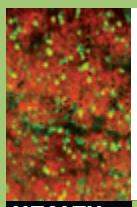
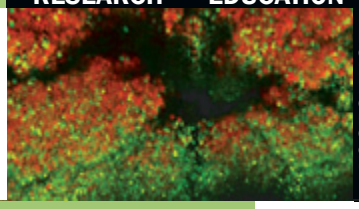
MONTANA STATE UNIVERSITY

Center for Biofilm Engineering

2013

RESEARCH • EDUCATION • TECHNOLOGY • TRANSFER

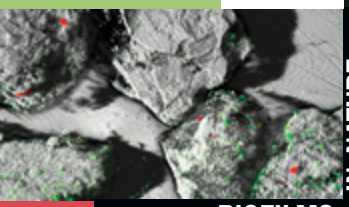




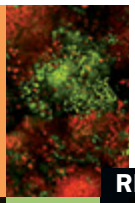
HEALTH • MEDICAL

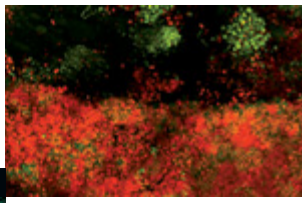
INDUSTRIAL SYSTEMS & PROCESSES

www.biofilm.montana.edu

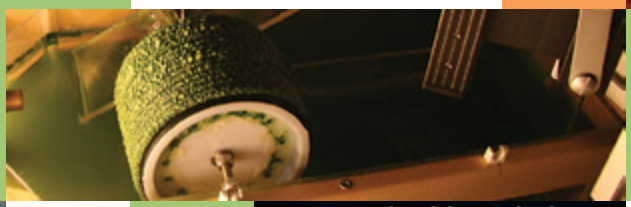


BIOFILMS • IN NATURE



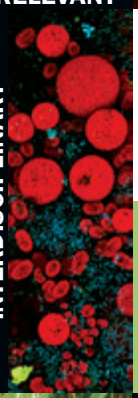


RELEVANT

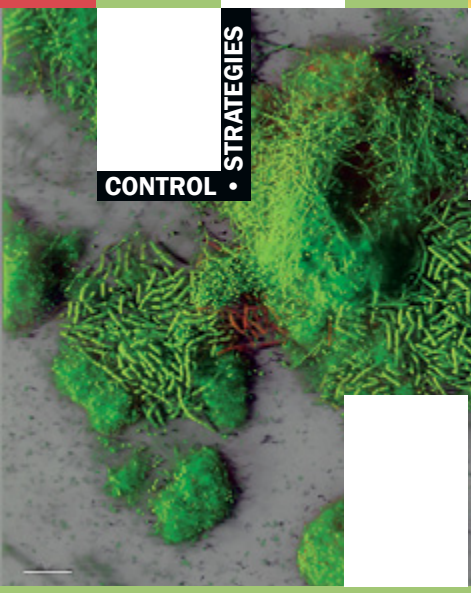


ENERGY SOLUTIONS

INTERDISCIPLINARY



COLLABORATIVE



CONTROL • STRATEGIES

STANDARDIZED METHODS

WATER • SYSTEMS

ENVIRONMENTAL TECHNOLOGIES

BIOFUELS

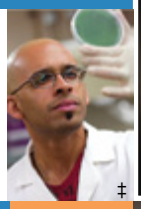
DIRECTOR'S MESSAGE

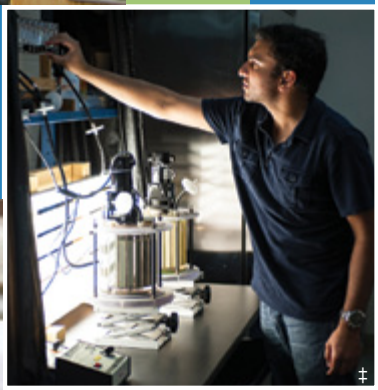
From the time of its inception in 1990 as a National Science Foundation Engineering Research Center, the Center for Biofilm Engineering has practiced interdisciplinary scholarship; engagement with the natural, engineered, and human world beyond our campus; and integration of research with innovative educational experiences for students. How gratifying it is to find these same themes resonating in Montana State University's new strategic plan (**www.montana.edu/strategicplan/**). As we report on our accomplishments from the past year in this annual report, look for the evidence of our success in contributing to the ideals of the University.

The CBE is also pleased to offer you a special feature in this report: "lessons" on key biofilm topics. We hope that, with this addition, our annual report will not only archive our activities and achievements of the past year, but endure as a living educational resource. Look inside to learn more about biofilm-mediated corrosion of materials, biofilm infections, and the enigmatic yet fundamentally important biofilm matrix. And then please share this report with colleagues who might appreciate and profit from instruction in biofilm concepts.

Finally, I would call your attention to the numerous faculty, staff, students, and visiting researchers pictured here, whose contributions in teamwork, excellence, inclusiveness, and creativity have once again made CBE a rewarding place to work and learn.

Phil Stewart





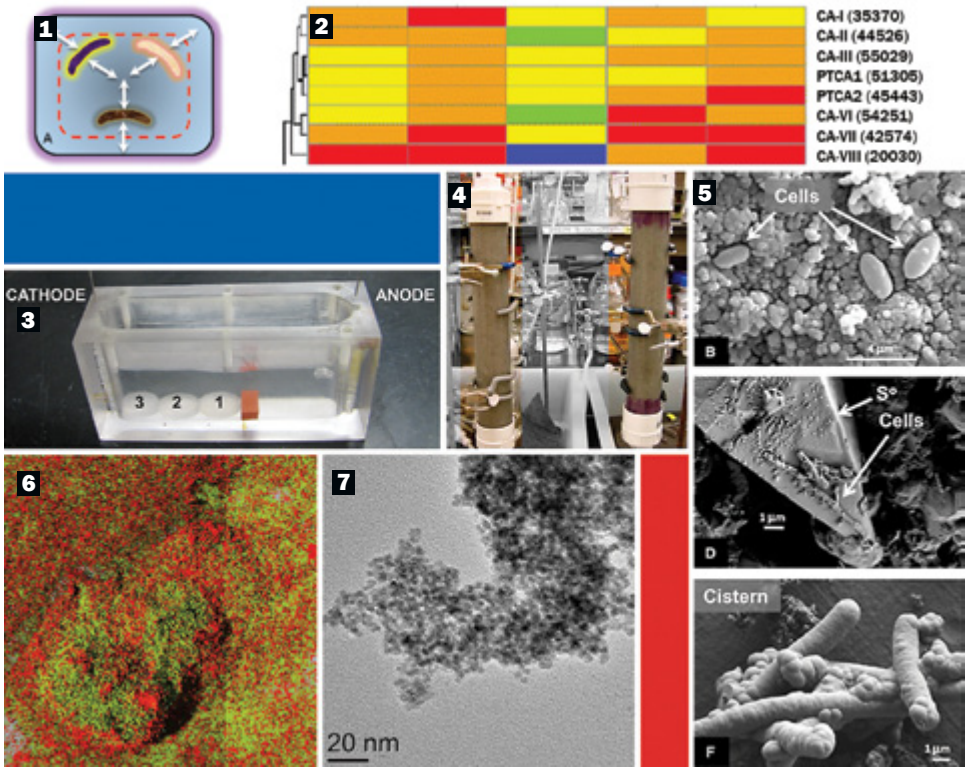
Access complete academic year 2012–13 information in the 2013 Appendix at:
www.biofilm.montana.edu/resources/annual_reports/

Special note. This report is dedicated to the memory of those we loved and lost this year: staff member Laura Bickle and Warren Jones, professor, civil engineering (**www.biofilm.montana.edu/warren-jones-memorial-scholarship.html**).

Photo credits. **Front cover**, from top: Betsey Pitts, Chris Wend, Amber Schmit, Alessandra Agostinho, Hans Bernstein & Rob Gardner, Karen Moll, Lindsey Lorenz, Otto Stein. **Portraits**: Peg Dirckx, Kristen Griffin, Tara Gunsch, and other generous CBE photographers. **Special thanks** to MSU News Services, Kelly Gorham, as noted by ‡. **Back cover**, from top: Laura Camilleri, Amanda Richards, Kelli Buckingham-Meyer.
Concept, editing, and design: Phil Stewart and Peg Dirckx.

RESEARCH
FUNDAMENTAL & APPLIED

CBE ***research impact***, measured by citations per paper over the last decade, leads all MSU departments, centers, and institutes.



publications in:

Analyst • Annals of Glaciology • Antimicrobial Agents and Chemotherapy • Applied Microbiology and Biotechnology • Biofouling • BioScience, Biotechnology and Bioengineering • Biotechnology for Biofuels • BMC Genomics • Bulletin of Mathematical Biology • Clays and Clay Minerals • Computational and Structural Biotechnology Journal • Discrete and Continuous Dynamical Systems • Environmental Science & Technology • European Physical Journal Applied Physics • Geobiology • Greenhouse Gases: Science and Technology • International Journal of Uncertainty Quantification • Journal of AOAC International • Journal of Applied Phycology • Journal of Bacteriology • Journal of Chemical Technology and Biotechnology • Journal of Inorganic Biochemistry • Microbial Ecology • MicrobiologyOpen • Numerical Linear Algebra with Applications • Physical Review E • PLOS ONE • PNAS: Proceedings of the National Academy of Sciences • Subcellular Biochemistry • Water Resources Research

1 Bernstein and Carlson. 2012. CSBJ.
2 Mus et al. 2013. Appl Microbiol Biotechnol.
3 Sandvik et al. 2013. PLOS ONE.
4 Sanderlin et al. 2013. Environ Sci Technol.
5 Macur et al. 2013. Geobiology.
6 Nagant et al. 2012. Antimicrob Agents Chemother.
7 Stewart BD et al. 2013. Environ Sci Technol.

Of the 39 articles published by CBE researchers this year, 35 (90%) name co-authors from at least two different disciplines. We are ***interdisciplinary***.

RESEARCH STAFF

RESEARCH

In a very tough climate for federal funding, CBE investigators had an excellent year for new grants. We are ***nationally competitive.***

grants & projects

APPLIED

Energy Solutions

- *Bicarbonate induced microalgae lipid production, PI: Peyton, Funding: Church & Dwight
- *Cultivation/characterization of oil producing algae, PI: Peyton, Funding: Little Big Horn College
- *Alkaliphilic microalgae-based biofuels and products, PIs: Gerlach-Peyton-Fields, Funding: NSF
- *Lignocellulosic feedstock conversion to lipids, PI: Macur, Funding: Sustainable Bioproducts
- *Sustainable algal biorefineries, PIs: Gerlach-Peyton-Fields, Funding: DOE
- Montana biodiesel initiative, PI: Peyton, Funding: DOE
- Biofuels/bioproducts from extremophilic microalgae, PIs: Peyton-Fields, Funding: DOE
- Fungal biofuels, PI: Peyton, Funding: NSF-ARRA

Environmental Technologies

- *Renewable organic fertilizer, PI: Macur, Funding: DOE-AIREI
- *Selenium biogeochemistry investigation, PI: Peyton, Funding: Teck Coal
- *Low-cost NMR technologies to monitor subsurface processes, PI: Codd, Funding: DOE
- Environmental responses to CO_2 sequestration, PI: Cunningham, Funding: DOE
- Risk assessment, monitoring for geologic CO_2 sequestration, PI: Cunningham, Funding: DOE
- Zero Emissions Research & Technology II, PI: Cunningham, Funding: DOE-ZERT
- Complete denitrification in treatment wetlands, PI: Stein, Funding: NSF
- Porous media microbial activity in mixing zones, PI: Gerlach, Funding: DOE-ERSP

Medical Biofilms

- *Novel anti-biofilm compounds to treat chronic wounds, PI: James, Funding: NIH
- *Biofilm mediation of keratinocyte apoptosis, PI: Kirker, Funding: NIH

Methods Development

- Antimicrobial test methodology, PI: Goeres, Funding: EPA

FUNDAMENTAL

Biofilms in Nature

- *Molecular level characterization of microbial metabolism and dissolved organic matter from Antarctica, PI: Foreman, Funding: NSF
- Integrated chemical and biological measurements in Antarctica, PI: Foreman, Funding: NSF

Education

- *Improving Montana community health, PI: Camper, Funding: NIH
- Graduate Fellowship (H Smith), PI: Foreman, Funding: NASA

Physiology & Ecology

- *Virtual institute for microbial stress and survival, PI: Fields, Funding: LBNL
- *Phototroph-heterotroph interactions, PI: Carlson, Funding: DOE PNL
- Role of non-coding RNAS in biofilm development, PI: Franklin, Funding: NIH
- Role of IbpA in viability of biofilm persister cells, PI: Franklin, Funding: NIH

TOOLS & TECHNIQUES

Modeling

- CMG research, PI: Klapper, Funding: NSF

***New grant awards for FY 2013 totalled $3,535,635**

Learn more about our research areas at:
www.biofilm.montana.edu/research-program.html

‡ Photo by MSU News Services, K Gorham

EXPERTISE

associated faculty

Jennifer Brown	ChBE	Rheology and biofilm mechanics
Mark Burr	LRES	Microbial community analysis
Anne Camper	CE	Biofilms in environmental systems
Ross Carlson	ChBE	Metabolic engineering, metabolic networks
Sarah Codd	M&IE	Magnetic resonance imaging
Kevin Cook	MET	Tool and machine design
Al Cunningham	CE	Subsurface biotechnology and bioremediation
Jack Dockery	MathSci	Mathematical models of biofilms
Matthew Fields	Micro	Physiology and ecology
Christine Foreman	ChBE	Microbial ecology in cold temperature environments
Michael Franklin	Micro	Molecular genetics, gene expression, alginate
Gill Geesey	Micro	Molecular and cellular interactions at interfaces
Robin Gerlach	ChBE	Environmental biotechnology and bioremediation
Darla Goeres	ChBE	Standardized biofilm methods
Marty Hamilton	Stat	Applied biostatistical thinking
Jeff Heys	ChBE	Fluid-structure interactions
Garth James	ChBE	Medical biofilms
Warren Jones	CE	Water distribution systems
Isaac Klapper	MathSci	Mathematical modeling
Zbigniew Lewandowski	CE	Microsensors, chemical gradients, biofilm structure
Richard Macur	ChBE	Biofuels, geochemistry, geomicrobiology
Aurélien Mazurie	Micro	Bioinformatics
Bruce McLeod	E&CE	Bioelectric effect
David Miller	M&IE	Experimental mechanics
Andy Mitchell	CE	Geomicrobiology
Al Parker	Stat	Statistical models in biofilm systems
Brent Peyton	ChBE	Environmental biotechnology and bioremediation
Elinor Pulcini	ChBE	Medical biofilms
Barry Pyle	Micro	Environmental, water, and food microbiology
Abbie Richards	ChBE	Environmental biotechnology
Rocky Ross	CS	Web-based, active learning education
Joseph Seymour	ChBE	Magnetic resonance imaging
Otto Stein	CE	Engineered waste remediation
Phil Stewart	ChBE	Biofilm control strategies
Paul Sturman	CE	Biofilms in waste remediation and industrial systems
Peter Suci	Micro	Fungal biofilms
Tianyu Zhang	MathSci	Mathematical modeling

www.biofilm.montana.edu/people/faculty

‡ Photo by MSU News Services, K Gorham

The CBE is led by award-winning faculty from ***10 academic departments.***

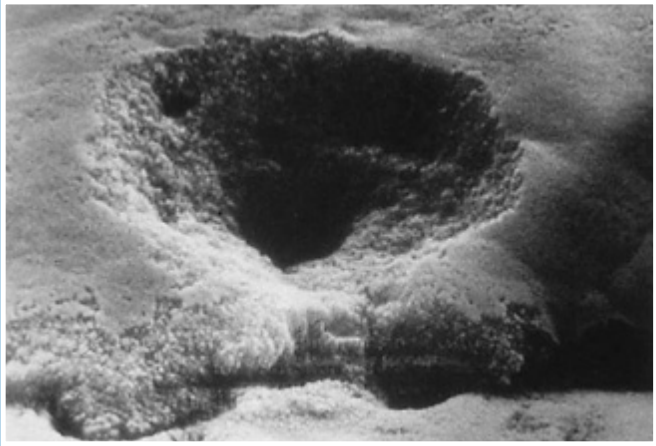
faculty awards & news

Sarah Codd: College of Engineering Lloyd Berg Faculty Mentorship Award
Christine Foreman: appointed College of Engineering Associate Dean of Student Success
Robin Gerlach: 2013 Cox Family Award for Creative Scholarship and Teaching
Darla Goeres: Awarded Fulbright Scholarship to study in Finland
Warren Jones: Lifetime Achievement Award from the Montana Water Environment Association
MSU 2013 Awards for Excellence
Al Parker: CBE Outstanding Faculty Award
Brent Peyton: appointed Director of the MSU Thermal Biology Institute
Abbie Richards: 2013 College of Engineering Faculty Award for Excellence in Advising
2012 National Outstanding Advisor, Tau Beta Pi engineering honor society
Otto Stein: Student Organization Advisor of the Year (Engineers Without Borders)

CORROSION

CBE archives

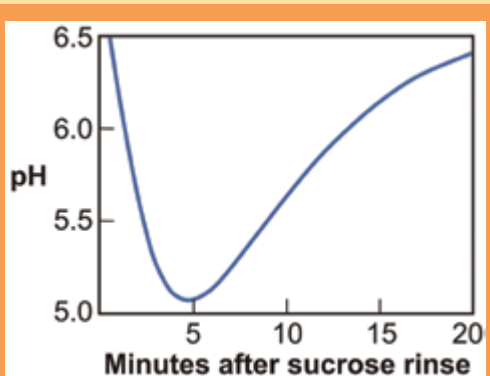
This is a cutaway view of equipment from an oilfield pipeline. The crusty deposit is a mixture of biofilm and abiotic corrosion products that have become incorporated in the sticky matrix of the biofilm. Microorganisms in the biofilm, in this case likely including sulfate-reducing bacteria, influence the corrosion process. Biocides are used in such systems to control fouling, souring, and corrosion problems.



Courtesy, A. Thylstrup

A pit in the surface of a tooth—imaged here once the dental plaque was removed—is a cavity. Bacteria such as *Streptococcus mutans* in biofilms on teeth ferment sugars to a mixture of low molecular weight organic acids. This decreases the pH at the tooth surface and promotes demineralization of the enamel. Dental caries is a biofilm infection and also an example of mineral corrosion by attached microbes.

The Stephan Curve



This graph illustrates the typical time course of pH in dental plaque after a rinse with a sugar solution. This drop and recovery in pH is known as the Stephan curve.

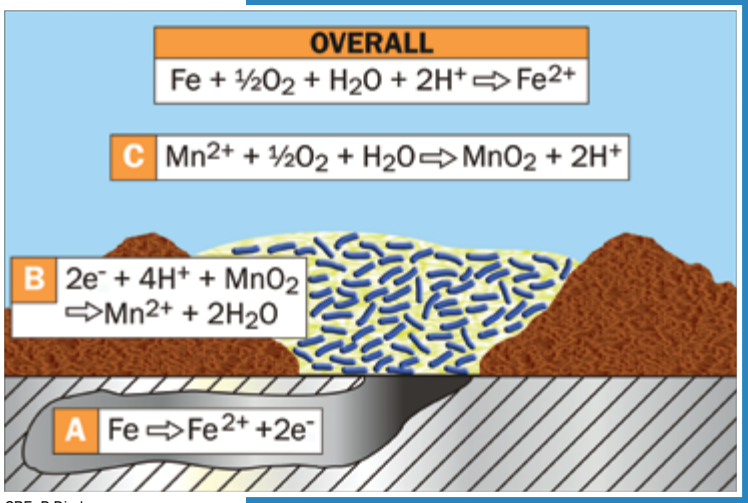
Stoichiometry of sugar fermentation to acidic products by *S. mutans*

$$100 \text{ glucose} \rightarrow \begin{matrix} 7 \text{ } D\text{-lactate} \\ 76 \text{ } L\text{-lactate} \\ 133 \text{ formate} \\ 73 \text{ acetate} \\ \hline 289 \text{ moles acid} \end{matrix} + 169 \text{ ethanol}$$

biofilm lesson 1:

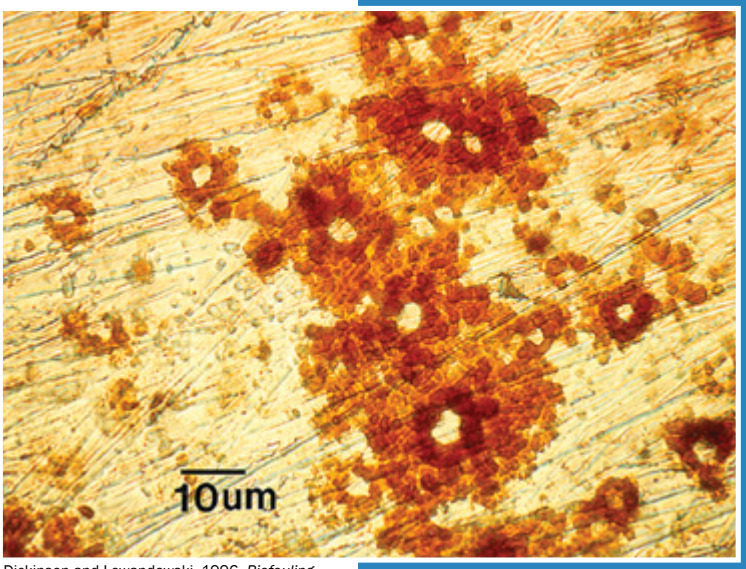
Microrganisms in biofilms, through their localized metabolic activity, can cause corrosion of mineral and metal materials.

Here, a diagram depicts one mechanism of metal corrosion by bacteria. **A**) When metallic iron corrodes, soluble Fe^{2+} is released to the surrounding water and electrons are conducted through the metal. **B**) For the corrosion process to continue, the electrons have to be consumed in a reaction somewhere on the metal surface. Manganese dioxide is an excellent electron acceptor. **C**) Manganese-oxidizing bacteria, such as those of the genus *Leptothrix*, provide this outlet by depositing manganese dioxide on the metal surface.



CBE, P Dirckx

Brownish manganese dioxide on a stainless steel coupon. The mineral was deposited on the surface by manganese-oxidizing bacteria.



Dickinson and Lewandowski. 1996. *Biofouling.*

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Dickinson WH and Lewandowski Z. "Manganese biofouling and the corrosion behavior of stainless steel." *Biofouling, 1996;* 10:79–93.

Len ACL, Harty DWS, and Jacques NA. "Proteome analysis of *Streptococcus mutans* metabolic phenotype during acid tolerance." *Microbiol, 2004;* 150:1353–1366.

INTERDISCIPLINARY

CBE *students excel.*

Alissa Bleem, ChBE
Goldwater Scholar
2012-13 Hughes Scholar

Eric Dietrich, CE (bio-resources)
Rhodes National finalist
MSU 2013 Award for Excellence
MT Society of Engineers Gold Medal Finalist

Mandi Durch, ChBE
internship at Procter & Gamble

Justin Nagy, Micro
participant, 2012 Complex Biological Systems Summer Undergraduate Research Program

Breana Pabst, ChBE
MT Society of Engineers Gold Medal Finalist

Matthew Sherick, ChBE
Goldwater Scholar
inducted into Septemviri honorary society

Amber Schmit, ChBE
ASM research fellowship honorable mention

Erika Whitney, Micro
2012-13 Hughes Scholar
participant, 2012 Complex Biological Systems Summer Undergraduate Research Program

Neerja Zambare, ChBE, presented her research at the Council on Undergraduate Research's Posters on the Hill program in Washington D.C. April 23–24, 2013.

Summary of undergraduate students 2012–13

39 undergraduate students,
26 female/**13** male,
representing **7** departments:

Cell Biology & Neuroscience
Chemical & Biological Engineering
Chemistry & Biochemistry
Civil Engineering
Mechanical & Industrial Engineering
Microbiology
Nursing (Bridges)

The CBE's practice of ***inclusiveness*** has created a work environment that supports and recruits diverse participants. Fifty-six percent of CBE students are women.

www.biofilm.montana.edu/msu-cbe-educational-experience.html

Note: Not all students are pictured.

EDUCATION

Summary of graduate students 2012–13

52 graduate students
29 female / **23** male;
40 PhD / **12** MS
representing **8** departments:

Cell Biology & Neuroscience
Chemical & Biological Engineering
Chemistry & Biochemistry
Civil/Environmental Engineering
Health & Human Development
Land Resources & Environmental Sciences
Mathematical Sciences
Microbiology

Graduate and undergraduate students work under the guidance of the CBE's multidisciplinary faculty in centrally located laboratories on the MSU campus to solve problems associated with biofilms in medical, industrial, and environmental contexts.

GRADUATES

Elliott Barnhart, PhD student, microbiology, was one of four recipients of an Outstanding Student Oral Presentation award at the Secondary Biogenic Coal Bed Natural Gas International Conference in Laramie, Wyoming

Kristen Brileya, PhD 2013, microbiology
2012 CBE Student Citizen Award

Kara De León, PhD 2013, microbiology
2013 W.G. Characklis Award
2012 CBE Student Citizen Award

Catherine Kirkland, PhD student, EnvE
National Science Foundation Graduate Research Fellowship

Adie Phillips, PhD 2013, ChBE
Outstanding Student Paper Award, 2012
American Geophysical Union (AGU)

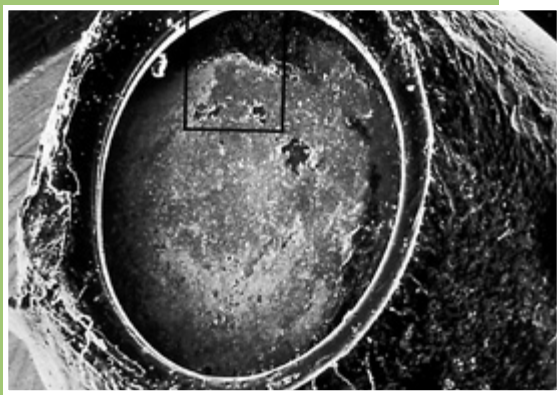
Liz Sandvik, PhD 2013, ChBE
W.G. Characklis Award

Sarah Jane Vogt, PhD 2012, ChBE
Special award for Exceptional Publication Productivity

CBE production of doctoral degrees relative to total research expenditures is more than 3.5 times the MSU average. CBE is a model for ***integration of research and PhD level education.***

biofilm lesson 2:

Microorganisms in biofilms cause diverse, slow-moving, yet persistent infections.



JW Costerton archives

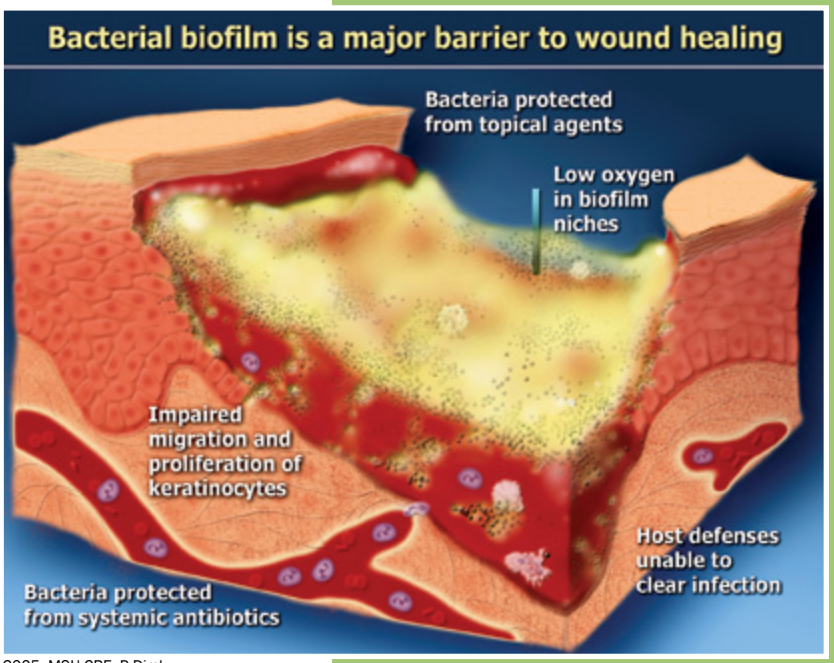
This is a scanning electron microscope view of a biofilm-encrusted pacemaker lead. The device came out of a man who experienced repeated bouts of septicemia: staph bacteria were cultured from his blood. He was hospitalized and placed on a strong IV antibiotic. He got better and was discharged. After a week or so, he was back with fever, chills, and localized tenderness in his upper torso. In the end he went through three rounds of treatment and relapsing infection before the entire pacing unit was surgically removed. The biofilm of coccoid bacteria on the lead wire is unmistakable. These are the classic sequelae of a biofilm infection. It is recurrent and difficult to clear with antibiotics or antiseptics.

JW Costerton archives

Periodontitis is caused by a biofilm infection below the gum line. You do not have to be a physician to see the chronic inflammation of the gums here. In the standoff between the biofilm and the host, the biofilm persists despite the body's continuing reaction to it while this assault takes a toll on neighboring healthy tissue. In untreated periodontitis this stalemate results in slow but progressive bone loss; teeth eventually fall out.

INFECTION

Some dermal wounds such as diabetic foot ulcers and bedsores (pressure ulcers) fail to heal even over periods of months. The biofilm hypothesis, diagrammed here, offers an explanation for this failure.



2005, MSU-CBE, P Dirckx

A few examples of biofilm infections
Catheters
Prosthetic joints
Rhinosinusitis
Dental caries
Chronic wounds
CF pneumonia
Acne

Market size for selected products (annual)	
Catheters	$21 B
Orthopedic implants	$9 B
Oral care	$5 B
Advanced wound care	$3 B

Common characteristics of biofilm infections
Form preferentially on foreign bodies, dead or damaged tissue
Slow to develop, but persistent
Respond poorly or only temporarily to antibiotics, antiseptics
Collateral damage to neighboring healthy tissue

BIBLIOGRAPHY

Marrie TJ, Nelligan J, and Costerton JW. "A scanning and transmission electron microscopic study of an infected endocardial pacemaker lead." *Circulation, 1982*; 66:1339–1341.

James GA, Swogger E, Wolcott R, Pulcini ED, Secor P, Sestrich J, Costerton JW, and Stewart PS. "Biofilms in chronic wounds." *Wound Rep Regen, 2008*; 16:37–44.

PRODUCTIVE OUTREACH

CBE attracts visiting students, scientists, and faculty from around the nation and around the globe. CBE is an ***international hub*** for biofilm research, education, and technology transfer.

visiting researchers, 2012–13

CBE visiting researchers include students, staff, and faculty from USA and international academic institutions, as well as health clinicians and industrial researchers from the USA and abroad. Visiting researchers may stay for a few weeks to a year or more. In each case, the CBE emphasizes learning, productivity, and collaboration.

In the 2012–13 period, CBE hosted 21 visiting researchers, including 12 students at the high school, undergraduate, and graduate levels. International visitors hailed from Brazil, China, Finland, Germany, Italy, Mexico, and Spain. USA visitors included researchers from the University of Connecticut, Rensselaer Polytechnic Institute, and Utah State University.

Five visitors in summer 2012 were participants in a collaborative research project between MSU's Department of Chemical and Biological Engineering, the CBE, and Little Big Horn College in Crow Agency, Montana. Participants investigated nitrogen-fixing strains of cyanobacteria that might be used to extract waste carbon dioxide from the coal liquefaction process on the Crow Reservation in the hope of developing an organic fertilizer product for crop production. Project Principal Investigators were MSU faculty members **Brent Peyton** and **Rich Macur**.

Note: Not all visitors are pictured.

In the past five years, 18 CBE visiting researchers (5 US and 9 foreign countries) have been co-authors on 23 peer-reviewed publications. CBE emphasizes ***substantive interactions***.

workshop on biofilm-induced mineralization

CBE faculty members **Al Cunningham** (CE), **Robin Gerlach** (ChBE), **Issac Klapper** (MathSci), and **Tianyu Zhang** (MathSci) organized a two-day workshop on biofilm-induced mineralization in the summer of 2012, co-sponsored by NSF and the CBE. Microbially induced calcium carbonate precipitation has been proposed for a number of engineered applications including carbon dioxide binding, protection of construction materials, soil stabilization, and environmental remediation. Participants, including experts in both laboratory experiments and mathematical modeling, presented and discussed the current state of knowledge and concepts in this field.

Visiting presenters were:

Benito Chen, University of Texas at Arlington
Yohan Davit, Oxford University, UK
Bruce Fouke, University of Illinois
Markus Hilpert, Johns Hopkins University
Andy Mitchell, Aberystwyth University, UK
Cristian Picioreanu, Delft University of Technology, The Netherlands
Marcel Schaap, University of Arizona
Tim Scheibe, Pacific Northwest National Laboratory
Qi Wang, University of South Carolina
Dorthe Wildenschild, Oregon State University

www.biofilm.montana.edu/visiting-researchers-cbe.html

INDUSTRY *ENGAGEMENT*

The CBE's Industrial Associates program continued to expand in 2013, to a new high of 38 subscribing members. Six new members joined the program, including some of the biggest names in petroleum (BP), water treatment (Ecolab), personal care products (Johnson & Johnson), and consumer products (Clorox).

Many companies continue to see the CBE as an extension of their internal R&D efforts—providing expertise in laboratory-scale test models to assess product performance under conditions relevant to their intended use. Over 38 companies funded a total of 58 testing and research projects for a total budget of over $920,000 in 2013. These projects range from short-term device-testing or surface-testing of a few weeks duration, to multi-year in-depth studies of biofilm phenomena.

The CBE continues to be at the forefront of biofilm methods development. Progress in 2013 saw the validation of the newest ASTM Method (the Single Tube Method) via an interlaboratory study as well as progress in the development of methods to grow and test organisms of environmental health concern, such as *Legionella* and *Listeria*.

On the regulatory front, CBE will co-sponsor a conference with FDA in early 2014 titled "Biofilms, Medical Devices, and Anti-biofilm Technology: Challenges and Opportunities." This conference will bring together regulators, industry, and academia in a forum to foster discussion of biofilm methods and product claims.

Memberships and sponsored projects through CBE have brought over ***$7M in industrial funding*** to Montana during the past 5 years.

www.biofilm.montana.edu/cbe-industry-program.html

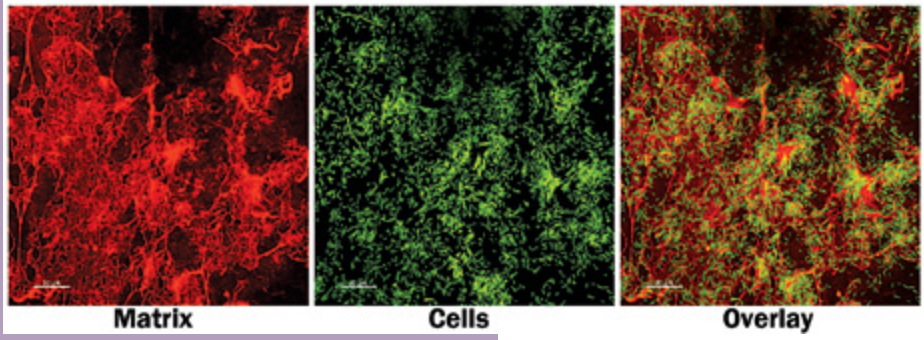
CBE ***engages with industry*** across a wide spectrum of markets and application areas.

Industrial Associates, 2012–13

Small business member * **Bold, new**

3M
Bard Access Systems
BASF
Bausch & Lomb
Baxter Healthcare
BCG Solutions *
Bend Research *
BP
CareFusion (formerly Cardinal Health)
Church & Dwight Company
Colgate-Palmolive
Covidien
Dow Corning Corporation
Dow Microbial Control / Rohm and Haas
Ecolab
ExxonMobil
ICU Medical, Inc.
Johnson & Johnson Consumer and Personal Products
Kane Biotech, Inc.*
KCl
Kimberly-Clark
Masco Corporation
Microbial Defense Systems *
NASA
NCH Corporation
Novozymes
Procter & Gamble
Reckitt Benckiser
Sample6 Technologies *
Sani-Marc, Inc.
Sealed Air Corporation
Semprus BioSciences *
STERIS
The Clorox Company
The Sherwin-Williams Company
Unilever
W.L. Gore & Associates
WuXi AppTec, Inc. *

THE MATRIX

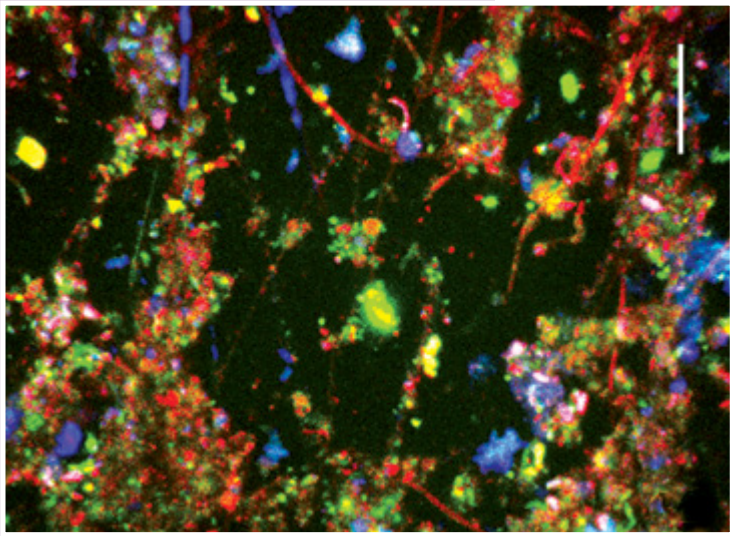


Pitts B. 2007. *Bioprobes 53*; July 2007, 53:3.

An uncharacterized constituent of the matrix of this *Pseudomonas aeruginosa* biofilm was stained with an amine-reactive dye (red). Bacterial cells (green) were tagged with a fluorescent protein. The matrix extends between the cells in a web-like fabric.

Constituent	Charge	Locus
Colanic acid	negative	*wca*
Polyglucosamine	positive	*pga*
Cellulose	neutral	*bcs*
Curli	neutral	*csg*
eDNA	negative	

Biofilm matrix polymers, also known as extracellular polymeric substances (EPS), reported for one bacterial species, *Escherichia coli*. Matrix polymers are chemically diverse, and a single organism may synthesize several polymers with differing properties.



Neu et al. 2001. *Microbiol*; 147:299–313.

This mixed species river biofilm was stained with multiple lectin probes. The marvelous variety of colors seen in the image reflects diversity in the specific chemistry of sugar residues of the extracellular polysaccharides.

BIBLIOGRAPHY

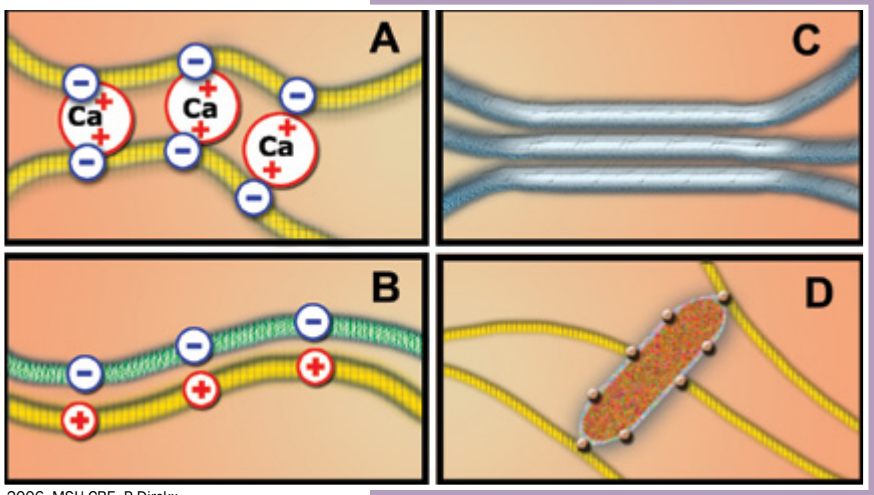
Neu T, Swerhone GD, and Lawrence LR. "Assessment of lectin-binding analysis for in situ detection of glycoconjugates in biofilm systems." *Microbiol, 2001*; 147:299–313.

Fujii T, Yano T, Kumagai H, and Miyawaki O. "Scaling analysis of the concentration dependence on elasticity of agarose gel." *Biosci Biotechnol Biochem,* 2000; 64:1618–1622.

biofilm lesson 3:

Biofilm cohesion depends on a crosslinked network of extracellular polymers that form a hydrogel.

Biofilm cohesion requires that extracellular matrix polymers interact to form a gel network. Crosslinks could be formed by: **A**) cation bridging between negatively charged polymer strands, **B**) direct electrostatic interaction between polymers of opposite charge—a polyelectrolyte complex, **C**) hydrogen bonding interactions between repeated units of the same polymer, or **D**) binding of an extracellular polysaccharide chain by a cell-surface associated lectin.



2006, MSU-CBE. P Dirckx

Gel theories predict a power law dependence of the gel elastic modulus (G') on polymer concentration (C), i.e., $G' = C^n$. This example with a common biopolymer, agarose, conforms to one of the theories in which the exponent $n = 9/4$ (2.25). One thing this means is that modest changes in the local concentration of EPS can lead to large changes in the strength of the biofilm. Polymer concentrations on the order of magnitude of 1% (w/v) are sufficient to form gels with mechanical properties similar to those of biofilms.

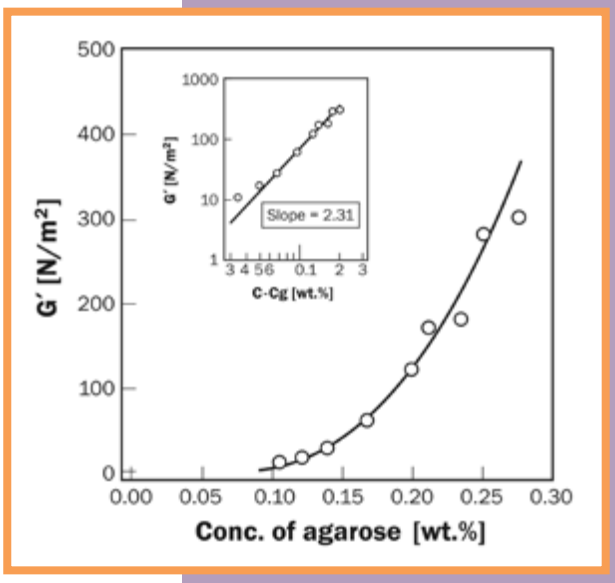
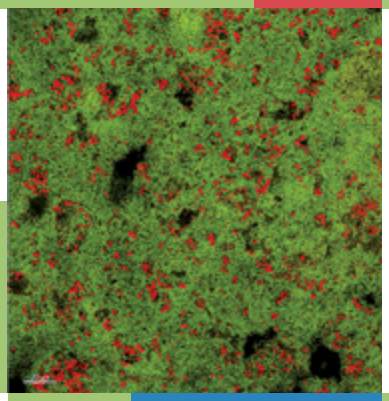


Fig: Fujii et al. 2000. *Biosci Biotechnol Biochem*; 64:1618–1622.

STUDENT *INVOLVEMENT*

Over 600 undergraduate students have participated in CBE research since 1990. Undergraduate students are highly valued team members in the CBE 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 students also 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



More than 220 master's and doctoral students have earned their degrees in the CBE's graduate research program since the Center 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.

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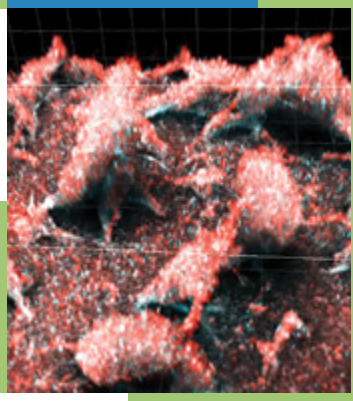

For more information, go to:
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