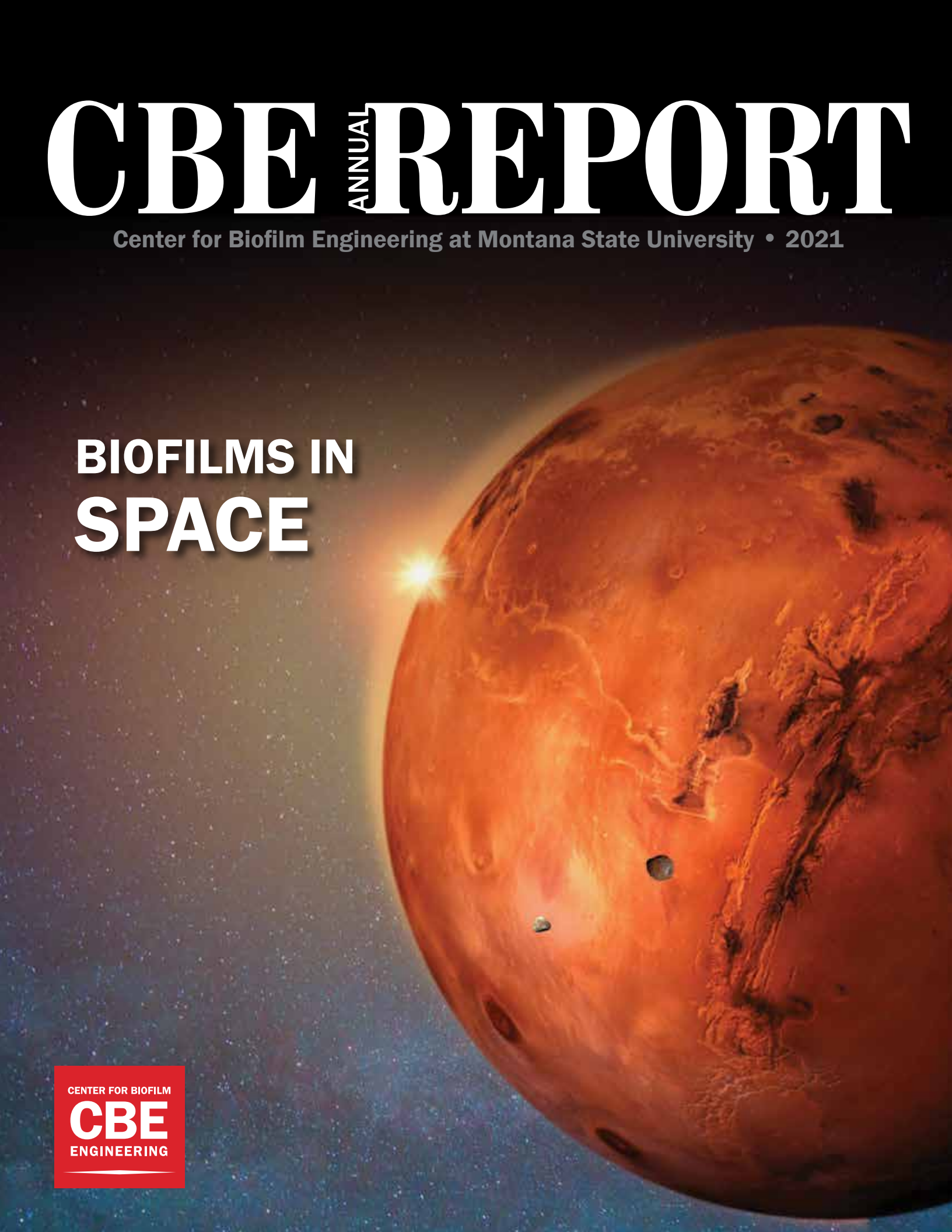
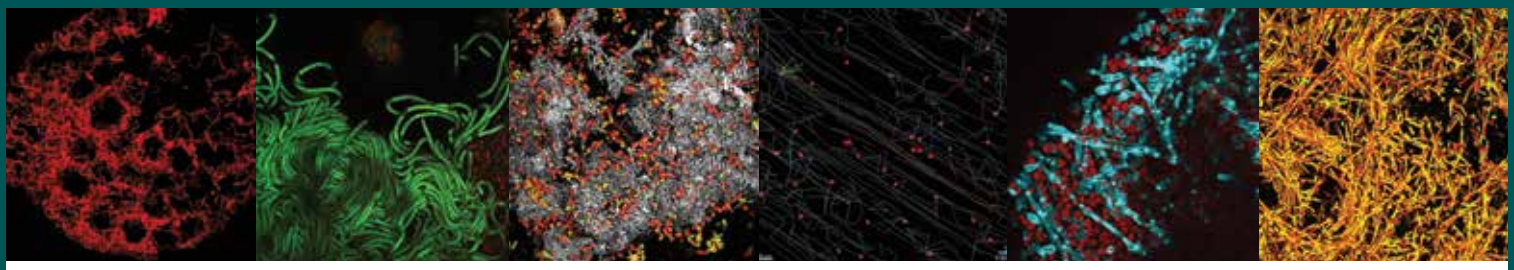
CBE ANNUAL REPORT

Center for Biofilm Engineering at Montana State University • 2021

BIOFILMS IN SPACE



CENTER FOR BIOFILM
CBE
ENGINEERING



A WORLD-CLASS FACILITY BUILT TO SOLVE REAL-WORLD PROBLEMS

CBE Bio-Imaging Facility

The CBE Bio-Imaging Facility is the world's most advanced, centralized microscopy lab uniquely suited for biofilm research. Three recent grants totaling $1.8 million have generated unprecedented momentum, enabling us to pioneer the next-generation of biofilm research. However, in order to enable our students and faculty to fulfill the promise of their groundbreaking research, ***we urgently need an additional $1.2 million to complete this keystone project.***

ADVANCED EQUIPMENT IS ONLY HALF THE EQUATION

Redefining the how-to

CBE is a leader in interdisciplinary research, and our Bio-Imaging Facility is mission-critical for projects that span areas of scientific inquiry. It is an MSU Core Facility utilized by students and researchers across campus, as well as visitors from around the world.

More than just magnification

Our microscopy tools make visible the components and processes of living biofilms without destroying them, as well as reveal their chemical makeup and create real-time video of biological processes.

HUMAN HEALTH

- Drinking Water Quality
- Chronic Wound Healing
- Implanted Device Infections
- Food Safety
- Antibiotic Resistance

ENVIRONMENTAL

- Bioremediation
- Wetlands
- CO_2 Sequestration
- Microbes & Mining Issues
- Renewable Energy
- Biomineralization

INDUSTRIAL/ MANUFACTURING

- Product Contamination
- Biofouling
- Biocorrosion
- Regulation

FUEL OUR MOMENTUM

Your contribution will directly propel the CBE closer to solving the world's biofilm challenges that ...

- cause thousands of deaths in the U.S. annually
- add $340 million to medical-treatment costs in the U.S. annually
- cause 296 amputations every day in the U.S.
- create billions of dollars of damage to industrial systems in the U.S. per year

STUDENTS CONTRIBUTE TO OUR SUCCESS DAILY

We invest in our students

We individually train each student to design relevant studies and help them share their field-defining discoveries with the world.

We teach students to succeed

The one-on-one training we provide each student allows them to expand their technical education, and deepen their understanding of the powerful tools we make available to them 24/7. This approach is instrumental in continuing the success of our student-research program that has helped many of them build notable careers in academia, industry, and government.

Women in STEM

Seventy percent of CBE undergraduate researchers were female in 2019-20. Madelyn Mettler, who joined the CBE as an undergraduate researcher, is now pursuing her PhD at MSU and helping NASA overcome a biofilm challenge that must be solved before humans can set foot on the planet Mars. See page 12 for more about women in STEM.

The Center for Biofilm Engineering is the world's first, largest, and best-known biofilm research center.

Contact CBE Director Matthew Fields at 406-994-7340 or matthew.fields@montana.edu

www.biofilm.montana.edu

www.montana.edu

Looking onward and upward in an upside-down world

In a world that's been spinning on its head for nearly two years, we've all had to adapt to new ways of conducting business (e.g. WebEx meetings, conferences, and seminars) and conducting research (i.e. solo lab time during off-hours). Like you, we have had to limit the number of visitors during the pandemic, we've worked remotely as much as possible, we've worried about our loved ones, and we've sanitized our hands so much that we're lucky to have fingerprints. Despite these limitations, the researchers at the CBE still found ways to propel their projects forward, including joining the battle to meet the challenges presented by a new coronavirus.

Today, as we face ongoing adversity of the unknown, we continue our work. The centerpiece of the *2021 CBE Annual Report* shows a glimpse of the multiple projects we've undertaken to help NASA solve a vexing biofilm problem that, without a solution, could scuttle its ambitious missions that otherwise would have left footprints on Mars. We also share with you the impressive success CBE-affiliated faculty member Christine Foreman has generated toward repairing the longstanding gender disparity in STEM careers. And, did you know fungi are showing promise as a building material that could reduce the amount of concrete used in construction projects? We're also working to upcycle plastics into building materials. Talk about two giant leaps for mankind!

Looking ahead, we are cautiously hopeful that we can gather in Washington, DC, come February for our annual regulatory meeting, "Pathways to Product Development." Of course, we'll only host the gathering in person if it's safe to do so. Should the coronavirus keep us apart, there is good news! We've learned how to excel at incorporating value-added programming to our online meetings in a way that leverages the technology rather than merely enduring it. The virtual 2021 Montana Biofilm Meeting was outstanding, with strong speakers, lively discourse, and a panel discussion that peeled back the mysterious biofilm matrix to consider what potentials it may conceal and exploring the challenges of realizing them. So, if we do go online, rest assured the medium will enhance your experience and advance our exchange of ideas. Whether we next meet in-person or virtually in this upside-down world, we will maximize our time together.

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CBE BY THE NUMBERS

FY2021

Industry

53 testing projects

35 sponsors

$1 million generated

Research

$4.3 million new research grants

44 publications

36 journals

Images

153 images downloaded
from the CBE image library

18 states
15 countries

3,648 images downloaded
since 2011 inception

50 states
40 countries

Education

119 students trained
61 undergraduates
43 female, 18 male
58 graduate students
26 female, 32 male

1,212 students trained
since 1990
293 graduate students
(graduated)
919 undergraduates

12 student departments

Architecture
Chemical & Biological Engineering
Chemistry & Biochemistry
Civil & Environmental Engineering
Computer Science
Directed Interdisciplinary Studies (Honors College)
Ecology
Land Resources & Environmental Sciences
Mathematical Sciences
Mechanical & Industrial Engineering
Microbiology & Cell Biology
Plant Sciences & Plant Pathology

46 affiliated faculty
7 faculty disciplines

Chemical & Biological Engineering
Chemistry & Biochemistry
Civil Engineering
Land Resources & Environmental Sciences
Mathematical Sciences
Mechanical & Industrial Engineering
Microbiology & Cell Biology

2020, 2021 INDUSTRIAL ASSOCIATES

The CBE's innovative Industrial Associates Program is a foundation of the organization itself. The IAs help guide much of the research we perform in our labs, ensuring these projects deliver real-world solutions directly to industry.

3M
MASCO
* Abradem Corporation
new Mölnlycke
* AMERICAN chemet CORPORATION
* NEXT SCIENCE
novozymes
ASP
OLYMPUS
Baxter
* PERFECTUS BIOMED
* BIOMENDICS
P&G
PPG
CHEM-AQUA
CHURCH & DWIGHT CO., INC.
CLOROX
* PureLine
QUEST Medical, Inc.
* D7 DECON SEVEN
* SANUWAVE
DeLaval
* Sharklet Technologies, Inc.
new ECOLAB
Smith+Nephew
new * ESL
SOLVAY
new * Spinnaker International
icumedical
* STERILEX
new kersia.
STERIS
new * LIBERTY BioSecurity
SHERWIN-WILLIAMS.
ZIMMER BIOMET
Lonza

* small business member

CBE plans to host in-person conferences in 2022

Just when it looked like we were about to defeat the coronavirus, along comes the delta variant. The volatility of this pandemic certainly complicates planning each of our annual conferences – the Pathways to Product Development in February and our Montana Biofilm Meeting in July. The past year, we hosted both virtually. And we found inventive ways to maximize our time together. While I'm proud of the experience we delivered virtually, there is no substitute for collaborating in-person. Therefore, we're planning to hold both the PPD and MBM meetings in person in 2022. Should conditions suggest either of these in-person gatherings pose a health risk to attendees or presenters, please know we won't hesitate to pivot and make the event a virtual one.

Survey Says ...

I'm grateful for the IA representatives who participated in our survey during the virtual MBM's Strategic Planning Meeting. Your responses help us craft our service to you. For instance, the vast majority of you said we should "ask our members to have at least one person attend each of our meetings." We couldn't agree more. And, of course, this reinforces our resolve to host our 2022 meetings in person if at all possible.

PARTNERSHIPS WITH INDUSTRY KEEP CBE RESEARCH RELEVANT TO REAL-WORLD PROBLEMS

Also, because you indicated just how strongly you value "convenient access to biofilm experts," we are in the process of developing new communication tools with you in mind: a podcast as well as a video series called "Biofilm First." Slated to debut this winter, our researchers will share the latest big-picture takeaways from their respective areas of expertise – areas that we hope will speak to the your company's wants, needs, and concerns. Thanks to you and your continued input. I encourage you to reach out to me with any questions, comments, concerns, and ideas you might like to explore.

Collaborations with Industry

Our contacts from a swath of industries kept our Medical Biofilm Lab and Standardized Biofilm Methods Lab especially busy this past year. Our researchers completed 59 testing projects for 55 companies totaling more than $1 million in revenue to the CBE. Of the 55 companies we conducted contracted work for in Fiscal Year 2020-21, 39 were Industrial Associates. I consider the other 16 as candidates for future membership.

If you know of someone who might be interested in affiliating with the CBE, please let me know.

Paul Sturman, PhD, is the industrial coordinator for the CBE. He is available at paul_s@montana.edu and 406-994-2102.

Inside the Matrix

CBE Industrial Coordinator Paul Sturman said the consensus from attendees and speakers alike was the 2021 virtual Montana Biofilm Meeting was informative, well-produced, and worthwhile. Sturman said one of the highlights that stood out to him was the panel discussion on the biofilm matrix co-moderated by the CBE's own Darla Goeres and Jim Wilking – an assessment that was universal based upon attendee feedback.

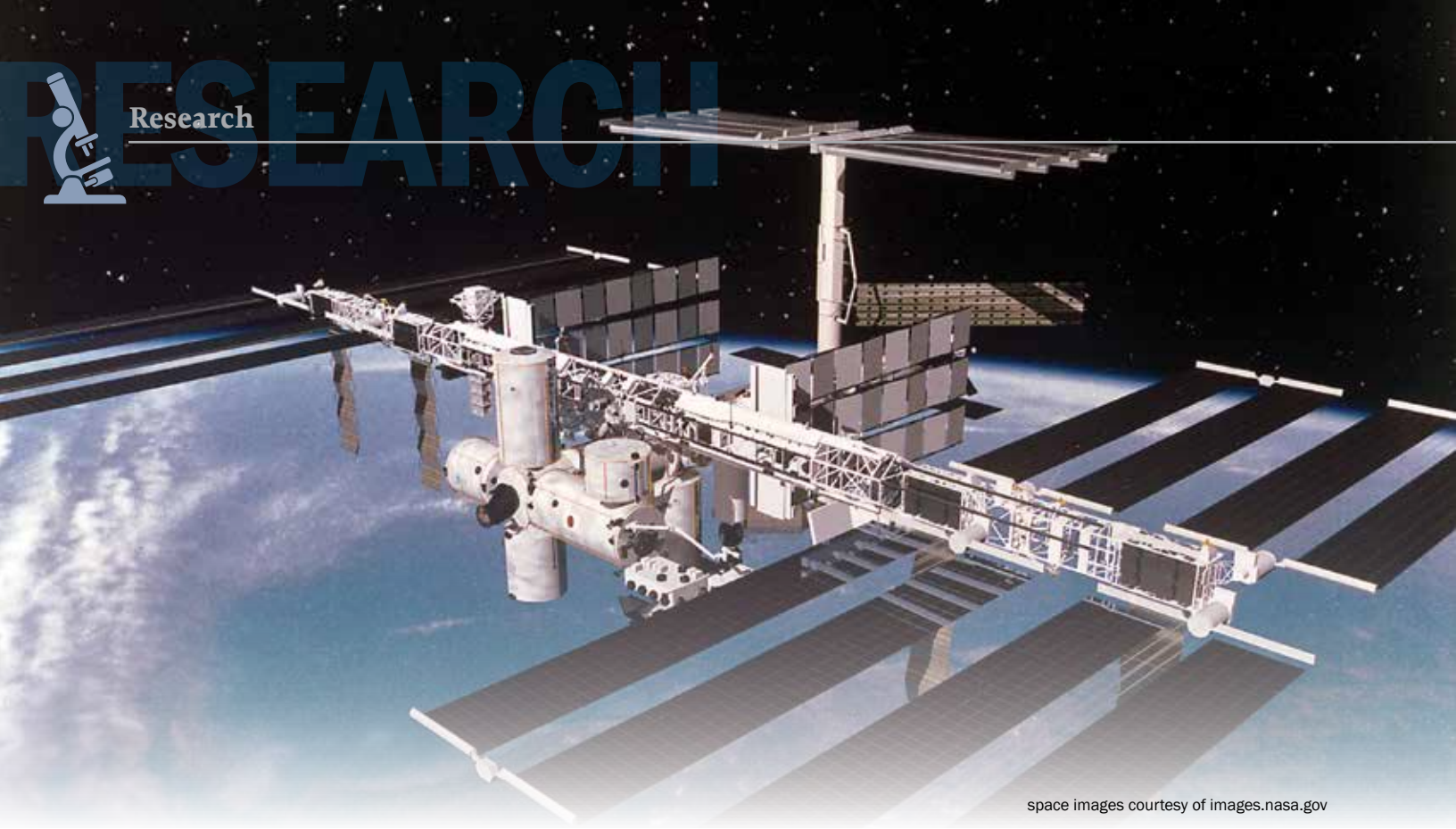
Liberty BioSecurity's road to membership

When Liberty BioSecurity joined the CBE's innovative Industrial Associates Program in 2021, it was the culmination of a relationship that began in 2017. Dr. Kyle Landry, then Liberty's chief scientist, now president, approached CBE-affiliated researcher Phil Stewart, who had just presented at a conference.

"Biofilm remains a global issue in multiple areas that we remain vigilant in working to innovate solutions and we look forward to partnering with the CBE," Landry said.

Landry visited the CBE in January 2018 and remained in touch of the next 3-plus years.

"Liberty BioSecurity develops clinical-stage pharmaceuticals," Sturman said. "They're interested in our research into the matrix – the mysterious substances that comprise biofilm to develop products that would impact biofilm-related infections including diabetic foot ulcers in implanted medical devices such as urinary catheters."



space images courtesy of images.nasa.gov

Biofilms in Space

By Skip Anderson & Marshall Swearingen

NASA has a biofilm problem. More specifically, NASA has a biofilm problem that, if unsolved, could impact its ambitious plans to send scientists to Mars in the 2030s.

Biofilms in space have been an issue since the earliest days of space stations, an era that began in 1971 when the Soviet Union placed into orbit a secret military space station. The US followed suit with Skylab, which remained in orbit about 272 miles above sea level from 1973 to 1979. However, it was only occupied for 171 days, limiting the opportunity for biofilm to become a problem. However, the Russian space station Mir, which was in low-earth orbit from 1986 to 2001, was plagued with biofilm that formed in its wastewater plumbing. The system eventually failed because biofilm had clogged it. By the end of its time in orbit, Mir's interior was coated in microbial gunk.

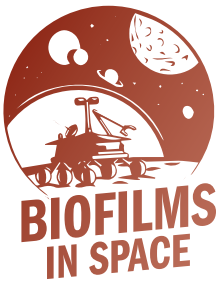
The International Space Station, which has been circling the earth around 15 times per day for nearly 23 years, also has biofilm in its plumbing. And, without a solution, so too will the spacecraft that eventually carries humans to our nearest planetary neighbor , the red planet Mars.

NASA's ambitious goal of establishing a sustained human presence on Mars in the 2030s will involve landing a crewed spacecraft on the distant planet, producing food and breathable air amid an inhospitable environment, even making rocket fuel from the Martian resources to power the journey home. When humans embark on the 2.5-year mission to the Red Planet, they'll carry all the water they need for the nearly 70 million-mile round trip, continually recycling it through pipes, tanks, and filters.

THE CBE LEADS THE WORLD IN THE NUMBER OF BIOFILM PAPERS PUBLISHED AND CONFERENCES HOSTED.

After learning about the biofilm problem aboard

When humans embark on the 2.5-year mission to the Red Planet, they'll carry all the water they need for the nearly 70-million-mile round trip, continually recycling it through pipes, tanks, and filters.



the International Space Station from a NASA Jet Propulsion Laboratory scientist at a conference roughly four years ago, the CBE invited NASA scientists to the 2019 Montana Biofilm Meeting. An hour after the meeting concluded, a new one began: NASA scientists hosted a brainstorming session with biofilm experts from the CBE and elsewhere to discuss NASA's biofilm problem.

"We plan to use these ideas to design concepts that we'll develop into a trade study," Layne Carter, manager of the water subsystem on the ISS, told the scientists and engineers at the meeting. "If it goes as planned, we'll do a technology demonstration on the ISS. Will that be in two years? Three years? I do not know. But it will be as fast as we can do it."

Ideas discussed in the free-form meeting included biocides, antimicrobial coatings, redesigned storage receptacles, limiting nutrients, and using the sun's ultraviolet rays as a disinfectant.

"There is plenty of opportunity for funding here," Carter said.

Two years later, it's clear that Carter was right. CBE-affiliated faculty have won two EPSCoR grants from NASA that encompass multiple projects to help the space agency leave footprints on Mars.

An EPSCoR grant is NASA's Established Program to Stimulate Competitive Research that supports science and technology, and research and development at colleges and universities. All projects are applicable to NASA's work in Earth science, aeronautics, and deep-space exploration. The schools that win such a grant will transfer research resulting from the projects to NASA, where it may be used as part of ongoing agency work.

Once in place, the first EPSCoR grant, titled "Integrated Biofilm Control Strategies for Water Systems during Extended Space Flight," will comprise three projects currently being undertaken under one umbrella, each with its own area of emphasis: surface biofilms, antimicrobials, and biofilm sensors.

Angela Des Jardins, an assistant research professor of physics, is the principal investigator on the grant. Biofilm-research pioneer Phil Stewart, a CBE-affiliated faculty member and Regents Professor of Chemical & Biological Engineering, is the ranking scientist. It's a three-year project that directly targets biofilms in space.

"These continuing NASA projects will soon fall under the first EPSCoR grant," said Paul Sturman, CBE Industrial Associate coordinator. "NASA was impressed with the early work on these three projects. So, it's fair to say they were instrumental in CBE receiving this prestigious EPSCoR grant."

The first of the three projects that fall under an EPSCoR grant was won by CBE-affiliated faculty members Christine Foreman, Stephan Warnat, and Markus Dieser. Their project, titled "Early Biofilm Detection in ISS Water Supply Systems Using Impedance Microbiology," takes a transdisciplinary approach to detecting biofilms in the microgravity environment of space. Warnat, a specialist in tiny sensors used to measure, among other things, water quality, wanted to study how the microbes grow on the ISS. He just needed a research device that could simulate the microgravity of low-Earth orbit. So, he enlisted the help of four mechanical engineering students who worked as a team over two semesters to design and build a working prototype of the device. The tool they made consists of a section of pipe that slowly rotates like a rock tumbler to prevent microbes from settling with gravity. Fluid is passed through the pipe, and embedded sensors measure biofilm behavior.

"NASA plans to use the device in future research efforts," Warnat said.

More **SPACE | P8**

GRADUATE STUDENTS

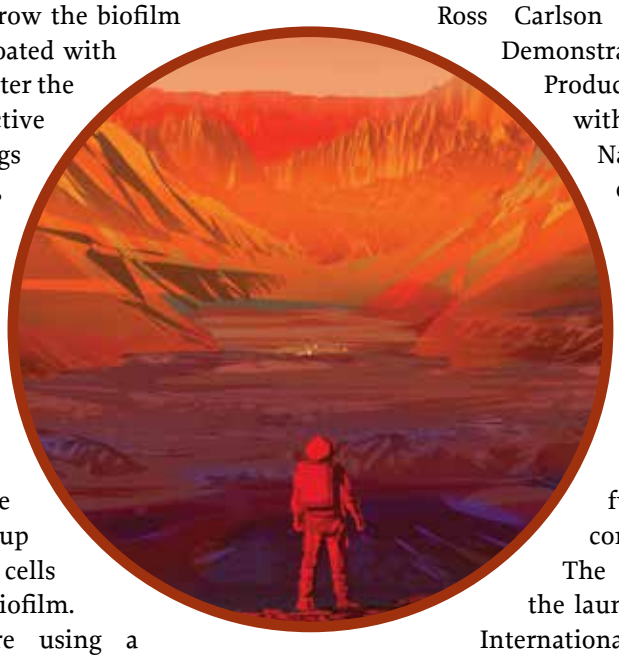
Foreman Lab
Madeline Garner
Mitch Messmer

Peyton Lab
Madelyn Mettler

Warnat Lab
Haley Ketteler

SPACE/ cont.

For the second project, Brent Peyton, CBE-affiliated faculty member and director of the Thermal Biology Institute at MSU, is testing highly specialized coatings and other strategies for preventing microbial buildup in spacecraft water systems. The research currently focuses on whether various coatings can prevent buildup of two microbes — a bacteria and a yeast — that are commonly found on the space station. The microbes grow together cooperatively to form a slimy, stubborn biofilm. Peyton and his team grow the biofilm in the lab on wafers that are coated with various materials designed to deter the microbes to determine how effective the coatings are. The coatings generally work by having sharp, microscopic spikes that pierce the cell walls of the microbes.



The researchers were initially surprised at how well the coatings worked. But biofilm eventually grew on the coatings. They suspect the cause may be that microbes that get pierced and die on the coating surface may be piling up to form a layer upon which live cells can survive and develop into a biofilm.

"I think it could require using a combination of just about every control strategy we know of," Peyton said.

That includes coatings, perhaps chemicals for water treatment that can be generated on demand, restricting the nutrients in the water, as well as using ultraviolet light and even high-frequency sound waves to inhibit the biofilm.

"We are hopeful there are solutions," he said.

The third of three projects that fall under the first EPSCoR grant brings to bear the expertise of four CBE researchers – Darla Goeres, Liz Sandvik, Phil Stewart, and Paul Sturman. These researchers will be assessing the efficacy of two strategies to control biofilm in the wastewater reclamation system of the spacecraft: removing key nutrients that feed the biofilm, and adding antimicrobial agents that suppress biofilm growth. The project is a continuation of ongoing NASA-funded work at the CBE. The work will use microorganisms isolated from the ISS wastewater system and will assess the performance of nutrient removal and biocide addition strategies in both short-term and long-term tests, simulating the anticipated intervals of system dormancy when astronauts are away from the station or colony. Sandvik is the point laboratory person for the antimicrobials research area.

The second EPSCoR grant from NASA focuses not on problematic biofilms, but instead, helpful biofilms and the production of healthy, fresh food (think: fungi) on deep-space missions. CBE-affiliated faculty member Ross Carlson is examining "Microgravity Demonstration of a Novel In-Space Food Production System." He is partnering with international food company Nature's Fynd, a company whose core technology was founded in Bozeman by former MSU researchers, to grow high protein fungi for NASA space missions. The EPSCoR project links synergistically with an ongoing NASA STTR project awarded to Nature's Fynd and Carlson, which developed fungal growth technologies compatible with NASA goals. The EPSCoR project will support the launch of the fungal system to the International Space Station in 2022, growth of the fungi in low Earth orbit, and the return of the fungal samples to Bozeman for analysis.

Unrelated to either of the EPSCoR grants, Christine Foreman is also working on a NASA-funded project that taps into her expertise locating microbial life forms in icy environments – a skill that NASA values in its search for extraterrestrial life. Foreman and her lab are also members of two NASA Research Coordination Networks, NASA's Network for Life Detection and the Network for Ocean Worlds.

"It is exciting to be part of so many great opportunities within the NASA community, especially for our students," Foreman said. "The interdisciplinary training that is foundational to the CBE experience really gives our students an advantage. PhD student Madeline Garner, a member of the Foreman Lab, recently received a NASA FINESST graduate fellowship award."

NASA also awarded a FINESST fellowship to George Schaible, PhD student affiliated with the CBE. ■

Small World

Murdock Trust, NSF grants expand CBE's microscopy capability

By Marshall Swearingen

A recent grant from the M.J. Murdock Charitable Trust will support continuing efforts by the CBE to significantly upgrade microscopy equipment, fostering world-class biofilm research aimed at, among other things, preventing metal corrosion, treating life-threatening infections, and stopping leaks in oil and gas wells.

Combined with a $1 million grant awarded by the National Science Foundation in 2020, the $513,000 has enabled the CBE to purchase a $1.5 million custom-made microscope. The NSF grant was awarded through its Major Research Instrumentation program, which is intended to support a broad range of research activity by financing equipment that would be too costly to purchase with traditional grants focused on specific research projects.

"Our huge thanks go out to the Murdock Trust, as we wouldn't be able to do this without them," said Matthew Fields, CBE director. "There's really nothing like this instrument in our region, and it's going to have a tremendous impact on what our faculty, staff, and students can do."

The new instrument, called a multi-photon digital light sheet confocal microscope, will allow scientists to see deeper into biofilms' complex communities of microorganisms without disturbing them. The microscope uses very short laser pulses to quickly scan samples contained in a special environmental chamber, allowing for non-invasive, real-time study of biofilms that are intact on surfaces like pipes or medical implants, according to Heidi Smith, manager of the CBE's Bio-Imaging Facility.

Smith, an assistant research professor in the Department of Microbiology and Cell Biology, said the instrument will open possibilities for answering fundamental questions about biofilms and will be immediately relevant to more than two dozen research teams across at least nine departments on campus, including in the fields of engineering, biochemistry, and cell biology.

Having earned her undergraduate and graduate degrees at MSU, Smith also noted that undergraduate and graduate students alike conducting research projects helped drive the need for the state-of-the art instrument and will be among those who benefit.

Jason Carter, MSU's vice president for research, economic development and graduate education, noted that the funding for the major microscope upgrade came as the CBE celebrated 30 years of cutting-edge research.

"This is yet another great adaptation for the center that will continue their positive impact on society," Carter said. "We're incredibly grateful for the support from the Murdock Trust, which is an incredible partner to Montana State."

> "There's really nothing like this instrument in our region, and it's going to have a tremendous impact on what our faculty, staff, and students can do."
>
> Matthew Fields, CBE Director

Meanwhile, the CBE also received a grant from the Defense Department for another powerful microscope. The $247,000 through the Defense University Research Instrumentation Program will allow for purchase of an epifluorescence microscope, which will use specialized stains and probes within an environmental chamber to image microorganisms in real time. The two microscopes will be complementary and will significantly expand the research the center can do, Fields said.

The Murdock Trust was established by the last will and testament of the late Melvin Jack Murdock, co-founder of Tektronix, lifelong resident of the Northwest and philanthropist. Since it was founded in 1975, the Murdock Trust has provided more than $1 billion in grants and support to more than 3,000 nonprofits in the Pacific Northwest. ■

Researchers find potential use for

Recycled Plastic in Concrete

By Marshall Swearingen

Millions of tons of plastic are discarded each day, and for much of it there are few options for conventional recycling. But that material could soon find a new and beneficial use thanks to microbes being harnessed by CBE-affiliated scientists.

In a recent study, CBE researchers found that plastic treated with certain bacteria could be added to concrete in significant quantities without compromising the structural material's strength. The study was published in the journal Materials in April 2021.

"These initial results are very encouraging as we consider potential applications," said study co-author Cecily Ryan, assistant professor in the Department of Mechanical and Industrial Engineering.

Typically, adding plastic or other filler material disrupts the mix that gives concrete — the world's most widely used building material — its ability to bind together and support heavy loads. But the team found that using bacteria to coat the plastic with a thin mineral layer allowed it to bind better. Concrete samples containing up to 5 percent of the bacteria-treated plastic had virtually the same strength as traditional concrete.

"That 5 percent is really a big increase from what's been allowable so far," said Chelsea Heveran, assistant professor of mechanical and industrial engineering.

Because concrete is used so widely and in such high volumes, replacing even 5 percent of it could result in massive reuse of plastic, Heveran noted. And because concrete is so energy-intensive to make, the plastic filler could significantly reduce carbon dioxide emissions, she said.

The researchers immersed the plastic in a water-based solution containing the harmless bacteria *Sporosarcina pasteurii*, which grows on surfaces to form biofilm. The microbes, left in the solution for 24 to 48 hours, consumed added calcium and urea — a nitrogen-based substance widely used in fertilizers — to give the plastic a thin, white coating of calcite, the hard mineral that constitutes limestone. The plastic was then mixed into small concrete cylinders that were crushed with specialized equipment to measure their strength.

"It's really exciting that we got this result with the mixture of plastics that typically aren't recyclable," said Adrienne Phillips, associate professor in the Department of Civil Engineering, who has used the same mineral-forming bacteria to seal tiny, hard-to-reach cracks deep underground in leaking oil and gas wells.

CBE researchers Adrienne Phillips (left to right), Cecily Ryan, and Chelsea Heveran; doctorate student Seth Kane and undergraduate researcher Michael Espinal show samples related to the study about recycling microbe-treated plastic into concrete. MSU photo by Adrian Sanchez-Gonzalez

The next step is to study the material's long-term durability as well as how the process could be scaled up so that the material could be manufactured in usable quantities, Phillips said.

"What's so cool about this project," Heveran said, "is that we're using microorganisms to make just a small change to a common material, but it could have a large societal benefit." ■

NSF awards $500,000 grant to make

Fungus-based Building Material

By Marshall Swearingen

The thread-like, branching fungus networks called mycelium play a key role in breaking down dead wood and leaves on the forest floor, sometimes popping up mushrooms that spread the organism with airborne spores. Increasingly, scientists are also finding ways to harness the fungal fibers' unique properties to make packaging materials and even replacements for leather.

Now, backed by a $500,000 grant from the National Science Foundation, a team of CBE scientists are exploring using fungi to make a recyclable building material that could have several advantages over traditional concrete.

"It's incredibly exciting," said researcher Chelsea Heveran, who is leading the project. "We're trying to take a whole new approach to making building materials."

The approach is similar to the way that human bone and seashells grow, by forming a scaffold of softer, living material that minerals then harden around, according to Heveran, assistant professor in the Department of Mechanical and Industrial Engineering.

Turning that into natural concrete would look something like this: The common, fuzzy, orange-tinged fungus in the genus Neurospora branches its mycelium into sand or a similar aggregate, "like the roots of a plant growing to fill their container," Heveran said. The fungus would then help to generate chemical reactions that harden the scaffold and produce a dense material capable of supporting loads.

Two researchers on the new project, Adrienne Phillips and Robin Gerlach, have used the harmless bacterium *Sporosarcina pasteurii* to produce calcium carbonate, the primary ingredient in limestone, as a way to seal hard-to-reach cracks in the cement shell that encases oil and gas wells. According to Gerlach, professor in the Department of Chemical and Biological Engineering, the biocement has some superior properties to natural limestone.

Fungi are known to produce the same enzymes as the well-sealing bacteria, and they have the benefit of weaving their mycelium into the aggregate, Heveran said. "Because they form this organic scaffold, we think we may be able to make a concrete-like material more rapidly," she said.

CBE researchers Robin Gerlach, left, Chelsea Heveran, Erika Espinosa-Ortiz, and Adrienne Phillips. Photo by Kelly Gorham

According to project researcher Erika Espinosa-Ortiz, assistant research professor in the CBE, the frontier of fungi-based building materials offers tantalizing possibilities.

"Fungi can adapt to a lot of different environmental conditions," she said. "They're very resilient."

Gerlach noted that there may also be implications beyond building materials, including in medicine. "If we can understand these interactions, we'll not only be able to engineer biological materials with specific properties, we may also be able to regenerate bone or dissolve kidney stones," he said.

Heveran also proposed the possibility of making durable, recyclable structures on Mars using the planet's native dirt. That "Big Idea" — as the NSF calls it — was one of seven entries selected from more than 800 proposals to win the agency's 2026 Idea Machine Competition at an award ceremony in February.

LISTEN TO YELLOWSTONE PUBLIC RADIO'S RELATED STORY FEATURING THE CBE'S ERIKA ESPINOSA-ORTIZ.

Foreman's decade-long effort yields milestone for

Women in Engineering

By Marshall Swearingen

For nearly a decade, CBE-affiliated faculty member Christine Foreman has advocated for female students in a field where men far outnumber them. So, it felt like a personal victory, she said, when the number of women majoring in engineering and computer science at MSU hit an all-time high in 2020.

Female enrollment last fall in the Norm Asbjornson College of Engineering reached 20 percent of the total of 3,650 students. Foreman also directs MSU's Women in Engineering program.

"I'm thrilled with the progress we've made," said Foreman. "I love being able to provide opportunities for young women and watch them exceed their own expectations."

Foreman took over as director of the Women in Engineering program in 2012, when women accounted for only 16 percent of students in the college. That year was also when Brett Gunnink became the college's dean and made recruiting female students a top priority.

"Christine's leadership, along with that of our other female faculty, has been key to promoting a culture in which women can achieve what they want to achieve," Gunnink said.

Madison Haagenson is a junior majoring in civil engineering.

"Christine has been a big influence," Haagenson added. "I can always go to her office and talk with her," including to get connected with student mentors and other resources to get through a tough class, she said.

Foreman, who was the first in her family to graduate college, said that during her nearly 20 years at MSU she has been inspired and mentored by CBE-affiliated faculty members Anne Camper and Sarah Codd, two women in the college who preceded her in earning the rank of professor. "What I've done was made possible by the truly amazing women who came before me and helped me along the way," said Foreman, whose research focuses on microorganisms in polar ice.

Christine Foreman, right, helped female enrollment in the Norm Asbjornson College of Engineering reach an all-time high. MSU photo by Kelly Gorham

Foreman pointed to a rising cohort of younger female faculty at MSU as another sign that the field is becoming more gender balanced. Nearly a quarter of tenure track faculty in the college are women. "We have a really exciting crew," she said.

OF THE 61 UNDERGRADUATE RESEARCHERS AT THE CBE IN FY2021, 43 WERE FEMALE.

Gunnink said the growing presence of female students and faculty creates a feedback loop that breaks down stereotypes and creates a welcoming environment for not just women but other underrepresented minorities in engineering and computer science. "The result is that we're becoming a much more diverse college in general," he said.

Foreman agrees. "Ultimately, it will be great when there are no barriers, real or perceived, for anyone who wants to become an engineer or computer scientist," she said. ■

Madelyn Mettler stays at CBE for PhD to work on

Biofilms in Space

By Skip Anderson

Madelyn Mettler joined the CBE in 2016 as an undergraduate researcher. A native of Littleton, Colorado, Mettler initially worked in the Standardized Biofilm Methods Lab, headed by Darla Goeres. There she learned the importance of meticulous recordkeeping when planning and conducting experiments. For her senior year, she joined Brent Peyton's lab where she worked exclusively on a NASA project to address a biofilm problem that has presented itself within the water-recycling system on the International Space Station. "If you can't have fresh water in space, you can't have astronauts in space," she says. Mettler graduated MSU in 2020 with a degree in biological engineering. The COVID-19 pandemic cost her a post-graduation internship at NASA's Jet Propulsion Laboratory in Pasadena, California. But she's not through with NASA. Mettler stayed on at MSU to pursue a PhD in chemical engineering where she's continuing her work in the Peyton Lab on NASA's biofilm project, which if it remains unsolved, would likely make manned missions to Mars an impossibility.

> "If you can't have fresh water in space, you can't have astronauts in space."
>
> Madelyn Mettler, PhD Student

Why did you decide to become an undergraduate researcher at the CBE?

When I visited MSU in high school, I walked around the halls of the CBE and I saw all the posters from the Montana Biofilm Meeting and all that research on biofilm, which I had never even heard of at the time. It stayed in my mind that the CBE would be an interesting place to work. So, when I got to campus, I had heard you could go to the front office and ask if any of the labs were hiring, and Standardized Biofilm Methods Lab had an opening. I sent in my resume and cover letter that same day. I got an interview the next day.

Madelyn Mettler joined the CBE as an undergraduate researcher. CBE photo by Skip Anderson

What did you learn from working with Darla Goeres in the SBML?

I learned the importance of being precise and consistent with your work, and writing everything down as you do it so you can replicate it. Standard methods, obviously, are critical in a lab. And that hit home with me.

You were in Brent Peyton's lab for your senior year. What types of projects did you work on as an undergrad?

I was there for one year, and the whole project was working with NASA's Jet Propulsion Laboratory. We were trying to figure out what type of coating

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BIOFILMS/ cont.

we could use on surfaces to reduce biofilm growth on the International Space Station. They're particularly worried about the water system. Biofilms can clog the plumbing and stop the recycling system from working. And if you can't have fresh water in space, you can't have astronauts in space. As a girl, I wanted to be an astronaut. And working to solve a biofilm problem on the International Space Station is as close as I'm going to get to that. It can be really intimidating to be in meetings with the head honchos of the ISS. It can be paralyzing if you let it.

How do you overcome that?

You have to be confident in your training. I think back to all of the individual projects I've worked on over the years. And when I do that, I know I am where I am because I deserve to be here.

The COVID-19 pandemic sent a wrecking ball through your internship plans. What were you going to be doing?

I was going to NASA in Pasadena at the JPL to continue my research in the water systems on the ISS. That may still end up happening this summer or the next, depending upon how COVID looks.

How did you decide to stay at Montana State for your PhD?

I already had this great relationship with Brent and everybody in the lab, and I still had all these questions about biofilms in space. So, it made sense for me to stay here.

Do you think you'll stay in academia after you graduate?

Initially, I had written off academia. But after working as a [teaching assistant], I'm more open to that now.

This interview previously appeared in the online version of the 2020 CBE Annual Report.

2020, 2021 CBE FACULTY SPECIALTIES

Applied dynamic systems
Scott McCalla

Biocorrosion and metal-microbe interactions
Iwona Beech

Biofilm control strategies
Phil Stewart

Biofilms in extreme environments, metagenomics
Luke McKay

Biofilms in waste remediation, industrial systems
Paul Sturman

Biology, imaging
Heidi Smith

Biomechanics; biomimetic materials
Chelsea Heveran

Cell Biology
Diane Bimczok

Ecology
Markus Dieser

Engineered waste remediation
Otto Stein

Environmental biofilms
Matthew Fields

Environmental biotechnology
Elliott Barnhart
Adrienne Phillips
Abbie Richards

Environmental biotechnology and bioremediation
Robin Gerlach
Brent Peyton

Environmental technologies
Erika Espinosa-Ortiz
Catherine Kirkland

Fluid-structure interactions
Jeffrey Heys

Infectious diseases, microbial ecology and evolution
Seth Walk

Magnetic resonance imaging
Sarah Codd
Joseph Seymour

Material science and technology
Roberta Amendola

Mathematical modeling
Tianyu Zhang

Mathematics and statistics
Martin Hamilton
Albert Parker

Medical biofilms
Garth James
Kelly Kirker
Elinor Pulcini

MEMS, sensors, and actuators
Stephan Warnat

Metabolic eng., metabolic networks; chronic wounds
Ross Carlson

Microbes in extreme environments
Dana Skorupa

Microbial activity
Roland Hatzenpichler

Microbial ecology
Rebecca Mueller

Microbial ecology in cold temperature environments
Christine Foreman

Microfluidics
Connie Chang

Microsensors, chemical gradients, biofilm structure
Zbigniew Lewandowski

Molecular genetics, gene expression, alginate biosynthesis; Pseudomonas
Michael Franklin

Physical and material biofilm properties
James Wilking

Polymer science; scanning probe microscopy
Lewis Cox

Polymers & composites
Cecily Ryan

Rheology and biofilm mechanics
Jennifer Brown

Standardized biofilm methods
Darla Goeres

Subsurface biotechnology and bioremediation
Al Cunningham

Tool and machine design
Kevin Cook

Wastewater Systems
Ellen Lauchnor

Skorupa teaches teachers

CBE-affiliated faculty member Dana Skorupa hosted two groups this summer, each aimed at learning research techniques. First was a group of undergraduate researchers who were on campus for 10 weeks as part of the NSF's REU program (see page 16). The other was comprised by high school teachers (pictured) from who Skorupa is showing how to use tools in the CBE Bio-Imaging Facility to examine microbial samples they collected in Yellowstone National Park earlier in the day.

CBE photo by Skip Anderson

CBE leads COVID-19 summit

CBE researchers, and MSU faculty and staff, helped organize and lead an ongoing international summit on how people can work together to help minimize the risk of COVID-19 spread in workplaces, schools and during travel. The Clean 2020 Virtual Summit convened leaders in business, policy, science and engineering to understand what is currently known about virus transmission in human-built spaces and how those leaders' fields can work together to control virus transmission. Jayne Morrow, assistant vice president of research, economic development, and graduate education at MSU, chaired the summit's steering committee. Also on the committee were Matthew Fields, professor of microbiology and immunology and CBE director; and Darla Goeres, research professor of regulatory science and principal investigator of CBE's Standardized Biofilm Methods Laboratory.

THE CBE TAKES SERIOUSLY ITS RESPONSIBILITY TO KEEP STUDENTS, FACULTY, STAFF, AND VISITORS SAFE FROM THE CORONAVIRUS.

Lab demo videos now public

During the 2021 Montana Biofilm Meeting, held virtually, the CBE created five videos demonstrating various research techniques. The short instructional videos – the longest only being around 5 minutes – covered topics such as using the colony drip flow reactor and light-based 3-D printing with channels. The videos proved popular when they debuted as part of MBM. CBE Industrial Coordinator Paul Sturman, who also produces each of the center's two annual meetings, chose to make them available to the public via YouTube.

SBML shares 2 new KSAs

CBE's Standard Biofilm Methods Lab recently published its 16th and 17th Knowledge Sharing Article (KSA) on standardized methods. The KSA series focuses on laboratory tests for surface antimicrobials and disinfectants. The 16th article is titled "Antimicrobial Test Methods: Multi-laboratory study design for assessing the reproducibility, repeatability, and responsiveness of an antimicrobial test method." The 17th is "Antimicrobial Test Methods: Assessing neutralization using ASTM E1054."

Researchers chart the future

In an effort to sharpen the focus of the international biofilm research community, the world's leading biofilm research centers – the CBE (US), the Costerton Biofilm Centre (DK), National Biofilm Innovation Centre (UK), and the Singapore Centre for Environmental Life Sciences Engineering, among others, formed a working group in 2020. The group met virtually twice monthly to determine the "priority questions" that are most pressing, thus most ripe for research. They collected input from more than 200 individuals and organizations around the world to look for areas of consensus as well as topics that might not be getting the scientific inquiry they warrant. The group is working to publish the results from the exercise. Follow us on Twitter `@Center4Biofilm` to follow this important project.

Undergrads visit for summer of 'extreme' research

Training undergraduates to become science and engineering researchers has been a hallmark of the CBE since its inception in 1990. In fact, the number of undergraduates working in its 13 laboratories rivals – and often exceeds – the number of graduate students they work alongside.

The CBE and the Thermal Biology Institute at MSU recently received a $400,000 grant from the NSF to start a new three-year Research Experiences for Undergraduates program that involves studying biofilms in extreme environments. Brent Peyton is the PI and Dana Skorupa, an assistant research professor in chemical and biological engineering, serves as co-PI and program coordinator for the "Extreme Biofilms" REU. Nationally, REU programs aim to recruit students from non-research intensive universities and broaden the participation of underrepresented groups in research.

"REUs are 10-week summer residential research programs that tap into the nation's diverse student talent pool and provide opportunities to increase the participation of underrepresented groups in STEM," Skorupa says. "Undergraduate research is a core principle at the CBE as well as across the MSU campus, which collectively ran eight REU programs this summer."

Ten undergraduate researchers participated in the program. The "Extreme Biofilms" REU is funded through 2023.

NSF grant to fund PhD students

In September 2021, the National Science Foundation awarded the CBE and the Thermal Biology Institute at MSU a coveted, five-year National Research Training grant in the amount of $3 million. This will fund two years of expenses for 21 PhD students.

NSF book features CBE

A book detailing the history of the NSF's Engineering Research Center program prominently features the Center for Biofilm Engineering as an early and sustained success story. The National Science Foundation and the American Society for Engineering Education published *Agents of Change: NSF's Engineering Research Centers* in August 2020. Courtland Lewis and Lynn Preston wrote the 700-page book, which is available to read at no charge online. The CBE is mentioned in nine of the book's 12 chapters. ■