glimpse

research *and* creative discovery

Clemson University

fall 2014

Renaissance
of the car

Peter Kent

rethinking the car

Is America's romance with the automobile running out of gas? Or will the next generation of cars—smarter and greener—make us yearn to take the wheel again? If there is a wheel? Page 12.

Cover photo by Craig Mahaffey

glimpse

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Bucking the tide of conventional wisdom, oyster biologist Andy Mount unlocked one of the neatest feats in nature: the making and repairing of a seashell. It all begins in places like this, Clambank Landing in the North Inlet of Winyah Bay, South Carolina, where Mount and his students find their oysters. Their work in the field and in Mount's Okeanos lab on campus helps explain how living organisms use the elements of biomineralization to make shell and bone, tooth and claw. It is also giving rise to new materials that can resist an ocean of abuse. Page 30.

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Productive upheaval

Almost anyone who works in business, government, or higher education has heard the term paradigm shift. These days, it's applied to almost everything, from military doctrine to shoe fashion. But when the term first appeared, in Thomas Kuhn's *The Structure of Scientific Revolutions* (1962), it referred to something far more dramatic than a change in trend or strategic direction. Kuhn was describing the rare and often wrenching overthrow of one scientific theory by another, a crisis that dismantles a body of knowledge, renders it obsolete, and replaces it with something else. He contrasted this kind of upheaval with what he called "normal science," the orderly progression of knowledge that accumulates in harmony with the prevailing theories of a discipline or field of study. By Kuhn's definition, a paradigm shift is the exception, not the rule. And so, when it seems likely that one is under way in our midst, it's time to sit up and take notice.

Andrew Mount, a Clemson biologist who studies shell formation in oysters, has for the last decade been fighting for what he believes to be a genuine paradigm shift in his field (page 30). Against stubborn skepticism, he and his research team have laid down layer upon layer of solid evidence that the long-held view of shell formation in oysters is demonstrably wrong. Mount has done this by using the powerful tools of modern biology to reveal how the shell-building process begins deep in the oyster's cells, guided by an intricate design encoded in its genes. Mount has published his results in some of the world's most prestigious journals, and has found widespread acceptance in Asia, but here in the U.S. the field has been slow to change. People don't easily surrender seventy years of scientific certainty.

Uncertainty is par for the course, though, in the highly competitive realm of automotive engineering and manufacturing. The only certainty most people in the industry seem to agree on is that old paradigms and pet theories about what a car should be are losing ground. Not since the time of Henry Ford has the automobile faced a period of such swift and dramatic change. In fact, even our sober-minded engineers at the Clemson University International Center for Automotive Research (CU-ICAR), people not given to hyperbole, go so far as to herald this moment in history as the "Renaissance of the Car."

What's driving this renaissance? Multiple factors seem to be converging: a new generation of drivers who would just as soon be doing something else, rapid changes in technology and materials, new theories about drivetrains and energy sources, and tougher fuel-economy standards on the horizon. We cannot pull back the shroud and show you exactly what the car of the future will look like. But in our cover story for this issue (page 12), we can give you a glimpse of things to come.

R. Larry Dooley
Interim Vice President for Research

zoom in

Image courtesy of Erbe, Pooley: USDA, ARS, EMU

What's bugging the bees?

This electron micrograph shows the aptly named *Varroa destructor* hitching a ride on its honeybee host. The mite feeds on immature bees, threatening colonies and the pollination of food crops.

Tidy bees are healthy bees

As premier pollinators, honeybees help feed the world. But something is eating *them.*

Can genetics help produce kids who have good grooming skills and prefer clean rooms? For now, that remains a parental dream, but it could be a reality for beekeepers. Research shows that tidy bees are healthy bees.

Clemson's new beekeeper, Jennifer Tsuruda, is part of a worldwide effort to identify honeybee behavior and genes that appear to make some bees better groomers than others. The good groomers are better at ridding their bodies and hives of *Varroa* mites, which can wipe out the honeybee colonies that help put food on our tables.

"Pollinators are involved in producing one third of the food we eat," Tsuruda says. "Bee research is a matter of food security—national security."

There are many kinds of mites, but the one that is the most serious problem is aptly named *Varroa destructor.* About the size of a pinhead, oval-shaped and reddish brown, the *Varroa* packs a double whammy on honeybees.

Hungry hitchhikers

A mature and mated mite female finds a honeycomb cell containing an immature bee to infest and feed upon. She produces a son and daughters who mate and feed on the developing bee, resulting in mated females that start the cycle over again. The feeding may or may not kill the gestating bee, depending on the number of mite babies and the viruses vectored by the mites. But that is not the end of the parasitical feast. The young mites leave the cells and climb aboard adult bees, feeding also on their hemolymph—bee blood.

Feeding their young off the bees is harmful enough, but the mites do even more damage. They also harbor viruses that carry lethal bee diseases, causing parasitic mite syndrome, which can devastate bee colonies.

But not all bees or colonies succumb to the *Varroa* mite.

Some bees work harder at grooming—using their legs to knock mites off their bodies. Others can tell when capped honeycomb contains mites and uncap it, a behavior called *Varroa* sensitive hygiene (VSH), which can kill the mite offspring and disrupt the mite's reproductive cycle. Tsuruda and other bee researchers single out the overachievers (and underachievers), analyze their genes, and breed them to develop mite-resistant colonies of "mite biter" and VSH strains of honeybees.

Starting with the queen

Tsuruda works with researchers and beekeepers who breed queen bees—the only egg layers in bee colonies—to focus on building bee stocks that are vigorous housekeepers.

"I don't think we will ever get rid of *Varroa* mites, but we can develop honeybees that have a better chance of managing infestation levels," Tsuruda says, adding that the genetic option brings other plusses.

"Traditionally, we have used nongenetic options, like removable drone comb and chemicals to control mites, but the chemical controls raise concerns," she says. "The mites could become resistant to overused pesticide, and there needs to be more long-term research on conventional chemicals and biopesticides."

As Clemson University's Extension apiculture specialist, Tsuruda divides her time between research and extension, which involves holding public education programs and meeting beekeepers. She works with the state's 3,500 beekeepers, who tend to about 33,000 hives. The value of pollinated crops nationwide is about $20 billion and more than $25 million in South Carolina. Palmetto honey alone brings in more than $1.25 million.

Jon Sullivan

When it comes to grooming, some honeybees are more fastidious than others.

You could say she has been as busy as a bee.

Tsuruda has talked with local beekeeper associations around the state and in neighboring states, organized a pollinator week celebration, taught beginning beekeeping classes at Roper Mountain Science Center in Greenville, showed 4-H campers how bees are similar and different from people, hosted a honey tasting on campus, and participated in the South Carolina Beekeepers Association annual meeting at Clemson in July.

Pollen stewardship

She also is working with Clemson Regulatory Services and Clemson Public Services on their bee reporting system, a part of the division's pollinator stewardship project. Beekeepers can report hive sites online, alerting pesticide applicators to bee locations.

Nationally, Tsuruda is working on the American Bee Research Conference as the vice president of the American Association of Professional Apiculturists, and is serving the Entomological Society of America as chair of a committee that serves young professionals.

Apiculture is one thing and culture is another. A California native is learning the lay of land.

"I'm adjusting to and enjoying the slower pace of life out here, except for the speed limits," Tsuruda says, laughing.

—Peter Kent

Jennifer Tsuruda is an apiculture specialist in the Clemson University Cooperative Extension Service. Peter Kent is a news editor and writer in Clemson's Public Affairs Activities.

Jennifer Tsuruda

Jennifer Tsuruda studies ways to control mites with better housekeeping from the bees.

Brain trust

Many female athletes won't risk reporting concussions if they can't count on support from their coaches and teams.

Concussions are common among athletes, and females receive nearly twice as many concussions as males in the sports they both play. Recent research suggests a discrepancy between male and female athletes in reported symptoms, concussion recovery times, and post-concussion outcomes on neuropsychological testing.

To bring awareness to this issue, Jimmy Sanderson and Melinda Weathers investigated female athletes' experiences in reporting concussions.

"Research regarding sports-related concussions has been limited to studies focusing on concussion rates, patterns of injury, and risk factors among high school athletes in football and other male collision sports," Weathers says. "Little to no attention, however, has been given to the communicative practices that may influence reporting concussions in sports."

Sanderson adds that public perception is part of the problem. "The media tend to focus on male athletes, and there is not a lot of attention given to female athletes, who, in some sports, experience higher incidence rates of concussions," Sanderson says. "So we wanted to look exclusively at female athletes to see what their experiences were."

The researchers partnered with Pink Concussions, a nonprofit organization for female athletes who experience head injuries, to collect data from more than 500 female athletes who play or have played organized sports.

Most don't report

The study's results reveal that the majority of participants had suffered one or more concussions while playing sports and continued to play without reporting the head injury.

"Overall we found that the majority of female athletes did not report concussions," Weathers notes. "Specifically, 445 female athletes in the study suffered a concussion and 366 of them continued to play."

When the researchers asked why female athletes did not report concussions, several themes emerged. Female athletes perceived a lack of severity in the concussion, hesitated to buck the cultural norms of their sport, or doubted that they would find the resources, knowledge, and support they needed to address the injury.

"There was a big fear of retribution from coaches," Sanderson says. "Also some of the players had no idea how to recognize a concussion."

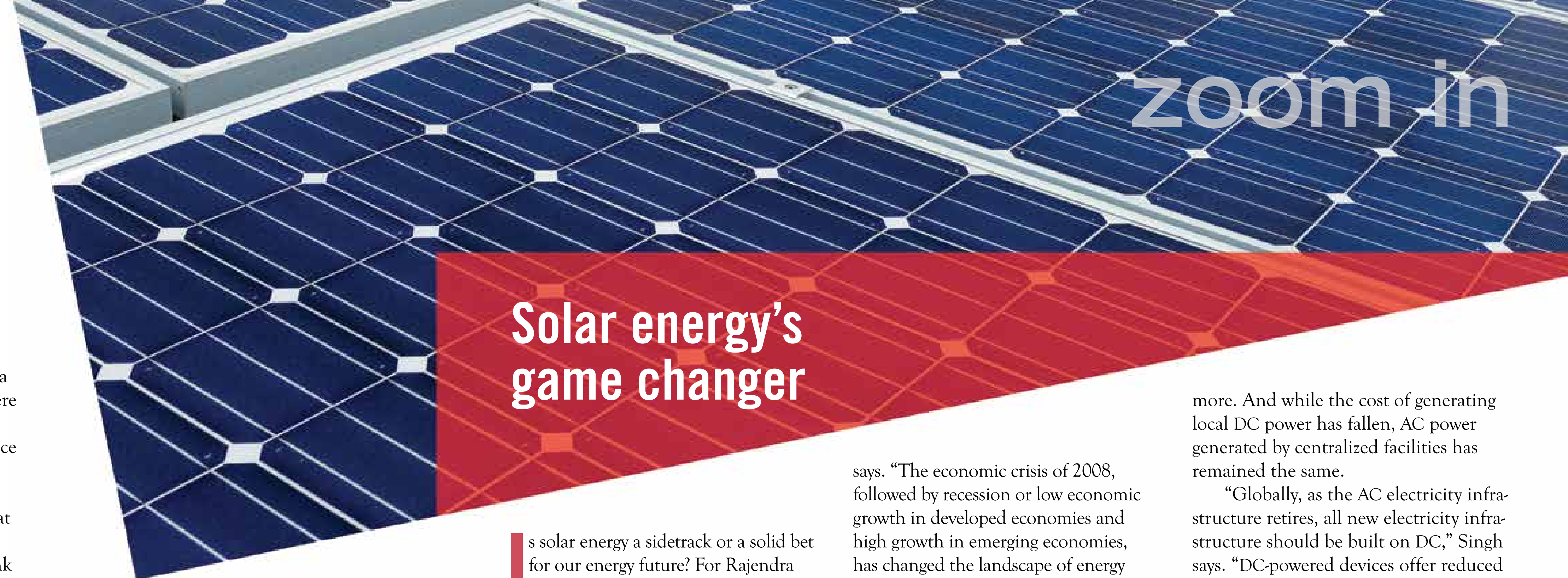
The researchers say that understanding the issues that influence concussion reporting has the potential to help female athletes after they experience head injuries.

–Brian Mullen

Jimmy Sanderson and Melinda Weathers are assistant professors of communication studies in the College of Architecture, Arts, and Humanities. Brian Mullen is the communications director for research.

Craig Mahaffey

Melinda Weathers (left) discusses concussions and communication strategies with undergraduate student Samantha Warren at Clemson's Social Media Listening Center.



Solar energy's game changer

Is solar energy a sidetrack or a solid bet for our energy future? For Rajendra Singh, the answer seems obvious: "Solar power now is a cost-competitive option that offers financial and environmental benefits and yields new economic opportunities for many Americans," he says.

On April 17, the White House honored Singh as a "Champion of Change" for his efforts to promote and expand solar deployment in the residential, commercial, and industrial sectors. He has become a national figure in the push to revamp the nation's power supply.

In a recent publication, he projects that if the current growth of production from photovoltaic cells (PV) continues, PV electricity with storage is likely to cost $0.02 per kilowatt hour in the next eight to ten years. According to the U.S. Energy Information Administration (EIA), the national average for electrical power was $0.1226 in March of 2014.

"Photovoltaics-generated power is cheaper than power produced by coal-fired plants when factoring the social costs of carbon," Singh says.

Singh has devoted himself to solar energy ever since he conducted his doctoral research on solar cells in 1973, during the Arab oil embargo. Over the last forty years he has worked to advance the PV technology, which converts solar radiation into DC electricity using semiconductors.

"The vision I had in 1980 is happening only now, thirty years later," Singh says. "The economic crisis of 2008, followed by recession or low economic growth in developed economies and high growth in emerging economies, has changed the landscape of energy business all over the world."

Because of its "inherent advantages," Singh says, "PV will take over wind and eventually serve as the dominant electricity-generation technology."

Retooling the grid

To make that happen, solar will need our aging electricity infrastructure to be improved. According to the EIA, about 70 percent of electrical energy is lost in generation, transmission, and distribution, wasting energy worth nearly $500 billion a year. Much of this energy loss results from using alternate current (AC) power transmission and distribution to service direct-current (DC) loads.

Solar panels generate DC electricity, but the sprawling grids that deliver electricity to most homes and businesses carry AC electricity. In AC, the flow of electric charge periodically reverses direction. In direct current, the flow of electric charge is only in one direction.

"More than a third of the energy can be lost in AC generation, transmission, and distribution," Singh says. "When AC electricity flows into homes and businesses, it has to be converted to DC in order to power DC devices." Those devices include lights, air conditioners, home appliances, cell phone chargers, and more. And while the cost of generating local DC power has fallen, AC power generated by centralized facilities has remained the same.

"Globally, as the AC electricity infrastructure retires, all new electricity infrastructure should be built on DC," Singh says. "DC-powered devices offer reduced energy loss, improved power quality, and greater lighting efficiency."

Singh advises shifting from large grids to microgrids that get their power from solar panels and distribute it as mini-utilities would, greatly reducing waste.

"Even in weather-related catastrophes, local DC microgrids will be more reliable and resilient than existing systems," Singh says. "We can also expect millions of new jobs to be created in this and coming decades."

Singh says the technology is available to bring electricity to the entire world in as little as five years while lowering utility bills in the United States. To transform global electricity infrastructure, Singh is advising leaders to use PV as the source of local DC electricity in the United States and in emerging and underdeveloped economies. He also works with civic groups to bring legislation in South Carolina to foster the growth of solar-generated electricity.

"It's a matter of integrating electrical components, finding a business model that works, and moving public policy in the right direction," he says.

–Brian Mullen

Rajendra Singh is the D. Houser Banks Professor of Electrical and Computer Engineering in the College of Engineering and Science. Brian Mullen is the communications director for research.

help for the overheated bull

In summer, a stealthy fungus can sideline the sire.

Bulls and men seeking to be fathers are susceptible to the same stress. Heat down under may affect the outcome. Bulls can't swap briefs for boxers, but they should stop grazing on grass infected with a fungus that alters their body chemistry, triggering abnormal body temperatures and other symptoms. Clemson researchers are searching for ways to neutralize the toxic effects.

Tall fescue is a robust perennial, providing millions of acres of pasture for livestock. Its hardiness in part comes from its relationship with a fungus. It thrives on popular varieties of the grass and in return helps the fescue resist insects, heat, and drought. But what is good for the grass is bad for the grazer.

Clemson University

Nick Hill, UGA

Slender tubes of the endophytic fungus *(Neotyphodium coendophialum)* occupy the intercellular spaces of tall fescue.

An endophyte, the fungus causes fescue toxicity, a condition that diminishes growth, health, and reproduction in cattle, horses, and sheep. About 8.5 million head of cattle graze on it. Infected fescue may lead to losses of as much as $1 billion yearly in lost body weight, illness, and fewer pregnancies, according to beef industry estimates. Symptoms typically occur during the "summer slump" as cattlemen call it.

Much of the research on fescue toxicity has focused on females, which can fail to become pregnant or spontaneously abort their offspring. The failure rate for cows can run as high as 35 percent. But one bull can have more impact on the problem than one cow. A bull can cover as many as twenty-five cows via natural reproduction.

Molecules and markers

At Clemson, Scott L. Pratt looks at the bulls from another angle. A molecular reproduction physiologist, Pratt focuses on the chemical molecules that deal with animals' reactions to the toxin. The consumed infected grass and summer heat hamper the bulls' ability to maintain normal body temperatures. Particularly heat sensitive are the testicles, where body temperature can affect sperm.

Pratt is working on finding genes and gene pathways that are affected by the toxin.

"The work we are doing to identify biochemical markers that are indicators of bull fertility may help with inconsistent breeding soundness exams, which is a big problem," Pratt says. "All labs have seen mild to no effects on the exams. Bulls on toxic tall fescue will pass a breeding soundness exam, but still be subfertile."

Currently, cattle producers must take their animals off infected pastures months before breeding. There are nontoxic fescues available, but planting them requires completely replacing a pasture, which can be costly and time consuming. Pratt's work could lead to better management strategies for bulls grazing on tall fescue.

–Peter Kent

Scott L. Pratt is an associate professor of animal and veterinary sciences, College of Agriculture, Forestry, and Life Sciences. Peter Kent is a news editor and writer in Clemson's Public Affairs Activities.

zoom in

bike happy

When the rubber meets the road, people are happiest pedaling.

Neil Caudle

When you leave home in the morning, are you making the trip with a smile? Eric Morris says you're more likely to be smiling if you ride your bike. Morris's research comparing the average mood of travelers led him to a simple conclusion: "Bicycling is the happiest mode."

The study used data from the American Time Use Survey to analyze the mood of cyclists, car passengers, car drivers, walkers, and riders of trains, subways, and buses. "People are in the best mood while they're bicycling compared to any other way of getting around," Morris says. Automobile passengers and drivers are second happiest, followed by walkers, then train or subway riders, with bus passengers coming in least happy.

The study doesn't draw firm conclusions about why bicyclists are happiest. Morris says it could be because cyclists are self-selected enthusiasts, or because physical exercise improves our mood. Cyclists may tend to be younger and more physically healthy, both of which tend to be associated with greater happiness, but the study shows cyclists are happier even controlling for these characteristics. Transit riders, he points out, may be more likely to be en route to work, one possible explanation for their lower happiness levels.

So what should we make of the results? Morris suggests that an emphasis on promoting bicycle trips in general is a good idea. He notes that countries such as Denmark and the Netherlands, both well known for their serious bicycle infrastructure, have about 18 and 26 percent of their trips respectively taken by bike, compared to 0.5 percent in the U.S. That level of biking in our country might translate into a significant increase in happiness, which is where Morris comes back to how transportation is typically considered in the United States.

Conventional transportation studies, Morris says, tend to focus on whether an aspect of transportation saves travel time or fuel costs. "Those things are just a means to an end," he says, "which is: Can we make people happy?"

–Mary Jane Nirdlinger

Eric Morris is an assistant professor of city and regional planning in the College of Architecture, Arts, and Humanities. Mary Jane Nirdlinger is a city planner and the executive director of planning and sustainability for the Town of Chapel Hill, North Carolina.

the Renaissance of the Car

by Scott Huler

photo illustrations by Neil Caudle

Ever since that flying police officer said, "All right, buddy, where's the supernova?" when he stopped George Jetson for speeding in a space-age bubble car, we've all known: The car is dying. It won't be around long. It will turn into flying hemispheres, or supertrains, or moving sidewalks, or jetpacks, or some kind of teleportation device. The car is a transition technology to…whatever's next. We know this. The car is doomed.

Ashley N. Jones

Imtiaz Haque: After one hundred years, we're redefining the car.

Except, it turns out, not so much. Or anyhow, the people at the Clemson University International Center for Automotive Research (CU-ICAR) don't see the car going anywhere. In fact, they see quite the opposite: They see the car going everywhere. The future of the car looks bright, not bleak, and not just because Google recently unveiled a fleet of autonomous, self-driving cars for testing. The future of the car didn't suddenly show up with Google's freaky-looking two-seaters. CU-ICAR has been there for years.

"These are very, very exciting times, because the whole industry is transforming," says CU-ICAR's Zoran Filipi, who studies the next generation of powertrains. "Cars as we know them today are going to be transformed by 2025."

Notice—not gone; not something else entirely. Transformed, to be sure, but still *cars*.

This notion doesn't set Filipi apart. It's rampant throughout CU-ICAR, where professors and researchers talk about the coming changes in automobile technology not as a crisis but as a rebirth. "It is a renaissance," says Imtiaz Haque, CU-ICAR's founding chair and executive director, "driven by this idea that there may be other ways to power the vehicle rather than just through fossil fuels."

In 2011, the Obama administration agreed to new CAFE (corporate average fuel economy) standards with the United Auto Workers and 13 major automotive manufacturers (virtually all the majors except Volkswagen). To comply with those standards, new cars and light trucks would, by 2025, need to average 54.5 miles per gallon of gasoline—about double the current average.

"We have been working on this for many years," Filipi says. "Progress has been continuous, but progress in the past was on the order of 2 percent per year. What we are looking at from today until 2025 is more on the order of 4 percent per year." That is, the automobile industry has been throwing everything it can at improving car efficiency for decades and has proceeded at a nice clip. But for the next decade it needs to move twice as fast. Small refinements, small improvements, will not cut it.

"That's why it's so exciting," Filipi says. "That's why people talk about a renaissance."

And maybe the time is exactly right. That people are thinking about cars and their meaning scarcely surprises us. In 1957, in *Mythologies,* Roland Barthes wrote, "I think that cars today are almost the exact equivalent of the great Gothic cathedrals: I mean the supreme creation of an era, conceived with passion by unknown artists, and consumed in image if not in usage by a whole population which appropriates them as a purely magical object."

A new age of automobiles

And what do you get after a Gothic period but a renaissance? For the automobile, it's a time of redefinition.

"We really are today where we were one hundred years ago," Haque says, thinking of a time when people were first trying to figure out what the car would be. "What would power it? Is it steam? Is it electricity? You know there were electric cars one hundred years ago. Is it the internal combustion engine?"

Advances in technology make that question relevant again, Haque says. "So when we think of the renaissance of the car, the powertrain area, the energy area—that, I think, is going to dramatically change. But there are many ways of doing that, not just by improving engine technology or putting in electric motors. We can get the vehicle to talk to the environment and know when there is a traffic jam or accident, or know when the terrain is changing, and thereby adjust itself. That I think is a big, big area."

Which demonstrates the complexity of the changes cars face.

Haque divides the new age of automobiles into three arenas of vast change: the drivetrain; connectivity, and the way that increasing computer power puts the very notion of what a car can be and do up for grabs; and automotive materials and manufacturing. In all of these arenas CU-ICAR engineers—and their students—are doing groundbreaking investigation.

First Haque identifies the drivetrain and its ability to more effectively use energy. Scientists openly consider everything from hybrid and electrical technology to the hydrogen fuel cells that seemed to be the answer a few years ago to improved internal combustion engines.

The second arena, he says, is simply that people are beginning to expect more from their cars. "A car used to be just a machine for getting you from one place to another," he says. But a car easily costs $30,000, a significant investment for something that "for twenty-three hours a day sits outside and provides no value and is depreciating," he says. So engineers, students, and consumers alike are looking to increase the car's value by asking the same question: "What else can I do with a car? What else can happen in a car?"

When reminded that your average high school student needs no help thinking of what else can happen in a car, Haque instantly agrees. "They did," he says cheerfully. "And the car wasn't designed for it!" Haque's point is not that teens ought to have access to higher-quality make-out dens but that cars have more jobs to do than to move through space. It's time to pay serious attention to that.

In response to that change in attitude about the very function of a car, the technological community is cranking out systems that enable the car to do new and all but magical things—drive itself, say, or keep in touch with its environment to improve its energy use and safety. These systems also engage the possibility—the likelihood, CU-ICAR scientists say—that the car of the future will be something utterly different than it is today.

"For most young people today, the car is a distraction from their cell phone," Haque says, not criticizing but simply stating facts. Young people by and large treat cars and driving as a necessary evil; they don't love cars the way their parents did.

So an entire area of research at CU-ICAR and in the industry as a whole is trying to figure out how to provide cars that enable people to do what they want to be doing in their cars instead of driving, whether that's eating lunch, gaming, sleeping, or watching movies.

The third arena Haque and his colleagues identify as foundational to the renaissance of the car is its materials and manufacturing. Just as the industry is rethinking how to power the car, it is also rethinking the materials that make it. "If we're going to bring about fuel efficiency in these cars, we need to lighten their weight significantly," Haque says. Which means more than just new composites and metals.

"The area that most people don't think about is manufacturing," he says.

Combining various metals, composites, and techniques does fine in concept cars. But when it comes to manufacturing, actual car manufacturers with actual plants have to find a way to replace old machines with new ones and somehow still build a car cheap enough that someone is willing to buy it.

"That's a very key area," Haque says. "You can't ignore the money piece." He notes that many consumers have resisted hybrid electric cars—"vehicles which make so much sense; they make *so much sense*"—because they cost a few thousand dollars extra.

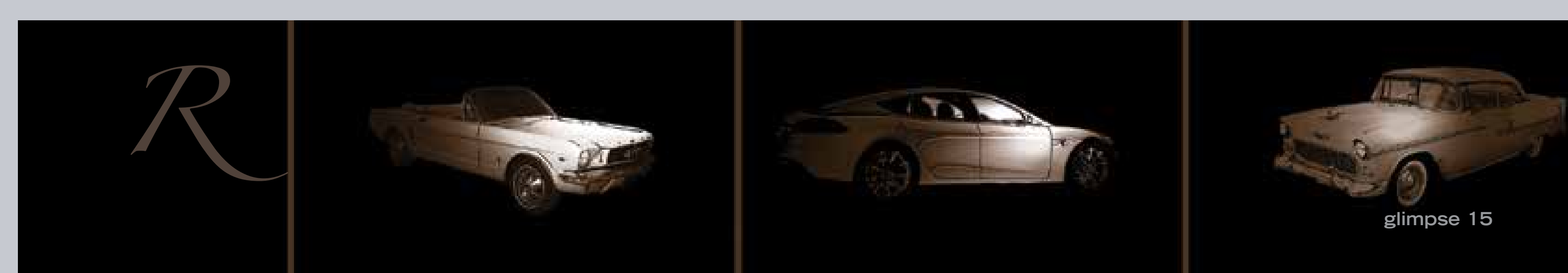
Ashley N. Jones

Clemson's International Center for Automotive Research is a 250-acre research campus where university, industry, and government partners collaborate using industrial-scale laboratories and testing equipment. The campus also supports graduate education in automotive engineering.

Patrick Wright

REVVING UP A RENAISSANCE

Zoran Filipi (right) and a colleague, Robert Prucka, discuss results from vehicle-exhaust emissions testing in CU-ICAR's chassis dynamometer facility, where researchers can assess the impact of new technologies on fuel economy and emissions. Filipi says the car as we know it is about to change, and change big. "That's why it's so exciting," he says. "That's why people talk about a renaissance."



"So it's great to have these technologies," Haque continues, "but the question is how do you make these things so people will pay for it?"

It's a question never far from the minds at CU-ICAR. Paul Venhovens, BMW Endowed Chair in Automotive Systems Integration, says that in their two-year graduate program his students collaborate with an actual car manufacturer—an original equipment manufacturer, or OEM—to design a car.

"The big question always goes back to consumers," Venhovens says, and it's a lesson his students immediately learn and don't forget. "Just being able to actually put a customer in front of a student," he says, helps the student learn that the job isn't solving equations.

"A customer," Venhovens adds, "talks a completely different language."

Because the Google autonomous vehicle prototype gathered so much attention in late spring, questions about autonomous vehicles now come up almost constantly in discussions about the future of the car.

Haque sees the autonomous vehicle as a thrilling opportunity. "From a safety perspective, they're huge and could provide a level of autonomy that has not been there before for the older generation. Imagine your healthy and engaged ninety-year-old parents being able to go to a meeting or appointment somewhere without having to ask someone to take them." But he's not convinced that the vehicles are ready. He cites barriers still to be overcome in technology, cost, and legal issues.

Getting our time back

David Smith, whose research involves software development, vehicle design, and the human-computer interaction, says that some aspects of the technology are already here in commercial vehicles. "Take a car with a lane-assist system [that keeps a car from veering from its lane]," he says, "and adaptive cruise control and you have autonomous highway driving."

On the road. Today.

Even something like antilock brakes constitutes an element of automotive autonomy. Cars park themselves, lock and unlock their doors, slam on the brakes if a kid walks behind while they're backing up. Smith simply accepts autonomous cars as a fait-soon-to-be-accompli.

What he's interested in is what that means.

"The bigger thing, from an interactivity standpoint, is you give people that time back, from when they were in their car driving places, to do more productive things." That is, while the car takes care of the driving, what do you do? "That's one of the things we're working on here. What could you do with that inside space when you're not worried about distracting the driver anymore?"

He gives the example of a trip to Disney World, nine hours from Clemson. "Imagine if you're Disney and you want to have people pay for a vacation, but you could start their vacation at their front door, rather than when they arrive at the resort, by providing a fully autonomous car full of Disney content where you could begin to engage in your vacation right away, and do it together as a family." Compare, he says, the traditional sullen ride with the kids wearing headphones, the parents irritably staring at the road, and everybody trying to ignore each other as best they can.

The point is, the autonomous car will be nothing like today's cars. "The last thing I want to do in an autonomous vehicle is sit forward and watch traffic," Venhovens laughs, and CU-ICAR students are pushing hard to figure out what a car can be when you no longer have to look out the windows and manage it. The car can be organized as a living room, an office, a bedroom.

Or as all of them, depending on the user's need. "We have a project going right now where we're trying to figure out just the basic interactions with a car with no steering wheel," Smith says. Say you've told the car where you want to go, but you see a store having a sale. "Most people think of that as trying to reprogram your navigation system," about which agonizing prospect the less said the better. "What we want to do is be able to say just with gestures and voice: 'Hey, over there!' And it will, you know, go there."

Smith is confident that onboard computers will recognize gestures and voices—the technical problems, he says, are being solved—so he's finding ways to incorporate that technology into the next, even more difficult step: an "augmented reality" inside the car.

"If I say 'there,' you might want to draw a big arrow on the window: *that* store, right *there*. That's a very complicated technological problem. Just trying to get the geometry right in a way that looks natural is extremely difficult."

Smith is also interested in making things that traditionally go in cars—tachometers, speedometers, radios—completely reconfigurable. "One of the projects we're working on is a digital dash type of thing." You'll take your tablet computer, use an app to sketch out where you'd like to have various elements—including not just instruments but ambient lighting, for instance. And then, like Tom Cruise in *Minority Report,* you will "just gesture it onto your dash," Smith says. "Place it, scale it, put it wherever you want." Same thing with a movie, or a game. The entire inside of the car becomes a designable touchscreen.

And, of course, you can save a personalized version of the inside of the car that you can take with you. From car to car.

Businesses, too, will find ways to profit from personalized vehicles. Shoppers will begin shopping when they get into their cars, running apps preparing them to maximize their time at whatever stores they plan to visit. Once cars become sufficiently autonomous, stores can create and program their own proprietary cars to pick shoppers up. Even mass transit drastically changes, Smith says, "when I can right now pick up the phone and call an autonomous car like I was calling a cab." Pickup? Van? Econobox? Whatever you want, it leaves its charging station, comes to get you, and takes you where you want to go. Since you can call another when you're done, parking garages become a thing of the past. "It could transform retail," Smith says. It could transform cities.

It will transform everything. In fact, to imagine the car of the future, Venhovens urges you to consider cell phones.

WHAT WILL YOU BE DOING, IF THE CAR DRIVES ITSELF?

What will we do with our time in the car, if we don't have to drive it? As he develops software and vehicle designs, David Smith is looking for ways to go beyond simple navigation and "augment reality" in the human-computer interface that operates the autonomous car. "You get people that time back from when they were in their car driving places, to do more productive things," he says.

Below: Smith and his Ph.D. student, Andreas Kasprzok, are developing an interactive dash software system.

Ashley N. Jones

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"A cell phone ten years ago could make phone calls. Nothing else," he says. Now it assists with half of what you do all day. "And to be honest," he says, "nothing is perfect on this smartphone. There is a better office environment, there is a better gaming environment. But just being able to do it here and now is what makes this device attractive." Just so, the car of the future will be an office, a bed, a lounge, a gaming station. And just so, he says, "none of these experiences will be perfect. There's probably a nicer hotel bed and a nicer gaming station at home, but just being able to be involved in that any time and any place will make that vehicle more attractive than just a piece of equipment traveling from a to b."

Venhovens and Smith's colleague, Pierluigi Pisu, is no less sanguine about the autonomous car. "Technologically? We are not that far," he says. Mass production, though, is still a ways off. All those sensors increase the cost of a car, to say nothing of the morass of legal and social issues that have to be hashed out. "I'm not doing anything," he says, imitating a passenger, "but the car crashes. Whose fault was that?"

He's interested in the way the enormous amounts of data being generated will improve fuel use. "We have been looking into ecodriving solutions for energy management." The car, for example, will receive information about the velocity profile of cars ahead, enabling it "to tell the driver what kind of speed he should be bounded by." Congestion ahead? Slow down now, rather than when you get there. And if you pass a wreck, keep up your speed—to avoid the gawker's delay. This will improve flow on the road, reduce congestion, and increase fuel economy by avoiding unnecessary acceleration and deceleration. The challenge, he says, "is large-scale deployment."

The data generated have to be managed either by some supercomputer at trustworthy agencies like departments of transportation or distributed to the cars themselves—"and that's only possible if the OEM decides that is something that

Ashley N. Jones

DRIVEN BY DATA

Pierluigi Pisu says technology has brought us very close to autonomous vehicles—cars that drive themselves. But the sensors and computing power required to operate a moving vehicle and to manage its safety, road fitness, and fuel economy are expensive and complex. "It requires deep knowledge of what the data mean," he says.

brings in additional benefits" so the customer will pay for it, Pisu says. "It doesn't make sense to design a beautiful car that nobody wants because it's too expensive."

Pisu is also working on vehicle diagnostics and prognostication of vehicle life—taking vast amounts of data about when parts wear out, what symptoms indicate a serious problem, and notifying drivers "before they happen, or before you get stranded somewhere." This involves more than just noticing that a timing belt in a certain car tends to wear out at 90,000 miles and notifying the driver at 85,000. It's more like seeing your gas mileage has dropped and recognizing from the behavior of similar models that you may need a valve job that will prevent engine failure.

"It's like big data," Pisu says, "but it's not the same—it requires deep knowledge of what the data means."

Everything works together, of course. With good data, cars drive appropriately, which improves road throughput, which improves car performance, which improves fuel efficiency. That interconnectivity is something Zoran Filipi thinks about all the time. If you avoid congestion by slowing cars down, "have vehicles travel forty-five miles per hour instead of sixty-five, but keep them moving, then you have achieved a lot for you personally, and you help with safety and save energy, and you've achieved a lot for society."

But Filipi saves his deepest love for the powertrain. "Let's talk about the beating heart of the vehicle," he says, grinning. Clemson's Department of Automotive Engineering has five faculty members devoted to drivetrain cardiology. If that sounds like a lot, remember something most eighteen-year-olds once knew: There's an awful lot to tinker with in an engine.

Filipi figures what's coming next for automobiles is "a very advanced gasoline engine with direct injection and possibly lean-burn combustion. Coupled with a transmission with a high number of gears—eight, nine, ten—and possibly a modest level of electrification." Think a small electric motor and a small battery, meaning the car could recover braking energy as current hybrids do without hauling around very heavy motors and batteries. Synergy will magnify the benefits of individual technologies to levels required by CAFE 2025, but without excessive cost.

To explain the work focused particularly on internal combustion (IC) engines, Filipi talks about research on a smart engine that he and his colleague Robert Prucka are carrying out. As new technologies become available, the number of variables to control becomes larger—for example the amount of fuel, the timing of when fuel enters a cylinder, the possibility of multiple injections of fuel, boosts in cylinder pressure, exhaust gas recirculation, and so forth. As complexity increases, advanced algorithms are needed to orchestrate the actions of multiple actuators in an optimal way.

The more you can control, the more complex the problem becomes, Filipi says, and the problem becomes intractable with traditional approaches. Instead, physics-based models can make the controller smarter and allow it to adapt as necessary. That's the only way to realize the full potential of the modern hardware.

More, in every cycle, literally, CU-ICAR must please three masters. One is emissions regulation; the second is efficiency. "The third, and maybe the most important, is you, the consumer," Filipi says. "Driver perception continues to be the differentiator." You like how the car accelerates, how rapidly the engine adjusts to changing conditions, and you buy the car.

Cleaning up combustion

CU-ICAR's projects on model-based control consider multiple, often conflicting objectives and evaluate them in the advanced testing facility under real-world conditions. OEMs aren't interested in much else. So CU-ICAR has projects on improving spark ignition efficiency, pursuing both CAFE standards and the kind of engine response drivers love.

Another direction that Filipi is particularly passionate about is fundamental combustion research. CU-ICAR explores even the notion of internal combustion, gasoline or diesel. A car with a traditional spark engine remains cheaper and cleaner, but diesel engines yield greater fuel efficiency. "A dream engine would marry the best features of both," Filipi says, "and give us an engine with diesel-like efficiency and clean exhaust."

So another goal CU-ICAR pursues is homogeneous charge compression ignition (HCCI). It's a sort of holy grail that will combine the mixing of gasoline and air, during the intake of a traditional spark ignition engine, with the unthrottled operation and high compression ratio normally used in diesel engines to achieve the high temperature required for the fuel to explode.

The trick is to avoid the locally fuel rich and very hot zones in the combustion chamber that normally occur when the fuel is injected late in the process, because that leads to excessive emissions of soot and nitric oxides (NO_x), the traditional banes of diesel engines. The researchers are trying to produce ignition with a homogenous "lean" charge, in which there is less fuel than the available air could combust. This would mean enough oxygen in the chamber for complete fuel burning, which would reduce soot. It also would enable the low combustion temperatures that reduce NO_x emissions to near-zero levels. The grand challenge is controlling this "uncontrollable" engine, since there is no spark to triggers combustion.

Imagine taking a piece of paper and trying to ignite it in the oven, rather than with a match. It would sit there for a while, until finally bursting into flames and turning to ashes in an instant. "Our job," Filipi says, "is to predict that point for gasoline, and to control the thermal environment in a way that will allow reliable ignition."

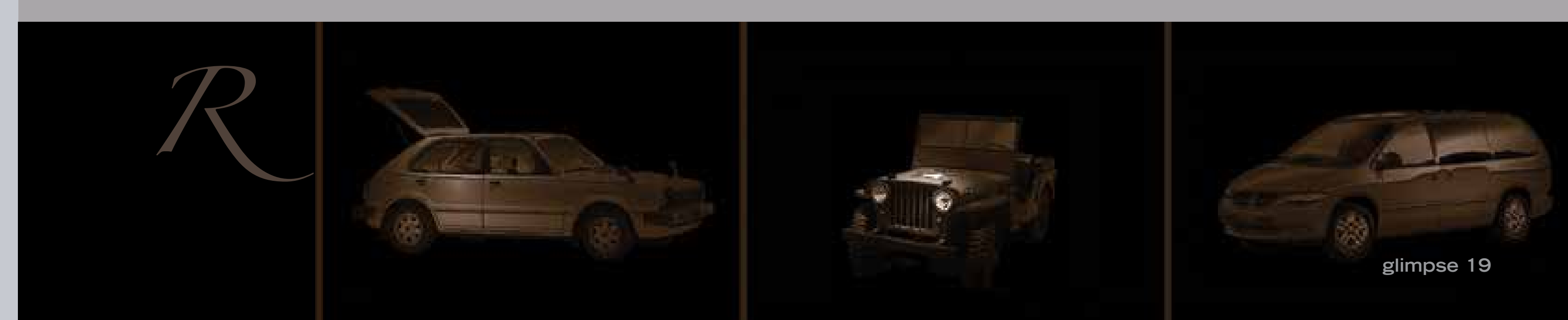
Ashley N. Jones

RETOOLING THE TOOLS

Laine Mears develops ways to machine new materials for the next generation of vehicles. The goal, he says, is to make manufacturing plants as nimble as the cars need to be. "The car I'm building today is not going to be the car I'm building tomorrow," he says.

Left: Vassilis Bardis, a Ph.D. graduate research assistant, helps Mears investigate how tools react to different materials in manufacturing.

Ashley N. Jones



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GREENER AND LIGHTER

Srikanth Pilla uses this big green machine (a supercritical fluid-assisted microcellular injection molding machine) to fabricate structural foams from environmentally benign gases, creating seat panels, dashboards, and other parts that have greater strength with less weight than conventionally molded components. In bioplastics, bacteria can help build a car and shrink its carbon footprint.

Left: Kelly Krumm, an undergraduate research intern, and Sohil Shah, a master's student, work with Pilla to set up a vacuum infusion process to fabricate thermoset composites reinforced with natural fibers.

Another challenge is achieving this over a wide range of conditions. On its way to this ideal, CU-ICAR is part of a project undertaken with the National Science Foundation (NSF) and the Department of Energy (DOE) called the Partnership on Advanced Combustion Engines.

Filipi says that, among other things they're looking into, different ceramic coatings on pistons could enable the engine to manipulate the temperature within the chamber. That would increase the combustion efficiency and expand the range of HCCI operation. Outside of that range, the engine could revert back to spark ignition operation. So an engine that can run as both diesel and spark could use spark ignition going uphill, passing, or pulling a load, and the HCCI combustion for cruising, which constitutes most of our driving.

Filipi says where it ends up is anybody's guess. "I can predict that there will be different end points and different paths chosen by different car makers." One OEM will adopt spark ignition with turbocharging and downsizing, and another will pursue lean-burn or straight HCCI. Add in electrification of the drivetrain, and the beating heart of the car grows even more complex.

The beauty of the times we live in, to be sure.

The move to a pure electric propulsion system has not yet become a reality primarily due to the weight and cost of these motors and batteries, Filipi says. Trip uncertainty too plays a role—drivers are fearful they'll run out of battery power with nowhere to charge up. So CU-ICAR's Simona Onori studies various battery chemistries and the impact of different battery cycling patterns on battery aging. Since harsh duty cycles lead to quick battery degradation, understanding the aging mechanisms and development of control systems capable of avoiding harmful conditions can lead to smaller batteries and greater market acceptance—while still ensuring desired system performance.

Trying to wrap your mind around drivetrain variables manages to make advances in materials technology seem welcoming by comparison. Srikanth Pilla, who works with composites, explains how advanced materials will, again, solve multiple problems. Pilla has literally written—anyway, edited—the *Handbook of Bioplastics and Biocomposites Engineering Applications.* The only way to reach federal CAFE standards, he says, is by lightweighting.

On the metallic side, CU-ICAR engineers are looking at increased use of aluminum and even at what Haque calls industrial origami. This involves building nonstructural parts of the car from thin sheets of aluminum, which are scored by lasers and literally folded into form.

A compostable dashboard

Pilla, though, focuses on bioplastics: biologically based thermoplastics and thermosets. Thermosets are composites that possess superior strength and stiffness but are neither recyclable nor biodegradable. Thermoplastics, on the other hand, are recyclable and potentially biodegradable. Bioplastics are carbon neutral—that is, the plants or microbes on which they are based absorbed at least as much CO_2 during their life cycle as the process of component manufacture emits. Thus bioplastics improve sustainability without compromising component performance.

Biobased thermoplastics have been created, but most currently available are based on sugars, which usually come from corn. Much current research pursues the creation of these materials out of non-sugar-based materials: "We don't want to snatch away food from the current generation," Pilla notes, "to provide sustainability for future generations, right?" Processes have been created to control the diets of microorganisms, causing them to synthesize the oils needed to create biobased polymers that can serve as the base of thermoplastics.

Pilla works—currently using sugar-based polymers—to create thermoplastic structural foams using techniques to reduce component weight without sacrificing such properties as strength or durability. As more non-sugar-based polymers become available, he can create thermoplastics for things like seat panels and dashboards that will be compostable, non-food based, and lighter than current composite materials. To do so he's pioneering a technique called supercritical fluid-assisted injection molding, which dissolves gases into the thermoplastic much as carbon dioxide is dissolved in soda. By decreasing the pressure during molding, Pilla allows the gas to expand, forming bubbles—called cells—within the molded piece (not at the edge, because the mold cools faster than its contents, forming an even surface you can rest your coffee cup on).

Microcells are micron-sized bubbles. Using special equipment he has recently purchased, he is introducing processes to make even smaller cells—nanocells—that will further reduce component weight without sacrificing strength and durability.

"I was able to achieve a reduction of almost 20 percent" in comparison to conventionally fabricated plastic components, he says. He hopes to get to 35 percent.

More detail?

"I have to stop there," he says, apologetically. Clemson has applied to host an institute of the Obama administration's new National Network for Manufacturing Innovation. For the time being anything else he says is secret.

Which is something you have to get used to hearing when you're at CU-ICAR. Paul Venhovens offers a guided tour of the classroom in which current graduate students are creating a car design. He offers, that is, with a caveat: "if you promise not to write anything about what you see on the Toyota project."

Okay, the Toyota project.

Venhovens leads the students through what CU-ICAR calls Deep Orange (*see "Introducing Deep Orange 3," Fall 2013,* Glimpse), a two-year project in which each entering class of automobile engineering graduate students works (in partnership with transportation design students at Art Center College of Design in California) with an OEM, designing a car.

"They don't build *any* car," Haque reminds you. "They build the car they determine is going to be for a given sector of society."

Students met with particular manufacturers to identify the OEM needs. That includes Toyota for the project Venhovens chastened me about and General Motors for a project students showed me certain aspects of, though not the parts for which they are applying for patents. For Deep Orange 3 (*see "Firing Up a Cool Hot Car," Spring 2012,* Glimpse) the students worked with Mazda to develop the car that greets you as you walk into the CU-ICAR lobby.

Sometimes the OEM needs a vehicle to provide mobility to the elderly, say, or one that will appeal to families. Then, with regular meetings, the students go through every aspect of vehicle ideation, concept, branding, and value—and then build the car themselves.

"I would call it almost the art of systems integration," Venhovens says. "It's really on a much higher level than understanding the systems of a combustion engine."

He leads them through the entire process of understanding not only the needs and wants of an OEM and its potential customers but a sense of where society is going, and coming up with a value proposition that they have to execute and build.

"We start from a white sheet of paper," he says. The students

Neil Caudle

HELP BEHIND THE WHEEL

Johnell Brooks finds ways to keep people safe on the road. Her simulator (below), with its realistic road scenes, enables drivers who are adjusting to injury or age to learn new skills before they try them in traffic. Human factors also guide the engineers who design new vehicle systems.

Neil Caudle

don't have a legacy manufacturing plant they have to think about depreciating, and they don't have to worry about old capital investments. And it's not just the students who benefit through this process, he notes. "We really *should* start with a white sheet of paper—to expose the world to different thinking."

And if you think it borders on the arrogant to claim that the automotive world should have access to the thinking of Clemson engineering students, step into the Systems Integration Laboratory and meet Chris Berry, assistant project manager for Deep Orange 5.

Sponsored by GM, Deep Orange 5 gave the students "the project to develop an urban mobility solution for Gen Y and Gen Z for the year 2020," Berry says, turning away from a group of standing desks and computers to face you.

"We're actually developing a vehicle for people who right now are age nine to twenty-four," Berry continues. "We've been challenged to create a vehicle for people living in megacity locations like New York or LA, a vehicle that really fits the needs of their daily life."

That is exactly what Chris Berry sounds like when you stop him unprepared as he walks by.

The lab feels more like a job site than a study hall. Computers and desks, to be sure, but also a getting-there version of Deep Orange 5, hood open, wires and components splayed. (Don't, by the way, point a camera.) Students climb step ladders, bend metal on jigs, use drill presses and band saws—all students, of course, wearing Clemson orange. A sign showing how many days are left until the car has to be ready for presentation to its OEM partners brings the concept of deadline home in a decidedly noncollegiate way. You're not likely to call General Motors the night before the project is due, explain about your grandmother's funeral, and ask for an extension.

A circle of fictional friends

Berry and his cohort have designed a vehicle called the Chevy Circle, based on the needs of two fictional personas they created. Berry explains, "They're not real, but they're real to us." The young man, Daniel, is in the service. The students have photographs of him and five pages of what his life is like pasted on the walls of their work space. The young woman, Sarah, is an intervention specialist and has about the same amount of fictionalized characteristics. Photos taped to a window show her on the beach, with her dog, as well as in costume with her equally fictional boyfriend as a peanut butter and jelly sandwich.

"We get the information we think is important to us from market research, and even YouTube videos," Berry says. "Even listening to people from these megacities discuss their daily lives."

The students brainstorm and come up with concepts. In this case, they created the Chevy Circle. You can be told that the entire inside of the car is reconfigurable into everything from a gaming station to a space for relaxing. Venhovens talks about addressing the needs of the person sitting in a car eating lunch, parked beneath a tree, sweating, or stuck in traffic looking for something to do, or getting some work done between two meetings.

Deep Orange 5 tries to address those concerns—as well as other elements of the lives of "Daniel" and "Sarah." They work all day—since the car may be sitting on the street, maybe it can be a drop box for products ordered online and delivered, so packages don't have to sit on apartment steps. Maybe the Chevy Circle should have a way to carry a bicycle without folding it up or taking it apart.

You can't be told much more; for some of its concepts Clemson has applied for patents, and the others should be shared with GM before anybody else. That's how it goes around CU-ICAR. But remember: Nobody loses track of that customer, the person who has to buy the car for the entire enterprise to make any sense at all. That takes more than just

CU-ICAR

OPEN TO THE BRIGHT IDEA

Above: Deep Orange 4, with flexible cargo space and a sporty design aimed at a niche market of performance-minded SUV customers, debuted August 4 at an industry briefing in Traverse City, Michigan. Sponsored by BMW Manufacturing Company, the vehicle is based on the BMW X3 reconceived by Clemson students, who developed a cost-efficient manufacturing plan detailing how a low-volume model could be assembled without disrupting existing BMW production processes.

"The ability to integrate more low-volume models without incurring capital-intensive retooling costs and efficiency losses will be key to success in the future as we strive to respond to changes in market needs faster and with more flexibility," says Rich Morris, vice president of assembly, BMW Manufacturing. "The students working on this phase of the project did an excellent job of keeping costs down while finding optimal integration opportunities."

Right: Paul Venhovens leads the Deep Orange program. His students' next project, Deep Orange 5, in partnership with General Motors, is under way and under wraps at the CU-ICAR lab. "We start with a white sheet of paper," he says, "to expose the world to different thinking."

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pages of description, photographs, and YouTube videos.

"We make them dress up in pregnancy suits and aging suits and make them think about that," says Johnell Brooks (*see "Drive Able," Spring 2013,* Glimpse), whose research focuses on aging and driving independence. "They wear glaucoma glasses. It makes them think about people who are not like them."

At the end of the Deep Orange process, reality steps in. Laine Mears, whose specialty is automotive manufacturing, talks about coming up with fabulous concepts—and facing down the reality of investment in current manufacturing equipment, the limits of existing infrastructure, and a completely different kind of inertia than the one a car experiences going around a curve.

Everybody knows carbon fiber vehicles would be strong and light, Mears says, "but we're not going to see carbon fiber vehicles driving around. The material's too expensive and the manufacturing infrastructure just isn't there." Same thing with aluminum cars. Long term? Sure. Short term? Not so much.

Mears continues, "Steel is where the industry grew up. We have press tooling sets that cost a million dollars. So what are you going to do with that. Going to throw it away? Can't use it on aluminum. Do I throw away those hundreds of robots that I have?" And don't even bring up the hydrogen fuel cell economy that has so far never emerged.

The goal, Mears says, is a new generation of plants as nimble as the cars need to be. "The car I'm building today is not going to be the car I'm building tomorrow. So why not set up the new manufacturing infrastructure to be not so rigid?"

In a typical meeting between designers and manufacturing, he says, the designers create a wonderful product and then go through a Design for Manufacturing (DFM) process during which manufacturing "degrades the design" based on its own limitations. "I have been to presentations at very large companies where the designers were very proud, 'We only had to degrade the design by ten percent!' [because manufacturing says,] 'Okay, they can't make that and you can't do that.'"

Mears smiles. "I love hearing the word 'can't' because that means research."

In his current research on formalizing pieces and functions of manufacturing processes, Mears says he's trying "to design a set of tools that allow designers to say, 'I can't make this, DFM told me this, but if I wanted to, what are the pieces of different manufacturing processes I might be able to bring together?'"

The DFM concept asks designers to keep in mind the manufacturing capabilities of the companies they work for. "Well, what about manufacturing for design?" Mears asks. "I'm not saying manufacturing must adapt itself to the ideas of crazy designers. But MFD is maybe a new way where we allow the designers to push back. Otherwise we're going to be incremental."

And as Haque and Filipi love to point out, incremental simply isn't fast or aggressive enough. Not that anybody actually knows what the future is—which is the entire point of Venhovens' (and CU-ICAR's) focus on starting, regularly, from a blank sheet of paper.

"We don't know the answers," Haque says. "It is very difficult to predict the future."

But CU-ICAR isn't trying to predict the future—it's trying to design cars to fit the future as it emerges. Cars that use not just new materials but the best-designed, lightest, strongest new materials that do as little harm as possible to the planet, and are manufactured in ways that respond to even newer materials. Cars that use gas and electricity and anything else, finding every possible way to squeeze the most motion out of the least energy. And cars prepared to be offices and lounges and bedrooms and whatever else the current crop of futurists can't even imagine to suggest, because as Haque says, futurists tend to be wrong.

Most of them, anyway.

Catching the Jetsons

Perhaps the place to stop is with that flying car George Jetson drove too fast. Descriptions of the new world of autonomous cars picking people up and transporting them in a traveling living room, passengers effortlessly flipping their games and videos onto the car's screens, may have seemed amazing enough. But then take one last visit to the office of David Smith, who admits that, apart from company-specific cars that could transform retail, he's got one more pet project.

"I guess the one other thing I haven't given up on is flying cars," he says, removing a little green 3-D printed model from his desk and demonstrating flight. The model is about the size of a Hot Wheels. "This would be how you would end up taking long-range travel in the future."

The model he's holding is a tilt-rotor car that would be "fully roadable," designed by Terrafugia. Website motto: "We make flying cars."

"We've done some modeling for them," he says. "But it's fully autonomous. So that trip to Disney World I'm talking about, maybe it's two hours in one of these. But all the interior stuff is just the same."

Maybe, maybe not; the DFM pushback alone would be fierce. On the other hand, it's the renaissance, and you get a lot of good ideas during a renaissance, and once they get up to speed, they move pretty quick.

All right, buddy, where's the supernova?

Zoran Filipi is the Timken Endowed Chair in Vehicle System Design. Imtiaz Haque is executive director of the Carroll A. Campbell Graduate Engineering Center at CU-ICAR and founding chair of the Department of Automotive Engineering. Paul Venhovens is the BMW Endowed Chair in Automotive Systems Integration and a SmartState Chair, South Carolina Center of Economic Excellence. David Smith is an assistant professor of automotive engineering. Pierluigi Pisu is an assistant professor of mechanical engineering. Srikanth Pilla is an assistant professor of automotive engineering. Johnell Brooks is an associate professor of automotive engineering. Laine Mears is an associate professor of automotive engineering and a member of the Center for Emerging Technologies. All are in the College of Engineering and Science.

Scott Huler (scotthuler.com) is a writer based in Raleigh, North Carolina, whose work has appeared in such publications as Scientific American, Slate, *and the* New York Times. *He is currently at work on his seventh book of nonfiction.*

Image courtesy of Spartanburg County Public Libraries

Leasing convict labor was a common practice in the post-war South. Above: At Camp Wadsworth in Spartanburg, South Carolina (photo 1910–1919), the U.S. Army Corps of Engineers used convict labor to grade Snake Road. Below: An early twentieth-century photograph shows convict laborers in Florida.

Wikipedia

CONVICT LABOR

Rhondda Robinson Thomas opens the record to find those who helped build a campus and a state.

by Jemma Everyhope-Roser

Clemson campus possesses the elegance of the modern blended to the stateliness of the historical. The concrete columns stand Grecian above a reflection pool. Oaks stud the green swathes of lawn. Squirrels chitter at sunbathing students. The electronic bells in Tillman Hall's clock tower chime "Under the Sea" in the humid air.

More than the distant drone of the cicadas, the named buildings around us hint at Clemson's origins as a Southern institution. Calhoun. Clemson. Tillman. Thurmond. Strode. Hardin. Bowman. But other names don't stand in bronze outside of brick-and-granite buildings. Wade Foster. Frank Taylor. Andrew Williams. Gabe Anderson. Jack Givins. There are about six hundred more where those came from.

If you're wondering who these individuals were, you're not alone. Rhondda Robinson Thomas, associate professor of English and a literary historian, wants to find out. But before we dive into the detective work (see sidebar, page 28), let's steal a page from H.G. Wells and travel back in time.

When the Americas were young to the colonials and old to the Native Americans, Cherokees walked the tracts of longleaf pine forests. The village of Essennaca stood but one mile from our modern-day campus. The Cherokee fought for the British in the American Revolution, attacking the Scots-Irish colonists in Fort Rutledge. After the war, the Reverend James McElhenny, rector and slaveholder, bought the land and expanded it to make Clergy Hall. Seventeen years later, Floride Calhoun purchased it. In 1825 John C. Calhoun, a slaveholder and the vice president of the United States, rented the land, renamed it Fort Hill in honor of Fort Rutledge, and ran a plantation on its grounds. Eventually, the estate went to Calhoun's son-in-law Thomas Green Clemson in 1875. By 1886 Clemson had drawn up a will to establish an agricultural college in Upstate South Carolina.

1886. Almost twenty years after the end of the Civil War, the North had tired of Reconstruction. The South, still devastated, could see its loss echoed in shattered buildings and shoddy infrastructure. Slowly, ex-slaveholders and opportunistic businessmen developed systems to utilize the massive labor force of emancipated blacks. Sharecropping. Peonage. Convict labor.

That's what piqued Thomas's interest. She says, "I wanted to better understand how the legacy of slavery played out in the use of convict labor in South Carolina."

As a source of revenue, the states leased convicts in groups to various industries. Convicts worked in mines, loading up tons of coal by the day. Convicts built roads, railroads, and bridges. Convicts molded bricks, harvested crops, and drained sap from trees to make turpentine.

How easy was it for a business to lease a group of convicts?

"Very easy," Thomas says. For a minimal fee, a business could rent men and boys, as well as women and girls, from the state, then pay for food, board, and transportation. It cost a fraction of paying a fair wage to free citizens. Legally, Thomas says these individuals were slaves of the state.

Thomas wants to be clear: "This wasn't an invention of the state legislature for Clemson. The trustees took an opportunity to participate in a system that was pretty pervasive—and normal, frankly, in the South after the Civil War."

When Thomas first came across references to convict labor being used to build Clemson University, she envisioned hardened men. But, after uncovering her first cache of data,

Patrick Wright

Rhondda Robinson Thomas learned that it was "very easy" for businesses and institutions to lease convicts for labor.

Thomas discovered that the convicts weren't only men but also included boys as young as twelve. The nineteenth century didn't have a juvenile court system, so adolescents were lumped in with sixty-year-old men.

What was more, the laws changed constantly, heightening offenses that are now misdemeanors to the level of felony. Many convicted men and boys pressed into labor at Clemson had been charged with theft. Thomas explains that these thefts were often petty. "One little boy stole women's clothing. What's he going to do with women's clothing? He's likely going to take it home to his family. So you see them stealing things that they needed."

Thomas calls these "crimes of desperation." At the time, much high-wage labor was forbidden to blacks, resulting in a culture of poverty. Like many communities with a large unemployed labor force, these men and boys did what they had to in order to support their families. Thomas says, "If you don't have work, if you don't have money, if you're living in a culture where it's very dangerous just to walk down the street if you're a person of color, then you see some very desperate people trying to survive because the conditions in South Carolina were just so dire for African Americans at that time."

For most people, Thomas says, their interest becomes keen when they hear of the youth of many of the convict laborers who worked to construct the Clemson campus. The labor was hard; the living conditions harsh.

The convicts lived in a stockade, located on the site of the current Strom Thurmond Institute. Strom Thurmond himself stands as a figure that embodies much of South Carolina's complicated history. An avid proponent of segregation, the politician had a daughter he did not publicly acknowledge, Essie Mae Washington, by his family's black maid, Carrie Butler. Now a nonprofit policy research facility at Clemson bears his name.

Although Thomas knows the location of the stockade, she hasn't found records that indicate the conditions for Clemson's stockade in particular. In stockades in Columbia, South Carolina, dysentery and tuberculosis ran rife among the men, slaying nearly one in six. In a camp in Edgefield County, the men slept on vermin-infested shelves and suffered from scurvy. Stockades, unheated and primitive, barely protected the men and boys from the elements.

"I have lots of questions about the conditions," Thomas says. "Were they segregated racially? Were they segregated by age? Because there were some fairly young boys, thirteen-years-old, mixed in with convicts who were in their sixties and fifties, both black and white."

Unfortunately, Thomas has not yet dug up the document that would tell us more about how these men and boys lived on day-to-day basis. And, although she is aware that after a few escapes early measures were taken to secure the convicts, what those were, she just doesn't yet know.

In the early years, the grounds of campus were forested, so the convicts cleared the land before they built. They erected a dike. Since Clemson was an agricultural station, the convicts also planted and harvested the crops. As Thomas says, "Any kind of labor that had to be done for the erection of this college was predominantly done with convict labor."

When I comment that it seems like the convicts were involved in building nearly every historical aspect of campus, Thomas says, "Yes, they were."

The convicts molded a million bricks—bricks that now make up Tillman Hall, which is yet another historical site on Clemson that embodies Southern history.

When Thomas teaches literature classes, students often know Tillman Hall but are unfamiliar with Benjamin R. "Pitchfork Ben" Tillman as a human being. Thomas says, "So I'll usually stop class and say, 'Pull out your phones. Google him.' And my students will go to websites and start reading descriptions of Tillman. He was a racist politician. No doubt about it."

But here's what intrigued Thomas about Tillman: He responded to personal pleas from African American convicts who met him on his visits to campus. He also acceded to political pressures, as when a jury of prominent white citizens begged lenience for an African American convict who'd murdered a man attempting to abduct his wife. In his role as governor, Tillman was the architect of Jim Crow but he was also beholden to his constituency on some matters.

Men of contradictions

Thomas believes it's important when looking at a figure like Tillman to keep in mind his complex, contradictory nature. "On the one hand," she says, "he sets in motion the laws that really set South Carolina back, almost resetting them to the time of slavery as far as African Americans are concerned. But on the other hand as governor when it comes to the pardon he responds favorably to some African Americans as well as to the pressure of politics."

When faced with these facts and overwhelmed, people will say to Thomas, "Well, take the names off the buildings then." But she says outright: "I do not want that, except in cases where buildings have been renamed, especially Tillman Hall. I don't believe Clemson should have its most prominent and recognizable building named in honor of a politician and trustee who was an avowed white supremacist."

Yet Thomas is careful to say that what she wants is recognition and balance for all involved in Southern history. "Most institutions in the South have a fairly complex history as far as African Americans are concerned," Thomas says, "and that's my area of research so that is what I focus on the most." But she's also interested in recovering the local Cherokee history as well.

As for what kind of labor the convicts did: Hard might be an understatement. Because the convicts did not have "resale" value in the way that a slave would, overseers had little reason to preserve their health or look after their wellbeing. Some overseers could—and did—work the convicts past exhaustion and into death.

"I stress," Thomas says, "that Clemson isn't unique in using convict labor or in having conditions that led to the deaths of convicts. It was pretty brutal work."

At Clemson, the convicts did a huge variety of labor, some less dangerous—and some more. Thomas has been able to document the death of one convict because it was recorded in the S. C. *Department of Corrections Central Register of Prisoners* after the man died in a mud cave-in, likely while building the dike.

"The value of African American rights was not as it is now," Thomas says, "so if someone died on a worksite they were often put in an unmarked grave. There didn't seem to be any effort to have a funeral, to have a marker, to contact family. That just wasn't done."

The exact location of the Clemson gravesites for the convicts remains unknown.

When I hear of the unrecognized graves on campus, the question of a memorial comes to mind. When I ask Thomas about that, she says, "It's a community decision. My goal is to initiate a conversation about how we should acknowledge our complex history."

But she does hope that if a memorial is created, it will include details about why men and boys were caught up in the penal and convict labor systems at the end of the nineteenth and early twentieth centuries. She would like to put a face to the name of each convict. She knows individuals who would be grateful to have their ancestors' contributions to Clemson included in Clemson's story.

However the Clemson community decides to pursue this discussion, Thomas says that she hopes "we will be courageous in our efforts to uncover and talk openly about the full story and to preserve it for future generations."

Close reading for clues

Thomas's fascination with the convicts who built Clemson began shortly after her arrival at Clemson in 2007. When she read university historian Jerome Reel's *The High Seminary,* a history of Clemson, she found several mentions of convict labor. The more she encountered the word "convict," the more curious she became.

"I was interested in the human face of the convicts," Thomas says. "I wanted to know their names. I wanted to know their ages. I wanted to know as much as I could about them as individuals and as human beings."

With a host of questions, Thomas inquired at Clemson's special collections but found only a few letters between the trustees and the State of South Carolina, as well as annual reports written by the trustees. The information she did find resembled databases, citing numbers of convicts and food expenses.

But Thomas wanted more than the numbers—she wanted to know who these men were. So she contacted the state penitentiary office in Columbia. Unfortunately, their records didn't go that far back, but they did refer her to the state archives.

Writing to the state archives, Thomas received an email reply within twenty-four hours. Thomas says, "When the archivist said, 'We have names, we have ages, we have where they're from, we have their crimes, their court dates,' I was like, 'Oh, wow. This is what I've been looking for.' And that was the first glimpse I got of who these men and boys were and why they ended up at Clemson."

Thomas has been able to locate a few of the men and boys in the census, so she's tracing them in order to learn more about them. She's attempting to discover who they were before they entered the penal system, and where they went after they left it. Newspapers with obituary columns will help Thomas track down these men and boys' families. She's found a few. Exploring family records and oral histories will help her uncover their identities.

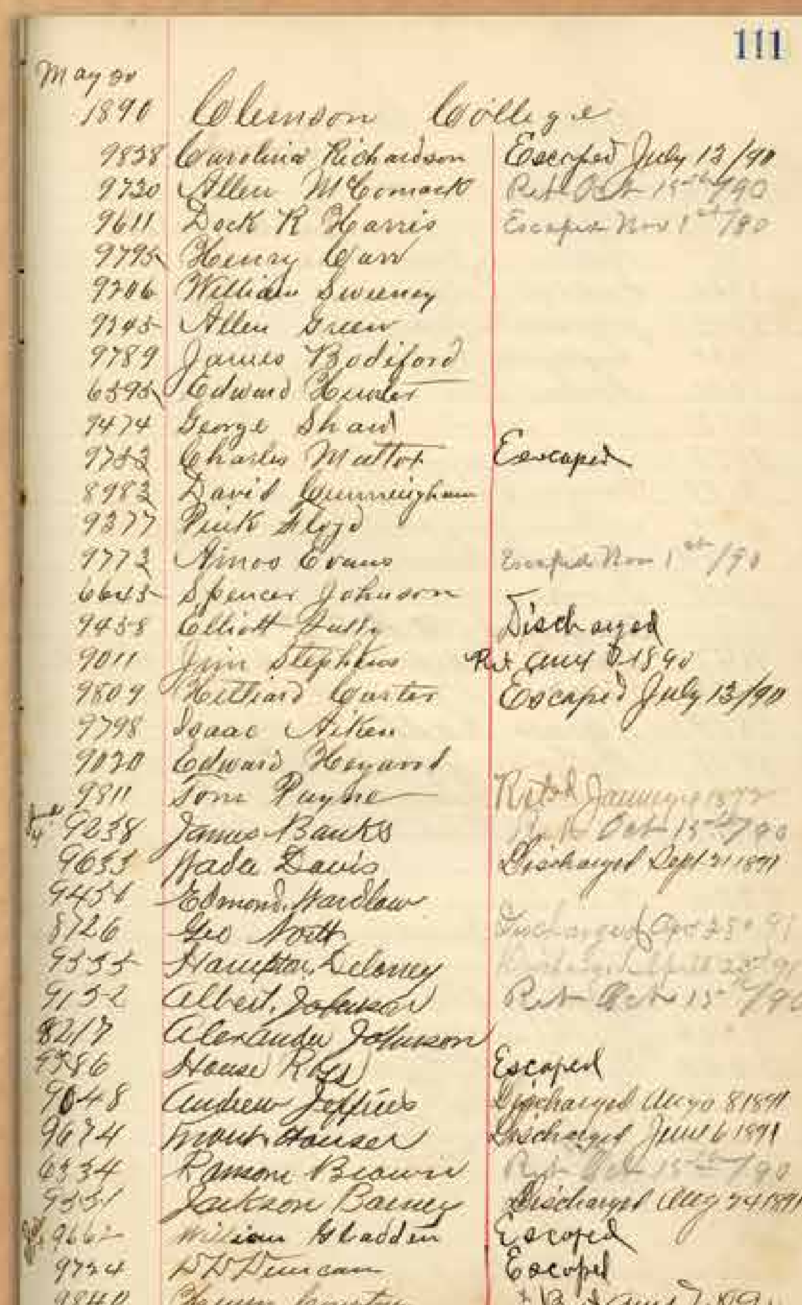
With nearly 600 men and boys listed on the farm and contract registers for Clemson, Thomas has her work cut out for her. "It's going to take a lot of time to track down all of these stories," she says.

Thomas will have to verify the information and try to uncover more. She'll burn gas as she travels from state to state. Then she'll wear out shoe leather roaming between county courthouses, small historical societies, and libraries with newspapers on microfilm. She'll continue going to the South Carolina archives to examine more records.

"Archival research is very hard work. It's very difficult and very frustrating," Thomas admits. "Sometimes I'm on a trail and it seems like I'm going to find something—only to have the trail go cold. Maybe a year later it becomes warm again. Someone will hear about my work and send me an email. Then it picks up again."

A trail can go cold for many reasons. Records get lost. Fires rage, reducing paper to ash. Boxes stashed in attics go forgotten, moldering. Neglected papers are shredded into mouse nests. Sometimes it's natural causes. The documents deteriorate, age returning them to dust. And, on occasion, someone will step forward and say, "Yeah, we threw those away."

Yet Thomas remains determined, saying, "I have to follow the trails."


111
May 30 1890 Clemson College
9838 Caroline Richardson — Escaped July 13/90
9730 Allen McCormack — Ret Oct 15th 90
9611 Dock R Harris — Escaped Nov 1st 90
9795 Henry Carr
9706 William Sweeney
9145 Allen Green
9789 James Bodiford
6595 Edward Hunter
9474 George Shaw
9782 Charles Mattox — Escaped
8982 David Cunningham
9377 Pink Floyd
9772 Amos Evans — Escaped Nov 1st /90
6645 Spencer Johnson
9458 Elliott Kelly — Discharged
9011 Jim Stephens — Ret Aug 1890
9809 Richard Carter — Escaped July 13/90
9798 Isaac Aiken
9030 Edward Hayward
9811 Tom Payne
9238 James Banks — Ret Oct 15 90
9653 Wade Davis — Discharged Sept 21 1891
9454 Edmond Wardlaw
8126 Geo Scott
9355 Hampton Delaney
9152 Albert Johnson — Ret Oct 15 90
8217 Alexander Johnson
9986 House Reed — Escaped
9648 Andrew Jeffries — Discharged Aug 8 1891
9674 Frank Hauser — Discharged June 6 1891
6334 Ramon Brown
9351 Jackson Barney — Discharged Aug 24 1891
9662 William Gladden — Escaped
9754 [illegible] Duncan — Escaped

A register of convict laborers assigned to Clemson College in 1890 indicates that several escaped. Source: Farm and Contract Register, 1889–1892, Department of Corrections. South Carolina Department of Archives and History, Columbia.

Sifting out the bias

Within these masses of data, Thomas faces another challenge. Many of the legal documents relating to these convicts that she's recovered so far weren't written by the men and boys themselves. Whenever she quotes a document, she always includes a caveat, stating who wrote the document. Thomas uses her training as a literary historian to sift out bias and determine distortions related to the writer's perspective. When a clerk takes notes on skin tone for the register of convicts, one person's chestnut is another's light brown.

"It just depends on who's looking," Thomas points out.

In her search to discover who these men and boys really were, Thomas says, "The only time I've gotten a hint of their voices is in a court document, when a court clerk is transcribing the voice of the person who's testifying."

But, Thomas says, "The gems are the letters from the men themselves."

Several African American convicts who labored at Clemson wrote letters to Governor Tillman for pardons. The men who were pardoned often have thicker files, sometimes containing letters from themselves, as well as supporters and detractors in their hometowns. But Thomas can sometimes hear, like a distant melody, a refrain of the men and boys' voices as they explain why they committed crimes, as they profess their innocence, as they confess at the indictment, as their neighbors tell their stories. Thomas assembles this information along with her knowledge of nineteenth-century South Carolina with the ultimate goal of telling these stories as accurately and fully as possible.

After applying her exhaustive archival detective work and her literary savvy to her findings, Thomas turns to another source of inspiration to gain understanding of these men and boys: her imagination.

"You have to think about that twelve-year-old boy," Thomas says. "He's scared. He's in this court system. The judge says, 'Can you tell me anything that will convince me not to send you to jail?' and he may be thinking, 'Here I am, without my parents, about to be sentenced and sent off to the penitentiary.' So what can he say that will change this man's mind?"

When an exchange like that takes place in a court document, imagination unites historical context with individual experience. Thomas says, "I try to gain as much insight into how to interpret those texts to the best of my ability and do right by all the participants, not just the African Americans in the penal system, but also the judges, the lawyers, the plaintiffs, and the police."

"We owe it to them."

Thomas thinks this research may take her a decade to complete. The preliminary research alone took her about two years until she found the first stash of documents, and in the last year she's devoted more attention to the project. But Thomas is up to the challenge.

"If that's how long it takes to tell this story correctly and accurately," Thomas says, "then I'll have to spend ten years doing it. I want to be true to these men and boys. We owe it to them."

In the cultural history Thomas plans to write, she wants to present the complex, contradictory story of Clemson's involvement in the convict leasing system in the South. Weaving together three strands—the building of Clemson, the history of South Carolina, and the stories of the men and boys—Thomas wants to express a fully nuanced history. But, as she says, "I want to be very up front about this. I'm at the initial stages. I expect to learn more and find more documents and stories."

She rarely shares her research at such early stages, but due to the high level of interest, she has spoken to the *Greenville News* and also written an article for the *South Carolina Review.* When she learns more, she'll make presentations at conferences or write a second essay for another academic journal. Thomas says, "As I learn more I'll be able to speak more. That's the danger of talking early about your research. I'm still trying to figure out where this project will take me."

But wherever the trail leads her, Thomas says, "The men and boys' stories are still waiting to be found."

Rhondda Robinson Thomas is an associate professor and literary historian in the Department of English, College of Art, Architecture, and Humanities. Sources of funding for her work include a Lightsey Fellowship provided by Clemson University's College of Arts, Architecture, and Humanities. Jemma Everyhope-Roser is the assistant editor of Glimpse.

Peter Kent

a sea change *in* shell science

Debunking decades of dogma, Andy Mount and his students set the record straight on how oysters build their shells.

by Frank Stephenson

Above: an oyster reef in the North Inlet of Winyah Bay, an estuary in South Carolina.

For starters, it's fair to say that the man loves oysters.

Whether on a plate or a Petri dish, the briny mollusks have captivated Andrew ("Andy") Mount since he was a kid growing up on the shores of New Jersey.

Recruited as a teen to shuck for an annual fried oyster festival at his mom's church, Mount couldn't have imagined he'd ever make his living as an oyster biologist. But he's been doing just that going on three decades now, and his work is clearly paying off. He's won a U.S. patent and has several pending applications for techniques that show commercial promise for exploiting what he's learned about oysters' most baffling secret, namely, how they build their shells.

Mount's research is slowly being recognized as the dawn of a fresh, completely new understanding of shell formation in *all* marine animals, not just oysters. The seemingly effortless way that a myriad of sea creatures build their shells still remains much of a mystery, even though it's common for oyster biologists to gloss over that fact when explaining how the bivalves grow. But what Mount and his team have discovered may hold the best clues yet about how oysters pull off one of the neatest feats found in nature.

Self-mending shells

Visitors to the Okeanos research lab complex on central campus aren't there long before they catch a whiff of the ocean. In a side room, a salty tang flavors humid air hanging over a two-hundred-gallon aquarium where dozens of large oysters, imported from the Mississippi Gulf Coast, lie in a swirling bath of cool, artificial seawater. Some are busy mending their shells, deliberately cut ("notched") to trigger their astonishing wound-healing response (see "Oyster Medics," page 37).

"This is how we begin studying shell formation," Mount says, "by notching the shells of adult oysters and studying how they heal themselves—which, I have to tell you, is quite remarkable. Our goal is to eventually study how they do it as free-swimming larvae."

Baby oysters arise from chance meetings of eggs and sperm released into the water column by beds of adults. Larvae soon develop their own internal organs, gills, and swim gear and begin building their shells while they are still pinpoint flecks of protoplasm swimming in the open sea. These dot-sized oysters soon start hunting for a hard surface—rocks, shells, pilings, and boat hulls are choice targets—where they'll anchor themselves for the rest of their lives. If they fail to find a good spot to settle down, they die.

A vast genetic repertoire

Beyond their famous culinary qualities, what most fascinates Mount and other Okeanos researchers about oysters is the power and agility of their genes. A specialist in cellular marine biology, Mount has managed to open a rare window into the complex world of oyster cell biology. It's a world where a vast genetic repertoire—far richer in fact than even the human genome—builds and controls an army of proteins equipped with the muscle to do amazing things.

Just *how* amazing finally came to light in 2012, when an international team of scientists led by Chinese marine biotechnologists succeeded in sequencing the oyster genome, giving science its first full genetic profile of a mollusk. Published in *Nature,* results of the two-year study revealed the complete genetic blueprint for the Pacific oyster *(Crassostrea gigas)*, the most common and commercially important oyster species on the planet.

Mount served as the team's top expert on biomineralization, the catch-all term for living organisms' immense capacity for turning carbon, calcium, oxygen, and dozens of other elements into hardened minerals for building a diverse array of bodily armament, from bones and shells to teeth and claws. Scientists have never fully understood how biomineralization works, but they do know that had the process never evolved, life on Earth would never have escaped those proverbial, primordial pools of salty water.

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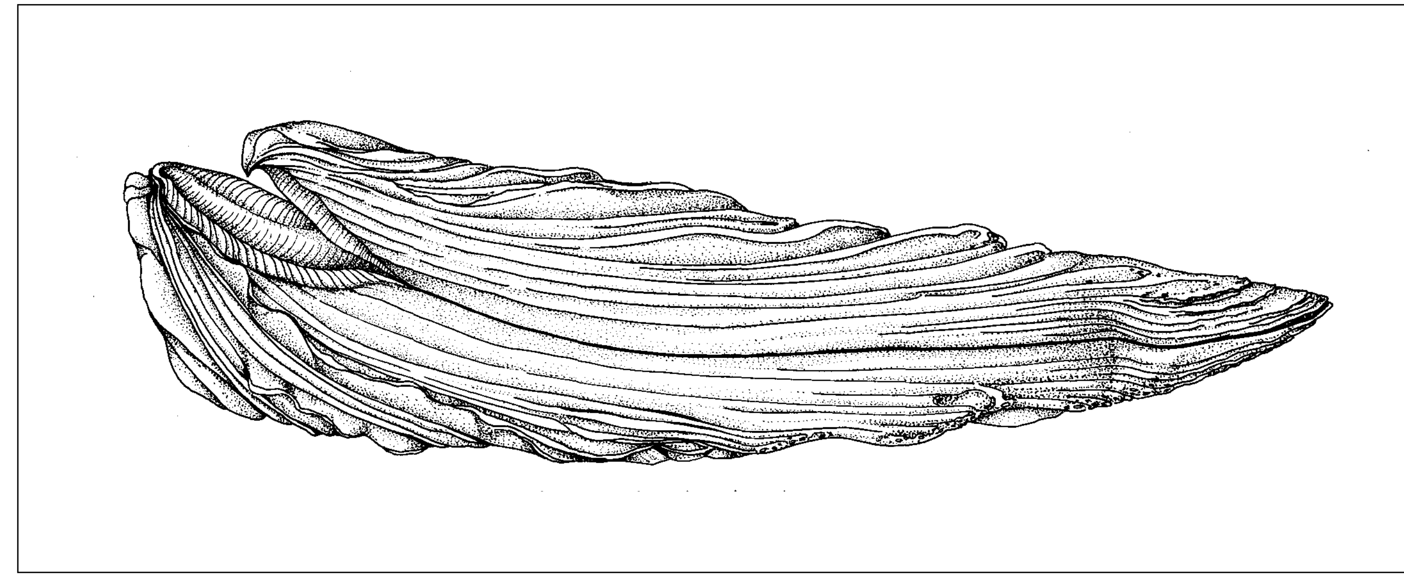
Andy Mount and his research team have found the "smoking gun," the very genes that drive shell formation. "But we're going up against seventy years of research that teaches something entirely different," he says, "and that's a tough thing to do."



For all his high-tech micrography, Mount still relies on the elegant line drawings of an earlier generation to teach basic anatomy. "We use this drawing in the lab all the time," he says. It shows a very old and large American oyster, *Crassostrea virginica,* from Stony Creek, Connecticut, and was drawn by Ruth Von Arx. From Fishery Bulletin 64, U.S. Fish and Wildline Service, 1964. Author: Paul S. Galtsoff.

As the Chinese oyster-gene study began to unfold, researchers were awed by what they discovered about the oyster's unique power to cope with life on a constantly changing Earth. Of the animal's 28,000 genes (roughly 7,000 more than humans carry), nearly a third were found to be specifically wired to help a sessile organism—an animal destined never to move during its entire adult life—survive against the unrelenting vagaries of nature. Since the days of the dinosaurs, this oyster genome has sustained an immovable, brainless blob of protein against dramatic swings in salinity, temperature, environmental toxins, and, thanks to incessant tidal flows, frequent exposure to air and sun—lethal to the vast majority of marine organisms.

Aside from its adaptive strengths, Mount would argue that the oyster genome's greatest triumph is its ability to wrap a spineless, soft-bodied creature in a hard, protective shell. To his delight, the Chinese-led analysis offered the first hard evidence that what he and his Clemson team had been saying for years—mostly to deaf ears—about how oysters build their shells is absolutely true.

"We made believers out of them," Mount says, referring to his Chinese colleagues on the study. "Finally, we were able to get people to take us seriously."

A clash of theories

In 2003, Mount's team had made a profound discovery. The researchers uncovered solid evidence that a generally accepted theory describing how marine organisms build their shells—an idea dating to 1945—was flat out wrong.

Published in the journal *Science* in 2004, the Clemson paper described the discovery of a new and highly specialized type of oyster white blood cell capable of synthesizing crystals of calcium carbonate—the chief component of shells, bones, and teeth—entirely on their own and within their own cellular compartment.

The finding clashed head on with the standard model of shell formation that had dominated scientists' thinking for nearly seventy years. The standard model holds that shell formation chiefly involves a rather strange, out-of-cellular-body phenomenon. According to the theory, when it comes time to build or repair its shell, an oyster somehow coaxes certain cells into excreting a rich, gel-like substance onto its mantle, the name for the delicate, outer layer of proteins that make up oyster "skin." This substance contains a complex matrix of organic material that then captures all the ingredients necessary for shell construction from seawater and starts synthesizing the building blocks of calcium carbonate crystals. This "matrix-mediated" process, as it's called, takes place entirely outside cell walls and runs autonomously, without any direct control from the oyster itself.

Mount's discovery countered all of that. Using innovative techniques to study the insides of live cells with scanning electron microscopes, deep within what his team subsequently realized was a new type of oyster blood cell, the team found nano-sized crystals forming inside specialized cellular organs called exosomes. Okeanos researchers witnessed what no other scientists ever had—busy intracellular factories where the "bricks" of shell construction were being made. Not only that, but the research also showed in striking detail how the bricks get carried outside an oyster's body and out to the "job site"—in other words, to wherever shell was needed, either for repair or for building an entire shell from scratch.

Normally, such a fundamental discovery would be big news

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Elizabeth Falwell, a Ph.D. candidate in Mount's lab, examines an oyster at the edge of Winyah Bay.

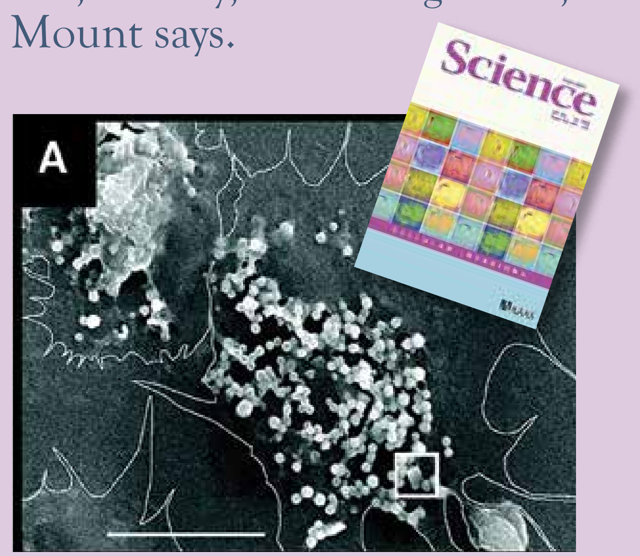
in the field of cell biology. But in this case, it was anything but. Not only did the 2004 *Science* paper fail to make a splash in the pool of mainstream thinking, Mount's observations—if considered at all—were dismissed as almost heretical. As a result, subsequent papers on the discovery went unpublished and Mount's application for a patent on what he'd found triggered flags by patent officers uncomfortable with his unconventional findings.

But the oyster genome project finally won Mount and his team the vindication they had long sought. Largely on the strength of the Chinese technologists' findings, in September 2014 the U. S. Patent Office approved a patent application covering the group's work. The patent, prepared and submitted by the university's Office of Technology Transfer, essentially gives Clemson a green light to license technology designed to create ultratough materials for industry using some of the same techniques that oysters have taken for granted for 200 million years.

The acid test

Biologists have reason to wonder—is there any limit to the power of proteins? Silently unfolding in their nanoworlds their myriad tasks, these muscular, molecular drivetrains put pedal to the metal at the drop of the first biochemical signal. Once fired up, they don't stop until the job is done, whether it's a subtle alteration in a host organism's response to environmental change or a full-scale transformation of the organism itself.

> "We see this as a fundamental advancement in the understanding of not just oysters but, frankly, of life in general," Mount says.



In the April 9, 2004, issue of *Science,* Mount published scanning electron micrographs (SEMs) revealing evidence of cellular crystal formation in oysters. In the decade since, the lab has continued to document how oyster cells make mineral "bricks" from ingredients in seawater and use them to build and repair their shells.

To transform a barely visible, free-swimming oyster larva into a rock-hard bottom dweller in just a few short weeks requires protein power of the first order. It was as a grad student in Clemson's biology department that Mount caught the fever to learn all he could about oyster proteins and, in particular, their role in building shells.

He spent six years studying proteins that he extracted by dissolving oyster shells in acid. Experiment after experiment showed the same results—the proteins seemed to be capable of cranking up the crystal-manufacturing process within individual cells. And perhaps just as astounding, these cells appeared to be crawling out of the oyster's body and transporting crystals wherever they were needed.

"I concluded that [shell formation] wasn't an extracellular process as the standard model had had it for so long," Mount recalled. "It had to be coming from somewhere else in the organism."

The *Science* article that appeared in 2004 was a breakthrough, but it wasn't enough to shake the faith of most biologists in a shell-formation model that had ruled for well over half a century. Even now, after seeing his findings validated by the 2012 oyster genome project, Mount is keenly aware that the so-called "matrix-mediated model" remains the reigning paradigm. And it frustrates him to no end.

"In the Chinese study, we found the 'smoking gun'—the very genes that drive the whole process of cellular-driven shell formation," he says. "But we're going up against seventy years of research that teaches something entirely different, and that's a tough thing to do. But the fact is, once people see these data and the images we've captured they're convinced."

From the oyster genome project, one of the most powerful pieces of evidence supporting Okeanos' work, emerged a profile done on all the animal's proteins that were known to play a role in shell building. Researchers knew that for the standard, "matrix-mediated" model to work, oyster cells must excrete proteins to build shells. But after 259 shell-building proteins were identified, fully 84 percent were found to be proteins that never get excreted at all. If most of the shell-building proteins weren't getting excreted, what was building the shells?

"They realized that the cells themselves were doing it," Mount says. "We now have the genetic proof for that whole process being cellularly driven. This means that all those biologists who stuck to the old model are in trouble."

The unobserved miracle

From one perspective, it's hard to see what all the fuss is about. Scientists have long known about and thoroughly studied examples of entirely cell-driven mineral assembly in a veritable menagerie of marine organisms.

Plankton, the diet that supports the bulk of Earth's marine life, is loaded with diatoms, foraminifera, and other microscopic life forms that build spectacular shells of infinite variety. One species of marine bacteria even makes crystals of magnetite, an iron-based mineral that the organism uses internally to exploit the Earth's magnetic field (for reasons not entirely clear).

In each case, it's a single cell doing all the work—making its own mineral "bricks" from ingredients pulled from seawater and then putting them together in bricks-and-mortar style to build their homes. The process, which mimics almost exactly what Mount has observed in oysters, is fully accepted by mainstream science.

"But when you get to a molluscan or a human system, that kind of thinking gets tossed out," Mount says. "Conventional wisdom holds that it's all done by a pre-formed organic matrix that gets pushed out of cells, and nature takes care of the rest by some kind of miracle. And that sort of miracle is just not observed by chemistry that I am aware of."

A big part of the disconnect problem, Mount says, stems from the fact that the biomineralization theory sprang almost entirely from the field of geology. Working in the 1940s, geologists studying certain rocks known to have biological origins, such as stromatolites—a marine fossil found in oceans around the world—first came up with the theory. Since then, most of the refinements in the idea also have come chiefly from geologists.

Somewhat incredibly, even though biomineralization is clearly a function of living things, Mount says it is still not being studied very much from a biological standpoint. The chief biological investigators involved tend to be oceanographers and marine ecologists, whereas the core of the phenomenon lies specifically within the purview of cell biology, Mount argues.

"What's missing in marine biology right now is that you've got people doing the pieces—doing ecology, biochemistry, physiology—but none of this makes sense by itself," he says. "The only way you can begin to understand how a system works is by looking at the problem from a cellular perspective. Once you understand what's going on in a single cell, all the other pieces fall into place. So, what's missing in modern marine biology is that cellular approach."

A paradigm shift

Despite being a latecomer to the debate, Mount is convinced that his team is leading a genuine paradigm shift in the science behind biomineralization. If so, he says that could have far-reaching consequences well beyond the realm of oyster biology.

"We're revealing a new cellular paradigm of how not just oysters but how all mollusks make their shells. We see this as a fundamental advancement in the understanding of not just oysters but, frankly, of life in general."

His point is that not only do marine organisms use cell-driven biomineralization to build shells, bones, and teeth, but that all land animals—including humans—may also be doing the same thing. Although a crystal-building cell of the type he's found in oysters hasn't yet turned up in the human anatomy, Mount believes it's entirely possible that such a cell exists. It's fun to speculate about what such a discovery could mean, he says. "If it's true that there are human cells that make crystals like this for making bones, teeth, and so forth, that could open up the prospects of bone-healing techniques that could heal bones in days instead of weeks."

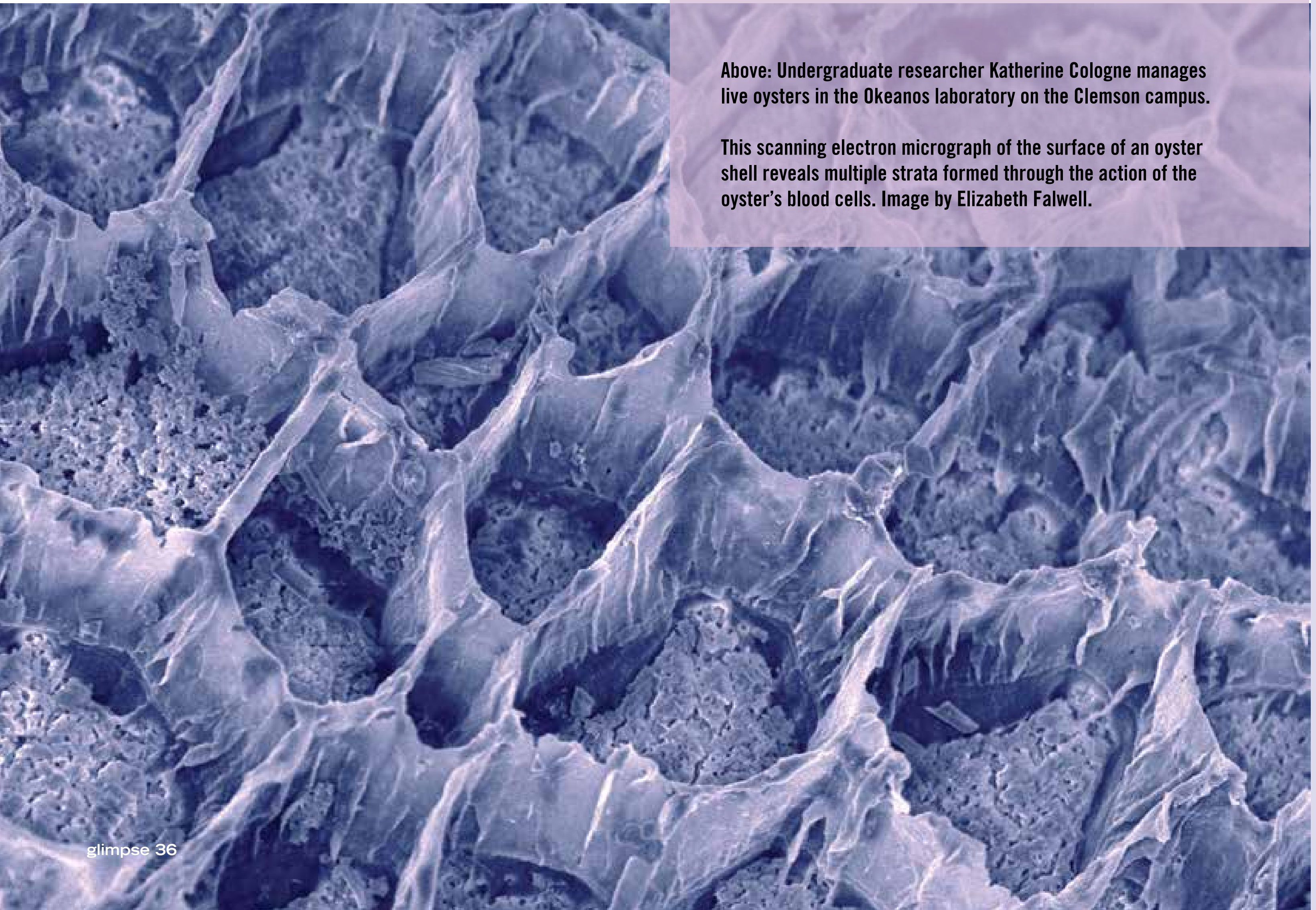
Speculation about its implications for medical technology aside, herein lies much of the impetus behind his latest patent. While yet to draw a lot of attention, the new patent is the first to describe biomineralization techniques that in theory can be taken almost directly from the lab to the marketplace. This holds the prospect of inventing whole new technologies for building stronger and more durable materials, a main reason that Mount's work has been supported by grants from the U.S. Air Force Office of Scientific Research. A top prospect is a tough new breed of ceramic, a synthesis of which Mount's patent specifically describes.

"Without question, there's tremendous potential for applications here," Mount says. "And all we're doing is looking at marine organisms from a cellular level. It's exciting to see."

Andrew S. Mount is a research associate professor with joint appointments in the Department of Biological Sciences, College of Agriculture, Forestry, and Life Sciences, and in the School of Materials Science and Engineering, College of Engineering and Sciences. He founded and directs the Okeanos Research Laboratory (www.clemson.edu/okeanos/). Frank Stephenson (blueholeproductions.com) is a writer and editor based in Tallahassee, Florida.

Patrick Wright

"The only way you can begin to understand how a system works is by looking at the problem from a cellular perspective," Mount says. "Once you understand what's going on in a single cell, all the other pieces fall into place."



Above: Undergraduate researcher Katherine Cologne manages live oysters in the Okeanos laboratory on the Clemson campus.

This scanning electron micrograph of the surface of an oyster shell reveals multiple strata formed through the action of the oyster's blood cells. Image by Elizabeth Falwell.

oyster medics

Old-style oystermen have always known about it but, as is their nature, don't make a fuss over it, or for that matter, over much of anything else an oyster does. Just part of the nature of a quiet little beast that appears to grow from nothing anyway.

Tongers—the people who use long-handled, steel-jawed rakes called tongs—know they can damage oyster reefs during periods of intense harvest. But they also know the silent beds of bivalves below them have a way of healing themselves if given enough time. As it turns out, how oysters do that is one of the great marvels in marine science.

Beth Falwell, a doctoral candidate in Andrew Mount's Okeanos lab, is a specialist in studying how oysters heal wounds to their shells. Her experiments on Gulf oysters are a key part of research that is changing scientific understanding of the curious phenomenon of shell formation in all marine animals, not just in oysters.

Falwell starts by using a grinder to cut a small notch in the lip of an oyster's tightly clenched shell. She makes the notch just deep enough to breech the occupant's internal cavity but not enough to seriously injure the animal. Then she watches carefully and records what happens, which, if written into a Hollywood movie script, might get a rise out of Steven Spielberg.

A nearly invisible army of gelatinous, amoeba-like cells soon emerges from the oyster's mantle (skin) and starts crawling toward the wound. Within a few hours, a fresh cut will be covered with these cells that stretch and pull themselves along in a manner straight out of *Transformers.*

Brick by brick

Every time she runs such an experiment, Falwell is witnessing how oysters have been building and repairing their rock-hard houses for hundreds of millions of years. Joining Mount's team in 2008, Falwell is at the forefront of research aimed at figuring out exactly how oysters—devoid of brains, nervous systems, and even circulating blood—manage to pull off this amazing feat.

In 2004, Mount's lab published in the journal *Science* an article documenting the discovery of a highly specialized oyster cell (the organism has several, and all are white) that contains an organ capable of manufacturing the basic building blocks for shell construction, nano-sized crystals of calcite, the most common form of calcium carbonate. The organ, called an exosome, contains a package of proteins fully capable of building these calcite "bricks" on demand. The research then revealed an even neater trick. To get the "bricks" to wherever they're needed, the special, exosome-carrying cells (called hemocytes) simply crawl out of the oyster's fleshy mantle and head for the "job site."

But how in the world do they know where to go? With no nerve endings (no nerves, period) to point the direction to an injury, how is it possible that this army of oyster medics can unerringly find it in short order?

"We know that some kind of signaling occurs, but what it is we don't fully understand yet," Falwell says, holding up a freshly notched oyster. "The healing response may be triggered mechanically by the vibration [of the grinding] or by some chemical pathway or maybe both."

The most intriguing clue she's come up with so far involves a powerful family of enzymes known to be involved in wound healing in a wide variety of organisms, including plants, but particularly in humans and other mammals. First isolated by biochemists working in 1962, the special enzymes are called matrix metalloproteinases, or MMPs. The key roles these compounds play in rebuilding damaged tissue have since been established and are thus considered part of an organism's disease-fighting immune system.

Picking up on research done by a former team member who isolated a promising MMP candidate involved in shell repair in 2009, Falwell has since found the compound in oyster hemocytes. When she implanted glass cover slips into oyster notches, she soon found MMP-loaded hemocytes aggregating by the thousands on the slips. Within twenty-four hours, the slip implant revealed a prominent growth of newly deposited calcite crystals. It was all she needed to conclude

Patrick Wright

Falwell notches the shell and watches the oyster repair the wound.

that MMPs play a powerful role in hemocytes' abilities to repair damaged shells.

Since then, she's found other evidence that suggests that oysters may use proteins in their mantle tissue to regulate MMPs, or to turn them on and off. Could this be a clue about how the organism knows when to order up a repair detail and where to send it? The answer lies in more research, Falwell believes.

Given the nature of molecular biology—organisms typically have a variety of ways to solve problems—chances are good that oysters have other means at their disposal to heal themselves, she says.

"I'm sure there are many pathways at work here, a built-in redundancy. But knowing at least one thing that's going on in shell repair would be cool," Mount says. *–F.S.*

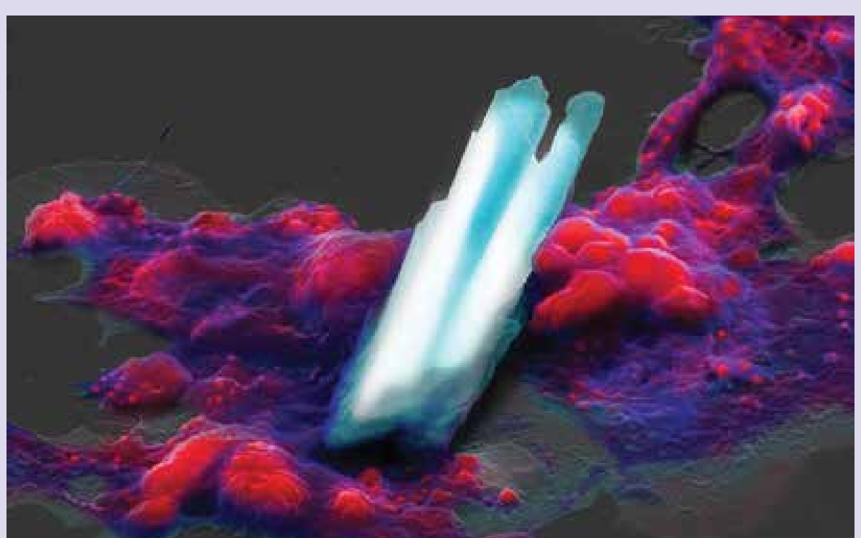
artful science

Joshua Mount, Andrew's son, has worked in the Okeanos lab. His scanning electron micrographs, colored to distinguish the features (he calls it pseudocolor), have been displayed in galleries for their blending of science and art.

"Folia" (top) shows the intricate mineral structures formed by organisms (biomineralization). The image shows shell mineral deposited onto a metal implant by the Eastern oyster, *Crassostrea virginica.*

"Cypria" (right) shows cyprid larvae of a barnacle, *Amphibalanus amphitrite*.

"Construction" (below) shows an oyster blood cell, or hemocyte, manipulating calcite crystals that will later help compose a seashell.



The Clemson University Research Foundation (CURF) is a 501(c)(3) nonprofit corporation dedicated to maximizing the societal impact of Clemson University research through commercialization of intellectual property. For more information on CURF and a portfolio of technologies available for licensing go to clemson.edu/curf.

For more on Andrew Mount's technology and patent portfolio go to curf.technologypublisher.com and search for Mount or contact CURF at contactcurf@clemson.edu.

Chthamalus stellatus by MichaelMaggs, Wikimedia Commons

no harm, no foul

How to stop barnacles from gaining a foothold on hulls and gear.

It's a problem that has plagued sea-goers since the dawn of maritime history—the accumulation of barnacles, algae, and other unwanted sea growth on their boat hulls.

Even today, despite a world of technological know-how in keeping the stuff off, mariners are still dogged by the scourge of biofouling, the collective name given to the phenomenon of boats bogged down by tenacious, tag-along sea life. Fighting the problem annually costs commercial and military maritime operations billions spent on time-eating maintenance, temporary remedies—usually in the form of applying some type of toxic bottom paint—plus the extra fuel required to run fouled fleets.

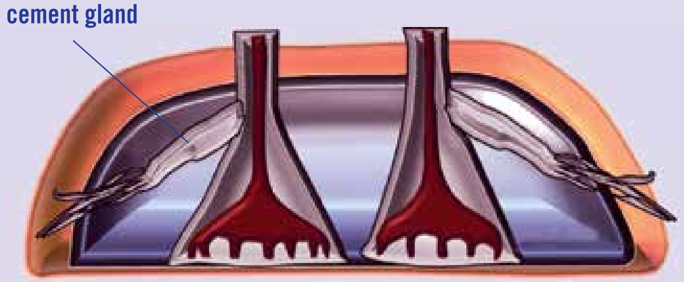
Researchers in the lab of biologist Andrew Mount say they have come up with an entirely novel approach to solving the age-old problem. Last spring, Mount's team applied for a patent on a technique that some day could revolutionize the global war on biofouling.

Steeped in research on his favorite marine organism—the oyster—in 2002 Mount ran across a paper published in 1986 by a couple of biologists working in oyster aquaculture who described a curious phenomenon. They had discovered that if free-swimming oyster larvae are given a dose of noradrenaline, a natural hormone that regulates heartbeats in mammals, they won't settle on each other. Instead, they settle out individually, where they grow up as single oysters instead of clumps of oysters fused together.

Intrigued, Mount began his own experiments that eventually caught the attention of one of his top grad students, Neeraj Gohad, who was looking for a good topic for a Ph.D. thesis. Gohad soon showed just how powerful the hormone could be in altering the oyster larvae's settling behavior. In 2005, his results persuaded the U.S. Office of Naval Research—an agency forever interested in fighting barnacles—to fund Gohad's research.

In the decade since, Gohad has used the Navy funding to refine his technique and to figure out how it works. The best news is that he's found that the technique also works against barnacles, tunicates, tube worms, bryozoans, and assorted other biofouling pests. The animals loathe noradrenaline and won't settle on anything touched by the stuff.

What all these biofoulers have in common, Gohad found, are special sensors embedded in their "feet," which their larval forms use to search for suitable spots to settle. These sensors are extremely sensitive to noradrenaline, which testing has shown to be otherwise completely nontoxic to marine life.



In the July 11 issue of *Nature Communications,* Nareej Gohad from Mount's lab proposed a new model for how barnacles attach themselves. This simplified portion of their illustration shows the barnacle's "foot" in section, with cement glands that release first a lipid and then a protein. The lipid may chase water from the surface, allowing the protein cement to do its job. The researchers have found that paint treated with noradrenaline can prevent the attachment.

A paint with promise

The patent that Gohad and Mount have applied for describes the invention of a completely new type of polymer-based bottom paint that contains just enough noradrenaline in a stable form to make the product an effective deterrent for biofouling organisms. The researchers have partnered with some private companies to develop and test various prototypes of the new compound and so far the results look promising. Much engineering remains to solve the usual scale-up problems that typically arise with any new technology, but Gohad and Mount are confident they're on the right track.

"Every marine organism we've tested is deterred from settling wherever these compounds are applied," Gohad says. "The organisms simply lose the ability to attach to the surface."

The technology also holds a decidedly "green" promise as well. Traditional bottom paints, even though highly evolved from yesteryear, still rely heavily on copper and other heavy metals as their active ingredients for repelling sea pests. Such paints wear off and otherwise leach their toxins into seawater and are thus identified as a serious source of marine pollution around the world.

"These noradrenaline compounds don't kill things," Mount says. "We see this as being particularly useful in the aquaculture industry, where fouled cages in oyster production, for example, are a major problem."—*F.S.*

SERIOUS SCIENCE, SAFER FOOD

IN THE FIGHT AGAINST FOOD-BORNE PATHOGENS, NOTHING IS OFF THE TABLE, NOT EVEN THE GROCERY BAG.

BY ANNA SIMON

Norovirus is no laughing matter.

Bathroom humor, however, is inevitable when 25 college students armed with swabs collect more than 5,000 samples from toilet seats, flush handles, sink faucets, and door knobs in more than 750 randomly selected restaurant restrooms across three states in search of the hardy virus in places where we eat.

In pairs, male and female, students posed as customers, ordered food, and surreptitiously visited restrooms to gather samples. Graduate student Chaoyi Tang says she checked bathrooms before eating and left her food untouched if the bathroom was nasty.

One student had just pulled on latex gloves when the restaurant manager walked into the men's room where he was about to take samples.

Awkward.

It's all for science, though.

Norovirus is the most common cause of food-borne disease in the United States, according to the Centers for Disease Control and Prevention (CDC). The virus is persistent in the environment and easily transmitted by infected people, contaminated food or water, or contact with contaminated surfaces. Symptoms include diarrhea, stomach pain, nausea and vomiting, with possible fever, headache, and body aches.

Remember when multiple *Norovirus* outbreaks sickened hundreds of passengers on cruise ships early this year? Cruise ships are not the most common setting for *Norovirus* outbreaks, says Angela Fraser, associate professor in Food, Nutrition, and Packaging Sciences and principal investigator for Clemson's $2.5 million piece of the U.S. Department of Agriculture project, NoroCORE, to reduce *Norovirus* outbreaks.

About 60 percent of outbreaks occur in health-care settings, particularly nursing homes, where patients are at higher risk because they are in close contact and in poor health. Day-care centers, where toddlers play on carpeted floors, also are common breeding grounds, Fraser says.

Cases of *Norovirus* infection attributed to food sicken nearly 5.5 million people in the United States annually and lead to more than 14,600 hospitalizations and 149 deaths. A whopping 11 percent of people who get sick with a *Norovirus* infection die, according to the CDC.

Fraser leads the outreach portion of the NoroCORE project. She and her team, who are working to improve the quality of training and information about noroviruses, were surprised at the lack of *Norovirus* knowledge among food-safety and public-health professionals "on the front line helping others prevent and control *Norovirus*," Fraser says.

"Information about noroviruses is readily available," she adds. "What we don't know is how clear and practical it is."

Food microbiology professor Xiuping Jiang heads the laboratory portion of the NoroCORE project.

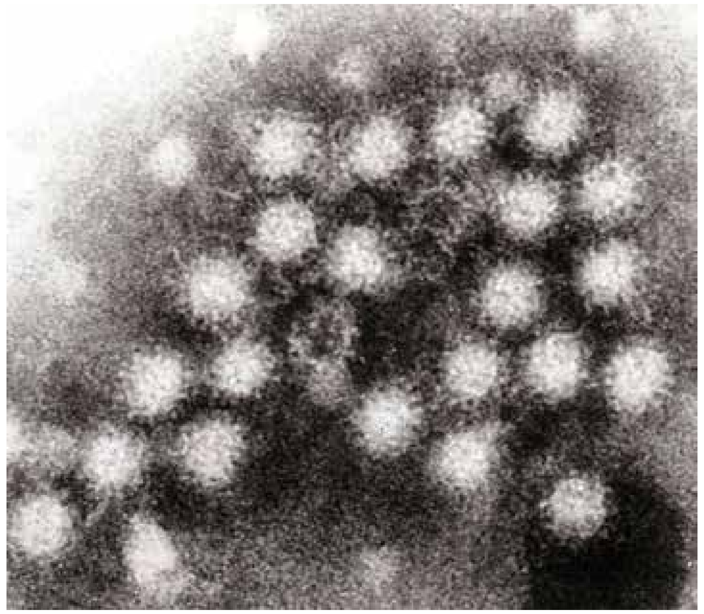
The thousands of swabs collected from bathrooms are stored in freezers in Jiang's lab. She and her graduate students extract nucleic acid from the samples, purify the RNA, amplify the target genetic sequences, and use fluorescent dyes to test for *Norovirus*.

Another project in Jiang's lab determines the efficacy of sanitizers used on surfaces such as carpets, upholstered chairs, and curtains. Much work already has been done on sanitizers used on hard surfaces, but information is lacking about sanitizers for carpets and other soft surfaces, which require more highly concentrated disinfecting solutions because of their fibrous structure, Jiang says.

Graduate student Thomas Yeargin is looking for ways to extract *Norovirus*, using surrogates of the virus, from carpet and other soft surfaces. "Case studies are implicating carpeting in a lot of *Norovirus* outbreaks," Yeargin says. "*Norovirus* is more resistant to disinfectants and sanitizers than some other viruses and bacteria."

The scientific community has become more interested in soft surfaces and development of textiles and draperies with antimicrobial properties, says Yeargin, who will be Clemson's first NoroCORE graduate and will start a paid internship with a national manufacturer of cleaning products as a visiting scientist studying surface sanitation.

Graham Colm



Micrograph of *Norovirus,* a common cause of food-borne illness.

This type of in-depth study of a virus is an emerging science, because *Norovirus* cannot be cultured in the lab, Jiang says. Researchers typically use surrogate viruses to simulate the behavior, she says. Researchers want to learn more about how long viruses persist, how they spread, how to control and kill them, and how to know when a virus is completely dead and no longer infectious, she says.

Lettuce eat safely

While centrifuges in Jiang's third-floor lab in Clemson's new life sciences building spin nucleic acid from swabs to study *Norovirus,* another area of her research focuses on produce safety.

Her targets include *Salmonella, E. coli,* and other bacterial pathogens that can taint fresh produce. One of Jiang's larger grants was spurred by what the industry calls "the two thousand and six spinach crisis" in California that caused 205 confirmed illnesses and three deaths.

Of four basic food categories listed by the CDC, produce is the culprit in 46 percent of food-borne illnesses and 23 percent of the resulting deaths. Meat and poultry are next, accounting for 22 percent of food-borne illness and 29 percent of deaths.

Food-borne disease sickens roughly one in six Americans, or 48 million people, per year; 128,000 of them are hospitalized, and 3,000 die, according to CDC estimates. The agency ranks *Salmonella* second, behind *Norovirus,* as a contributor to food-borne illnesses, and first in hospitalizations and deaths.

Salmonella, Jiang says, is very hardy and persistent in the environment. It's been found in fertilizers made from animal waste—fertilizers typically used to grow fresh produce, Jiang says.

Even though producers compost animal waste to generate high temperatures that deactivate pathogens, science-backed guidelines are lacking. Jiang leads several studies, supported by the Fresh Express Produce Safety Initiative, the Center for Produce Safety at the University of California, and the USDA, to determine the temperature needed and how long it must be maintained to do the job, along with other factors in composting. The findings will be used to establish guidelines for manufacturing organic fertilizer that will be safer for growing fresh produce.

Another area of Jiang's research examines rendered animal byproducts in order to reduce *Salmonella* in animal feeds. When an animal is slaughtered, 42 percent of the animal, including the bones and intestinal contents, goes to the rendering industry, Jiang says. Ultimately, the research could help prevent *Salmonella* from being carried up through the food chain to our dinner tables, as well as protecting our family pets from food-borne illness.

The meat of the matter

All too often, contamination finds its way into packaged meat. Kay Cooksey, with expertise in food and packaging science, is developing antimicrobial materials to protect sliced deli meats from contamination. Pathogen pathways in a deli environment can include meat slicers, improper use of gloves, and countertops where food is prepared, Cooksey says. It takes eight hours to disassemble and clean a meat slicer, and a person must be specially trained to do it, Cooksey says.

Cooksey and her doctoral students have designed layers of a material containing an antimicrobial agent to place between meat slices to reduce growth of pathogens (*see "Wrapping up food safety," Spring 2013,* Glimpse). A private company is interested in the potential product, and a patent application has been filed, Cooksey says.

The process still must be refined before it can be commercialized for large-scale, high-speed manufacturing. For example, a step for drying the product, which happens overnight in the lab, would have to occur almost instantly in a manufacturing plant, Cooksey says.

Cooksey's research is developing other antimicrobial safeguards, as well. One is a countertop that contains durable, long-lasting antimicrobial agents. Another is an antimicrobial material to protect sliced tomatoes and bean sprouts used in the restaurant industry. The material slowly releases a vapor that prevents spoilage during shipment to restaurants without affecting the taste.

What's on the menu?

Meanwhile, two of Cooksey's colleagues, Julie Northcutt and Paul Dawson, have taken what might be called a hands-off approach to food safety. Northcutt and Dawson have studied, for example, restaurant menus, and the results have convinced Northcutt to wash her hands each time she touches one.

The menu study is one of a series of quirky popular science projects Dawson places before undergraduates as Creative Inquiry studies to whet their appetite for research. In the menu study, students discovered that 10 to 11 percent of bacteria on people's hands were transferred to menus during handling.

Neil Caudle

Paper or plastic?
(Or bring your tote?)

Your habits with grocery bags can affect not only the environment but the safety of your food.

Other such projects have debunked the three-second rule on dropped food, have found bacteria spread by blowing out candles on a cake, and have documented the risky behaviors of double dipping, shared drinks, and shared dishes of food.

Unexpected results of a Creative Inquiry project on washing fruits and vegetables found that successive rinses, after the first, failed to lessen bacteria concentration in the rinse water, particularly for vegetables such as lettuce and broccoli compared to smoother-surfaced apples and grapes, Dawson says. Results varied widely: Between 20 and 90 percent of the bacteria removed in five rinses of common fruits and vegetables were removed in the first rinse.

Beer pong was the subject of another Creative Inquiry investigation. On a home football weekend, Dawson's students looked for tailgaters and partiers playing a game that involves tossing a ping pong ball into drinks. Students traded new ping pong balls for used ones to study and found millions of bacteria on them, especially on the balls used in games played outdoors. The highest level of bacteria found on ping pong balls was 2.9 million and the least was 180, and the alcohol in the drinks didn't kill the germs. Dawson likens the game to Russian roulette with one's health.

In the lab, Dawson and Northcutt collaborate with Furman University chemists on a quick and thorough way to determine cleanliness in commercial food-processing facilities. They use microscopic substances called liposomes that can be designed to change color in contact with bacteria. The idea is to be able to swab a surface, add liposomes, and immediately know if a surface is microscopically clean, Northcutt says.

The concept is much like the pills dentists have children chew that color areas missed in brushing their teeth, Northcutt says. The process, which is close to commercialization, would help protect our food supply, help the food industry comply with regulations, help inspectors spot issues, and enable line workers to make immediate decisions rather than wait on lab results, Northcutt says.

Paper or plastic?

Even when our food is free of contamination at the point of purchase, we can foul up the works when we bag it to take home. Reusable, nonwoven fabric bags, the type typically sold at supermarkets for 99 cents, must be washed frequently to prevent cross-contamination from one shopping trip to the next, Cooksey says. The problem: Only 15 percent of people who use reusable fabric bags wash them often, and 28 percent of people who use them never wash them, according to a study by Edelman Berland, a market research firm, Cooksey says.

Clemson researchers Bob Kimmel, director of Clemson's Center for Flexible Packaging, and Cooksey, together with Allison Littman, a Clemson alumna, conducted their own study to evaluate the environmental impact of four common types of grocery shopping bags. At a time when cities and counties of all sizes across the nation are considering legislation to deal with perceived plastic bag litter, the researchers wanted a scientific answer to the checkout-line question: paper, plastic, or reusable?

"There are so many misconceptions," says Kimmel, principal investigator for the study. "The popular press picks up unconfirmed data and environmental groups latch onto it. There are always preconceived notions on what is good and what is bad. One reason for the study is to separate fact from fiction."

Kimmel, Cooksey, and their students examined the cradle-to-grave impact of four types of bags: brown paper grocery bags, lightweight plastic grocery bags, reusable fabric bags, and heavyweight plastic retail-store bags.

They considered twelve environmental impacts including carbon footprint, energy use, and chemical impacts on soil, water, and air. They looked at reuse, recycling, and recycled material recaptured in making new bags. Some bags hold more than others, so an undergraduate Creative Inquiry group analyzed how many of each type of bag would be needed on an average shopping trip for a family of four.

Of the two types of bags intended for one-time use as grocery bags, paper and lightweight plastic, plastic was a clear winner, largely due to the manufacturing and waste recovery processes. Although paper bags are made from trees, a renewable resource, and can be recycled at curbside, the water- and energy-intensive processes of turning logs into cellulose fibers then paper tip the scales in favor of the lightweight plastic bags. Although lightweight plastic bags can't be recycled at curbside because they foul up the sorting machinery, about 93 percent of U.S. residents have access to recycling locations at many supermarkets and other retail points, Kimmel says. In addition, lightweight plastic bag manufacturers can use recycled bags to make new ones.

The researchers found that when compared on a one-time use basis, paper bags are on average four to seven times more detrimental to the environment, Kimmel says.

The analysis is trickier between lightweight plastic and the two types of reusable bags and depends in part on how many times the reusable bags are reused and whether the lightweight bags are put to secondary uses, such as trash-can liners or to carry other items, Kimmel says.

A separate survey by Edelman Berland found that while the average number of reuses for the heavy plastic bags is 3.1 shopping trips, 6 to 9 trips would be needed to make them more environmentally friendly than the lightweight plastics, Kimmel says.

Nonwoven fabric bags must be used at least 20 times to be equivalent in their average environmental impact to lightweight plastic bags, Kimmel says. This number increases to 33.5 times if secondary uses of lightweight plastic bags are taken into account.

Reusables get dirty

The national survey showed that the average person uses his or her fabric reusable bags for 14.6 shopping trips, Kimmel says, and only 20 percent of people who use the nonwoven fabric bags use them more than 44 times. Right now, about 6 percent of the nation's population lives in areas covered by some kind of plastic bag legislation, which is heavily concentrated on the West Coast, the Northeast, and in Texas, he says. Average use is 17.3 shopping trips in legislated areas and 13.9 trips in nonlegislated areas. "So people in legislated areas still aren't using their bags that many more times than the average and still not enough times to make their average environmental impact less than that of the lightweight plastic bags," Kimmel says.

"Reusable bags are great if you reuse them enough times and keep them clean," Kimmel says. "The majority of people today aren't doing that." Typical legislation calls for stores to sell the customer a paper bag if they don't bring a bag with them, "which is the wrong choice for the environment," Kimmel says.

Kimmel and Cooksey recommend, based on their study, that "consumers should be given a choice between reusable bags and lightweight plastic bags and that the use of paper bags should be discouraged."

"Much more attention," they write, "should be focused on educating consumers to make an informed choice of which bags to use by providing them facts—facts about reusable bag use, facts about proper recycling or disposal of lightweight plastic bags, facts about the potential environmental impacts of their choices—based on sound scientific evidence."

Angela Fraser is an associate professor in Food, Nutrition, and Packaging Sciences and is principal investigator for Clemson's $2.5 million portion of the U.S. Department of Agriculture's $25 million NoroCORE project. Xiuping Jiang is a professor in the Department of Biological Sciences. Kay Cooksey is the Cryovac Endowed Chair, and Julie Northcutt and Paul Dawson are professors in the Department of Food, Nutrition, and Packaging Sciences. Bob Kimmel is an associate professor of packaging science and the director of Clemson's Center for Flexible Packaging. All are in the College of Agriculture, Forestry, and Life Sciences. Anna Simon is a freelance writer based near Pendleton, South Carolina.

a pipe full of star power

Five years ago, Chad Sosolik came back from Washington with a crazy idea. Look what followed him home.

by Neil Caudle

If you had a star, you could strip a great storm of electrons away from its atoms and make all of the highly charged ions you might need. But you couldn't hang around to watch. Or you could do what Chad Sosolik has done: You could harness a rare and remarkable beast known as an electron beam ion trap, an EBIT, one of only six in the nation, and the only one not housed in a national laboratory or institute. You could use that million-dollar marvel of high-tech plumbing to simulate stellar forces on an Earth-bound, observable scale. You could trap a cloud of highly charged ions and shoot them at targets. You could use the beams to irradiate, say, oxides or carbons or plastics.

And that's what Sosolik and his colleagues and students are doing, at the moment: blasting various materials with very highly charged ions. "We're experimenting with things that never have touched, at least on Earth, these ions before," he says.

Sosolik is a lean, rangy Texan, the kind of guy who might well indulge a bit of boyish delight in blowing stuff up. But destruction, in this case, is only a means to an end. He has a hunch that a new generation of advanced materials, patterned by highly charged ions, awaits discovery by those with the right kind of tools. And that's what Sosolik has installed in the basement of the Kinard Laboratory of Physics: the right kind of tool.

If his hunch is correct, a great deal of knowledge and technology will flow from his futuristic pipework. Sosolik can imagine, for example, materials that could eventually become semiconductors or capacitors or high-precision filters. And the EBIT, he believes, will give Clemson, already a player in the high-stakes game of advanced materials, a significant home-field advantage.

But why Clemson? How did this coveted tool of plasma physics wind up here, and not in some powerhouse lab in the research elite? The answer, in short, is that Sosolik was in the right place at the right time, and he knew how to ask.

And it all started with an overheated lab.

Looking for cool

About seven years ago, Sosolik's lab building was due for an overhaul of its air-conditioning system, and he and his graduate student faced the prospect of baking themselves in an oven all summer. Sosolik, looking for a more temperate spot for his student to work, called on a colleague he'd known since graduate school, Joshua Pomeroy, who'd wound up as a staff scientist at the National Institute of Standards, NIST, in Gaithersburg, Maryland.

"In the lab where he works, he has the second EBIT built in the U.S.," Sosolik says. "It's an older machine, from the early nineties."

With the summer heat arriving, Sosolik swung a deal

Craig Mahaffey

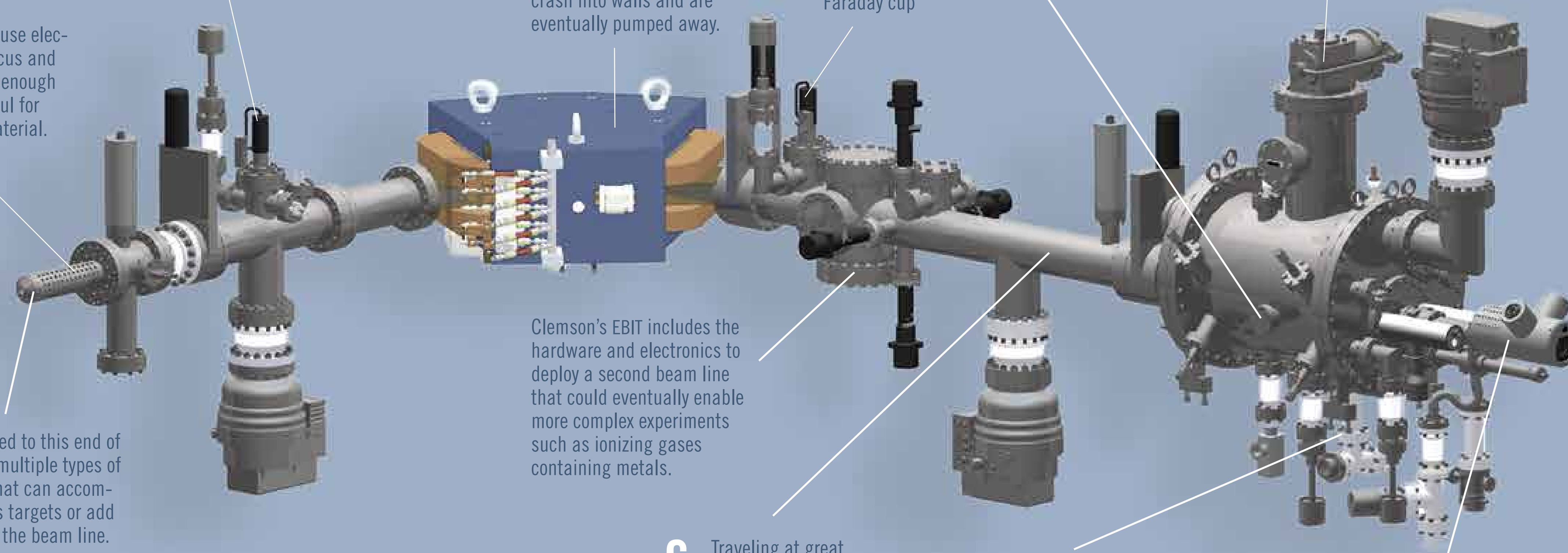
shooting with star stuff

The latest cool tool in physics is a machine that replicates forces in the belly of a star. The idea is to harness those forces to develop useful new materials here on Earth.

This marvel of engineering is an electron beam ion trap or EBIT. Clemson has one of six EBITs in the U.S. and the only one outside a national lab or institute. This one brings several advantages. It can recirculate the scarce and costly liquid helium required to supercool its superconducting magnet. (Several older EBITs sit idle because labs can't afford to keep piping fresh helium into their magnets.) It's new, with all the latest bells and whistles. It accepts various attachments to expand its versatility. And, of special relevance here at Clemson, it's been designed to help investigate and develop new materials. Combined with faculty expertise in physics, materials science, and engineering, the EBIT makes Clemson a leader in the race to apply space-age technology.

The illustrations on these pages offer a brief, highly simplified introduction to the EBIT and how it works.

EBIT image courtesy of DREEBIT GmbH.
Conceptual illustration of target adapted from McAllister Technical Services.



8 Special lenses use electric fields to focus and slow the beam enough to make it useful for working the material.

A Faraday cup catches charged particles, allowing researchers to measure the ion beam current.

7 A powerful magnet bends the beam around a corner. By adjusting the magnetic field here, researchers select the type of ions they will direct toward the target. Only the selected ions make the 90-degree turn. The others crash into walls and are eventually pumped away.

A beryllium window into the trap allows researchers to study ion activity by imaging the X-rays produced during ionization.

Liquid helium circulating in a closed loop through the superconducting magnet keeps the magnet cold enough to do its job.

Faraday cup

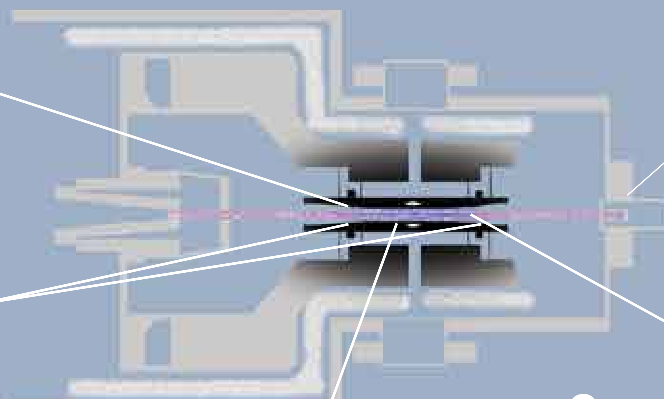
Fittings attached to this end of the EBIT allow multiple types of attachments that can accommodate various targets or add new devices to the beam line.

Clemson's EBIT includes the hardware and electronics to deploy a second beam line that could eventually enable more complex experiments such as ionizing gases containing metals.

6 Traveling at great speed, the beam of ions races toward the target.

Researchers introduce the gas here, where they attach a bottle and leak its contents into the drift tubes.

1 A cathode (a terminal where current flows out) shoots a beam of electrons.



2 The electron beam passes through three drift tubes, which contain argon, neon, or various other gases.

3 The electron beam, compressed by a powerful superconducting magnet, collides with atoms in the gas, stripping off electrons and producing highly charged ions.

4 Electric fields on the endmost drift tubes trap and hold the ions along the electron beam's path. The electron beam also exerts a trapping force that confines the ions even more. The trap can hold ions for as long as several hours.

5 Lowering the electric field at this end of the trap releases the ions into the beam line.

9 The target material, often in a wafer about the size of a nickel, is mounted at the end of the beam line, where the ions can modify it.

with his friend at NIST. "My student went up there to work in an air-conditioned lab and never came back," Sosolik says, laughing. "He got a Ph.D. from Clemson, but all of the research was done there, at NIST, with their EBIT. So because of that student I got very involved in this kind of research."

So EBITs were on Sosolik's mind one day in the summer of 2009 when he happened to be sitting on a review panel at the National Science Foundation (NSF), just as Washington was ramping up the economic-stimulus program known as the American Recovery and Reinvestment Act.

"The NSF program manager walks in and says, 'We just found out we're going to make a special call for big equipment proposals, and if you guys have any good ideas, you're the first ones to know,'" Sosolik recalls. "And then, typical of NSF, he says, 'You guys have thirty minutes for lunch. Go.' So I just walked next door into a mall that's connected to NSF and sat down in a fast-food joint and got on my phone and called this guy at NIST and said, 'What do you think? Maybe we could buy a spectrometer or something?' And he's like, 'Get your own EBIT.' And I said, 'You're insane.'"

Insane or not, they kept talking, and Sosolik began to warm to the idea. Trouble was, even at the NSF, an EBIT was a rarified exotic that few understood. He would have to sell the idea, and fast, to get a jump on the competition.

"I made a few calls, changed my flight, and stayed at NSF for an extra day," Sosolik says. "I walked from office to office, and I told people what an EBIT was, and that I was going to put a proposal in for one, just to explain it to them, just so they'd know it was coming. Then I came back to campus and wrote a proposal, and we formed a team."

In the normal course of research funding, an NSF project on this scale requires a substantial match from the institution—a staggering hit for the budget at Clemson. But in this case, the feds had decided to give some less-affluent schools a fighting chance. "They sent out a list of 'research-one' universities, and if you didn't cross a certain threshold in terms of per-capita funding at your university, there was no required match," Sosolik says. "So I went down that list very closely, and I kept going and going, and finally I got to the line, and I thought, 'We're not on it.' It was that rarest of rare equipment grants. We didn't have to come up with a match."

Clemson won the award; the request was fully funded. It was time to go shopping.

"I have a million. What can I buy?"

Sosolik had long aspired to buy an EBIT from a group at Lawrence Livermore Lab, where the first EBIT in the United States was built. "But when I called the guys at Livermore they said, 'We don't make it anymore.' They'd had some technical difficulties. One of their EBITs sits at Harvard right now, and it's turned off. There was one in Stockholm as well."

His friend at NIST had told him that a group in Germany could build a turnkey EBIT with all the modern bells and whistles. "So I got on the phone to Germany," Sosolik says, "and said, 'I have this million-plus dollars. What can I buy?' I think they were stunned."

The power of this thing is other-worldly.

At the factory, a beam went astray during testing and melted the welds. But things are working fine, now, Chad Sosolik says. Just keep your distance, if you're using a pacemaker.

Neil Caudle

Jim Harriss manages the EBIT from a glass-walled control room, using a computerized panel with digital readouts.

Improbably, Clemson had leaped to the head of the line for this newest and coolest of EBIT machines. "We would be the only institution in the United States that would be set up to do this kind of radiation on materials," Sosolik says. "There are other EBITs, but they're older, and they cost more, and they're not set up to do targeted research in materials, which is a strength here at Clemson."

So a crew in Dresden went to work building the new machine. It was almost finished when an electron beam went astray during testing and cut through some welds at the back of the machine. "They de-welded it, basically," Sosolik says.

To make up for the resulting nine-month delay, the Dresden team threw in an extra feature Sosolik had coveted but hadn't thought he could afford: a special fitting that would let him access the beam line and trap from a different angle. The machine arrived at last and, after a period of installation and testing, went online in April of 2013. By pure accident, I'm visiting the lab on the EBIT's one-year anniversary. I ask Sosolik if he's planning to celebrate, thinking there might be cake.

"Well, I'm running a half marathon tomorrow," he says.

Look but don't touch

So I'm wondering, as I sit behind a computerized control panel peering through glass at a room full of futuristic hardware, hearing it chitter like some great hive of alien arthropods, just how safe we are, given that the EBIT's beam has already proven itself more than potent enough to melt welded steel.

"Do you have a pacemaker?" Sosolik asks.

"No," I say. "Not yet."

"Well, you should be fine."

Should be. That's encouraging. The EBIT uses a superconducting magnet operating at six tesla—hence the caution about pacemakers.

We cover a few more of the risky forces inherent in this kind of physics. For example, there's a portal through which researchers will observe the ion cloud by capturing images of the patterns of X-rays it emits. The portal is X-ray transparent, but I shouldn't worry about getting irradiated, Sosolik says. The machine isn't running today, and besides, the portal can be closed or blocked with whatever device is attached to it. And the high-voltage electrodes, each carrying tens of thousands of volts? They are protected by insulators, smaller versions of the kind we see on power poles. The electrodes are also sealed, so I can't accidentally stick my fingers in there.

All of this high-powered hardware generates tremendous heat, the enemy of metal and magnets. The EBIT uses four separate cooling systems, including three for circulating purified water and one for cycling helium in and out of the superconducting magnet at 4 kelvin, which is very, very cold. To dump heat from the circulating water, the team hooked up a heat exchanger connected to the main campus chilled-water system. In effect, the EBIT keeps its cool while the campus takes the heat. But there's plenty of cooling capacity to handle the load, Sosolik says.

All of this cooling depends on reliable power, so the backup generator gets considerable attention and is still being tweaked. If the power should happen to go out, the system will automatically contact both Sosolik and his partner in the lab, Jim Harriss, so they can hustle back to the lab and shut things down in an orderly fashion while the backup generator keeps the cooling system running.

Turning the corner

Its safeguards having been tested and proven, the EBIT is working according to plan. But the power of this thing is otherworldly. And it all begins, innocently enough, with a modest little cathode and a teeny, tiny hole.

Harriss, who has been putting the EBIT through its paces and teaching people how to use it, explains what happens, at the most basic level, when the EBIT is running. At the front end of the EBIT, the cathode fires a beam of electrons through an opening five millimeters in diameter. The electron beam proceeds through a chamber full of gas, and the beam knocks electrons off the atoms in the gas, creating ions. Electric fields

Neil Caudle

A campus takes the heat.

A heat exchanger (gray plates, lower left corner) allows heat from the EBIT's three closed-loop water-circulation systems to migrate into the campus chilled-water system.

Neil Caudle

A window on the target.

Hardware for holding the target material is visible through a reinforced window in a housing attached to the end of the EBIT.

at each end of the chamber trap the charged particles.

"The electron flow itself will attract the ions, and concentrate them toward the center of the trap," Harriss explains. "But also, wrapped around all of this, is a very strong magnetic field, which also helps trap the ions." The magnetic field, he says, compresses and concentrates the electron beam to make it more efficient.

After the beam has knocked enough electrons off their atoms, the researchers lower the voltage at the end of the trap, releasing a pulse of ions downstream toward a left-hand turn. Forcing ions around a corner is sort of like herding cats, but that's how the researchers select the kind of ions they want from the beam. As various ions race down the line carrying various charges, the researchers apply a powerful magnetic field to bend them off course. Only the selected ones bend at ninety degrees, turn the corner, and head for the target.

All of that is much easier said than done.

"In order for us to get ions from there"—Sosolik points to the segment where the trap is housed—"around the corner, without the beam just blowing up, we have to transport at high velocity, which means high energy. The whole thing gets floated up at several thousand volts, which effectively tricks the ions into thinking they can travel faster if they go around the corner. So we get them around the corner fast and then there's a lot of special optics at the end to slow them down, get them focused, and direct them to the target."

The optics includes special lenses made of electrical fields, not glass, but they work much the same way as lenses for focusing light. "The math's exactly the same," Sosolik says. "If you work out the math for a classic ion-electron lens, and make your formulations for optics, you get exactly the same optics as light optics. You can get a concave lens, you can get a convex lens—you can do all the same stuff."

And to change the focal properties for an ion-electron lens, the team does not have to replace the lens or regrind some glass. They just dial up a new set of voltages.

By slowing the flow with optics, Sosolik says, the ion beam has time to work its magic on the target material. "If you don't slow it down, you're not letting the physics play out on the target," Sosolik says.

The iron in the wind

So far, Sosolik and his team are making ions from elements called noble gases, a group that includes helium, neon, argon, krypton, xenon, and radioactive radon. Noble gases are odorless and colorless, they have similar properties, and they can be used to make highly charged atoms. Sosolik can buy these noble gases in bottles, attach a bottle to a port in the EBIT, and leak in some gas.

But eventually, Sosolik would like to branch out and try, for instance, some metals. After all, if you have a device that can replicate some of what happens in stars, why wouldn't you study the physics of high-powered phenomena such as solar winds, the fantastical streams of plasma released from the sun?

"Solar wind has iron in it," Sosolik says. "So how do I get the iron in there?"

To put metals in the mix, he'll need the extra fittings and controls that came with the system because of the delay. He'll install another beam line, perpendicular to the first, shoot a beam into the EBIT with a liquid metal ion source, turn it, and load it into the trap. A new hire in physics, Endre Takacs, who has worked the EBIT at NIST, will lead this part of the research.

The potential for working with metals has attracted a group of Australian researchers who plan to come to Clemson to study manganese ions, among others, using the EBIT. In fact, the plan all along has been to make the EBIT what Sosolik calls a user facility, a resource for research teams who can pay the fees, take the training, follow the rules, and do some good science.

Meanwhile, Sosolik's team is conducting its first experiments with the EBIT, using them to set benchmarks for the equipment but also to learn how materials react to the ions. For example, by studying how various doses of ions affect the kinds of oxides used as a thin film on semiconductors, Sosolik and his collaborators may be able to scale and control the ion doses to engineer the material. When an ion strikes an oxide, he says, it leaves either a crater or a hill. So a well-controlled flow of ions might pattern a surface in predictable and useful ways, for microelectronics, fluid filtration, or some other technology.

As a byproduct of this kind of work, the team can also test materials that might be used in outer space, because the EBIT can simulate the kinds of radiation common there. Sosolik and his coinvestigator, Rod Harrell, submitted a proposal to NASA for a project that would test materials coated with silicon carbide, which is far less sensitive to high-energy radiation than the silicon used in most electronics.

Meanwhile, the team is still learning how to track the many forces and counterforces unleashed inside the EBIT. How many millions, billions, or trillions of ions should they send down the pipe at one time? How do they account for the recoil of electrons that are hitting the walls of the machine? How do they make sure the oxide they're using for a target doesn't gain so much positive charge that it repels the very ions sent to shape it?

"The questions are important," Sosolik says, "not just because they're the sort of geeky little things that physicists like to chase. The questions would also be important if you wanted to do this in an industrial context."

Certainly, industrial applications are a goal. So the lab is firmly grounded in the pragmatics of engineering and materials science. But when you're using a tool that can simulate some of the rarest and most dramatic forces in the universe, you can't help but think big, now and then. Sosolik has been part of a project, funded by the Defense Advanced Research Projects Agency (DARPA), investigating ways to form diamonds by simulating the forces in exploding stars.

"People have found things like carbonaceous meteorites with pockets of diamond inside them, and inside those pockets they see xenon, little xenon atoms," Sosolik says. "That probably means that some highly charged xenon came flying in and actually turned a piece of that thing into diamond."

It's too early to say, at the moment, whether Sosolik and his team will be making any diamonds, literally or figuratively, any time soon. There's a lot of hard science to do before the researchers can push the machine to its full potential. But if you're fortunate enough to land an EBIT, it might just pay to keep your feet on the ground and your head in the stars.

Chad Sosolik is an associate professor of physics and astronomy. James E. Harriss is a research associate in physics. Endre Takacs is an associate professor of physics and astronomy. W. Rod Harrell is an associate professor of electrical and computer engineering. All are in the College of Engineering and Science. *Funding for the work described here primarily came from the National Science Foundation and the Defense Advanced Research Projects Agency.* Glimpse *briefly introduced the EBIT in the Spring 2012 issue, soon after the machine arrived on campus.*

THE MYSTERIOUS CASE OF THE *Renegade Receptor*

OR, THERE'S MORE TO INDIGO THAN BLUE.

by Neil Caudle

If you're grilling a steak, serve broccoli. That will help you avoid a problem with promiscuity.

Seriously. That's the term scientists use for the AH receptor hanging out in your cells: promiscuous. It consorts with all kinds of shady characters, including the cancer-causing compounds that form when we're charring a burger or steak on the grill. The AH receptor will bind to those compounds and, worst case, trigger runaway cell proliferation that leads us down the road to ruin. Compounds in broccoli, cabbage, cauliflower, and other cruciferous vegetables tend to block the receptor and turn the intruders away.

No, this won't be another long lecture about eating your vegetables, worthy as that theme might be. This is a mystery story. A whodunit.

Most receptors are monogamous: They cleave to their usual partners, their dedicated ligands. They don't sleep around. So why has nature afflicted us with this one promiscuous receptor and allowed it to lurk in the doorways of our cells, luring the villains inside? Villains that include not only the compounds in charred meat but toxic pollutants such as PCBs and dioxins, some of the deadliest toxins on Earth?

Scientists know that the AH receptor does have a legitimate role to play, especially in development, cell-cycle control, circadian rhythms, and general environmental sensing, but the ligands involved bind weakly and don't hang around long enough to turn toxic. The receptor has been on the job for millions of years, since the very origins of vertebrate animals. But we don't know for sure how it got here, or what its natural partner—its endogenous ligand—might be. The AH receptor is, to date, an unexplained orphan of nature. That's another word scientists use to describe it: orphan. Provenance uncertain. To muddy the waters, it also comes in one flavor for mammals but multiple flavors in lower vertebrates. Scientists don't yet know why the receptor needs so many guises, but somewhere along the line, in its millions of years of evolution, many genes, including the AH receptor, saw the need to diversify, or duplicate. As vertebrates evolved these duplications were thrown out. For the purposes of our little story, we'll talk about all the AH receptors as one.

Clues to our mystery of the renegade receptor have been turning up in the strangest of places. In the beards of pirates and the turbans of Tuareg nomads of the Sahara. In seashells. In a fish that eats poisonous slime. In thousands of years of Chinese herbal medicine. In a plant called indigo, a botanical powerhouse that changed the course of South Carolina history.

The AH receptor is an ancient puzzle with all of these pieces and more, and the puzzle has only recently begun yielding to science. Charles Rice and his students, concentrating on the immune system, have started to place a few pieces.

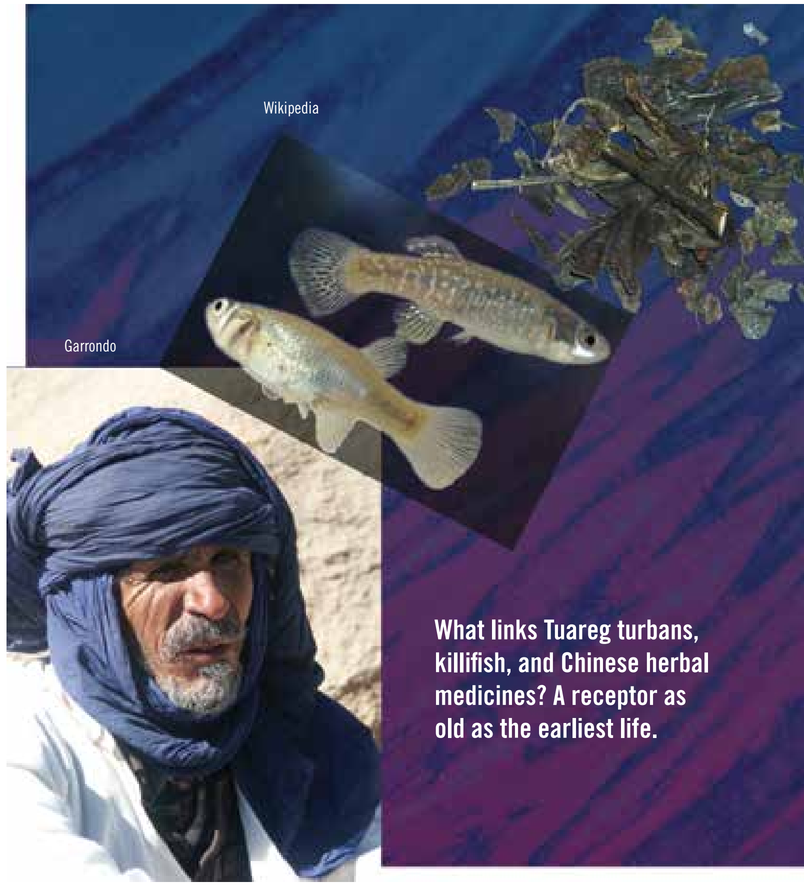
Indigo: a red-state, blue-state kind of thing

Last fall, in this magazine, we ran a cover story about the history of indigo, a cash crop in colonial South Carolina that made fortunes here and abroad because African slaves could extract from its pulverized, decomposing tissues a vivid blue dye (*see "The Colors of Indigo," Fall 2013,* Glimpse). Rice read the story and emailed to say that we'd missed something. Indigo, he said, has an alter ego: indirubin, which is red.

"If you could go back to colonial South Carolina, and find a brick of indigo dye, somewhere inside that brick the color varies from blue to red," Rice says. "Every time you put something around these molecules it changes the way they absorb or reflect light. It takes almost nothing to change that molecular structure, because they're just different sides of the same thing."

Two colors, two distinct sets of compounds. And the red version, Rice says, yields some potent magic of its own.

He knows this because he's been studying red indigo for thirteen years, ever since a colleague invited him to a conference in Le Eyzies, France. The topic was indigo—the science and the history. That's where Rice learned, for example, that Bluebeard



What links Tuareg turbans, killifish, and Chinese herbal medicines? A receptor as old as the earliest life.

the pirate used indigo to kill microbes that grew in his beard.

When Rice returned from that conference, coming home to a state whose flag shimmers indigo blue, he had a notion or two about the red side of indigo's split personality, an isomer known as indirubin.

"The interesting thing about indigo and indirubin is that they're both based on the natural product tryptophan, which is an essential amino acid we find everywhere," Rice says. "So this process happens all around us in nature. If you look inside a seashell and see that dark blue with a reddish iridescence? That's indirubin. And for hundreds and hundreds of years, people have dyed their turbans with indigo, and the most costly ones with the highest status have this iridescent sheen. That's indirubin."

The ancient powers of indigo and indirubin probably evolved as a self-defense strategy for plants and animals alike, Rice says. Bluebeard was onto something, when he colored his beard with the stuff. Certain mollusks produce blue and red indigo to guard against microbes, protecting eggs from infection. Other animals and plants produce it to shield against damage from ultraviolet light. So indigo, in each of its versions, seems to be one of nature's oldest and best strategies for self-defense.

Humans don't sport an iridescent sheen of self-protection, but we aren't exactly strangers to indigo and indirubin. For one thing, our AH receptors readily bind to them both. For another, we can actually make the stuff, sometimes, in our bodies. "Under certain circumstances," Rice says, "patients in a hospital can have too much tryptophan, and the bacteria in the gut can turn it into indirubin, and the patients pee red. It's called purple urine bag syndrome."

From China, a dose of detox tea

As he dug into the human dimensions of indigo's history, Rice learned that people weren't just wearing blue and red indigo to look better, they were also consuming it to *feel* better. "This goes back thousands of years, to Chinese herbal remedies," Rice says. "The Chinese had this herbal tea, and it contained eleven different plant products, and it was used to help detoxify patients from whatever drug they were on, maybe even too much alcohol. It was also used to treat certain cancers and runaway fever. Eventually, they discovered that the active ingredient was this thing called indirubin."

Indirubin, Rice learned, showed strong potential for reducing inflammation. Medically, that's significant, because scientists have found that many human ailments, including heart disease, diabetes, and some cancers, can begin with inflammation.

But here, the plot thickens. While indirubin does fight inflammation, it also has a nasty habit of hooking up with—you guessed it—that promiscuous AH receptor. And when that happens, things can go awry in a hurry.

Why, scientists wondered, would indirubin, a natural compound as old as the hills, consort with the very same AH receptor as nefarious newcomers like PCBs and dioxins? Rice has some notions, but no final answer. He suspects that over millions of years of evolution organisms made good use of tryptophan-related or tryptophan-derived compounds, including indirubin, to stay alive, and may have done so via the AH receptor. If that's the case, then indirubin may well be one of the natural, endogenous partners for the orphan receptor. And somehow the nasty carcinogens such as PCBs and dioxins usurped the receptor and its pathway, with deadly results.

Rice explains that most tryptophan-derived compounds that bind the AH receptor are metabolized and eliminated quickly, so the ill effects of AH activation tend to be minimal. PCBs and dioxins are difficult to metabolize, so the AH receptor is activated for a prolonged period, leading to severe toxicity.

Whatever its original function might have been, the AH receptor's ancient affinity for hooking up with indirubin becomes problematic, if the goal is suppressing inflammation. Could that hookup be prevented?

Amy Anderson, a Ph.D. student in Rice's lab, went to work on the problem, analyzing various indirubins, many of them derivatives concocted by medicinal chemists. To begin, she looked for indirubins that could fight inflammation. She found them.

At this point, we'll need to introduce a rather warlike new character: the macrophage. Macrophages are soldier cells in our immune system; they defend against invaders. There are two kinds of macrophages, killers and rebuilders, known respectively as M1 and M2. The killers deploy and destroy, assailing enemy pathogens at the site of a wound—the short-term inflammation our bodies use to stop infection. The rebuilders, M2s, promote the proliferation of new cells to heal the wound. Trouble is, M2s also help proliferate tumor cells, and they show up in the kinds of long-term, chronic inflammation associated with heart disease and cancer. One goal, Rice says, is to "polarize" the macrophages to yield more M1s and fewer M2s.

Ashley N. Jones

Amy Anderson and Charles Rice in the lab. Rice refers to their field of research, which blends comparative physiology, molecular biology, and biomedical approaches to understand adaptation to harsh environments, as evolutionary biomedicine.

Ashley N. Jones

Vials in Rice's lab display a wide range of colorful variation in the isomers of indigo. Indirubin, in the center vial, is the active compound in several herbal remedies for treating cancer, inflammation, and drug toxicity. Other vials, left to right, contain indigo, indirubin-3-monoxime, natural indirubin, indirubin-E804, and indirubin-5-sulfo.

So Anderson went looking for an indirubin that would not bind to the AH receptor and would fight the kinds of inflammation caused by M2s. Apparently, she found that too.

In her dissertation, which this spring earned her a Ph.D., Anderson reports that an indirubin known as E804 suppressed inflammation (she found very little M2 macrophage activity in the cell lines she tested) but did not seem to bind to the AH receptor, or at least not very well. When a compound does bind to the receptor, the body mobilizes a protein to detoxify the intruder. With E804, Anderson found no signs of the protein.

There are at least two possible reasons the protein didn't show up, Rice and Anderson say. The first is that E804 did not bind to the receptor at all. That means, in theory, that E804, or something like it, might turn out to be safe for treating inflammation, assuming that researchers get similar results from studies with other cells lines and with laboratory animals. One possible application, Rice says, might be a topical ointment or cream for skin ailments such as eczema or psoriasis. Cosmetically, that would require some pharmaceutical finessing, because no matter how you formulate it, indirubin is red. "To take the redness out, you'd have to take the goodness out," Rice says.

But a second possible explanation for why E804 didn't mobilize the detoxifying protein is even more intriguing. What if E804 did bind to the receptor but did not cause toxicity? What if it's a broccoli-like compound that sits on the AH receptor and blocks the door? What if it can shield our cells from toxins, even as it fights inflammation?

If that turns out to be the case, then the potential for medical treatments might well be huge. But all of this is highly speculative, at this stage. And the biologist in Rice keeps circling back to the heart of the mystery, the nature of this inscrutable, promiscuous orphan, the AH receptor. What is it up to, and why?

Enter the red herring

At this point in any respectable mystery story, you might expect a red herring. And sure enough, this is where the indirubin tale turns fishy. The fish at hand, in this case, is not a herring but something smaller: the killifish, a common sight around docks in brackish and marsh shallows of coastal waters.

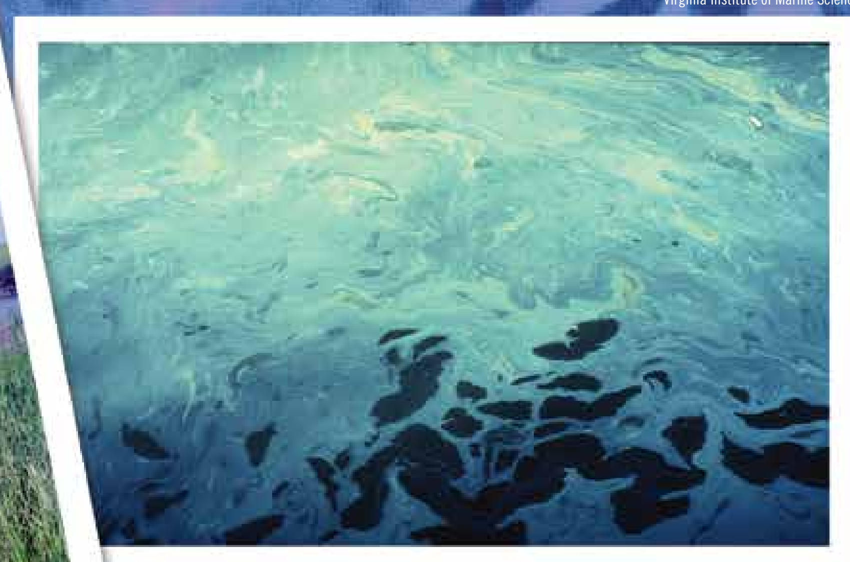
Charles Rice grew up in Virginia, on the Chesapeake Bay, near Reedville, a fishing village famous for menhaden fisheries. For as long as he can remember, he's been fascinated by the little fish that people call bull minnows, the Atlantic killifish. And for years now, he has studied a particular population of killifish unlike any other. They thrive in what Rice calls "one of the most polluted places on the planet."

According to the Environmental Protection Agency (EPA), the Atlantic Wood Industries (AWI) superfund site includes forty-eight acres of land on the industrialized waterfront of

Virginia Institute of Marine Science

Charles Rice

Virginia Institute of Marine Science



Learning from a toxic environment

Top: Waters at the Atlantic Wood site, long contaminated by a wood-preservation facility, are so toxic that blue crabs "scoot out as fast as they can," Rice says.

Above: Creosote, once used as a wood preservative, floats to the surface. Despite heavy pollution, adapted killifish thrive here, offering clues to factors in human immunology and cancer biology.

Left: Lee Ann Frederick, who earned a Ph.D. with Rice and now teaches at the University of Texas, Arlington, samples fish at the site.

Portsmouth, Virginia, and thirty to thirty-five acres of contaminated sediments in the southern branch of the Elizabeth River. From 1926 to 1992, AWI operated a wood-treating facility at the site, discharging into the surrounding waters creosote and pentachlorophenol (PCP), both of which attack multiple tissues and systems in the human body and are classified as probable carcinogens. For a time, the U.S. Navy leased part of the property from AWI and disposed of abrasives and sludge from the production of acetylene there.

The site's toxic soup of creosote and various other chemical wastes is stubbornly persistent, Rice says. "Even today, you can jam a stick into the sediment, and these big blobs of oily stuff come up. People tell me that if you go out and walk in this place called Atlantic Wood, it will eat your rubber boots right off your feet."

And yet, killifish in those waters are thriving. "This population of killifish has adapted to the point where they're absolutely tolerant of the contaminant," Rice says. The fish live just as long as other killifish—about three years—and they grow even larger, perhaps because their natural predators steer clear of the pollution. "Things like blue crabs that feed on these killifish, they just scoot out as fast as they can," Rice says.

Survival in such a toxic environment is no small feat, Rice says. "If you take fish from clean environments, fish that are not adapted to that site, and you expose them to sediments from the Atlantic Wood site, they get these typical-looking lesions, these sores that are breaking apart, and it's really nasty."

Now here's the truly mystifying part. If you take the Atlantic Wood killifish out of their foul habitat and put them in clean water, they die. "They start forming those same kinds of lesions," Rice says. "The histopathologist I work with, he just looks at it and says, 'I can't explain this. It's bizarre.'"

To repeat: In clean water, the toxin-tolerant killifish *die*.

In a whodunit, this would be the ultimate plot twist. The victim was alive and well after having been poisoned with arsenic, stabbed with a knife, strangled with a rope, and bludgeoned with a wrench, but later dropped dead while being treated to a good rest, clean water, and wholesome food. Talk about the perfect crime.

This kind of thing was not supposed to happen. But it does.

"As an immunologist," Rice says, "my question has always been, if the fish live in this toxic environment, surely their immune system is blown out. It has to be." He shakes his head no: "They're basically healthy enough to reproduce, as long as they stay put."

The Atlantic Wood killifish swim, eat, grow, and reproduce as normal. But that's not to say they swim around unscathed. Killifish from the site show high levels of chronic inflammation, and they don't possess the normal blood-circulating antibodies that other fish depend upon for defense against bacteria. And their livers? A disaster zone, Rice says. "By the time these fish become adults, between seventy and eighty percent of them have liver cancer, and almost all of them have some kind of liver damage, which you'd expect in that environment. Almost their entire liver can be a tumor, and they're still looking fine from the outside. If that happened to us, we'd be dead."

What's not killing the killifish?

For scientists studying cancer, these improbably adapted killifish represent a living laboratory of chemical carcinogenesis. But how can any killifish survive without a full of set of antibodies and a functioning liver? And what kills them, when they take a long swim in clean water? Rice has suspicions, but no smoking gun. At least not yet.

He has been looking for clues at the site itself, the shallow waters around Atlantic Wood. "What is unique about this spot is that when the tide is low you see a thin biofilm of algae, bacteria and stuff, growing on top of the sediments. You don't see that anywhere else."

When you take a living killifish out of the water, he explains, it throws up whatever it's been eating. In clean-water habitats, that typically would include a lot of baby crabs and small worms. But the Atlantic Wood killifish disgorge almost exclusively a black-and-green slime.

"The thing is, I haven't seen this biofilm anyplace else," Rice says. "One of my colleagues at the Virginia Institute of Marine Science thinks that this biofilm is completely adapted to that environment, and lives on those contaminants there as a food source."

The killifish are eating the biofilm, Rice thinks, and he and his students have explored the possibility that the biofilm itself somehow helps protect the fish. But an initial round of experiments with cell cultures did not find evidence to support that idea, so the mystery remains. But it seems likely, Rice says, that the AH receptor holds the key. His colleagues at Duke University and Woods Hole Oceanographic Institution have found that modifying the AH receptor prevents some of the deformities that appear after fish larvae or embryos adapted to clean water are exposed to toxins. "So we know that the AH receptor is involved, somehow," Rice says. "We don't know exactly how, yet, but it's involved in adult fish."

The biology of all this remains rather murky and rather noir, much to Rice's fascination and delight. For one thing, the adaptation of killifish to a toxic habitat may not result from genetic mutations of the kind we usually think about when we're talking evolution. The changes may instead be *epigenetic,* Rice says, which means that a code of biochemical tags called methyl groups may be turning certain genes on or off. Flip the switches one way, the fish can gobble black slime and thrive in toxic water. Flip the switches another way, they die.

Whatever flips the switches, the renegade receptor is no doubt involved. And to learn that receptor's true calling, its reason for being, is one of those quests that drive a scientist like Charles Rice to spend a good part of his summer collecting black slime from toxic sediments and hauling it back to the lab like so much *Teenage Mutant Ninja Turtle* ooze. What he learns about the stuff, well, that will have to play out in the chapters to come.

Charles D. Rice is a professor of biological sciences in the College of Agriculture, Forestry, and Life Sciences. Funding from the National Institutes of Health has supported the research described here.

The chemistry of math

Making and modeling better membranes could help unclog pharmaceutical pipelines.

by Anna Simon

When Lea Jenkins looks at a bowl-shaped stadium, she sees a parabola. "I see the world as a bunch of math equations," she says. But she also sees people, and ways to solve their problems. "Math's more interesting if there's some application I'm moving toward," she says.

Lately, Jenkins, an associate professor of mathematics, has been working with chemical engineer Scott Husson and two graduate students—Juan Wang from chemical engineering and Anastasia Wilson from mathematical sciences—to help people get affordable medication. Their idea is to speed up a key separation process used to manufacture pharmaceuticals.

A recent morning finds Jenkins and Wang deep in conversation in Husson's lab on the second floor of Earle Hall. They stand next to a piece of machinery about the size of a carry-on suitcase with lots of plastic tubes running in and out of it. The machine is an AKTA purifier, explains Wang, who holds a thin, circular piece of porous white material called a membrane adsorber. The adsorber, placed between connecting tubes, separates fluids and captures proteins. Jenkins and Wang are discussing how to fine-tune the membrane structure to eliminate clogging and separate fluids faster.

Speedier separation of protein from fluid could dramatically increase yield and efficiency for manufacturers of medications known as biologics, improving availability and lowering cost for consumers, Husson says.

Biologics include blood-pressure medications and chemotherapy drugs, as well as medications for chronic conditions such as rheumatoid arthritis, macular degeneration, and multiple sclerosis.

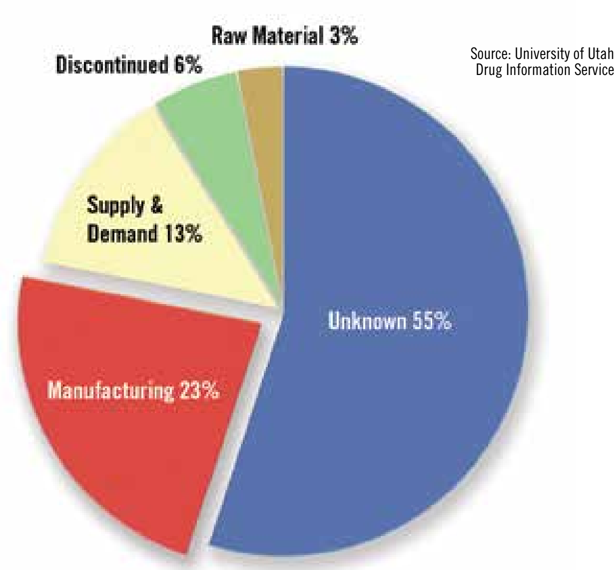
Trouble is, manufacturers can't make enough of some medications to keep up with demand. A high of 267 drug shortages were reported in 2011, according to the University of Utah Drug Information Service. The number dropped to 140 in 2013. A chemotherapy drug shortage made headlines in 2013, when 83 percent of oncologists and hematologists surveyed in a study reported shortages. Nearly all of the doctors reporting shortages also said patient care was affected.

Making and modeling

The shortages have multiple causes, but one major factor is filtration. Manufacturers of biologics manipulate cells in their laboratories to produce protein and then harvest the cells to get the protein out, Husson says. Clogged filters slow the flow.

To solve the problem, Husson, Jenkins, and their students are working to improve the membrane, finding the optimal pattern for its structure. The chemical engineers fabricate the membrane. The mathematicians use computerized models to simulate the behavior of fluids transported through the membrane and optimize the structure.

"We use math to model and simulate a physical process, so they don't have to go into the lab each time a parameter of the project changes," Jenkins says. "We can do thousands of computations within minutes to screen many different combinations."



Causes for U.S. drug shortages: More efficient manufacturing could improve the supply.

Husson says the researchers can increase production speed by two orders of magnitude. That's comparable to producing 500 grams of medication in the same time and with the same volume of separation from material currently yielding 5 grams, Husson explains.

Husson and chemical engineer Jinxiang Zhou have formed a Greenville-based company, Purilogics LLC, and are working with a pharmaceutical manufacturer to commercialize the technology. A Clemson patent is pending and they intend to license the product, Husson says.

"It's a good time to be in it," Husson says. "By two thousand sixteen, eighty percent of the top ten drugs made in the U.S. will be biologics, and fifty percent of the top one hundred drugs made in the U.S. will be biologics."

Beyond the spreadsheet

The mathematics of fluid and flow, it turns out, apply to more than drug making. Jenkins has developed models to protect aquifers from chemical spills, and she has worked with oil companies to get oil out of the ground more efficiently. She has also provided models simulating water flow under various conditions to help berry farmers in drought-stricken areas of California better manage their water resources and recharge aquifers, including factors such as time to market and cost of production.

"The framework can apply anywhere," Jenkins says. "Optimizations change with parameters. You can model all of that with equations."

It's math that goes beyond the spreadsheet and into applications, and that's the kind of math that excites Jenkins.

"That's a great part of working with the engineering community," Jenkins says. "They develop new models. They give them to me and I'm one of the first people to work with them to develop simulation tools and supplement their lab work in finding the answers they're chasing."

This type of collaboration between mathematicians and engineers opens new doors for graduate students on the brink of their careers as well. Wang says she's gained an ability to travel seamlessly between her own discipline of chemical engineering and that of mathematics, enabling her to translate computations into physical properties in the lab. Wilson says working on the joint project makes her a more "well-rounded applied mathematician," which increases her marketability after graduation.

"Working with people outside of the field of math shows that I can understand material that is outside of my field in addition to showing that I can communicate complex mathematical ideas to people who have varying degrees of mathematical knowledge," Wilson says.

Wilson had considered switching from math to engineering in graduate school to work with applications that produce tangible results. She stayed in math because she also enjoys "the focus on the mathematical foundations behind the applications," she says.

This project allows her to do both.

"The answers that I obtain from my research have the potential to help Scott and Juan optimize their membranes, that is, make the membranes work more efficiently when separating proteins," Wilson says. "Much of the time, the protein separation process is used for the purification of proteins for therapeutics, so I get a lot of fulfillment in my research knowing that the results will improve the world we live in."

Anna Simon

Mathematician Lea Jenkins (left) and Juan Wang, a doctoral student in chemical engineering, use mathematical equations to optimize membranes used to manufacture drugs.

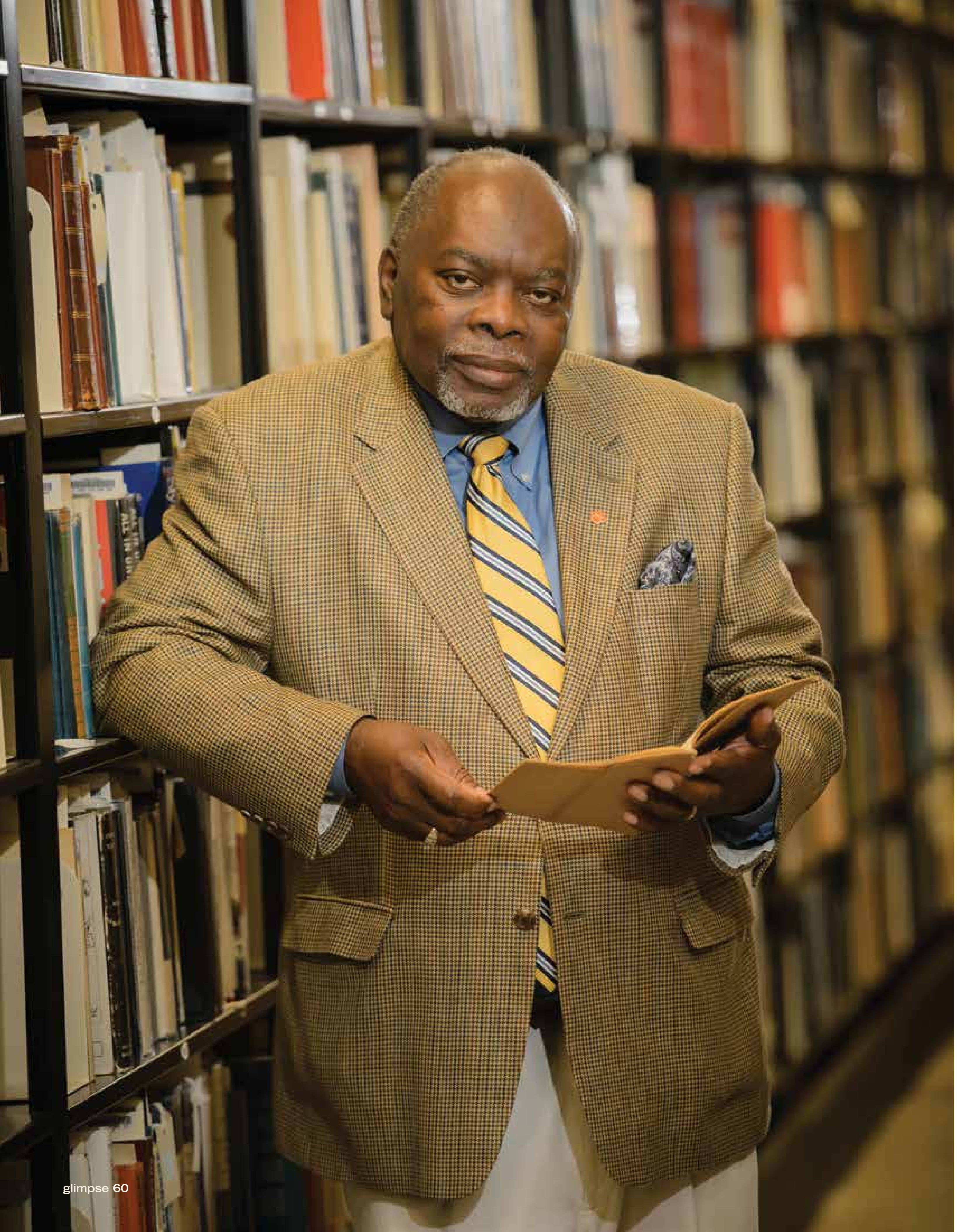
Craig Mahaffey

Wang discusses a new membrane formulation with her advisor, Scott Husson, from chemical engineering.

Eleanor W. Jenkins is an associate professor of mathematical sciences. Scott M. Husson is a professor of chemical and biomolecular engineering. Both are in the College of Engineering and Science.

The study of chemotherapy drug shortages cited here was conducted by researchers at the Abramson Cancer Center and the University of Pennsylvania's Perelman School of Medicine; it was presented at the annual meeting of the American Society of Clinical Oncology.

Anna Simon is a freelance writer based near Pendleton, South Carolina.



Writing Toward Freedom

How a slave savant charmed his masters even as he denied their right to own him.

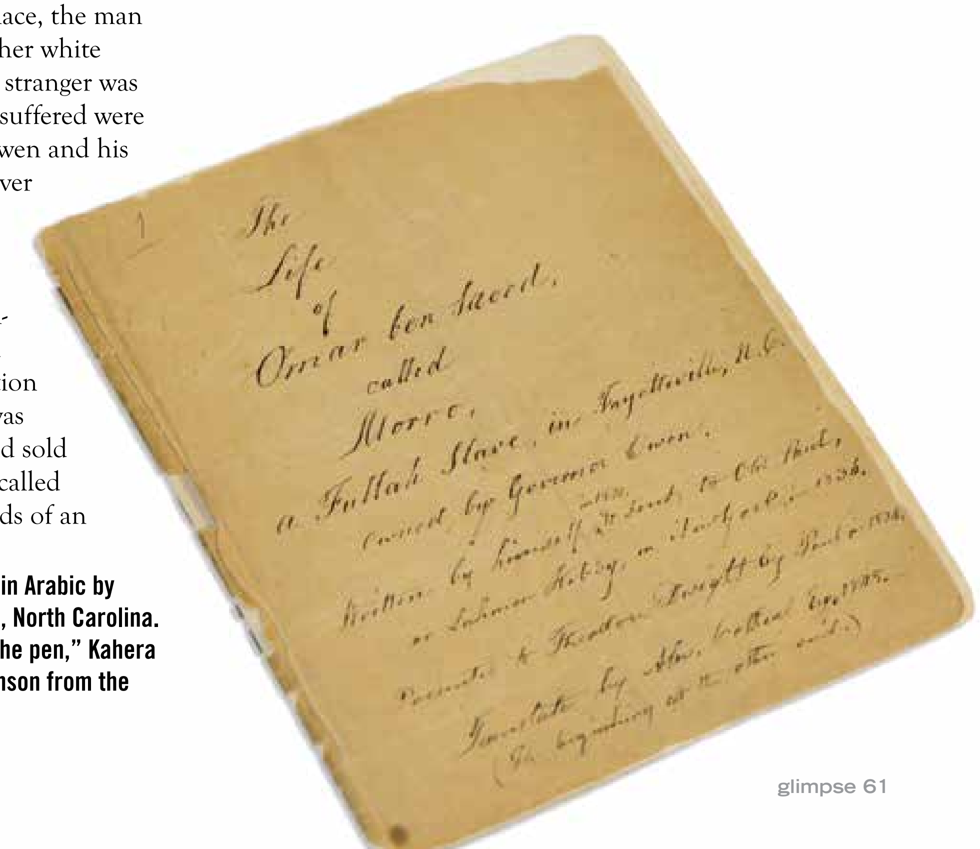
by Neil Caudle

The year was 1810. People in the streets of Fayetteville, North Carolina, began spreading the word about a stranger, a black man under lock and key in the local jail. He was a slight man, perhaps forty years old, worn thin from scant rations and heavy labor—a runaway slave who had been captured in a church, where he had found shelter to pray. In his jail cell, the man had been writing—a remarkable thing in itself for a slave. He had reached into a pile of ashes, fished out the nuggets of coal, and used them to fill up the walls with odd symbols.

People who had witnessed this curious behavior claimed that the man wrote backward, right to left, in a strange kind of language none of them had ever seen. Very soon, the man was a local phenomenon, a sensation. White people stopped by to watch him and marvel. After sixteen days, having written his way into the sympathy of Fayetteville's populace, the man walked out of his jail cell in the custody of another white owner, a man by the name of James Owen. The stranger was still a slave, but the beatings and privation he'd suffered were over. "They are good men," he wrote later, of Owen and his brother, "for whatever they eat, I eat; and whatever they wear they give me to wear."

The text on the jailhouse walls was in Arabic, and its author was Omar ibn Said, a Fulani Muslim tribesman of Futa Toro, modern-day Senegal. Born around 1770, he had devoted twenty-five years of his youth to religious education then worked as a teacher and trader before he was captured, in 1807, by a warring African army and sold to a slaver. His journey across the big sea, as he called it, through the Port of Charleston, into the hands of an abusive owner named Johnson, was cruel enough to crush a lesser man. But Omar survived, and so did his faith in the power of words.

Omar's original manuscript about his life journey, *The Life of Omar Ibn Said, Written by Himself* (1831), now occupies a place of honor at Clemson, on loan from its owner, the collector Derrick Beard. It's a remarkable document, not only for its historical eminence as the only autobiography written in Arabic by a slave in America but also as a mysterious and multilayered appeal on the subject of dominion: Who has the right to master other men? Only God, Omar argued, is entitled to hold such power. This was his topic and his striving—in effect, his *jihad*. Quoting passage after passage from the Qur'an, weaving them together with lessons from the Christian Bible, Omar was writing for his life.



Facing page: Akel Kahera with the manuscript written in Arabic by Omar ibn Said while he was enslaved near Fayetteville, North Carolina. "In some ways he made himself free by the power of the pen," Kahera says. The original manuscript (right) is on loan to Clemson from the collector Derrick Beard. Photos by Craig Mahaffey.

A treasure rediscovered

Akel Kahera, an architect and scholar, first took an interest in Omar ibn Said when he was a Ph.D. student at Princeton University in the mid-1990s. Kahera, who had learned Arabic in the Middle East and had worked for ten years as an architect in Saudi Arabia, knew that Omar's autobiography, rediscovered while Kahera was at Princeton, was an international treasure. Most slaves in America had been forbidden to read and write, and here was a manuscript by a slave who had not only written a document of substantial historical interest but had done so in Arabic, with "a level of literacy that was strong and serious," Kahera says. In the sweep of his prose, Omar could draw upon the teachings of two great religions and his own remarkable life on two continents with very different cultures. "All of that gave it incredible importance," Kahera says.

The manuscript, which had been missing since 1920, was for sale at a gallery in New York, Kahera learned. "I was trying to get Princeton University to buy it," Kahera recalls, "so I went to New York with one of my mentors, the late John Ralph Willis, to examine the document, and that was an incredible moment—to hold this thing in my hands."

Princeton declined, but Kahera befriended Beard, the collector who eventually bought the manuscript. Because of that relationship, Kahera says, Beard has agreed to let Clemson keep the document for two years.

As Kahera sees it, the writing that began on the walls of that Fayetteville jail cell and flowed through the pages of Omar's autobiography probably sustained the man, body and soul. Omar's talents, Kahera says, helped to spare him from backbreaking labor, charming and impressing not only the Owen family but a long list of white luminaries, including Francis Scott Key, who came to visit the savant-like Omar. Owen brought him a Bible

University of North Carolina at Chapel Hill Libraries

This daguerreotype of Omar ibn Said was made in the 1850s, when he was about eighty years old.

Below: The manuscript opened to its Arabic text.

Craig Mahaffey

translated into Arabic and an English edition of the Qur'an, and apparently encouraged Omar's erudition.

Why would a white slaveholder and his friends celebrate the talents of this one fragile man? We don't know for sure, but Kahera thinks the answer might involve the rising sentiment at the time, in some quarters, favoring abolition. "I often wonder if the interest was to use Omar to help support the abolitionist agenda," Kahera says. "Here is a slave who has a mind and can think, so he's a human like us. He was exhibit A. Case closed. And Owen was trying to find out where Omar fit in the larger story. How many people were there like him? As far as we know, there were many."

It's been estimated that more than 20 percent of African slaves brought to the United States were devoted Muslims, many of them proficient in Arabic. But most slaves, no matter how literate, were forbidden to read and write. Omar was that rarest of men: a slave allowed his voice. "In some ways, he made himself free," Kahera says, "by the power of the pen."

An appeal to his God

Some scholars have questioned Omar's fluency in Arabic, based on the occasional quirkiness of his phrasing. The phrase he uses for the Fayetteville jail, for example, is "the big house." But Kahera has read the manuscript in Arabic, and he's impressed. "I think he was very good with the language," Kahera says. "He was able to remember the Qur'an because as a young boy he was immersed in it until it became indelible in his mind. So when he writes about Africa and his religion, that part was easy for him. But when he tries to write about Fayetteville, North Carolina, in Arabic, he's having to listen to Americans speaking with a Southern accent, using English, which is not his native language, and then try to transliterate that into Arabic. Even so, he does a pretty good job."

Omar's literacy, in Arabic and English, was certainly good enough impress to the many visitors who stopped by Bladen County to ponder his considerable humanity. But Omar was doing more than showing off for whitey to save his own skin, Kahera says. He had embarked on what Christians might term a *calling*. A Muslim would call it *jihad*.

"There's a concept in Arabic that's known as the jihad of the pen," Kahera says. "That word jihad has been misconstrued as 'holy war,' but it means 'struggle.' Omar's was a jihad of the spoken word, a jihad of the pen."

Kahera finds clues to this jihad in Omar's compulsion to write on the walls of his jail cell. He was probably composing a kind of invocation, Kahera says, an appeal to his God. "Part of the Qur'an has this power to invoke what's known as *dhikr,*" Kahera says. "This is something that would allow the force to be with you, so to speak. It allows you to reach out and petition your God to relieve you of your hardship."

In an essay published in the Spring 2014 issue of the *South Carolina Review,* Kahera builds a compelling case that Omar was also writing to condemn, with considerable finesse, the institution of slavery. It is no accident, Kahera argues, that the central text of Omar's argument was a chapter from the Qur'an titled Al-Mulk, which means "dominion" or "sovereignty." Al-Mulk asserts that only God has dominion over people. Quoting its verses again and again, Omar consistently "undermines the practice of granting slaveholders dominion over other human beings," Kahera writes.

In short, Omar was a slave denouncing slavery, along with its popular justifications in Christian doctrine of the time. This was dicey business, at best. Some scholars have assumed, after reading Omar's writings and other accounts from the time, that he converted to Christianity during his years with the Owen family. Like many other Muslim slaves, Omar would have felt considerable pressure to convert, and he did attend church and read the Bible in Arabic. His conversion might have afforded a measure of tolerance and protection.

But Kahera isn't convinced. "The big question is whether he converted to Christianity," Kahera says, "and I take the position that he didn't." Even when Omar quotes the Bible, he introduces the scripture with a *surah* from the Qur'an. What emerges is a tapestry of both. Strange as it may seem today, Omar's intermingling of Christian and Muslim texts underscores their common themes and their roots in the Abrahamic tradition, Kahera says.

The power of a legend

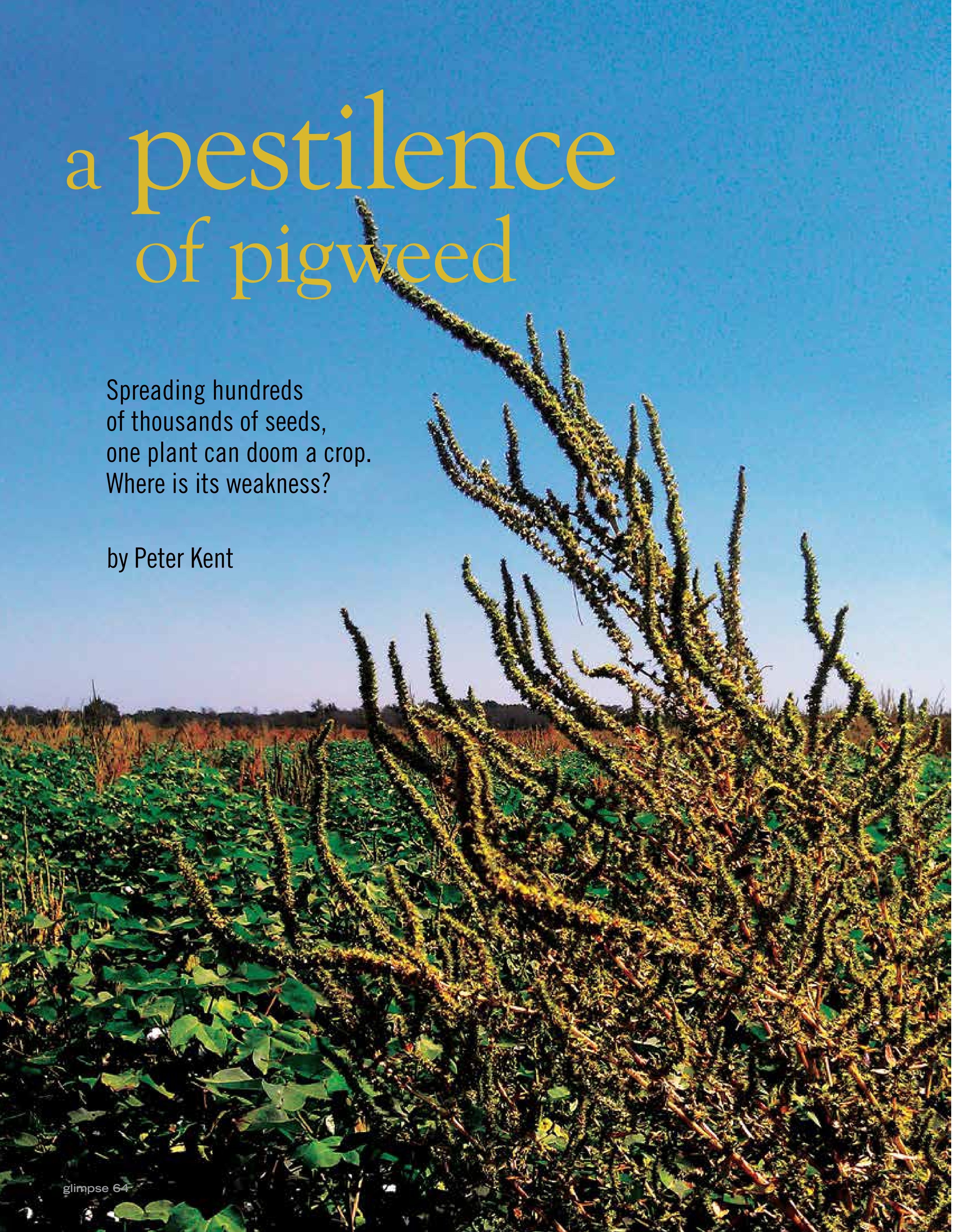
Omar may indeed have allowed Owen and others to believe that he had converted, professing enough Christianity to pass as a convert without denying Islam. If so, he played the angles with considerable aplomb. "He became a legend," Kahera says. "People looked at him as someone who had some kind of special power."

What was the source of that power? "I draw a parallel between Omar and Martin Luther King, Jr., especially in his famous 'Letter from a Birmingham Jail,' to Omar's struggles," Kahera says. "When you put someone in very acute circumstances it raises the level of consciousness and you see the world in a way that you wouldn't normally see it."

It may be safe to assume that Omar could not have pulled any of this off without concealing, quite artfully, a great deal about himself and his motives. Kahera has many questions about the man behind the text. "I think there's a secret side of him that we really don't know," he says. "I am curious for example about why he did not want to be repatriated to Africa when he had the chance. Some slaves did go back. I think he had reconciled himself to accept that God his creator had destined him to be at this place in this time under these conditions. I see him as a man of tremendous faith and piety."

Omar was also a man who used his jihad of the pen to influence the very culture that enslaved him, Kahera says. "Maybe he thought his influence could bring some relief to others who were in the same condition he was, so they'd be looked upon as human."

Akel I. Kahera is a professor of architecture and the associate dean for research and graduate studies in the College of Architecture, Arts, and Humanities. The manuscript of The Life of Omar Ibn Said, Written by Himself, *will be exhibited in the Strom Thurman Institute, Special Collections Library, October 1, 2014, to April 30, 2015. An exhibit reception is planned for 2–3 p.m., October 17.*



a pestilence of pigweed

Spreading hundreds of thousands of seeds, one plant can doom a crop. Where is its weakness?

by Peter Kent

If Palmer amaranth were a smell, it would be skunk odor. Unlovingly called pigweed, the plant is pervasive and enduring, and a little of it goes a long way. One plant can ruin a field if untreated.

"I know when I see it, I have got to kill it," says Matt Fischer, who oversees crops on Clemson's Simpson Experiment Station, a cattle and crop research farm.

If he doesn't, where there's one pigweed today, there may be half a million by next growing season. It's a weed population bomb, and defusing it is getting harder and harder.

Amy Lawton-Rauh studies plant species and populations, looking at speciation mechanisms, which is how evolutionary forces give rise to separate populations and new species. She specializes in the "capture and escape" genetic processes of plants grown as crops. Her work can mean the difference between profit or loss for farmers and between food or famine in the future for much of the human population.

"Basically we're studying plants that are weedy wild relatives of crops—the escape artists that have escaped domestication—and the plants that evolve to adapt to crop conditions and get captured in the agricultural ecosystem by competing with crops for resources, exploding in population size, and rapidly becoming huge problems," Lawton-Rauh says.

"My work as a population geneticist is to explain variation in traits and genomes," she adds. "What we do is figure out how different gene variations—they're called alleles—occur in a population and how these variations move around populations and species through gene flow."

A new species can occur because of geographical isolation and new mutations, interbreeding, or environmental pressure. Whatever the cause, the populations establish themselves and persist. For an adaptation to endure, it must be passed on to new generations. Lawton-Rauh wants to know how populations originate and adapt, and how adapted alleles spread among populations and species. She also seeks how to manage this spread and prevent disasters.

"We strive to contribute to and translate the latest research in population and evolutionary genetics into problem-solving approaches," she says. "There are amazing examples of how humans have created strong selection pressures, leading to highly adapted populations. Why not use these examples as tools to aid research-informed decisions?"

Roundup and Roundup Ready crops were meant to be a boon to farmers and help a hungry world by killing weeds. It hasn't worked out as expected.

When Monsanto discovered glyphosate in the 1970s, it hit a home run. The product became the most popular weed killer in farm fields and home gardens. Then Monsanto hit a grand slam. In the 1990s, the company launched the first Roundup Ready crop, a soybean genetically altered to tolerate glyphosate. Roundup Ready plants were unharmed while the weeds were killed, and glyphosate was relatively safe to handle. It also decomposed rapidly, minimized the need for tilling, and reduced the need for other herbicides. Eventually, cotton and corn joined soybean as Roundup Ready crops. But then nature took a turn.

Palmer amaranth, also known as pigweed, grows fast, resists herbicides, and spreads like wildfire. Photo by Amy Lawton-Rauh.

"Nature bats last," says environmentalist Bill McKibben about the relentless power of adaptation.

The weeds have taken the lead.

Around 2004 some weeds became Roundup resistant. Horseweed, water hemp, giant ragweed, and Palmer amaranth have spread near and far, from South Carolina throughout the South and Midwest to Brazil, China, and Australia. Referred to as "superweeds" by some, they capture fields, crowd out crops, and run costs up to hand weed, plow under, and spray with other herbicides. The superweeds are major threats to production agriculture, environmental safety, and food security.

Pigweed quickly caught the attention of Lawton-Rauh, who studies evolutionary genetics.

"It is an example of a capture plant because it used to be minimally distributed in the southeastern United States and was even used as a food source by foragers and some Native American tribes," she says. "Now it is a highly adapted, more broadly distributed, aggressive agricultural weed."

Pigweed can grow three inches a day, reaching seven feet tall, with a deep tap root and stout stalk. Pigweed's most impressive feat is its reproduction.

"One plant can produce as many as five hundred thousand seeds," Lawton-Rauh says. "You can imagine what happens when a field has five plants—two-and-a-half million seeds. This is like two-and-a-half million genetic experiments. The seeds are very small and easily transported. When we work with them in the lab, we put up signs not to enter."

Lawton-Rauh works with researchers and producers in Arkansas, along with colleagues in North Carolina, Georgia, and Europe. Cotton growers have been devastated by pigweed, and Cotton Incorporated has been a primary funder of the research. In June, *Southeast Farm Press* wrote about a *Weed Science* journal report of Palmer amaranth's impact on Arkansas cotton fields. In the study, researchers determined what would happen if 20,000 seeds—2 percent of the seed potential of a single plant—were released on a square mile test area. The headline was: "One weed leads to complete crop failure."

Cotton isn't pigweed's only conquest. More than forty crops, including soybean, corn, and potatoes, fall prey to pigweed as it invades fields and monopolizes water, nutrients, and light. Yield losses can run nearly to half from pigweed infestation.

What the researchers want to know is the origin of adaptive gene variations in Palmer amaranth and how these variations spread across populations through gene flow. It can't be just because of all those seeds. There can be too much distance between outbreaks, even though seeds can easily hitch a ride on floodwater, tornado winds, or muddy boots.

"Our work indicates that glyphosate resistance also spreads by independent mutation," Lawton-Rauh says. "That many seeds mean that there are millions of opportunities for new mutations, adaptations, and genetic combinations leading to possible survival across many conditions."

Glyphosate works by binding within a protein known as EPSPS, which is coded by a part of a plant's DNA, preventing the production of essential proteins. Normally, there's only one copy of the gene in a cell, which makes it easy for glyphosate to block the protein and kill the plant. Pigweed has adapted by making hundreds of copies of the gene and scattering these throughout the plant's genome so that massive amounts of the EPSPS protein can be produced. Glyphosate can't lock into every EPSPS protein produced. Pigweed flourishes.

"We weren't the ones who found the gene copy number correlation with glyphosate resistance," Lawton-Rauh says. "We were the ones who found out that resistance can arise independently and how the number correlates with origins and adaptation in populations—how copy numbers and genetic variations arise and move around pigweed populations."

The correlation is not one-to-one, but above a general threshold number of copies there is some glyphosate resistance.

To test her hypotheses, Lawton-Rauh collects pigweed samples. They arrive in brown paper bags holding the snipped seed heads sent in by research scientists working with Clemson extension agents and growers who have been trained in how to collect samples. The researchers use the seeds to grow plants and then analyze the leaves.

"Our research will help us understand basic evolutionary genomics processes, how herbicide resistance develops, and how to manage crop production to reduce the pressures put on weeds to adapt," Lawton-Rauh says.

Where Palmer amaranth increased gene variation by adding gene copies to adapt, another plant escaped its domesticated genes. "Our escape artists are rice populations where crop rice interacts with its wild relatives and weedy populations. These interactions can lead to aggressive weedy rice or sometimes crop rice plants that go wild and become weedy," Lawton-Rauh says. "Weedy rice is an excellent model for understanding how weediness happens in production agriculture and for the stability of the domestication process."

Rice cultivars feed more than half of the world's seven billion people, and by 2050 production will need to increase by roughly 40 percent to meet the demands of some nine billion people. Weedy rice will yield empty bellies.

Rice breeders selected traits that would enhance yield, satisfy culinary tastes, and reduce production effort. They developed varieties that were compact and had heavy seed heads that matured and dropped seed predictably. Weedy rice develops at different times than its crop cousins, escaping harvest. It also produces fewer rice grains of poorer quality and is difficult to control. Changes in the way growers plant rice, using seed drilled into the soil instead of farmhands planting seedlings, mean fewer watchful eyes to identify weedy rice and remove it.

"Weedy rice has a long seed dormancy, which allows it to come up during the next growing season," Lawton-Rauh says. "Crop rice is nondormant to prevent its growing. We want nondormant seed so it won't compete with another crop in rotation, such as soybean."

Finding the gene variations in the weedy rice genome that trigger the emergence of undesirable traits like seed dormancy contributes towards basic scientific knowledge. It's also one step toward controlling weedy close relatives of crops.

Another step will be to compare the weedy rice population genetics around the world to determine how it spreads in order to develop management strategies.

One solution being tried in the United States is herbicide-tolerant rice cultivars, which would let growers spray to kill the weeds but not harm the rice crop. Already there is concern about weedy rice becoming herbicide resistant.

Nature steps up to the plate for another at bat.

Amy Lawton-Rauh is the principal investigator of the Lawton-Rauh Laboratory for molecular evolution and population genetics, and an associate professor in the Department of Genetics and Biochemistry, College of Agriculture, Forestry, and Life Sciences. Peter Kent is a news editor and writer in Clemson's Public Affairs Activities.

Brad Rauh

Amy Lawton-Rauh studies the escape artists that have broken away from domestication, such as weedy rice, and also plants that evolve to capture an agricultural ecosystem, including Palmer amaranth.

Ashley N. Jones

Back in the swing

Clemson's Foucault pendulum, idle for most of a decade, is back in full swing.

First designed and built in the 1960s by the late Professor Albert R. Reed, the new version of the pendulum still dangles Reed's brass-covered lead bob from the wire he artfully braided from nineteen strands of stainless steel. He suspended the pendulum in a four-story, glass-and-brick tower between Kinard Laboratory of Physics and Martin Hall, where it swung for thirty years, propelled by magnets to offset air resistance and friction in the wire, before age and disrepair took a toll.

Over the last several years, physics students built a scale model of the pendulum, updating its design with an optical sensor, a microprocessor, and digital controls to track the course and activate the magnets. The model worked, so Chad Sosolik, associate professor of physics, put together a team of Creative Inquiry students and set about rebuilding the original.

They got funding from the student senate—a gift from the class of 2013—and help from Mike Chappell, a Clemson alumnus (1983), who built and installed most of the electronics along with hardware supplied by his employer, Izumi International in Greenville.

The Foucault pendulum is named for the French physicist Jean-Bernard-Leon Foucault (1819-1868), who built the first one to demonstrate that the Earth rotates on its axis. Unlike the pendulum in a grandfather clock, which swings in two dimensions, the bob of an oscillating Foucault pendulum travels a three-dimensional circuit, completing its precession in one "pendulum day," which is forty-two hours at Clemson's latitude.

The pendulum, Sosolik says, is a perpetual, visible reminder of some of the forces that govern our world. "We hope people will come to see this and learn how it works," he says.

For a feature on Chad Sosolik's research, please go to page 44.

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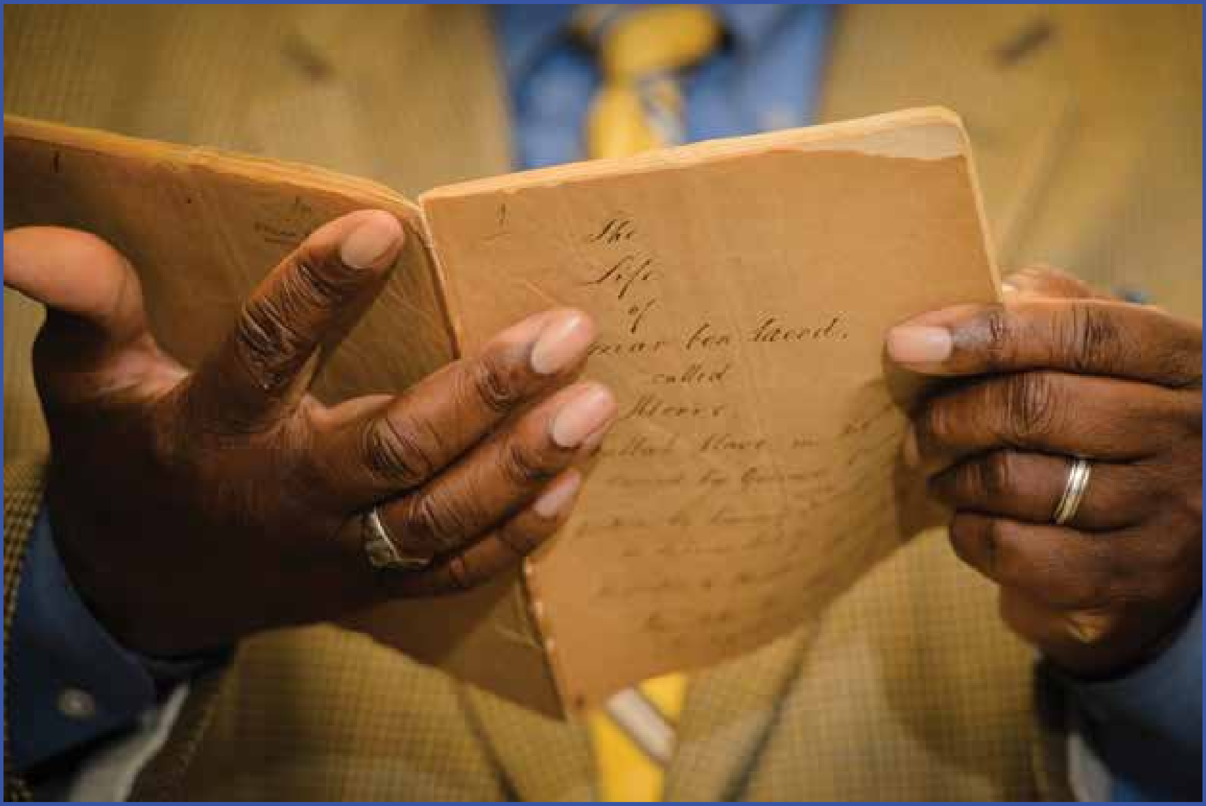

Words from a slave writing for his life

Omar ibn Said's autobiography invoked both Muslim and Christian traditions to dispute the right of anyone to own another human being. Akel Kahera, who has studied the text in its original Arabic, remembers his first encounter with the manuscript: "That was an incredible moment," he says, "to hold this thing in my hands." Page 60.