

09/14/2011

**2011 Annual Report**  
**Student Success Stories** *from the* **Center for Biofilm Engineering**  
**Montana State University College of Engineering**  
[www.biofilm.montana.edu](http://www.biofilm.montana.edu)

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See the back cover for information about the CBE graduate and undergraduate programs.  
See the 2011 Appendix online for additional details about CBE activity and people during the past year.  
Credits: Our thanks to MSU News Service and to the many CBE people who contributed to this report. Cover microscopy by Alessandra Agostinho. Editing/design: Peg Dirckx. Photography by CBE staff and students unless otherwise noted.

**From the Director, Phil Stewart**

Montana State University's Center for Biofilm Engineering is widely known as a center of research excellence, but, as readers of previous annual reports and CBE visitors know, we also view ourselves as an education center.

In this year's report, we spotlight CBE contributions to student learning by taking a student-centered look at activity from the past year. Our 41 graduate students and 48 undergraduate research assistants represent 10 departments and programs from 5 colleges across campus.

The CBE offers its students an interdisciplinary learning environment, diverse mentoring and leadership possibilities, opportunities to interact with industry, and a chance to co-teach our Microbes in the Environment course. These transformative experiences prepare our students to tackle real-world problems and to work effectively as team members.

The depth of opportunity in independent research afforded to our students is illustrated this year by the publication of four peer-reviewed journal articles crediting an undergraduate student as first author.

The CBE's education outreach is global in that we regularly host visiting students from around the world. In the past five years, 34 students from all over the United States and also from Brazil, Chile, France, Germany, Greece, Ireland, Italy, Korea, Mali, Mexico, Russia, South Africa, and Spain have spent time in CBE laboratories.

You can see in the following pages how students make research, education, and technology transfer come alive.

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**Research Overview**

A glance at this year's 52 publications (listed in the annual report Appendix, page 10) quickly conveys the breadth of ongoing research activity at CBE. Among the topics intersecting biofilms on this list are: chronic wounds, mathematical modeling, membrane fouling, microbial life in ice, transcriptomics, metal toxicity, viscoelasticity, antibiotic tolerance, hydrodynamic dispersion, and mineral precipitation. New grants from NSF, NASA, and DOE reinforce projects on microbial processes in constructed wetlands, bacterial ecology in icy niches, biofuels, and subsurface carbon sequestration. A pair of awards from NSF and the M.J. Murdock Charitable Trust, providing over \$900,000, funded a major overhaul of the CBE's confocal microscopy equipment.

**Liz Sandvik, PhD student, chemical and biological engineering**

Is there a future for medical use of the "bioelectric effect"—a purported increase in antimicrobial efficacy in the presence of electric current? CBE graduate student Liz Sandvik has been evaluating experimental results targeting staphylococcal biofilms, which are implicated in medical implant infections. She has found that, under physiologic salt conditions, an electrolysis reaction related to chloride is likely a main contributor to the efficacy of direct current application. In other medically relevant work, Liz is studying the possible use of magnetic fields to control biofilms; see the abstract for the paper

she co-authored with **Bruce McLeod**, professor, electrical engineering, at: <http://www.biofilm.montana.edu/resources/pubs/2010/2010-001.html> .

McLeod BR, Sandvik EL, "A biofilm growth protocol and the design of a magnetic field exposure setup to be used in the study of magnetic fields as a means of controlling bacterial biofilms," *Bioelectromagnetics*, 2010; 31(1):56–63.

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### **James Connolly, PhD student, environmental engineering**

James used the CBE's new confocal microscope to image *Sporosarcina pasteurii* (green: healthy cells; red: compromised cells) on a calcium carbonate crystal (gray), above. The bacterial cells influence their immediate environment, creating local ion gradients that facilitate calcium carbonate precipitation. These precipitates are of interest because they could be used in deep subsurface systems to stop the flow of water and contaminants in soil and rock fractures. This bacterially induced precipitation process is a promising alternative technology for manipulating hydrodynamics in regions of the subsurface at less cost and with less harm to the environment than conventional methods.

### **Kristen Brileya, PhD student, microbiology**

Kristen has been using the new microscopes to complement Fluorescence In Situ Hybridization (FISH) analysis of biofilms containing two organisms (imaged above in green and red) that have been identified as end-stage contributors to the bioremediation of contaminated soils. A 2010 NSF IGERT grant enabled Kristen to attend a 1-week international course on FISH techniques in Vienna and work in a microbial ecology lab there for 6 weeks. The course, limited to 14 participants worldwide, allowed her to develop proficiency with the techniques using her own biofilm samples. Using the CBE's new confocal equipment, she performs additional imaging of her samples with world-class speed and specificity.

### **Two brand-new customized confocal microscope systems will revolutionize biofilm study**

In the fall of 2010, the CBE received a National Science Foundation award of \$498,400 to fund the purchase of new confocal microscope equipment. This award complemented a cost-sharing grant of \$406,500 from the M.J. Murdock Charitable Trust. Together, the awards have enabled the Center for Biofilm Engineering to purchase two customized Leica SP5 Spectral Confocal systems that will revolutionize the microscopic study of microbial biofilms.

The new systems are so advanced that there are only five other similarly equipped confocal microscopes in the U.S. None of them are in the Northwest, and none of them have been configured with biofilm study as the primary intent. The microscopes will facilitate interdisciplinary science and engineering on diverse topics ranging from algal biofuels to biofilms on medical devices.

The microscope facility is a centerpiece of the CBE student research experience and training. Students are currently taking the lead in exploring the capabilities of the new equipment. They develop a deeper understanding of microscope physics and technology while benefitting from the collaborative working model promoted by the CBE. With the resident expertise and management of Betsey Pitts, the microscopes have also been developed as an MSU core facility, accommodating the imaging needs of researchers across campus.

### **Betsey Pitts, staff, MSU 2011 Employee Recognition Award**

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**Christine Foreman**, associate research professor, land resources and environmental sciences, received the **2011 CBE Faculty Award** in April. Christine received this award in recognition of her commitment to interdisciplinary research and education, exceptional mentoring of graduate and undergraduate students and visitors, and unselfish contributions to CBE teamwork.

## **Heidi Smith, PhD student, land resources and environmental sciences**

Heidi has taken the concept of working in the field to the extreme. She has already been to Antarctica twice, under the leadership of faculty member Christine Foreman, and is making plans for her third trip.

Why study microbial communities in Antarctica? Heidi says that Antarctica is a model system for learning about nutrient cycling and food web dynamics. Microbial communities allow scientists to study these processes in a simplified ecosystem.

She adds that, with growing evidence of global climate change, it will be important to have a foundational understanding of cold temperature ecosystem processes to better evaluate the effects of potential temperature changes on icy environments.

Heidi, who received a competitive three-year \$30K per year **NASA Earth and Space Science Fellowship** (NESSF) for her project, cites **Christine Foreman's** mentorship and the opportunity to work closely with people from a variety of different disciplines as reasons she values being a part of the CBE.

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One measure of the CBE's commitment to providing undergraduates with meaningful research experience is the number of peer-reviewed papers with undergraduate first authors. This is a list of recent authors.

### **Undergraduate first authors**

**Lipp C**, Kirker K, Agostinho A, James G, Stewart P, "Testing wound dressings using an in vitro wound model," *J Wound Care*, 2010, 19(6):220–226.

**Vo G**, Brindle E, Heys JJ, "An experimentally validated immersed boundary model of fluid-biofilm interaction," *Water Sci Technol*, 2010, 61(12):3033–3040.

**Vo GD**, Heys J, "Biofilm deformation in response to fluid flow in capillaries," *Biotechnol Bioeng*, 2011, 108(8):1893–1899.

**Zuroff TR**, Bernstein H, Lloyd-Randolfi J, Jimenez-Taracido L, Stewart PS, Carlson RP, "Robustness analysis of culturing perturbations on *Escherichia coli* colony biofilm beta-lactam and aminoglycoside antibiotic tolerance," *BMC Microbiol*, 2010, 10:185.

**Garret Vo**, UG physics; MS mechanical engineering

**Chelsea Lipp**, cell biology and neuroscience

**Trevor Zuroff**, chemical and biological engineering; *photo, MSU News Service*

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## **EDUCATION**

For over 20 years, the CBE has provided MSU students with opportunities for innovative, interdisciplinary, hands-on research experiences. This year more than 30 MSU faculty from 8 departments contributed expertise to biofilm projects. Their guidance allows CBE students to do research that is relevant outside the university, including work in chronic infections, remediating contaminated soil, mitigating fouling and corrosion in industry, and developing constructed wetlands to treat wastewater.

### **Matthew Sherick, undergraduate, chemical and biological engineering**

“My project involves the extraction of bacterial alginate from *Pseudomonas aeruginosa* biofilms and the analysis of alginate gel formation. This project has applications in the biomedical field, particularly concerning cystic fibrosis (CF) and artificial tissue reconstruction. Aside from demonstrating to me the specifics of our project, **Hilary Fabich** has introduced me to the general guidelines of academic research. Hilary pays great attention to detail, and I have learned from her to do the same. Professor **Joe Seymour** has helped provide me with the tools to solve problems on my own, but has also taught me not to hesitate to ask questions when necessary.”

### **Hilary Fabich, undergraduate, chemical and biological engineering**

In addition to excelling in research and mentoring, Hilary received MSU’s **Ethelyn C. Harrison Award**, presented to a senior-class woman who exemplifies high standards and concern for others. Fabich is a member of **Engineers Without Borders** and the **MSU Symphony Orchestra**. She has been an undergraduate researcher in the Magnetic Resonance Microscopy Lab, with professors **Sarah Codd**, mechanical and industrial engineering, and **Joe Seymour**, chemical and biological engineering, for over three years.

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“Undergraduate **John Blaskovich** never puts himself in the limelight, yet has been very reliable, hardworking, and productive. He worked with doctoral student Erin Field and was instrumental in her progress in the past one-and-a-half years.”  
- Robin Gerlach, associate professor, chemical and biological engineering

**Anitha Sundararajan** and **Mari Eggers**, both PhD candidates in microbiology, received the CBE’s 2011 W.G. Characklis Outstanding Student Award in January. Mari (faculty mentor **Anne Camper**, civil engineering) was recognized for her dedication to community-based participatory research on water quality and the health of the Crow Reservation community. Anitha (faculty mentor **Matthew Fields**, microbiology) received the award in recognition of her original science at the interface between biofilms and microbial physiology.

### **Summary of undergraduate students**

#### **2010–11**

48 undergraduate students,  
5 Native American students;  
22 female / 26 male,  
representing 11 disciplines:

- Cell Biology & Neuroscience
- Chemical & Biological Engineering
- Chemistry & Biochemistry
- Civil Engineering
- Immunology & Infectious Disease
- Land Resources & Environmental Sciences
- Mathematical Sciences
- Mechanical & Industrial Engineering
- Microbiology
- Nursing (Bridges)
- Physics

### **Summary of graduate students**

#### **2010–11**

24 female / 17 male;  
31 PhD / 10 MS;  
representing 10 departments and programs:

- Cell Biology & Neuroscience
- Chemical & Biological Engineering
- Chemistry & Biochemistry
- Civil/Environmental Engineering
- Health Sciences
- Land Resources & Environmental Sciences
- Mathematical Sciences
- Mechanical & Industrial Engineering
- Microbiology
- Molecular Biosciences

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**Otto Stein**, professor in the Department of Civil Engineering, was selected as one of two 2011 recipients of MSU’s **Provost’s Excellence in Outreach Award**. Stein is lead faculty adviser for the MSU student chapter of **Engineers Without Borders**. He has empowered students to be global thinkers and actors, while simultaneously overseeing an infrastructural revolution in the Khwisero region of rural western Kenya.

## **WATER TREATMENT WETLANDS**

Photo: Constructed wetlands team members Johnson, Burr, Hisey, Allen, and Collazo Ortiz.

In the fall of 2010, Drs. **Otto Stein**, **Anne Camper**, and **Mark Burr** were awarded a three-year, \$303K grant from NSF: "Plant, season, and microbial controls on complete denitrification in treatment wetlands." Additional team research explores the mechanics of *E. coli* removal in treatment wetlands. Five undergraduates and two graduate students—representing microbiology, civil/environmental engineering, and land resources and environmental sciences—contributed to the research this year.

**Chris Allen, PhD student, environmental engineering**

## **ALGAL BIOFUELS**

**Brent Peyton**, Department of Chemical and Biological Engineering, and **Matthew Fields**, Department of Microbiology, were two of four MSU faculty members who won this year's **Charles and Nora L. Wiley Faculty Awards for Meritorious Research and Creativity**.

**Tisza Bell, PhD student, microbiology**

**Rob Gardner, PhD student, chemical & biological engineering**

**Tisza** and **Rob** secured two of only twelve positions in the **2011 US-EC course in Environmental Biotechnology** held in Lausanne, Switzerland. The 2011 central topic, Microbial Catalysts for the Environment, emphasized identification and selection of microbial strains suitable for environmental applications.

**Rob Gardner**, with MSU faculty **Keith Cooksey** and **Brent Peyton**, discovered that baking soda, added at a specific time in the growth cycle of algae, dramatically increases the production of the key oil precursors for biodiesel. It turns out that this common substance is the elusive chemical trigger that scientists have sought since the early 1990s to increase algal oil production. When added at just the right time in the growth cycle, algae produce two to three times the oil in half the time of conventional growth models.

**Nicole Schonenbach**, undergraduate senior in chemical and biological engineering, received a **\$30,000 NSF Graduate Research Fellowship**.

## **ENERGY PRODUCTION**

**Elliott Barnhart, MS, microbiology**

Methane is a natural gas alternative that can be extracted from wells drilled into subsurface coal beds. While high-grade coal beds produce methane thermally, all of the methane in sub-bituminous coal beds is microbially produced. A native of Broadus, Montana, **Elliott** is well acquainted with how the coal-bed methane industry has impacted land-owners, ranchers, and the landscape in eastern Montana and Wyoming. With **Matthew Fields**, he has been investigating microbial communities acquired from existing coal beds and hopes to find ways to make the methane production process more efficient and less destructive to the environment. With his master's degree work completed in August 2011, he plans to pursue a doctoral degree at MSU in the fall.

**Elliott** received MSU's **Torlief Aasheim Community Involvement Award** in 2009. He earned **Academic All-American** honors in football, received the **Montana Athletes in Service Award**, and was the 2006 Offensive Player of the Year and 2007 Bobcats team captain. He was also a member of the **University Choir** in the spring of 2008. Off-campus, as a youth group leader and as a student athlete, **Barnhart** has been an **active volunteer** in the President's Day Plunge for Special Olympics and the Relay for Life.

## INDUSTRY

### Industry highlights

In 2011 the CBE's Industrial Associates program participation remained at a robust 32 subscribing members (26 full members and 6 small business members). Participation remains strong among healthcare and biomedical companies, consumer products manufacturers, specialty chemical companies, testing laboratories, and US Government-funded agencies and laboratories. After more than a decade hiatus, ExxonMobil rejoined the CBE industrial program, and other energy-related companies have shown recent interest as well. The Montana Biofilm Science & Technology Meetings continue to be the major venue for industrial interaction, with over 140 current and prospective member scientists attending one or both of the meetings over the past year. Industry-sponsored testing and research project work continued at a very high level in 2011, with 33 total projects for 25 different companies, 60% of whom were CBE industrial partners. Through our semi-annual meetings (February and July of each year), our biofilms methods workshops, visits to companies, and regulatory outreach, the CBE seeks to expand the value of membership to our partner companies.

### Sabrina Behnke, PhD student, microbiology

Sabrina first came to the CBE in 2005 as a **visiting undergraduate student from Germany**, at the urging of her microbiology professor there. She enjoyed the friendliness and team spirit at the CBE during her visit and decided to pursue her graduate studies at Montana State University. During her tenure at the CBE, she won the **Montana Water Center Research and Fellowship Award** (January 2008) and the CBE's **W.G. Characklis Award** (February 2010). Her work on chlorine disinfection, under the mentorship of **Anne Camper**, civil engineering, was sponsored in part by **Unilever UK Central Resources Ltd**.

"A unique part of the education at the CBE is the interaction with national and international companies. Here, students have the opportunity to present their research, discuss it with scientists from various fields of expertise, and potentially collaborate with them. During my time at the CBE, I was able to conduct a project with an international company that eventually helped me fund my graduate research. This collaboration was an extremely valuable experience in addition to the education I got through my classes, teaching assignments, and the interaction with other CBE scientists. I feel confident that the very comprehensive and interdisciplinary education I received at the CBE will help me be a valuable addition to the R&D team at **Reckitt Benckiser**."

### Jennifer Hornemann, PhD, 2009, chemical & biological engineering, employed by ExxonMobil

"Being part of the CBE team at MSU gave me a unique opportunity to learn the value of collaboration. Having diverse teams of people from various technical, cultural and geographical backgrounds working towards the same goal gave necessary and beneficial perspectives to approach research challenges. This experience has proved imperative in my current job, as we work to solve multifaceted, costly, immediate research needs for the oil and gas operating environment."

### Willy Davison, PhD, 2008, chemical & biological engineering, employed by W.L. Gore & Associates

"The CBE's Industrial Associates program allowed me to develop relationships with many industry representatives, including my current employer, W.L. Gore & Associates, Inc. (Gore). At Gore, we believe in the power of small teams and ultimately rely on our Associates' expertise and knowledge to help solve problems. Similarly, the CBE fosters collaboration with a multidisciplinary, cross-functional approach to microbial biofilm research. The knowledge I gained and skills I developed during my time at the CBE have translated directly into my current role at Gore."

## STANDARDIZED METHODS

"In October 2008, **Innovotech** began working with the CBE's **Standardized Biofilm Methods** group to perform the testing necessary to have the company's **MBEC Assay™** approved as an ASTM International standard for high throughput disinfectant efficacy testing against *Pseudomonas* biofilms. In April 2011 that standard was approved as **ASTM E2799-11**.

The process was extremely smooth and efficient. The expert advice, professional service and guidance received from this group were critical to the success of this method's rapid development and review process."

*Nick Allan, Contract Research Manager, Innovotech Inc.*

*Ken Boutilier, president and CEO of Innovotech, Inc.: "This approval paves the way for a new generation of disinfectants in the food industry and in hospitals, designed specifically to address the issue of biofilms, thereby reducing the number of deaths and sicknesses resulting from foodborne and infection related illnesses."*

**Myles Perkins**, undergraduate, chemical and biological engineering assisted with the development of the MBEC Assay™.

## **2010-2011 INDUSTRIAL ASSOCIATES**

*(Boldface indicates new members)*

3M | **Agile Sciences** | BASF | Bausch & Lomb | Baxter Healthcare | Bayer MaterialScience | BD Medical | Bridge Preclinical Testing Services | CareFusion | Church & Dwight Company | Colgate-Palmolive | Covidien | Dow Microbial Control | Embro Corporation | **ExxonMobil** | Glanbia Nutritionals | ICU Medical | Johnson & Johnson Consumer and Personal Products | Kane Biotech | Kimberly-Clark | Masco Corporation | NASA | Novozymes A/S | Procter & Gamble | **Reckitt Benckiser** | Sandia National Laboratories | Semprus BioSciences | **STERIS** | The Sherwin-Williams Company | Unilever | W.L. Gore & Associates | WuXi AppTec

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## **SPONSORED PROJECTS**

Industry-sponsored project work is focused in both the Standardized Biofilm Methods Laboratory and the Medical Biofilm Laboratory. Both labs use students and full-time staff to ensure project continuity and a broad understanding of methods that yield field-relevant results and cost-effective solutions.

### **Needle-free connectors**

The CBE's **Medical Biofilm Laboratory** (MBL) team, under the direction of **Garth James**, has been working on needle-free connectors with member company **ICU Medical, Inc.** since 2005. This work has included comparing bacterial transfer through a wide range of different connector types and, more recently, downstream effects (e.g., catheter colonization) of bacterial passage through connectors. The MBL has also tested a variety of prototype connectors and provided data included in a successful 510K application to the FDA. The results have been presented at a variety of national and international meetings, including the Society for Healthcare Epidemiology of America (SHEA). This work was conducted in collaboration with Marcia Ryder, PhD, RN, of Ryder Science.

### **Bacterial migration**

Member company **Covidien, Inc.** sponsored a project in the MBL to evaluate bacterial migration along electrocardiogram (ECG) wires. Surprisingly, non-motile *Staphylococcus aureus* (in this case, MRSA) migrated along the wires at approximately the same rate as the motile *Pseudomonas aeruginosa*—an alarmingly rapid rate of 48 mm per day.

### **Pat Secor, PhD 2010, cell biology and neuroscience**

Pat began working at the CBE in 2004 as an undergraduate researcher in the **Medical Biofilm Laboratory**, characterizing bacterial communities in chronic wounds. By December 2010, he had completed his doctoral work on the impact of *Staphylococcus aureus* biofilm-conditioned medium on human keratinocytes—specialized cells that are active in the early stages of wound healing. He found that exposure to medium in which biofilms had formed decreases keratinocyte viability dramatically and increases their likelihood of undergoing apoptosis, or programmed cell death. Exposure to biofilm medium also upregulates genes for cytokines and chemokines associated with inflammation. Pat's association with medical collaborators on the CBE's NIH chronic wound project led to his current postdoctoral position at the University of Washington's Center for Lung Biology.

*S. aureus* biofilm conditioned medium induces dramatic morphology changes in human keratinocytes including rearrangement of the actin cytoskeleton (green) and nuclear fragmentation (blue). Microscopy, P Secor

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## **OUTREACH**

### **VISITING RESEARCHERS**

**Debora Barbosa**, Visiting postdoctoral researcher and dentist, Universidade Estadual Paulista, Brazil

**Mery De La Fuente**, Visiting PhD student, Universidad de Concepción, Chile

**Anozie Ebigbo**, Visiting postdoctoral researcher, Universität Stuttgart, Germany

**Megan Elam**, Visiting MS student, Oregon State University, Corvallis, OR

**Marion Fontagneu**, Visiting MS student, Université de Pau, France

**Buntu Godongwana**, Fulbright visiting researcher, Cape Peninsula University of Technology, South Africa

**Mijeong Jang**, Visiting postdoctoral researcher, University of Seoul, Korea

**Irina Khilyas**, Visiting PhD student, Kazan Federal University, Russia

**Danielle Kinsey**, Visiting undergraduate, Fort Belknap College, Harlem, MT

**Fidel Martínez Gutiérrez**, Visiting scholar, Universidad Autónoma de San Luis Potosí, Mexico

**Trond Møretro**, Visiting research scientist, Nofima MAT, Ås, Norway

**Sai Nagarajan**, Visiting postdoctoral researcher, University of Montana, Missoula, MT

**Indra Sandal**, Visiting research scientist, Virginia Tech, Blacksburg, VA

**John Tobiason**, Visiting faculty, University of Massachusetts, Amherst, MA

**Yi Wang**, Visiting faculty, Xi'an University of Architecture & Technology, Shaan'xi Province, China

Caption: Above, **Federica Villa**, University of Milan, Italy, a student visitor in 2009; and, left, visiting researcher Anozie Ebigbo, Universität Stuttgart, Germany.

### **Visiting graduate student first authors**

Most visiting students work at the CBE for a period of several months, while others—like Anozie Ebigbo, above, who is now a postdoctoral researcher—have visited the CBE several times over a period of years as they collaborate with CBE researchers.

**Cotter JJ**, O'Gara JP, Stewart PS, Pitts B, Casey E, "Characterization of a modified rotating disk reactor for the cultivation of *Staphylococcus epidermidis* biofilm," *J Appl Microbiol*, 2010, 109(6):2105–2117.

**Ebigbo A**, Helmig R, Cunningham AB, Class H, Gerlach R, "Modeling biofilm growth in the presence of carbon dioxide and water flow in the subsurface," *Advances in Water Resources*, 2010, 33:762–781.



Kim J, Hahn JS, Franklin MJ, Stewart PS, Yoon J, "Tolerance of dormant and active cells in *Pseudomonas aeruginosa* PAO1 biofilm to antimicrobial agents," *J Antimicrob Chemother*, 2009, 63:129–135.

Villa F, Albanese D, Giussani B, Stewart PS, Daffonchio D, Cappitelli F, "Hindering biofilm formation with zosteric acid," *Biofouling*, 2010, Aug 26(6):739–52.

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### **Graduate program**

More than 200 master's and doctoral students have earned their degrees in the CBE's graduate research program since the CBE was founded in 1990. CBE graduate students acquire valuable experience by designing and performing research that crosses traditional academic discipline boundaries and has direct impact on current environmental, industrial and medical issues. In addition, the CBE's Industrial Associates program brings students into working relationships with potential employers. CBE graduate students are encouraged to develop their communication and leadership skills by presenting at research conferences, mentoring undergraduate students, organizing the CBE's seminar series, and assisting with outreach efforts. The CBE's standing in the international research community attracts visiting students and faculty from all parts of the world, providing a culturally diverse and stimulating academic environment. Graduate students pursue their degree in a discipline offered through one of the science, agriculture or engineering departments at Montana State University while conducting research in CBE laboratories.

For more information, go to:

[www.biofilm.montana.edu/cbe-graduate-education.html](http://www.biofilm.montana.edu/cbe-graduate-education.html)

### **Undergraduate program**

Nearly 600 undergraduate students have participated in CBE research since 1990. Undergraduate students are highly valued team members in the MSU Center for Biofilm Engineering and are fully integrated into the research process. Our undergraduates learn to design and implement experiments that will provide results relevant to industry and the science community—and they develop the skills that will broaden their career opportunities and make them more valuable to prospective employers. For undergraduates who decide to pursue graduate degrees, their CBE research experience is often cited as a key component in being selected by their program of choice.

For more information, go to:

[www.biofilm.montana.edu/cbe-undergraduate-education.html](http://www.biofilm.montana.edu/cbe-undergraduate-education.html)

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