia's renewable energy programs. He oversaw grid-based renewables programs that included wind, solar, and geothermal energy.

"We were joined at the hip with NREL. There were a lot of collaborations," Torres said. He visited NREL frequently and even toured the Energy Systems Integration Facility (ESIF) "when the paint was still wet. I was familiar with some of the things that went on here for grid modernization," he said. Eventually, he became the deputy to Sandia's vice president for Energy and Climate Programs.

Although Torres wasn't looking for a change, he was ready when the opportunity arose.

## Coming Home to Colorado in an Uncertain World

In June 2017, Torres began as NREL's new ALD for Energy Systems Integration. He was leading research teams that included renewable energy systems integration, cybersecurity, grid modernization, and energy systems security and resilience.

Torres was thrilled to return to his home state. "I had gotten to know quite a few people here, so coming to the lab was welcoming," he said.

The backdrop of his new job was a world that has undergone radical changes in the past decades. "I remember the Cold War and participating in war exercises through my assignment at Peterson Air Force Base. We've gone from watching for an attack from Soviet Union bombers and subs launching missiles from outside our continental border, to a time where now we don't know where the threat is," he said. "Threats can come from within our borders or from cyberspace. Our task is not just about hardening the perimeter, like the mentality in Cold War days. Now, the soft organs of our country are exposed physically and electronically."

As examples, Torres cited as areas of concern the nation's infrastructure with transmission lines running down the highway corridors, with pipelines out in the open, and wind and solar plants fully exposed. "As we evolve this energy infrastructure, I don't know that we've taken fully into account what the threat is or what it could become," he said. "Have we adequately thought of resiliency?" Another area of concern is climate. "Weather is changing. We have to be aware of how that is going to impact future energy infrastructure," he said.

> "How do we think of these systems and make them more resilient—to hackers, storms, physical attacks—from the beginning?"
>
> —Juan Torres

Another tricky space is that of new technologies that did not exist on the grid a few years ago but do now. "A lot of those technologies don't necessarily incorporate cybersecurity from the beginning," said Torres. "Our focus has been on low-cost, high-performance clean energy. Cybersecurity has been an afterthought. How do we think of these systems and make them more resilient—to hackers, storms, physical attacks—from the beginning?"

Yet, for all his awareness of problems, Torres said he's not a worrier. "I'm very practical," he said. Stress just makes him more focused. "I have a lot of passion around energy security. I developed a skill set that's unique, like a Reese's Peanut Butter Cup: two great flavors that taste great together, but you don't normally combine them. I have a background in security and renewables. You don't find many people who have an understanding and awareness of both."

The security and renewables worlds are very different, culturally and technically. "People work in each of those respective areas for very different reasons," Torres said. That was the case more than 20 years ago when he first began thinking about cybersecurity for the power grid. "At that time, we couldn't find anyone who understood the operation of the power grid and also understood cybersecurity. At utilities, the power engineers would not let the IT security folks touch their grid-control networks. So, we took power engineers and immersed them in cybersecurity. We ended up with something unique. It is very analogous to where we are with renewables today."

**Julie Baker.** *Photo by Dennis Schroeder, NREL 61238*

After all, Torres is living the American dream. "I was able to follow my passion, which included elements of all these things I thought I really wanted. Ultimately, what it came down to is that I like to create," he said. Don't be surprised, then, to see Torres blend artful and practical solutions to renewable energy security challenges.

## Julie Baker—Taking Root as NREL's COO

**Julie Baker's** Idaho roots go deep. NREL's Chief Operating Officer lived in that state since fifth grade and had spent her entire 27-year professional career at the Idaho National Laboratory (INL) before coming to Colorado.

"It was such a difficult decision, leaving INL" to become NREL's ALD for Facilities and Operations in May 2016, Baker said. But one aspect of the ALD job proved irresistible. "NREL's clean energy mission is really exciting, and the researchers are so passionate. Coming from nuclear energy, I find the clean energy space not so controversial. People love it," she said. INL, the nation's lead laboratory for nuclear energy research, is a place where, according to Baker, "Unfortunately, there's a lot of misconceptions and public concern about nuclear energy and risk."

And while she is thankful for the many opportunities she was given at INL—where she gained experience in both the operations and research side of the laboratory—Baker admitted there were some drawbacks. For one, its location on an 890-square-mile desert meant a one-way daily commute of more than an hour to a site where the buildings were at least 50 years old. By contrast, NREL is an easy commute from the family's home in Evergreen (which she likens to Idaho), and the laboratory has "beautiful new facilities," she said.

At NREL, Baker began by overseeing the laboratory's Environment, Safety, Health, and Quality Office; Laboratory Protection; Site Operations; and Information Technology Services. It was a wide-ranging responsibility, but she was enthusiastic because NREL is about half the size of the 4,000-employee INL. NREL is, she smiled, "a place that you can actually wrap your arms around, eventually."

### Experience in Research and Operations Leads to a Vision at NREL

It wasn't always a given that Baker would become an engineer. During high school, and for a time in college, she was undecided about her career options. "I thought that I was either going to be a doctor, a teacher, or an engineer," she said. She pursued medical-related activities for a while and then, "I came to the realization that I just couldn't avoid taking problems—the empathy stuff—home with me. That ruled out teaching and medicine."

Instead, she chose the "logical field" of engineering. At 20 years old, she started in INL's nuclear operations as a non-degreed operator in its chemical processing plant, running a uranium extraction process to recover reusable nuclear material. At night, she completed her technology degree at the University of Idaho. She gradually moved up at INL, first becoming an engineer, then a nuclear facility manager. "It was 24/7," she said. "Our shifts ran around the clock" to coincide with reactor and other fuel reprocessing. "Operations is kind of a hard life. Maybe being a doctor would have been easier," she laughed.

To broaden her knowledge, she took a leap and became deputy director for research at INL's Materials and Fuels Complex, going from operations to the research side. "I think that gives you the perspective of being a customer," she said. "You are learning researchers' feelings about why work isn't getting done and why things are breaking down. You hear people asking, 'Why are you so conservative in shutting down every time there's an issue?'"

Finally, she shifted to what she describes as the third part of the INL research-operations-business triumvirate, becoming director of business. "It was good to have to do the finance, documents, project management, and training. It wasn't as exciting as operations and research, but necessary—and it definitely made me more well-rounded," she said.

In 2010, she was chosen to be special assistant to INL Director John Grossenbacher, a retired Navy vice admiral. "The idea is to pull someone from the field, to give your opinions to the lab director and deputies, and to learn," she said. "You get that big picture about how an entire laboratory works—combining the primary missions, nuclear energy, homeland security, and energy and environment." Those two years were invaluable. And, as part of her assignment, she traveled to Washington, D.C., and several foreign countries, getting an overview and "learning the politics, structure, and governance of national laboratories," she said.

It was during her years at INL that Baker developed a basic philosophy. "I always say that operations and support should be like breathing," she said, something out of the spotlight. "Things like building maintenance shouldn't be first and foremost on the researchers' minds." Instead, she feels researchers should know the equipment is working, the ventilation is running, IT systems are up, and roadways are clear. "You try to make that stuff a little bit easier and more transparent," she said.

Based on experiences at INL, Baker developed the concept of a triangle with "mission" at the top and "safety" and "efficiency" comprising the base. It is, she said, something that resonated with Keller's intent to strengthen the science and engineering culture at NREL.

Baker was ready to apply her knowledge. "I had been through a whole culture change of research first at INL's Materials and Fuels Complex," she said. This mindset made her eager to approach this assignment at NREL because "I think I can make a difference."

To begin with, Baker focused on "the facility operations model," and she was determined to "ensure that we are allowing everybody to do things differently enough to meet their different facility needs: The ESIF is obviously different than the Flatirons Campus or the S&TF, which has numerous labs in it. Everybody does something different, so you want a model that works but that doesn't hinder what needs to be done," she said.

Her operations successes led to an advancement in December 2019 to deputy laboratory director for laboratory operations and chief operating officer. In promoting her, Keller cited Baker's other contributions, such as executive sponsor for the Women's Network and co-chair for NREL's Giving Campaign.


**Julie Baker welcomes guests and partners at an autonomous vehicle celebration at NREL in 2019.** *Photo by Dennis Schroeder, NREL 59372*

## Navigating the Uncharted Territory of a Pandemic

All of Baker's training, as well as her instincts, were tested in 2020 as NREL navigated uncharted waters.

On March 12, the NREL leadership team issued an order to evacuate hundreds of staff, calmly, from the Research Support Facility because of a suspected COVID-19 exposure there. This came just days after a similar case at one of NREL's labs. Before long, most of the laboratory—about 86% of NREL's nearly 3,000 staff—were teleworking productively in compliance with a statewide order for Coloradans to stay in place.

Then, for the first time in the laboratory's history, NREL operations staff brought the facilities to "idle state," with just a few long-running experiments continuing, while only basic maintenance was performed.

As part of NREL's newly formed Pandemic Response Team, Baker said she knew that leaders had to convey clearly and accurately what they were doing—so the leadership team began sending daily emails to the staff to keep them informed.

Baker helped focus on work-life integration while providing continuity. Under the new normal, Keller held his first virtual all-hands meeting from his home office. NREL even assembled a virtual Take Our Kids to Work Day in April.

"Our goal was to ensure that the NREL family, as we call ourselves, stayed connected," she said. Gradually, researchers were brought back to campus with adjustments for safety. "With diligence, we were able to reboot the labs. And, eventually, more than 500 staff were on campus at a given time, doing the work our mission prescribes," she said.

As Baker summed up in 2020, "We have a strategy and are proceeding with caution. Of course, things have changed. There are very few visitors and the majority of NREL staff continue to telecommute." Things changed again. And in April 2022, the leadership team invited NRELians to a series of events leadership called the Future of Work Orientation. This signaled a new era of hybrid work for many at NREL.

## Work-Life Integration Is Key

Even as she has worked intensely, Baker is clear about her personal boundaries: "My family is my priority," she said, adding that she's been fortunate to have sponsors and supervisors who helped her maintain a work-life balance. It was a major consideration in her decision to move.

Baker's family is happy that they don't have to abandon an Idaho lifestyle by relocating 600 miles to Colorado. "We get the same mountains, skiing, mountain biking, and scenery of Idaho," Baker said. And both she and her husband, John, are happy that their sons are already Colorado Rockies and Denver Broncos fans. "This was an ideal time to move, while they're young enough to be agile," she said.

Baker shares parenting duties with John, an electrician by trade, who ran the electrical apprenticeship program in southeast Idaho for the International Brotherhood of Electrical Workers. Together, they take family trips to attend their sons' baseball tournaments and other activities. "I love my work, and I love being a mom," Baker said. "There's not a lot of time to do anything else. So, I do whatever my kids do."

Baker is among a long line of those who have come to NREL, grown with the laboratory, and left their marks in the laboratory's evolution.

# Peter Green—Former Sprinter Stays at Head of Pack

Growing up in Jamaica, **Peter Green** dreamed of winning Olympic medals as a sprinter. Even before Usain Bolt's global domination, the island had an impressive track resume—and Green figured he'd be part of that tradition.

"The role models were there," said Green, NREL's deputy laboratory director for Science and Technology, recalling his vision from his upbringing in Port Antonio. "I was running times they ran at my age," he said. To teenaged Green, school seemed a bit less of a priority than competing in the 100-, 200-, and 400-meter dashes or playing soccer.

"I felt confident I could go to the Olympics—but my mom put an end to it," he smiled. Both she (a banker) and his father (a barrister who had grown up in poverty and worked hard to be educated in England) saw another direction for their son, a lad who had begun studying calculus as a young teen in a British-based education system. The family held strong professional aspirations—Green, a sister, and a brother eventually ended up at Ivy League schools. Track scholarships weren't needed.

But if Green couldn't become the Bolt of his generation, he did take something from sports and its discipline. Throughout his

Peter Green. *Photo by Dennis Schroeder, NREL 39622*

career, he could sit for extended stretches, solving problems, abetted in part by exercise. "I found I could work much longer hours and not get mentally fatigued," he said.

Yet that drive wasn't only gained at track meets. In Jamaica—a country that served as a global melting pot for the British Empire and, as a result, shaped Green's accent—students learned early on not to judge anyone's abilities merely by appearance or race. Rewards went to those who earned them—and the goal for successful people in his hometown was to leave the sleepy tourist spot to explore the world. "A lot of people who grew up in the Caribbean come away with a message like that. You work, and you work, and you work. And if you don't, success is not going to happen," he said.

Toward the end of high school, his world pivoted when the family vacationed in New York City. In the late 1970s, Jamaica was in turmoil, and Green's plans to hang out there with his girlfriend (now wife), Yvett, changed. "The future didn't look perfect. I had to rethink my priorities very, very carefully," he said.

At his mother's urging, Green applied to some American colleges. He had notions of becoming an economist—the equivalent of a track star for brainy Jamaican kids—and so began at New York's Hunter College with the idea of earning combined bachelor's and master's economics degrees. The tug of track didn't entirely disappear—and he even took a class in coaching track and field. "But my mom said, 'Don't do this, please.' I couldn't afford the time to study and practice. I had to do something all the way, or not do it. I was thinking about the future," he said.

The budding economist appeared to be on his way—except economics classes were often filled before he could register. Looking around for another option, he recalled a picture in his 1970s high school physics textbook depicting how atoms looked on a surface. "It always intrigued me," he said. That image became a signpost for Green on his journey.

## Hunting for a Career at Hunter

Because of the enrollment roadblocks, Green considered switching to another field. "I was already ahead in physics because of high school and did some soul-searching, asking myself 'Where do I think I can make a difference?'" He even pondered a transfer to an engineering or business school. The chair of the physics department at Hunter got wind of the plan and offered Green a research job as an incentive to stay in New York City.

Green had always been intrigued by labs—and there were subtle signs pointing him to that realm. Once, during a college visit, Green randomly ended up in a materials science lab, peering through an electron microscope. Images of atoms from his physics book flooded his mind. "I was fascinated and asked a bunch of questions," he said, which surprised the researcher there. Green was impressed by the setup, thinking, "Gee, I must be from a really poor place, because we can't afford an electron microscope in my high school."

Steered by curiosity, he accepted Hunter's offer, trotting off on a new path with an unexpected result. "That's where I learned that research can be fun," he said. After four years at Hunter, he finished his master's thesis, handing it to his adviser on a Friday; the man asked to speak with him the following Monday. As Green recalled, "He said, 'This is great. If I'd known what you could do, I'd have set the bar higher!'"

Green chose Cornell University for his doctoral work. "I knew people from the Caribbean who were there, so it seemed natural," he said. Plus, the prestigious school met the approval of Green's dad—"someone who didn't give a lot of compliments."

## A Young Scientist Finds Mentors Aplenty

In 1981, Green went to Exxon's facilities at Linden, New Jersey, on his first research job. There, he encountered Christopher Wronski, an intense man who had earned his Ph.D. in physics from Imperial College in London. Green was at first unaware of the man's stature but grew to appreciate this pioneer in photovoltaic cells. "He did very important work," Green said, including the discovery of the Staebler–Wronski effect, which explains light-induced changes in silicon.

The scientist had a profound effect on Green, too. "It was one of the most important decisions I made when I took that job. I learned how to think about a problem you'd never seen before. And I learned how to look at research results and put together a hypothesis to understand what's going on and design experiments around that," he said.

Wronski would tell Green what researchers wanted to know, then let him go off to figure out how to find answers. "He'd say, 'If you have difficulty, you can talk to so-and-so.' He left everything in my hands. That's when I began to understand the collaborative process and how much you can learn by talking to people," Green said.

One surprise came when the mentor informed the young scientist that he was expected to make a presentation to the staff—a pressure-filled assignment because Green only had a few days to assemble it. "I put it together in a short amount of time. He and colleagues were extremely complimentary," Green said.

The other stellar mentor was at Cornell, where Green connected with Professor Edward Kramer, whose contributions to materials science are called "legendary." After finding the adviser, Green began digging deeper into materials science literature. "I saw that people were looking at how these things are organized—and spent their careers doing that. I said, 'Son of a gun. There are applications to physics and to all material sciences." At times, Green would be working late in a lab and Kramer would show up, interested in seeing what the novice was doing. "When I got excited, I could always find him," Green said.

The fact that all of this came from the spark of a textbook picture amuses Green—because only later did he learn that this picture of atoms was an artifact. "I talked to British friends later who used the same textbook, and none of them recalled the image," he said.

Kramer's inspiration led him to take his next step after getting his materials science and engineering Ph.D. in 1985. "I had more and more nagging questions," he said, about a topic that seemed to elude his complete understanding. Those understanding gaps led him to Sandia National Laboratories as a postdoctoral fellow in physical properties of polymers, ion solid interactions, and defect physics. It was the start of a 10-year stint there—as well as his return to an old passion when he became head of that laboratory's track club. In that capacity, he recruited a distance runner named Dan Arvizu. And it was around that time that Green learned about the Solar Energy Research Institute.

## Nagging Questions Lead to a Quest

While "nagging questions" were what led Green to Sandia National Laboratories from Cornell in upstate New York in 1985, there was another reason to move. "I wanted to see the West," he said.

Additionally, he was aware of groundbreaking work at Sandia in materials science. Once there, he learned about Angelo Mascarenhas and others at the fledgling SERI. He soon became familiar with SERI when some Sandia colleagues relocated to the Colorado laboratory.

But Green was in no hurry to move.

For one thing, the 25-year-old postdoctoral researcher was enjoying his role as head of Sandia's track club, a legacy from his high school love of the sport. It was in that capacity that he tracked down Arvizu—the future NREL director could run distances. By this point, heading on his parents' preferred track—that of a career—Green was no longer subject to his mother's reluctance about his pursuit of running. In fact, he continued competitively running master's races into his mid-40s, and his mom "didn't care at all," he said. His mother knew he'd found his passion.

Green's quest to understand materials expanded, and he moved up the ranks at Sandia, eventually becoming manager of glass and electronic ceramics research. Still, there were nagging, unanswered questions about this world of matter. He sought a fresh start. And, in 1996, he headed off to Austin, Texas, to become an associate professor of chemical engineering and, subsequently, the B.F. Goodrich professor of materials engineering at the University of Texas.

According to Green, "My research direction was driven by this vexing sense that I didn't understand" many complex issues in the newly emerging area of nanomaterials. "It drove me in a new direction, and that was good. I published a lot of papers." Yet, even for him, some of the academic conversation was so deep in vastly different areas, "I couldn't get [everything], but I became fascinated by the topic."

Coincidently, it was in Austin that he became a fan of college football. That love would fully blossom on his next stop, when he went to the University of Michigan in 2005 as chair of the materials science and engineering department and the Gorguze professor of engineering. It is perhaps fitting that the man who endowed that chair, Vince Gorguze, once said, "You've got to work hard and be lucky—and the harder you work, the luckier you get." That saying rings true for Green and sums up his style.

Not only does it reflect the work ethic he grew up with, but it adds the traits acquired from several of his mentors. For one in particular, his Cornell adviser, Edward Kramer, the equation was proven. "He understood that if you invest a lot of time and have a lot of information, the odds of succeeding and being creative are very much higher," Green said. Kramer was "always prepared," a quality Green took to heart. "It's not just because someone's smart that he or she always performs well. If you prepare yourself well, things will be fine," he said. In Green's opinion, such a lesson is especially applicable to the sciences. "If you have an interest in a topic, and enjoy it, invest sufficient time, set reasonable goals, and measure how you're performing—you'll have no reason for regrets," he said.

It was at Michigan that such a philosophy found a concrete expression.

## Michigan Teamwork Creates Momentum for a DOE Center

While Green's life was always busy at Michigan—where he was a professor of chemical engineering, macromolecular science and engineering, and applied physics—it became even busier when colleagues urged him to lead a group applying for one of the new DOE Energy Frontier Research Centers (EFRCs).

"I was not so sure I wanted to do it because I already had a job as department head," he said. Further, he knew from experience that if one leads a big, time-consuming proposal and it fails, there can be plenty of finger-pointing. "My colleagues didn't take 'no' for an answer," he chuckled. And although he hadn't done any investigations specifically in the field of energy, he did pride himself in having a deep knowledge of the field of materials science and engineering.

Green learned a great deal about scientific leadership from volunteering and networking in organizations. He was a member of the National Academy of Sciences committees that prepared studies about intellectual challenges and societal benefits of condensed matter physics. And, in 2006, he became president of the Materials Research Society.

For the EFRC, "It was apparent to me that many technical problems [in energy] have a base in materials science," he said. So, even with a lack of personal experience working specifically on energy problems, he would be able to work with colleagues who had complementary expertise.

Eventually, Green said, they submitted a highly collaborative EFRC proposal, with very creative ideas. "We learned a great deal from each other during this process," he said. Fortunately, their proposal won. And from 2009 to 2014, DOE spent $20 million on the Center for Solar and Thermal Energy Conversion. At the center, which was based on fundamental scientific discoveries, Green said, "We designed and synthesized new materials for high-efficiency photovoltaic and thermoelectric devices. We wrote many provisional patents and published more than 250 scientific papers in the very best journals."

Another opportunity presented itself. Green, who knew about SERI and NREL, was intrigued by the chance to finally come to the laboratory.

## A Green Vision in the Race for Renewable Energy Solutions

When Green began at NREL on Aug. 1, 2016, he had a clear mandate: Keller declared he was responsible for NREL's science goals, strengthening the laboratory's core capabilities and enhancing NREL's research portfolio.

Green was aware of the role NREL had played through the years in making scientific discoveries that impacted renewable energy technologies, working with industry, and technology commercialization.

"If you go back to the early stages of the lab, with its roots in solar research, it wasn't clear where that would eventually lead. Later, wind energy and bioenergy were included in the activities of the lab," he said. Over time, strong programs emerged, having global impact. However, things have evolved. "We're competing seriously with the rest of the globe in different areas of renewable energy," he said. "We're doing well, but the competition is strong. Lots of universities now have their own energy institutes."

As Green sees it, the future of the laboratory will depend on its ability to develop partnerships with industry, academia, and other agencies. "There is no shortage of problems to work on. That part's not tricky. What is tricky is how creative we are in identifying impactful problems. How do we pick the right problems so that we can convince people to fund our activities?" Green said.


Luxembourg Ambassador Nicole Bintner-Bakshian (second from left) stands with (from left) Derek Passarelli, DOE Golden Field Office director; Jeffrey Weltzin, Honorary Consul of Luxembourg; Martin Keller; Juan Torres; and Peter Green outside the ESIF in 2021. *Photo by Werner Slocum, NREL 66172*

Based on his experience, much of Green's approach comes down to the following challenges: "How can we make it so that people have time available to think beyond their current projects? How do you ensure that you create an environment where people want to win and give you everything they can?" he said.

He convened people who normally don't collaborate to learn from each other about important topics, such as deep decarbonization, water, or materials science. The approach paid off. In 2020, the laboratory harvested a bumper crop of R&D 100 Awards.

"The fact that we did so well reflected significant and strategic efforts of the NREL R&D 100 selection committee, together with excellent nominations by the center directors, the principal investigators, and the folks who wrote the nominations collaboratively," Green said in 2020. "After we completed this year's selection and nomination process, I was cautiously optimistic that we would have an outstanding outcome, considering the level of competition."

Green said the laboratory was elated with the results. "That NREL placed in the top three among all national laboratories was even more rewarding," he said—a way to finish in the medal race.

## Ex-College Oarsman Bill Farris Understands That We're All in the Same Boat

Growing up during the late 1960s in sleepy Seattle, **Bill Farris** got hooked on nature.

"I loved the outdoors," said the ALD for Innovation, Partnering, and Outreach. "I was an Eagle Scout and got the taste for being outside early on."

For instance, he has climbed all the major peaks in the Pacific Northwest, attempting the 14,410-foot Mount Rainer five times, summiting twice. Once, when 15-year-old Farris was part of a special high-adventure scouting program, his group reached about

12,000 feet above sea level when they were blasted by a freak August snowstorm.

"We were well prepared with tons of gear and pro-quality leaders," he said. "So, we hunkered down for three days. I remember tearing up a Star Wars book into quarters so that all four of us could read it—out of order." Farris' love of the outdoors and snow, in particular, led to a continued love of the mountains and skiing.

Farris also was influenced by the environmental movement of the 1970s. Because of that, even though his father was a Boeing aircraft engineer, "I never saw myself as an engineer like my father."

Still, science fascinated him. Farris' mother was a teacher, and as a boy, he was attracted to what is now known as STEM (science, technology, engineering, and math) classes. He also caught the photography bug from a middle school teacher who had convinced the school district to build a massive school darkroom. Farris and his father even assembled one in the basement of their house—and Farris remains an avid photographer, documenting Colorado scenery.

When Farris enrolled at the University of Washington (UW), he decided to study Earth science, intrigued as much by geochemistry as being among rock formations. During that time, there was another legacy interest that called to him: competitive rowing. Farris' grandfather had won a local crew race on Seattle's Green Lake as a young man, and he grew up hearing those tales.

"When it was time for college, I thought, 'Let me see if I can walk on,'" he said. No small feat, because UW is a rowing powerhouse—and Farris, a high school swimmer, had never rowed before. "It turns out, I was just big enough, at 6-feet-1½-inches and 185 pounds, to be the smallest guy on the freshman heavyweight 'eight' [eight-man boat]. The stroke [lead rower] was a giant at 6-feet-7-inches and 250 pounds," said Farris. Still, he made the team. "I could pull hard for my weight and was able to learn how to row faster than some of the others learned."

Farris and the other crew members went out every day at 5:30 a.m., rowing in the rain and chill of Lake Washington. The usual route was from the boathouse through the Montlake cut, Portage Bay, Lake Union, and out to the Ballard Locks. "As the city was waking up each day, we were out there in a cotton sweatshirt, a pair of shorts, rowing in 40 degrees. That was just what we did. It's not like we were ever that cold," he said. Along with about four other freshman eights, this practice was part of the daily routine. "You never felt you were suffering," said Farris. "You were part of the big team."

However, during the next couple of years, the bigger athletes caught on and could overpower him. Farris faced a choice at a university where coaches expected athletes to make rowing their top priority. In the end, he decided to lay down his oars. "I was there for an education. I wasn't on scholarship," Farris said. No regrets, he said. "I made the right play." Still, the lessons learned lasted a lifetime.

Unfortunately, when he graduated with his undergraduate degree in geology, it was a bad time to find employment in Earth sciences. Instead, Farris continued at UW graduate school in radiological science.

Farris met his wife, Jill, at UW while in graduate school, and in 2022 they have two children: a daughter, Kristin, 24, and a son, Stuart, 27, who are both Colorado School of Mines graduates. Also, while at grad school, he landed an internship in 1985 at PNNL and soon learned that he enjoyed working there. In 1987, he joined a PNNL team investigating environmental impacts of nuclear materials. During that time, they examined several high-level radioactive catastrophes, including nuclear reactor meltdowns in Chernobyl, Ukraine, and at Three Mile Island in Pennsylvania.

Farris was part of a team doing mathematical environmental impact calculations on early computers. The group tried to predict

**Bill and Jill Farris enjoy a bike ride in East Vail.** *Photo by Bill Farris, NREL* what actions to take that would be safe in the long term. If you do such-and-such with radioactive substances, given the long half-life of materials, how will this be a problem 20,000 years in the future? Tricky business, to say the least.

Farris began to pivot in his career. “The calculations were super-academic, and you were never going to be around to know if you were right or wrong. I thought maybe I could work on something where you see the beginning and the end—and see what impact it had,” he said.

By changing his trajectory, Farris said he “got a bit more on the business side of things, which got me out of the academic calculations.” This new path would allow him to see the tangible enhancements from one energy technology generation to the next, and so on. This track fit him.

That background would pay off in an unexpected way. In 2008, the Department of Energy decided to compete the management contract of NREL. Farris—who was responsible for PNNL’s Commercialization, Economic Development, Business and Competitive Intelligence, and Commercial Relationships offices—was tapped by Battelle management to help write the commercialization portion of the Alliance proposal. Battelle and the Midwest Research Institute (MRI) had formed the Alliance to submit an NREL bid.

## Rowing to NREL

“It wasn’t a foregone conclusion that I’d come to NREL if we won,” Farris said. After all, he’d spent nearly 20 years at PNNL, located about a three hours’ drive east of his hometown. However, the Alliance proposal did win—in part, because of the heavy emphasis on commercialization, which DOE had asked for.

However, Farris said that there were some unproven ideas that seemed possible. Intrigued by the challenge, he agreed to come to NREL with the new leadership team in August 2008.

Because of his STEM background, Farris was always drawn to certain questions: What makes something go? What innovation led to the next innovation that led to the next innovation?

“That’s how civilization advances,” he said. The question is simple: “How can I make an improvement? That’s what our NREL researchers do today.”

Still, there is a familiar critical refrain questioning why the national laboratories aren’t better at spinning off startups. At NREL, Farris and his team set out to change that narrative.

Across an array of areas, Farris and his team began building. “With the technology incubation model, we’ve landed on something that’s unique, maybe to NREL. We take the best of what we have to offer: Find the entrepreneurial talent outside the labs and couple them to what we are doing. Our magic recipe is that mix of entrepreneurial talent, largely from outside of NREL, and access to state-of-the-art lab capabilities and passionate researchers. That’s what we bring. Then we add a corporate sponsor, like Wells Fargo or Shell,” he said. Recently, DOE’s Advanced Manufacturing Office has supported the new West Gate incubation program.

“That is a much better way to do technology-rich, new business economic development innovation programs,” Farris said. “We promised a bunch of stuff and chipped away at it. It has made a difference over 13 years.”

A prime example, the Wells Fargo Innovation Incubator ($IN^2$) is a clean technology incubation program funded by the Wells Fargo Foundation and co-administered by NREL. So far, $IN^2$ has tallied 56 tech startups, and the program is only about halfway complete. Those companies have recorded some $1.1 billion in follow-on funding. “That wouldn’t have happened without NREL,” he said. Likewise, NREL formed the Shell GameChanger Accelerator Powered by NREL (GCxN), which partners early-stage cleantech companies with the resources, expertise, and facilities available at NREL and Shell.

As written in the proposal, the Alliance also launched the Colorado Center for Renewable Energy Economic Development (CREED) as a joint effort between NREL, the state of Colorado, and affiliated stakeholders to provide opportunities for cleantech economic development in Colorado. NREL’s commitment to economic development will now hit the big time with the establishment of the Global Energy Park, in concert with DOE and the state of Colorado.

Also, since the Alliance took over, NREL projects with external partners have totaled more than $1 billion in research project funding—and that number is growing. “That’s a big number given NREL’s size,” Farris said. The partner list ranges from startup companies to the city of Los Angeles.

Farris is especially proud of the effort that led to the Los Angeles 100% Renewable Energy Study (LA100), a wide-ranging project to convert Los Angeles to using only renewable energy by 2045—or earlier. “Looking at the LA100 project, we knew it was high risk. It grew out of business development, where our people were doing what they should have been doing: casual conversations to learn about their challenge, then following up with the right people.”


Bill Farris speaks at the 2019 Partner Forum at NREL. *Photo by Dennis Schroeder, NREL 58821*

But it was no accident that this project unfolded. Backed by Laboratory Director Keller, who said, "Bill has shown incredible leadership and vision," Farris and his team went forward. "Had we not been looking for a high-impact project, with our skill set to solve those problems, it wouldn't have happened," Farris said. He argued that perhaps only NREL—with its energy science and technology, analysis, and high-performance computing capabilities—could have pulled off the first-of-a-kind project with a partner such as Los Angeles.

"It's the reference project that proves what's possible," he said. "We set out a goal to enable the energy transition. Now others look to it to replicate it at various scales."

That is the hallmark of his target for partnerships and innovations. "We want to do things that have never been done before," said Farris. "That's how we think about a project. We're not trying to find another million-dollar project just to add another million dollars." As a result of its novel approach, NREL has become "the poster child" for the DOE national laboratories in commercialization and partnerships.

As he said, this path is "why I think I'm a pretty good fit for NREL. We think about those things that build on the basic research," which provides the foundation and starting point. For example, NREL first looks at creating a perovskite cell that's stable and has longevity. "Now, what are all the other pieces that have to come together for that technology to be successful in the marketplace? We are thinking about those things in addition to the technology. That's so NREL."

As Farris likes to say, this type of innovation as well as commercialization is part of NREL's DNA. "The impact is really what drives us. NREL started in the late 1970s. There was no viable photovoltaic industry. Zero. No commercial wind industry. No hybrid-electric or electric vehicles in the marketplace. In the 40-plus-year lifespan, our fingerprints are in all those energy advances. The things we are working on in our research labs and analysis groups are going to underpin market impacts that we will see 5, 10, and 20 years in the future. Every NRELian should be excited about our ability to change the world," he said.

All of this, in a way, seems to come back to the tippy wooden boats and those frigid mornings on Lake Washington.

"There's a common vision to go in a same direction," he said. "You can use the metaphor of rowing: 'Keep your head in the boat.' You have to be synchronized or you're not going to make progress in any given race." And finally, the most obvious: teamwork. "You can't win an eight-person race without all eight—nine, including the coxswain—pulling together. You can't do it all yourself," he said.

Of course, these are just a handful of the current and past leaders at the laboratory. But in their career arcs a pattern emerges: This collection of enthusiasts continues to reinvent the spirit of NREL.

**Bill Tumas.** *Photo by Dennis Schroeder, NREL 39718*

## Bill Tumas: A Scientist and Sports Enthusiast Who Thrills at Discoveries

Growing up in Pennsylvania and upstate New York, **Bill Tumas** toyed with the idea of playing professional baseball then competitive skiing—first racing, then freestyle.

Two things happened to change that trajectory for the future NREL associate laboratory director for Materials, Chemical, and Computational Sciences. Tumas said that he realized "I couldn't be a pro in either." And then, his lifelong interest in science surged after his junior year in high school. "I spent that summer at Ithaca College doing chemistry research and fell in love with chemistry and the academic lifestyle."

So strong was that chemical bond that, upon graduation, he turned down offers from the California Institute of Technology (Caltech) and MIT, opting instead for undergraduate research at Ithaca College in 1976. No longer focused on baseball diamonds or ski slopes, instead, Tumas said, "From day one of my freshman year, I spent all my time in the research lab." He developed an interest in physical organic chemistry and understanding reaction mechanisms.

His interest in understanding the effect of solvents on chemical reactions led him to doctoral research at Stanford University from 1980 to 1985, where he studied the dynamics and mechanisms of gas phase ions (i.e., chemical processes without solvents at all) using high-power infrared lasers.

He took a course in organometallic chemistry—still an emerging field then—and went on to pursue his fascination for transition metals as a National Institutes of Health postdoc and Chaim Weizmann fellow at Caltech. At Caltech, he was mentored by Bob Grubbs, who went on to win the 2005 Nobel Prize in Chemistry.

"In addition to learning how to synthesize organometallic compounds, Bob, who sadly passed away in December, taught me how to rock climb," Tumas recalled in 2022. "Most importantly, he also reinforced in me the work-hard and play-hard mentality along with work-life balance."

### Finding a Clean Groove at DuPont

Since his undergraduate days, he had really only considered an academic career, but once again, his trajectory shifted. "After six of my 11 academic interviews and several really good job offers, I realized I actually did not want a university job," Tumas explained. "But I hadn't applied anywhere else."

He contacted a few companies and then landed in 1987 at DuPont Central Research Department in Wilmington, Delaware. "It was the Bell Labs of chemistry back then," he said, referring to the research giant. This began what has become a careerlong interest in cleaning up the environment. To this day, he likes to say, "We all know that it's much easier to not create problems in the first place than to have to fix them later."

At DuPont, he was a project leader in catalysis and the Central Registration Depository (CRD) representative on the corporate environmental technology panel. His research pivoted to assessing and developing waste treatment technologies, examining dozens of DuPont waste streams in his lab. He helped write an International Union of Pure and Applied Chemistry (IUPAC) standard on treatment using advanced oxidation processes. These use potent oxidants, such as photochemically generated hydroxyl radicals, that can destroy dilute contaminants in wastewater.

Tumas seemed on track for upward mobility at the internationally renowned site. Then, one day, he happened to ask his 1- and 2-year-old daughters what they wanted to do that weekend. "They said, 'Go to the mall.' Hearing that, I said, 'That's it. We're outta here.' We headed to the mountains of northern New Mexico and Los Alamos National Lab."


Bill Tumas speaks to researchers and guests on Aug.13, 2019, at the dedication of the bioreactor in the hydrogen facility at the Energy Systems Integration Facility.
*Photo by Dennis Schroeder, NREL 58731*

## Building a Career at Los Alamos

His interest in catalysis and waste treatment led to an exploration of green chemistry, the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances.

"I was one of the founding board members the Green Chemistry Institute, which promotes the development of non-hazardous chemical processes and Earth-friendly products that will prevent pollution," Tumas said. That institute became part of the American Chemical Society and remains vibrant in 2022. He also chaired the Green Chemistry Gordon Research Conference in its early days.

Spotting his expertise, Los Alamos management asked him to run the hydrogen program, and ultimately he became the applied energy programs director. At Los Alamos, Tumas said, "I really enjoyed recruiting and working with highly talented scientists and engineers, from students and postdocs to senior level staff."

During those 17 years, Tumas discovered another trait. "I found that I liked brainstorming and forming diverse teams to tackle big challenges," he said. One such effort led to the landing of a $30 million, five-year Chemical Hydrogen Storage Center.

As an aside, Tumas was actively engaged with the Army Chemistry chemical demilitarization program helping destroy the U.S. chemical weapon stockpile, first as a member of the National Academy Stockpile Committee, then as a consultant.

He also started walking the halls of the Department of Energy (DOE) and visiting and building collaborations with other national laboratories—a practice he still enjoys. "To date I have helped build collaborative projects with 10 different national labs," he said in 2022.

## Growing With NREL

One of those national laboratories that piqued his interest was NREL. Retired ALD Ray Stults recruited Tumas as Chemical and Materials Science Center director in 2009. "As my daughters were graduating from high school, I gladly said yes," he said.

That bond was immediate. "NREL has been nothing but a blast since I got here," he laughed.

Although Tumas said he knew a number of the senior NREL scientists already due to their reputations, he was "so pleasantly glad to see how many awesome early-career scientists were in the center, many of whom are now leaders in their field only a decade later."

He also had to stretch his knowledge to fit his new role.

Armed with a background in photochemistry but only an elementary experience in materials science, Tumas said he "found joy talking with folks as I tried to glean at least the rudiments of photovoltaics and related science and challenges." Slowly, he transformed. "I started to have to 'speak materials science,' although I still think much better in the chemical bond space."

His impact has been widespread. "Bill has brought a keen understanding of basic science to an array of critical NREL laboratory objectives. His ability to envision the next big steps and anticipate energy challenges has helped keep NREL at the cutting edge of our mission space," NREL Director Martin Keller said.

An early success was due to Tumas's competitive drive and experience. "I learned how to read budget requests at Los Alamos," he said. And Tumas spotted a call for an R&D center for solar research collaboration between the United States and India. "We were off to the races," he said. Along with NREL fellow Dave Ginley, solar pioneer Larry (Kaz) Kazmerski, and a team of more than 30 institutions from India and the United States, he helped launch the Solar Energy Research Institute for India and the United States (SERIIUS) in 2012. During its five-year run, SERIIUS pursued disruptive technologies through foundational research in sustainable photovoltaics (PV) and multiscale concentrating solar power (CSP).

About the same time, Tumas took over leadership of the Center for Inverse Design, a DOE Energy Frontier Research Center (EFRC), in 2011. The center addressed a crucial scientific grand challenge by utilizing a new approach to material science. "It was like drinking from a fire hose on first-principle theories, doping concepts, and materials synthesis," he said. In 2014, working with NREL scientists and a new team of external collaborators, he led the Center for Next Generation Materials Design.

"I am proud of how many young folks who were postdocs came through these EFRCs and are making major contributions at NREL," he said. "Many of the capabilities we built together for materials discovery form the basis of some key science projects at NREL today."

When he became ALD in 2013, Tumas set out to help understand and help continue NREL's PV R&D impact, relevance, and prominence, impacts that predated his arrival by decades. "We had some serious bumps in the road as we had to sunset some programs, build programs in new areas, and pivot some of our research and capabilities to other areas," Tumas said. Through the insight and hard work of many, NREL remains a leader in PV research—vital for a planet that will need many terawatts of solar energy. PV has quickly evolved from a focus on cost, efficiency, and reliability to include important concepts such as bankability, scalability, and large-scale manufacturing, circularity, and sustainability.

"It's great to watch senior people bring their skills to the game and a cadre of young scientists and engineers join in," he said, mentioning Nancy Haegel, Sarah Kurtz, Teresa Barnes, Bryan Pivovar, Pete Sheldon, **Tony Burrell**, and Jao van de Lagemaat, among others.

As NREL's point of contact for Basic Energy Science, he continues to work with leading scientists to ensure delivery on NREL's high-profile fundamental science portfolio and develop new projects in areas aligned with NREL's strategy and mission.

## The Future Looks Even Brighter

Tumas has actively sought out ways to help young researchers build their careers. It is this cadre that he envisions will ensure our energy system transformation.

The veteran scientist said that he is really excited about NREL's role in fueling the future. He believes that hydrogen and coupling energy sectors through electrons to molecules will be central to our energy transformation, along with massive amounts of clean solar energy, and that new materials and chemistry will be gateways to energy storage. And last, but not least, will be an emphasis on creating a circular economy for energy materials, he said.

Tumas knows that while reducing environmental hazards is always important, there are increasing concerns about the world's stewardship of material resources as a whole. As he said, the era of "take, make, and dispose" to create economies is rapidly ending. "As we transform our energy system, we need to know how to be sure we include the concept of circularity early on. All of us have to ask probing questions from the beginning. For battery manufacturing, for example, we must ask just how much cobalt in the world will we need? Where will it come from, and how will it impact the environment?"

"We need a system with circularity—one that can reuse materials instead of simply dumping them," he said. "As we convert, store, and use terawatts of clean renewable energy," he said, "we must ensure that we do not create future waste problems and must incorporate sustainability into our energy transformation."

His thinking helped inform a key part of NREL's 10-year vision for research, which includes the "Circular Economy for Energy Materials" and "Electrons to Molecules" as two of the three pillars. This effort, begun in 2018, also stands with "Integrated Energy Pathways" (focused on grid modernization and renewable power generation). "We need to be much better at interconverting renewable, electrical, chemical, and thermal energy," Tumas said, "and that is an important part of our research agenda."

Clearly, creating a circular economy isn't easy. "There are a number of scientific and technical barriers," he said. "But there are already efforts in this direction. Many support recycling items ranging from polymers to lithium batteries and silicon solar cells." Instilling circularity into energy systems cannot only avoid large amounts of future waste, but also keep a large part of the carbon footprint within the system and help ameliorate projected issues with the availability of many materials and critical elements, he said.

Tumas said that a prime example can be found in NREL's capabilities and expertise to upgrade and recycle polymer waste. This will be critical not only for bulk polymers and mitigating further ocean pollution, but also for energy technologies, as polymers are in almost all of energy technologies from the back sheets of photovoltaics to the membranes in fuel cells and from electrolyzers to battery systems.

As part of the efforts, NREL is a partner in the DOE's ReCell Center based at Argonne National Laboratory. This collaboration has the most complete suite of battery life-cycle R&D facilities in the nation. But Tumas believes that's only one step.

"We'll need adaptive materials for energy systems. At NREL, we're trying to learn from natural systems in order to develop energy technologies that are cheaper, lighter-weight, more flexible, more resilient, and more adaptable to their environment," he said.

This discovering mindset in Tumas' view will keep NREL research moving ahead with the design and development of new materials, innovative concepts, and next-generation technologies for sustainable energy conversion, storage, and utilization. He is delighted that his directorate is the steward of NREL's high-performance computing, as this mission will need to draw up new tools, data, analytics, and science for discovery, understanding, and lifetime prediction of new, recyclable or upcycled materials, components, processes, and systems.

Tumas, who for years was an enthusiastic skier, has been forced recently to move on from the sport following two severe crashes, the latter one requiring multiple surgeries on his leg. His first crash did introduce him to Mitzy, now his wife, with whom he still seeks adventure, including a renewed love for sailing. Keller, who skied with Tumas in the past, noted that "Bill is a force of nature in the outdoors, and whether skiing or sailing, always pushes himself to the limits."

Whether on water or in the laboratory, Bill Tumas wants to keep being a force of nature.

## Fellows Also Help Lead NREL

**Joe Berry** and **Ingrid Repins**, who became NREL senior research fellows in 2020, are comfortable with metaphors to describe their lives.

Berry is an athlete/scientist who employs sports metaphors. For example, he described his NREL materials science team's research into perovskites—an increasingly promising material for solar cells—as needing a "solid double play" in terms of proving the efficient material's stability and scalability. He also invoked another baseball metaphor to explain one challenge to figuring out the material's stability: Researchers "cover all the bases technically and scientifically to try to understand how to project and predict where you'll be in 30 years" with a potential perovskite module.

Growing up in Indiana, Berry played both baseball and soccer in high school, and he continued his run on the soccer pitch through college. After finally giving up softball as an adult—fearing that it was the perfect activity for an injury—he nonetheless continues to play center midfielder in a Boulder, Colorado, over-40 men's soccer league.

But as a boy, Berry did not expect to grow up to be a jock. His parents were both professors at Goshen College in Goshen, Indiana. "Science and math were high on my list," he said, in part because he has mild dyslexia. "Spelling was not a thing for me. I can look at words that have a red squiggly line under them, but I can't see anything wrong with them," he laughed.

His father, who taught political science and Latin American history, is an African American who grew up in the segregated South. "He might have been a scientist, but he never had the opportunity given things involved." His mother, of Swiss descent, taught elementary education. Even in elementary school, Joe was exposed to computer programming. "I think my dad lived vicariously through me."

Going to their college in Goshen made sense for Joe Berry; the price was right. And it opened doors for the physics major. Because of his laboratory expertise, and through a collaboration with nearby Notre Dame, he took part in a study of zinc selenide activated with tellurium in 1995. He also co-authored a paper with NREL emeritus Dick Ahrenkiel and Fellow Mowafak Al-Jassim, among others. Interested in further studies of semiconductors and magnetism, he chose Penn State for graduate school.

"I learned a lot there and did cool things," he said, and—to borrow another baseball term—he was a heavy hitter in publishing, establishing a strong track record. That's why, when he went to

**Joe Berry (far right), along with another Senior Research Fellow, David Ginley (left) and Graduate Research Assistant Ke Yi, view a pulse laser that deposits material on a solar cell at NREL's Pulse Laser Deposition Laboratory.** *Photo by Dennis Schroeder, NREL 17602*

defend his thesis on Sept. 12, 2001, it was a foregone conclusion that he would get a Ph.D. "It was a little surreal," he admitted, finishing up his dissertation during the 9/11 attack. Fortunately, he and his wife, Karin, whom he met at Penn State, had chosen to drive to Colorado to begin their postdoctoral positions. "So, my postdoc at the National Institute of Standards and Technology (NIST) was only delayed a day or two," he said.

Berry's day job was specializing in development and application of narrow-band spectroscopies to the studies of III-V quantum dots. But soon, the former high school catcher was playing on the NIST softball team. While they won a league championship—Berry having switched to the more skilled second base—rather than catcher—in softball, he eventually hung up his mitt. "At some stage, that was a sport specifically set up to create injuries," he explained. "Where else do you sit around, have a beer, twist, and then run as fast as you can?"

NREL noticed this rising star. In 2006, he joined NREL with a background in semiconductors. Oxide-based semiconductors were a target because of their wide band gap and applications for PV. Eventually, Berry transitioned to looking into details of how to make an interface with two materials. He became intrigued with combining "something that's a traditional inorganic material with something that's soft and squishy, like an organic."

## Perovskites Become a Passion

Enter perovskites. Berry explained, "They're kind of hybrid materials. They have this organic component but also are much more like traditional semiconductors." By late 2013, he was engaged in a work-for-others contract with an industrial partner. Around that time, Kai Zhu and Joey Luther had gotten an LDRD project funded to spin off some perovskite-related efforts. The three then teamed up to submit a research proposal to DOE and the National Center for Photovoltaics. Their proposal was accepted. "We've been working on it ever since," Berry beamed.

He and others benefited from the efforts of Ingrid Repins, who explored copper zinc tin sulfide (CZTS) as an absorber for photovoltaics and learned that the material had difficulties for PV technology. The path forward was not obvious, although Berry was drawn to the unique features of hybrids such as perovskites.

"Our goal was to figure out if these materials have fundamental problems as PV absorbers. You need high performance if you want to be high performance at the module level. Something showing 10% efficiency isn't going to matter if that's as high as you could go. You need to get to something that's more like 20%," he said. The math of the marketplace was unforgiving. The three tasks were to improve efficiency of the material, make it highly scalable ("easy to say, not easy to do," he added), and ensure stability. Because perovskite cells are easy to make, they degrade quickly from humidity and heat.

"It wasn't clear whether it was going to be two years and done," he said. In those days, it seemed possible there could be problems that could not be solved. If so, they'd have to move on. But that's not what happened. While they have not hit a homer yet, "we have made remarkable progress," he said.

Berry noted that researchers have increased perovskite stability by more than an order of magnitude while also increasing the efficiency. And they have demonstrated larger-area devices.

"There are engineering challenges, but there weren't fundamental physical issues" to perovskite devices. As he said, the material is the highest-performing polycrystalline thin-film PV technology. Period. "That's happened faster than any other technology. I'd like to think that's partly because we know a lot more about solar cells, generally—and making them—than when we started just eight years ago," he noted.

The stability question remained in mid-2020 when he spoke.

"If you think about how long it takes to make an evaluation of efficiency, that's a test you can do in five minutes in the lab. If I want to demo a large-area device, that takes maybe a couple weeks to develop an initial prototype and demonstrate that one can get some kind of device with some kind of efficiency," he said. However, there's one more need. "There's the question of stability: We want to know, ideally, in five minutes where their device will be after 30 years of operation out in the field. So that's a much more technical level of understanding that we need."

NREL is working with U.S. companies to advance the science. Sandia National Laboratories and NREL are also in a new DOE center to further perovskite research into reliability. "Now, we are trying to do this for a new technology, faster and at an earlier stage, to get to market more quickly," he said.

If that's the case, Berry believes in his team—and is vocal in saying so.

According to Jao Van de Lagemaat, "Joe is well known with people working in the SERF building as impossible to avoid when walking in the hallways. Of course, some of that has taken a back seat to COVID recently," he said. "But I can still often hear Joe from the other side of the building holding court near one of the staircases where he will be driving science and collaboration ideas as well as managing lab issues."

**Joe Berry inspecting solar cells in 2008.** *Photo by Mike Linenberger, NREL 15400*

To Van de Lagemaat, "This is truly wonderful, as it builds and maintains a very collaborative atmosphere. Running into Joe is often the highlight of my day. In COVID times, Joe somehow even has brought this enthusiasm to Teams meetings that are equally positively spirited."

Berry acknowledges that he and others often have differences of opinions. "That's why I value them so much," he said.

That energy of diversity has helped forge stronger bonds.

## A Fellow With Goals

Berry is realistic about what he wants to accomplish as a fellow.

"I don't think it'll change too much how I go about doing things. It's about doing things the right way," he said. "I can continue doing more of it. Being a scientist generally means you're not terribly satisfied with whatever the explanation is—or whatever your level of understanding is of a problem."

He is willing to represent his own history. "I think I'm a fellow because of who I am. But I think who I am has clearly been informed by the fact that I'm African American," he said. "I have experiences that are different from people who haven't had them. That's like the Sword of Damocles. It cuts both ways."

He is aware that, relative to many of his African American peers, he has "had all kinds of advantages. To be super-clear, I'm mixed race. My dad is African American, and my mom is of Swiss extraction," he said. "I've had all kinds of advantages a lot of people who look like me haven't had. You don't get to do science at this level, if you haven't had a lot of those advantages.

"Having had those experiences makes you who you are, and I certainly think that diversity—both technically and in life experiences—helps make the best science," he said.

For Berry, NREL is a great place. "That doesn't mean we can't be better. That's a quintessentially American thing. American exceptionalism isn't that we're perfect, but that we recognize the imperfections; we acknowledge them and work really hard to make them better," he said. "To me, being a lab fellow, my colleagues are in some sense relying on me to make sure that I'm there to try to facilitate the improvements to allow us to do our jobs better. That's related to the science."

For a final sporting reference, he chose soccer. "The best teams expect accountability," he said. "It makes me better" on the field when teammates do make demands. The same is true in the laboratory.

As for goal, he's looking to score breakthroughs and swinging for the fences. Expect Berry's voice to be among the loudest cheering on the "amazing perovskiteers," as Luther calls the crew who hopes to, as they say, make perovskites a reality for everywhere between here and Pluto. And with that sentiment, Berry will not disagree. He likes being on a winning team.

Repins relies on a different set of storytelling comparisons.

Her tale begins when she was a 12-year-old girl and decided to tackle the world's energy woes. Maybe that resolve set Repins on her path. But whatever started her momentum, the NREL senior research fellow believes there was a sort of serendipity to her experiences.

"I'm totally Forrest Gump," she exclaimed. Like Tom Hanks' film character about a man in the thick of historic events, Repins found herself in the right places for iconic career moments in solar research. Whether it was working at a Silicon Valley startup or joining a semiconductor equipment manufacturer before it went belly up, she's been where the action is.

And without pushing the comparison too far, both Forrest and Repins are rooted in rural America. Repins grew up in Corvallis, Oregon, a region of farm country. Her parents were immigrants from Germany. Her father grew up on a farm; her mother, who was born Jewish in 1931, fled Germany with her family.

"They had a very strong work ethic. Much to my chagrin, that meant that you don't sit around and rest in the summer. You go and get a job," she said. For her, it was picking blueberries, paid by the pound. Still, although her father eventually became a college dean of agriculture, farming was not her calling.

"I was a science-y and math-y kid. I liked figuring out how something works. As a grade-schooler, I would love to take things apart in our house and, most often, put them back together. Sometimes they were broken when I started, and I fixed them," she said.

She gravitated toward science naturally, influenced subtly by her mom's pre-family career as an aeronautics engineer. "Not everyone loved 7th-grade science class, but I did. It was such a revelation to me that energy just changes forms," she recalled.

To Repins, the concept that energy is a constant in the universe—changing from kinetic to chemical to whatever—simply blew her mind and raised questions at the same time. In the 1970s, much of the world had been shocked by oil embargoes. American cities were getting polluted. "I thought, there are so many different ways to get energy, so many different places—why are we stuck on this thing with gasoline?" she said.

Repins realized she wasn't typical because of her passion. "I was a bit of a strange kid. When I was 12, I decided I was going to solve the world's energy problems. And I'm not sure that many people at that time realized that we had energy problems," she laughed. Seeking alternative energy sources "seemed to me such an obvious solution" to these problems.

Another way to describe her was ambitious—and a bit naïve. "I thought that I would have that [solution] finished about the time I graduated from high school, because high schoolers know everything," she recalled. "It turned out to be a more difficult problem than I expected."

Ingrid Repins. *Photo by Dennis Schroeder, NREL 42329*

## Plug Away, Repins—on the Quest for Energy Solutions

In the Hollywood film and novel on which it was based, Forrest Gump discovered an ability to run fast. Repins, on the other hand, was more methodical.

"I kept plugging away. Eventually, I studied physics as a Stanford University undergrad and decided solar cells might be a way to wean the country from fossil fuels," she said. Arriving at Stanford had connected her to a whole new set of possibilities. "I loved that it was not just science-y and math-y students. It was people who were excited about all varieties of learning, whether about language, politics, science, or engineering."

That sort of environment was a glimpse of her future. "One of the things that makes NREL an excellent place, too, is that we bring a lot of different talent to renewables: people who deal with soft costs; who do solar cells and count electrons and move them around; chemists; and biomass experts. It's diverse for a place with a technical mission."

Maybe, just as Forrest kept bumping into memorable figures, reaching NREL was inevitable for Repins. Her trajectory seemed to bend naturally toward the laboratory. After arriving at Colorado State University to pursue graduate work which finished with a Ph.D. in physics, she took part in research projects at SERI.

At one point, she was engaged with lasers in the basement of the SERF just after it was first built. "Not all the doors were working," she recalled. "Sometimes you'd go through a door in the SERF and you'd turn around to find no doorknob on the other side."

It was after graduation that her inner Gump compass really kicked in. First, she experienced the "very dynamic environment" of an early computer curriculum company in nascent Silicon Valley. Then, to pursue her desire to solve the energy crisis, she joined a 15-person firm that manufactured equipment for semiconductor deposition.

> "It really played into my experience at NREL later when I was doing solar cells. I could make them do what I wanted because I had this experience."
>
> —Ingrid Repins

The firm, Materials Research Group, closed its doors after she was there five years—but not before Repins learned how to put custom vacuum-deposition machines together and take them apart. "It really played into my experience at NREL later when I was doing solar cells," she said. "I could make them do what I wanted because I had this experience." Of course, it stung her that the company shut down—but it was not an unusual occurrence for those in the fledgling PV field. "In the early days of solar cells, you couldn't say you'd been there until you had at least one company go under."

Her journey took her to ITN Energy Systems in Littleton. "I was on the research side of things, less on the equipment side," she said. She entered the field of copper indium gallium selenide (CIGS) solar cell manufacturing. Learning another aspect of the industry, almost by chance, she witnessed how a manufacturing line was set up. "It was very valuable," she said. While at ITN, Repins led a team in collaboration with NREL that received a 2004 R&D 100 Award for the development of "Lightweight Flexible Thin Film CIGS PV Modules."

Having private-sector experience also deepened her perspective on research. "We did many things differently than at NREL," she said. "And I am thankful we do some of the things we do here now. I put 'safety' in that column." Still, her impressions of small entities enabled her to see benefits, such as the ability of smaller companies to be more agile, switching projects more easily than at a larger institution.

In personal terms, Repins' agility was never in doubt. Around this time, she and her husband had the first of their two sons—and Repins took some time off professionally. Then slowly, she started picking up freelance work.

## NREL and Two Solar Paths

Despite, or maybe because of her freelance connection, Repins' compass led her to NREL after she got a call from people she knew in the CIGS group. She started as an NREL scientist in March 2007.

She was still on her childhood quest to save the planet, and the laboratory was a natural destination—although, she said, NREL was much smaller than today and a bit harder to get a handle on how to join.

Despite her early lofty intent, energy issues persisted around the world. However, the goalposts kept moving on the answers and solutions. "My understanding of what the problem is, what the solutions are, keeps evolving," she said. "I'm sure everyone at NREL is aware of that."

Her work in two thin-film photovoltaics technology platforms—CIGS as well as copper zinc tin sulfide/selenide (CZTS) —was promising, raising hopes of commercialization. However, the pace of PV innovation sped up. "It's wonderful how the industry has grown, and how rapidly," she said.

Unexpected things began to happen. For example, the price of silicon PV modules, once assumed to be stable because of fixed materials and manufacturing costs, began to drop. "We used to think they would never go below $3 per watt," she said. "Now it's in the range of 20-something-cents per watt."

Some alternatives to silicon began to seem pricey. It was Gump-time again, this time intentionally. She decided to switch to reliability research for solar cells. She's happy with her move. "I used to think that solar [energy] was about maximizing electrons. As I went on, it was about the cost per watt of the solar cell," she said. Then she concluded the target was actually "the cost of what you generate" that is most important. As such, "it really matters how long systems last."

But how do you know? This, of course, is an easier question to ask than answer.

"I tried the Ouija board," Repins said, but that didn't help. So, it was back to painstaking research. Today, she's leading a team that is observing PV degradation, testing to reproduce that degradation, and forming international standards to provide greater PV reliability. A goal is to help investors and industry understand their energy bills for developing PV.

"We need to predict the future. It's high-impact work, and we're still at a stage where [reliability research] can benefit from NREL's help. Anything that affects the energy yield over the lifetime of the module is of interest to us," she said.

Her work has won praise at NREL and worldwide.

"Repins is an internationally recognized leader in PV and the type of highly effective and collaborative scientist and leader that often drives the most important things we do at NREL, someone whose actions and work speak louder than words," said Materials Science Center Director Nancy Haegel. And Sarah Kurtz, a solar pioneer and current fellow, supported Repins' nomination as an NREL fellow. "The designation as a senior research fellow recognizes the leadership Repins has shown and the international respect she has gained," Kurtz said.

Joe Berry added, "Ingrid is one of the people whose insight and perspective you always want when you are making a big decision or trying to develop a strategy to address an issue, technical or otherwise. She is thoughtful, well considered, and a great person to interact with. Her advice was critical to putting together our perovskite efforts for DOE."

On the big screen, Forrest was awarded the Medal of Honor for his heroism by President Lyndon B. Johnson. Under slightly different circumstances, Repins was named a fellow.

## A Yogini and a Fellow

At times, part of her journey outside of science has found a way back into her career. For instance, 30 years ago, Repins was suffering from back pain and decided to take up yoga. "It was magical," she said. Repins has been an enthusiastic yogini since.

“I’ve learned so many things from yoga along the way.” On occasion, she’s stepped up to teach yoga classes at NREL. “When the good volunteers can’t make it, I teach,” she quipped. In her opinion, yoga once a week is good for injury prevention and clearing the mind, easing stress.

Now that she’s a senior research fellow, she hopes to share some of her wisdom.

“NREL is a wonderful place. Yet, sometimes when I look around at my fellow researchers, I see people who are extraordinarily stressed out. What is it that’s stressing them, and how can we make the work environment so that they’re not stressed out and they can produce more?” she said. Because the way we work has changed during the past decade or so, she’s hoping to analyze what factors are causing the stress. If some are out of NREL’s control, that’s one thing. “I want to try to identify and use data from social research [to learn] how to make things better for people.”

In spring 2020, while recovering from a broken leg suffered in an accident on a family ski outing at Loveland, Repins took time to ponder the future. It will undoubtedly involve yoga, reliability milestones, and ways to ease stress. But her path is perhaps best summed up by former NREL Principal Scientist Rommel Noufi, who hired her. In his letter on behalf of her becoming a fellow, Noufi cited the first line of her resume. Her stated objective, he repeated, was “to help staff make renewables huge, immediately, while they have fun doing it.”

That’s an approach that Forrest could run with, too.

## A Salute to All the NREL Family

That is our story, and we are sticking to it—for now.

The fellows, leadership team members, and current director are united in looking forward, armed with a strong vision and a world-class facility filled with innovators from around the globe. They know there are many more tales and chapters because the journey has only begun.

But whether it is a veteran who helped launch SERI or the newest intern or postdoc, the story of NREL will continue to unfold as one that impacts the nation and the world. ■

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