Toward a

Greener Energy Landscape

How Caltech chemist Kimberly See is energizing battery research.

by Emily Velasco

Shrinking glaciers and a shriveling snowpack, dying forests and dwindling water supplies. These are just some of the challenges faced by the state of Colorado as global temperatures continue to rise. Colorado is, of course, not alone in facing these challenges. But for Caltech chemist Kimberly See, that's where it hits home. She grew up in the state, and it was there that she developed an appreciation for the natural world and an acute awareness of the harmful effects humans can have on it.

Both that appreciation and awareness drive See's research at Caltech, where her lab is pursuing the future of batteries, work she sees as critical for easing humanity off its dependence on fossil fuel.

See's story begins a little outside Golden, Colorado, a former mining town turned Denver suburb. Golden sits where the Rocky Mountains' towering peaks begin to blend with the plains and prairies that grow ever flatter as they stretch out to the Mississippi River. A pair of craggy mesas overlook the city's downtown, and a creek tumbling out of the foothills bisects it. It was a place with an abundance of opportunities for an adventurous and curious child to explore the outdoors and ponder how it all works.

"I was always hiking and playing outside when I was a kid," See says. "I started getting really interested in science as a way to understand what was going on in the world around me. I wanted to know things like, 'How does this plant use sunlight to grow?' and what I ended up realizing was that chemistry was a really great way to find out."

Her interests in chemistry and nature grew in stepwise fashion, punctuated by pivotal moments: first, the day a high school teacher gathered her class to watch as she threw a chunk of sodium metal into a pond to demonstrate an explosion, and second, watching a water-splitting reaction while an intern at the National Renewable Energy Laboratory in Golden.

Solid Effort

The first attempts to build solid-state batteries began in the late 1950s. These attempts did not succeed because the materials of the day were not sufficient.

"That's when I started doing photoelectrochemical water splitting, and that's when I started to really like electrochemistry," she says. "I also saw what we're doing to the environment, and I found that was a cause worth fighting for. Diversifying our energy landscape and reducing our impact on climate change is directly related to my love for nature."

In grad school at UC Santa Barbara, See was presented with an opportunity to study batteries, and she took it, seeing it as an extension of her previous studies in electrochemistry and a way to have an effect on climate change.

"It was this great combination of studying concepts from a perspective of electrochemistry and solid-state chemistry, with applications in electric vehicles, grid storage, and all of these things that would help with the CO_2 emission problem," she says.

Now an assistant professor of chemistry at Caltech, See has established her own lab and continues her work on batteries. Her research is focused not on making incremental improvements to the same batteries we already use but rather on inventing new batteries with new uses.

"We work under the assumption that lithium-ion batteries are reaching their theoretical limitations. To provide the change that's needed for widespread electric vehicles or inexpensive grid storage, we need a new mechanism to store energy," See says.

> "What we're doing is kind of jumping 10 steps ahead and saying, 'OK, well, why don't we try to develop an electrolyte that allows us to conduct magnesium or zinc?'"

That new mechanism could come in the form of batteries that ditch the liquid electrolyte present in essentially every modern battery currently in use and replace it with a solid electrolyte. These solid electrolytes would come with a few advantages: they would never leak, unlike the batteries left in a remote control for too long; they're not flammable, unlike the liquids used in lithium batteries; and they could allow for the use of dense metal anodes, so batteries could pack more energy into a smaller volume.

See's lab hopes to combine solid-state electrolytes with elements other than the ever-popular lithium. Currently, the team is looking at zinc and magnesium as contenders.

"What we're doing," she says, "is kind of jumping 10 steps ahead and saying, 'OK, well, why don't we try to develop an electrolyte that allows us to conduct magnesium or zinc?'"

It is not a trivial proposition. Liquids are exceedingly good at conducting ions, but solids not so much. That is because a liquid's molecules are mobile, and that mobility makes it easy for ions to travel through them. In a solid, the molecules are much more rigidly fixed in place, which makes it difficult for ions to squeeze past them.

So, the challenge for See's lab is to design a solid that lets the ions slip through on their way from the battery's anode to its cathode. Recently, the research team announced their first success in doing so. The material they designed is a solid, but it contains a molecular structure that is somewhat flexible. That flexibility allows its bonds to bend out of the way as zinc ions pass through. Previously developed materials of this sort needed to be brought to high temperatures to work, but the team's new material works at near room temperature.

Graduate student Sarah Bevilacqua says that innovative approach to batteries is just one of several things that drew her to See's lab.

Energy density is the amount of energy a material can pack into a volume. Modern lithium-ion batteries are still 100 times less energy dense than gasoline.

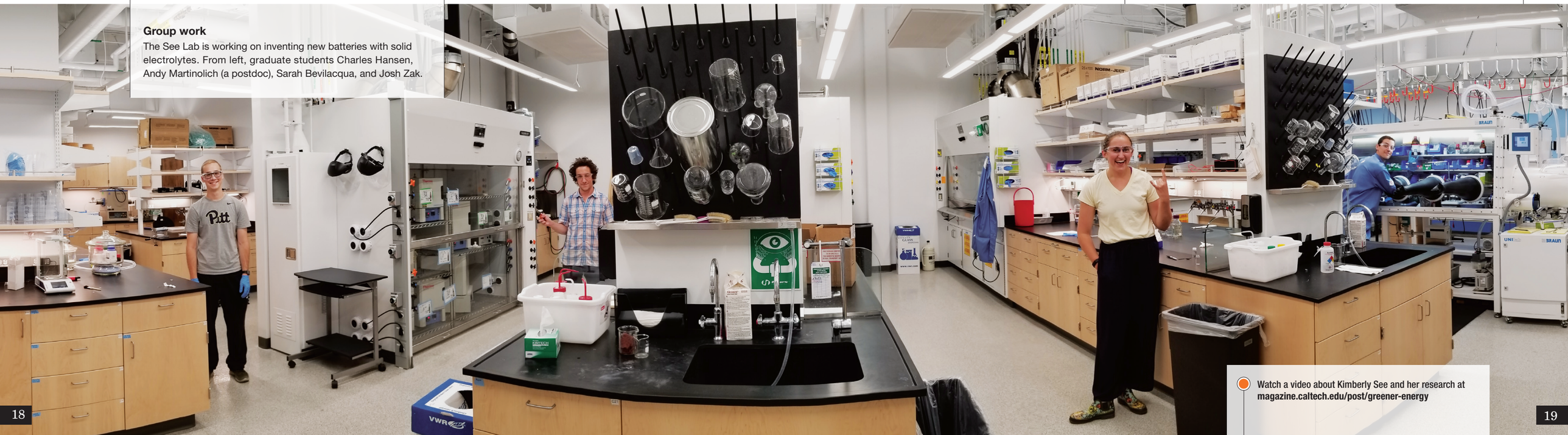
"She's the most genuinely enthusiastic-about-science person I've ever met," Bevilacqua says. "And she really wants us to succeed. Whenever I've got frustrations, or I'm not making progress, she makes time for me."

But the best thing about working in See's lab, Bevilacqua says, is helping to take science into completely new territories.

"We're really trying to implement new chemistry," Bevilacqua says. "There's a huge chemical space to play around in, so the possibilities are pretty exciting, as opposed to taking a lithium-ion battery and making it just 1 percent better. The world is our oyster when it comes to new batteries."

See, for her part, is excited as well. She says she has found Caltech's environment stimulating, and that has inspired collaborations with Marco Bernardi, assistant professor of applied physics and materials science; Kathy Faber, Simon Ramo Professor of Materials Science; Theo Agapie (PhD '07), professor of chemistry; and Scott Cushing, assistant professor of chemistry.

"The support here at Caltech has been amazing. They really give you the tools you need to do the science you want to do, which has been such a privilege," she says. "To build a lab that's geared toward the science you want to do is a really, really amazing experience."



Group work
The See Lab is working on inventing new batteries with solid electrolytes. From left, graduate students Charles Hansen, Andy Martinolich (a postdoc), Sarah Bevilacqua, and Josh Zak.

Watch a video about Kimberly See and her research at **magazine.caltech.edu/post/greener-energy**