

2009 Annual Report

New dimensions in biofilm research

Text-only version

Center for Biofilm Engineering
366 EPS Building
Montana State University
Bozeman, Montana 59717-3980
USA
www.biofilm.montana.edu
Phone: 406-994-4770
Fax: 406-994-6098

From the director

Earlier this year, CBE faculty envisioned the future of the world of biofilms. We gathered to brainstorm about the research questions, technologies, and outreach opportunities that we saw on the 10-year horizon. You will recall that January 2009 was a time of global economic distress. Ruminating on the future in the middle of a recession may sound like a prescription for indigestion. But our goal was to follow the long-term trajectory of our collective dreams. This exercise was motivational, as we reaffirmed our commitment to working and building together.

Distributed throughout this year's annual report, you will find a sampling of the fruits of our brainstorming. Where you see a page about to turn, you will find a glimpse of our vision of future biofilm science, technology, and education. We invite your partnership in these areas.

Despite the soft economy, the CBE had a solid year. Proposals were written and grants were funded. Students were mentored by faculty, staff, and each other. Papers were published. Visitors were welcomed. We played kickball. Our member companies continued their loyal support, for which all of us at the CBE are especially grateful. And we are ready for the future and the exciting prospect of seeing biofilm science translated into new theoretical and practical outcomes.

RESEARCH

This year's slate of new state and federal research grant support tallied \$3.8 million. Research topics of these awards ranged from targeting biofilms in chronic wounds with bismuth compounds, to studying microbes in Antarctic glacier ice, to using biofilms to sequester carbon dioxide underground. For an appreciation of the diversity of grant funding at the CBE, consider the alphabet soup of agencies that support our active projects: DOE, EPA, INL, MT, NASA, NSF, NIH, ONR, USDA. On top of this support, we did a record \$1.3 million of business in industry sponsored research and testing projects during the last year. These 37 projects were sponsored by 30 different companies.

Research areas

Biofilm control strategies | Energy solutions
Environmental subsurface technologies | Health & medical biofilms | Industrial systems & processes
Standardized biofilm methods | Water systems

Looking ahead. . . BIOFUELS. . .

We see microbial processes for the production of biofuels that will reduce reliance on fossil fuels and contribute to lower emissions of atmospheric carbon dioxide. Microalgae have the potential to transform sunlight and CO₂ directly into energy-dense lipids that can be converted to biodiesel fuels for vehicles. Biofuel-producing microbes from environmental biofilms and water in saline lakes and Yellowstone springs are being developed for scaled-up application by teams of engineers and microbiologists in current MSU projects.

New faculty

Kevin Cook, a Professional Engineer and Assistant Professor of Mechanical Engineering Technology, has been working with senior undergraduate students and the Standardized Biofilm Methods group to design improvements to the Center's biofilm systems, such as the CDC biofilm reactor. Mr. Cook's interests are machine design, tool design, and manufacturing processes, as well as applications in mechanical systems in buildings.

Al Parker is a statistician from the Department of Mathematical Sciences who has begun providing statistical design and analysis to several Center projects. His CBE home base is with the Standardized Biofilm Methods team. He shares an office with biostatistician emeritus and mentor Marty Hamilton.

Jeff Heys is an expert in modeling of fluid-structure interactions and is an Assistant Professor in the Department of Chemical and Biological Engineering. Dr. Heys and his students have begun computational fluid dynamic simulations of biofilm deformation and flow. These simulations can capture the viscoelastic behavior of biofilm life in a moving fluid.

Tianyu Zhang is a mathematician with special expertise in mathematical modeling and scientific computation. He began working on biofilm modeling problems even before joining the faculty in Mathematical Sciences in the fall of 2008. Dr. Zhang has been working with CBE collaborators to develop multiphase models of biomineralization phenomena—the process of mineral deposition facilitated by microbial activity in a biofilm.

Cover graphic:

Chemical & Engineering News, Volume 86, Issue 23, June 9, 2008, American Chemical Society
CSLM imaging of *Pseudomonas aeruginosa* by Susana Sánchez, visiting researcher, and Betsey Pitts, Center for Biofilm Engineering, 2007. Cover mechanicals reproduced with permission from Chemical & Engineering News, © 2008, American Chemical Society.

CBE researchers authored 40 publications in 2008-09.

New initiatives

CBE shares in \$1.4 million grant for carbon sequestration research

In September 2008 researchers at Montana State University, Montana Tech, and the University of Montana were awarded a three-year \$1.4 million grant from the Department of Energy to study the effects that carbon sequestration sites may have on the surrounding environment. The project will study the environmental effects of geologic carbon sequestration, which involves injecting large volumes of liquefied carbon dioxide deep underground. Storing CO₂ underground keeps it out of the atmosphere and keeps it from contributing to global climate change.

Al Cunningham (pictured at right), the grant's principal investigator and a professor at MSU's Center for Biofilm Engineering, noted the importance of carbon capture and sequestration to the development of "clean coal" technologies in Montana. Developing ways to keep CO₂ out of the atmosphere, he said, will allow the state to use its large coal reserves without contributing to net global CO₂ emissions.

The grant comes from the Department of Energy's Experimental Program to Stimulate Competitive Research (EPSCoR). Five DOE national laboratories will also be involved in the funded research.

Wound biofilm retreat

An increasing number of research organizations have begun to investigate the potential role of biofilms in chronic wounds, including the CBE, which has a P20 Exploratory Research Center Grant from the National Institute of General Medical Sciences. As part of the CBE's outreach program for this exploratory center, we held a Wound Biofilm Retreat in Bozeman in conjunction with our February 2009 conference. This retreat brought together scientists, clinicians, and company representatives to present and discuss the latest research on the impact of biofilms on wound healing. Attendees included representatives from 25 companies and 12 universities with backgrounds in clinical practice, microbiology, and immunology.

Ammons MCB, James GA, Stewart PS, "Letter to the Editor: Highlights from the Montana wound biofilm retreat," *Wound Rep Reg* 2009; 17(4):626-627

Looking ahead. . . ANTIBIOFILM SURFACES. . .

We see a new generation of antibiofilm surface chemistries or coatings that inhibit, delay, or prevent biofilm formation altogether. These surfaces will be less reliant on conventional antibiotics or antimicrobial agents, instead making use of approaches that reduce attachment, inhibit elaboration of the biofilm matrix, or interfere with biofilm defenses or signaling circuitry. Disposable medical devices could be an obvious early application; such surface treatments could reduce the incidence of device-related infections.

Some of the places we presented this year:

Bringing the U to You, MSU–Great Falls, MT

International Biofilms III Conference, Munich, Germany

SGM Conference, Dublin, Ireland

NSF Engineering Research Centers Annual Meeting, Bethesda, MD

Bioelectromagnetics Society, San Diego, CA

NASA Astrobiology S&T, Pasadena, CA

ASM Boston, MA

NIH's IDeA Conference, Washington, DC

Japanese Society for Chemotherapy, Okayama, Japan

EPA Drinking Water Workshop, Cincinnati, OH

NIH Summit: The Science of Eliminating Health Disparities, National Harbor, MD

Society for Advancement of Chicanos and Native Americans in Science, SLC, UT

Institute for Biological Engineering Conference, Santa Clara, CA

Sir Peter Mansfield Magnetic Resonance Centre, Nottingham, England

11th International Conference on Wetland Systems for Water Pollution Control, Indore, India

Earth Sciences Colloquium, Rice University, Houston, TX

International Society of Microbial Ecology 2008 Meeting, Cairns, Australia

Pacific Northwest National Laboratory, Pasco, WA

Ciba Specialty Chemicals, Tarrytown, NY

ASM Philadelphia, PA

EDUCATION

Summary of graduates 2008–09

43 graduate students from 8 disciplines:

- Cell Biology & Neuroscience
- Chemical & Biological Engineering
- Civil & Environmental Engineering
- Electrical & Computer Engineering
- Geology
- Land Resources & Environmental Sciences
- Mechanical & Industrial Engineering
- Microbiology

19 male / 24 female

11 MS candidates / 32 PhD candidates

Summary of undergraduates 2008–09

36 undergraduate students from 12 disciplines/programs:

AgBiotechnology	Computer Science
AIRO (Bridges)	Environmental Science
Business	Mech. & Indus. Eng.
Cell Biology & Neurosci.	Microbiology
Chemical & Biological Eng.	Nursing (Bridges)
Civil Engineering	Psychology

21 male / 15 female undergraduates

79% from Montana

Graduate student highlight

Doctoral student hopes corrosion research will make the world a bit ‘greener’

Adapted from an article by Michael Becker, MSU News Service

Montana State University doctoral student Jennifer Hornemann didn’t start her college career with any intention of studying biofilms. Instead, she started out studying physics because, she said, it sounded hard. Recently, Hornemann accepted a new challenge. Having finished her doctorate at MSU in June 2009, the 32-year-old chemical engineer will take what she’s learned at MSU’s Center for Biofilm Engineering and Magnetic Resonance Transport Phenomena Lab to Houston. There, she hopes to help Exxon Mobil expand its research into the corrosive havoc that microbes can cause to pipelines and other equipment.

“I want to build a bridge between the Center for Biofilm Engineering here at MSU and Exxon Mobil’s research division,” she said. “That would be a great win-win scenario for Exxon Mobil and MSU.”

Microbes living together in colonies called biofilms can corrode pipes and other hardware vital to getting oil from one place to another, Hornemann said. That damage can affect the oil supply, which in turn affects the price of gas and diesel fuel. At MSU Hornemann used nuclear magnetic resonance microscopy to study the ways that biofilms absorb and use nutrients and other substances. Understanding how substances move through and around biofilms could lead to better techniques for removing, preventing or killing harmful biofilms. Better, more efficient techniques would need fewer chemicals to get rid of biofilms, and that would decrease the environmental impact of dealing with biofilms, an outcome that pleases the environmentally conscious Hornemann.

The full article above and more information about CBE students appear in the APPENDIX.

Looking ahead. . . HYPERTEXTBOOKS. . .

We see interactive textbooks that talk, move, calculate, and provide feedback. The electronic text can be delivered on a DVD and navigated as a web site. The CBE's "Biofilms: The Hypertextbook" is a leading example. It will fill a gap in the area of biofilm education, where there are many research articles but few texts suited to instruction. The flexibility afforded by this platform will allow it to be customized for use by diverse audiences from undergraduates to medical students to industry practitioners. Check out the prototype at: www.biofilmbook.com

Undergraduate student highlight

Engineering student works to inspire a new generation to save the world

Adapted from an article by Michael Becker, MSU News Services

Chemical engineering senior Trevor Zuroff has always wanted to help other people, but that desire became a passion when he came to Montana State University. In addition to his regular classes, preparing for graduation, and the business of applying for graduate school, the Glendive, MT, native volunteers for so many activities around MSU and Bozeman that he needs a list to remember them all.

Zuroff is involved with Big Brothers Big Sisters and the Wellness Community, a cancer support group. On campus, he's president of the MSU chapter of the American Institute of Chemical Engineers and a member of the Engineering Ambassadors. He's also a tutor for the Montana Apprenticeship Program (MAP) and for the Learning Engineering by Application Program (LEAP). Those summer programs invite Montana middle and high school students to MSU for hands-on research experiences with science and engineering.

Alongside his studies and volunteering, Zuroff works in two laboratories: one in the Department of Chemical and Biological Engineering and another at the Center for Biofilm Engineering.

At the CBE, Zuroff studies quorum sensing, the ability of bacteria in biofilms to communicate with each other and act as a unit. Zuroff is interested in how biofilm bacteria can be used to create things like biofuel and bioplastics. Using bacteria to create these products can be more efficient than traditional methods, which use fossil fuels. Zuroff knows that the alternative energy and manufacturing processes he's studying will be important to the future of the U.S. and the world, which is all the more reason to pass those lessons on to younger students today, he said. ***Read the full article in the Appendix.***

Picture caption:

Logan Schultz, masters candidate in Chemical and Biological Engineering, center, displays a used kitchen sponge that he will put under the CBE's stereo microscope to show visiting middle schoolers what microbes are growing there. CBE students Natasha Mallette and Trevor Zuroff also taught these students, who participated in the Learning Engineering by Application Program (LEAP), July 7–8, 2008. LEAP offers hands-on activities in math and science such as building LEGO robots and viewing how engineering applies to everything from building an iPod to dealing with pollution.

Mentoring + motivation = Success

Christine Foreman, Associate Research Professor, Land Resources & Environmental Sciences (LRES), and Markus Dieser, PhD candidate, LRES, were honored at the AIRO (American Indian Research Opportunities) 2008 Recognition Dinner on December 5, 2008, for their part as research mentors to Mervin Failing, a 54-year-old Sioux-Assiniboine Indian from Fort Peck, Montana, who decided to pursue a career in education by applying to Montana State University's BRIDGES (Bridging Tribal Colleges to MSU) program. Failing presented his research at two subsequent conferences, and his poster "Response of bacteria to freezing" won the outstanding poster award at the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS), held in Salt

Lake City in October 2008. **Read the full MSU News coverage about Mervin Failing's story of success in the Appendix.**

NSF Advance Seminar participant

Laura Jennings, visiting PhD student from Cornell University who conducted her research at the CBE (graduated September 2008), was selected to attend the NSF Advance Seminar, October 5–7, 2008 at Rice University. The seminar workshop “Negotiating the Ideal Faculty Position,” was designed for female PhDs and postdocs interested in pursuing an academic career in science, engineering, or psychology. Only 75 out of 1000 applicants were selected to attend. **See the Appendix for other CBE student awards and the list of this year's graduates.**

2009 W.G. Characklis Award

Both Pat Secor, a PhD candidate in cell biology, and Jennifer Faulwetter, a PhD candidate in microbiology, received the 2009 W.G. Characklis Award in February. Nancy Characklis presented the award at the CBE's winter Technical Advisory Conference. This award was created in honor of the Center's founder and is presented to a PhD student based on his/her contributions in research, education, outreach, and industrial interaction. Jennifer was also recipient of the Microbiology Department's Ferguson Graduate Student Fellowship in recognition of her contributions in research and teaching.

Looking ahead. . . DEMYSTIFYING THE MATRIX. . .

We see manifold opportunities for new science and discovery by focusing on the still enigmatic biofilm matrix. The cohesion afforded by extracellular polymeric substances enables multicellular interactions in biofilms and underpins the tenacity of biofilm infections and fouling problems. Breakthroughs in biofilm ecology, physiology, and control will follow discoveries related to the biofilm matrix running the gamut of disciplines from genetics to biochemistry, polymer physical chemistry, transport phenomena, viscoelastic mechanics, and visualization and imaging.

TECHNOLOGY TRANSFER

In FY 2009, the CBE maintained an Industrial Associate membership base of 31 subscribing members (26 full members and 5 small business members). The fastest growing industry segment continues to be medically oriented companies, but also strongly represented are consumer product manufacturers, specialty chemical companies, and US Government entities (e.g., NASA and Sandia National Laboratories).

In FY 2009, the CBE conducted 36 industry sponsored testing and research projects with a total budget of over \$1 million. Although today's economy squeezes R&D budgets at many companies, the CBE's industrial support base maintains its strength. Membership provides a mechanism for technology transfer, both at our semi-annual industrial meetings and through individual communications.

In their own words...

“My funding is getting tight, so I came to this meeting thinking it would be my last. However, the TAC [meeting] rejuvenated me and is sending me back with new ideas....so my thinking now is how can I find the funds to continue membership.” —Susan Altman, Sandia National Laboratories

“I see the unity you achieve (in biofilms) from diversity (in microbiology, biophysics, engineering)...one of the best conferences I have attended.” —Prasatnhi Geda, Cubist Pharmaceuticals

“The scientists at the Center are very enthusiastic and open to sharing their expertise...this is one of the greatest strengths of the CBE. Having so many industries contribute and participate is a feat few centers in the world have achieved.” —Harsh Trivedi, Colgate-Palmolive

CBE Industrial Associates

3M | Alcon Research | Bausch & Lomb | Baxter Healthcare | Bayer MaterialScience | BD Medical | Bridge Preclinical Testing Services | CareFusion (*formerly Cardinal Health*) | Church & Dwight Co. | Ciba Specialty Chemicals (*now part of BASF*) | Colgate-Palmolive | Covidien | Embro Corporation | Ethox International | Glanbia Nutritionals | GlaxoSmithKline | ICU Medical | Kane Biotech | Kimberly-Clark Masco Corporation | Mölnlycke Health Care | NASA | Novozymes A/S | Procter & Gamble | Quiescence Technologies (*formerly QuoNova*) | Rohm and Haas (*a wholly owned subsidiary of The Dow Chemical Company*) | Sandia National Laboratories | Sherwin-Williams | Unilever | W.L. Gore & Associates | Whirlpool

Regulatory outreach

The CBE continues a close association with scientists in the EPA's Biological and Economic Analysis Division (Office of Pesticide Programs) to promote sound science in regulatory decision making and to lead the development of biofilm-related methods. The EPA regulates pesticides under the statutory authority of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

Biofilm is considered a "pest" by the EPA. Although biofilm is regulated under FIFRA, there are currently no validated methods that may be used to determine the efficacy of disinfectants against biofilm bacteria. Performance standards have not been established for biofilm and there are no standard claims such as: *kills biofilm bacteria, removes biofilm, inhibits biofilm growth, or prevents biofilm formation*. Aware of these gaps, the EPA has begun the process to validate a biofilm efficacy test method.

The CBE is participating in this effort under a recently funded multi-year project. As part of the method development process, the EPA will consider the claims a particular method will address, as well as the performance standard a disinfectant with a biofilm claim must achieve. The EPA will also provide guidance for labeling anti-biofilm products. The CBE's contribution will be to insure that biofilm-related methods are scientifically valid.

Looking ahead. . . REGULATORY CHANGES. . .

We see regulatory approvals of biofilm-based products and claims on the horizon. The CBE supports the development of these new pathways by brokering a three-way dialogue and educational exchange related to biofilm methods between academia, EPA and FDA, and industry. Good regulatory decision-making depends on having reliable, repeatable, standardized biofilm methods that are broadly accepted by academia, industry, and regulators. The CBE is leading this initiative through its Standardized Biofilm Methods research area.

Standardized methods update

A newly approved ASTM International standard is the latest in a series of biofilm standards being developed by Committee E35 on Pesticides and Alternative Control Agents.

The new standard—E2647, Test Method for Quantification of a *Pseudomonas aeruginosa* Biofilm Grown Using a Drip Flow Biofilm Reactor with Low Shear and Continuous Flow—is under the jurisdiction of Subcommittee E35.15 on Antimicrobial Agents.

The standard describes how to grow a repeatable *P. aeruginosa* biofilm using a drip flow biofilm reactor. "The goal is to grow a biofilm relevant to the environment where a disinfectant will be applied, then test the disinfectant under real use conditions," says Darla Goeres, assistant research professor and an E35 member. Biofilm grown in a drip flow reactor could represent biofilms found in a wide variety of places, including cooling towers, produce sprayers, on food processing conveyor belts, on catheters, and in lungs infected with cystic fibrosis.

“The primary user of this standard is any industrial, government and/or academic laboratory interested in conducting biofilm research,” says Goeres. “In particular, the drip flow reactor has generated a lot of interest with companies and research laboratories interested in medically relevant biofilms.” Goeres also notes that an important difference between bacteria in suspension and biofilm bacteria is that biofilm is tolerant to high concentrations of disinfectants or antibiotics.

Currently, E35.15 is working on a guide that will describe properties of the various biofilm growth methods and issues that must be considered when working with biofilm bacteria.

Caption:

Medical doctors from the Johns Hopkins Wound Center participated in a Biofilm Methods workshop in February 2009 and stayed for the Biofilm Wound Retreat after the CBE’s winter conference.

Montana Biofilm Science & Technology Meeting

To better reflect the content of our industrial associates meetings, we’ve changed the name of the meeting from Technical Advisory Conference to the Montana Biofilm Science & Technology Meeting.

Kane Biotech and the CBE on “The Economic Report”

The CBE was featured prominently in a segment of *The Economic Report*, a business-based television show hosted by Greg Gumbel that highlights technological advances. The segment, shot on location at the CBE, focuses on CBE small business member Kane Biotech of Winnipeg, Manitoba, and their new biofilm control strategies.

Caption:

Thomas Neu, from the academic staff of the Helmholtz Centre for Environmental Research, Germany, was an invited instructor for the summer 2008 microscopy workshop, held in conjunction with the CBE’s Technical Advisory Conference.

Looking ahead. . . MOLECULAR DIAGNOSTICS. . .

We see a day when the plate count, the microbiologist’s standard method for enumerating microorganisms, is supplanted by DNA-based detection technologies. Sequencing and microarray techniques continue to become more affordable. They also reveal many organisms that fail to grow in culture and speak to ecology not just numbers. The CBE seeks to be at the forefront of learning how to interpret these data for real-world diagnostic applications for everything from infections on artificial hip joints to corrosion in oilfield pipelines.

OUTREACH

Caption:

Awarded a Partners in Science program grant from the M.J. Murdock Charitable Trust, Elinor Pulcini, Medical Biofilm Laboratory Research Manager, and Paul Andersen, a teacher at Bozeman High School, collaborated on the research project “Effects of antibiotic resistance on biofilm formation capabilities in clinical isolates.” The Partners in Science program was established to give high school science teachers the opportunity to work with mentors at the cutting edge of science and to revitalize their approach to teaching science.

Caption:

CBE personnel were offered a unique opportunity to make friends in far places and encourage their dreams. MSU retired business professor Dean Drenk (back row, center, in white shirt) and MS student from Mali, Sidy Ba

(immediately right of Dean), started the Nine Villages project in 2006 to be a catalyst for sustainable grassroots improvement in the Nine Villages community in Mali. CBE contributions prompted a special thank-you (right) from children gathered in their new schoolroom. Learn more about this non-profit organization at: www.ninevillages.com

Visiting researchers

Greg Characklis, Associate Professor, University of North Carolina, Chapel Hill, NC

Alim Dewan, Graduate student, Washington State University, Pullman, WA

Claudia Doberenz, Masters graduate on a Fulbright fellowship, Halle-Wittenberg, Germany

Mariana Fittipaldi, Graduate student, Universidad Nacional de Salta, Argentina

Jordan Gruber, Undergraduate and Procter & Gamble intern, Clemson University, SC

Anna Heinkel, Undergraduate, University of Duisburg-Essen, Germany

Patrizia Peters, Undergraduate, University of Duisburg-Essen, Germany

Jennifer Lloyd-Randolfi, Undergraduate, Johns Hopkins University, Baltimore, MD

Yvonne Reinhardt, Graduate student, University of Stuttgart, Germany

Federica Villa, Graduate student, University of Milan, Italy

NOTEWORTHY

Faculty and staff awards

Sarah Codd, Associate Professor, Mechanical and Industrial Engineering:
2009 MSU College of Engineering Excellence in Research Award

Tricia Cook, CBE Fiscal Manager:
One of the five recipients of the 2009 MSU Employee Recognition Awards

Matthew Fields, Assistant Professor, Microbiology:
2009 CBE Outstanding Faculty Award

Betsey Pitts, Research Scientist and Microscope Facilities Manager:
2009 CBE Outstanding Researcher Award

Rocky Ross, Professor, Computer Science:
2009 MSU College of Engineering Excellence in Teaching Award

Changing of the guard

John Neuman, CBE Technical Operations Manager, retired in December 2008. For 14 years, John dedicated himself to teaching and training student and staff researchers, ensuring safe and professional practices in CBE laboratories, and managing the operation and maintenance of equipment and facilities. John shared with us his expertise in analytical chemistry, oversaw an excellent safety record, trained and mentored many, many students, visitors, and staff, understood and supported the larger mission of the CBE, and helped make us proud to work at CBE.

A capable successor as Technical Operations Manager was found in Ann Willis, whose 17 years of professional experience in private industry, as a high school science and math teacher, and laboratory manager at MSU made her a great fit for the job.

Looking ahead. . . FOLLOWING NATURE'S LEAD. . .

We see elegant, green solutions to biofilm-related problems and technology opportunities through biomimicry. Biomimicry is a design process that takes inspiration from nature to arrive at innovative engineering that is efficient, sustainable, and attractive. We might learn how to manage biofouling from a marine sponge or how to make an underwater glue from aquarium slime.

Report Contributors: Members of the MSU Center for Biofilm Engineering faculty, staff, students, and visitors.

Executive editor: Phil Stewart

Design & editing: Peg Dirckx

Microscopy imaging and photography contributed by: Alessandra Agostinho, Kristen Brileya, Melinda Clark, Kara Bowen DeLeón, Dean Drenk, Steve Fisher, Christine Foreman, Kelly Kirker, Brent Peyton, Betsey Pitts, Logan Schultz, Pat Secor, Ellen Swogger, CBE staff and students, and the MSU News Services

Montana State University is an equal opportunity/affirmative-action institution. The printing of this publication is not financed by state-appropriated funds. Copyright © 2009, MSU Center for Biofilm Engineering