# Michigan Technological University

## Department of Chemical Engineering
## Graduate Program Brochure

Michigan Technological University
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Houghton, MI 49931-1295
http://www.chem.mtu.edu/chem_eng/

**Stature**
The chemical engineering program has a strong industrial component. Industry funds more than 25 percent of the research programs in the department. Sponsoring firms include Dow Chemical, Dow Corning, 3M, Amoco, BASF, Honeywell, Allied/Signal, Kimberly-Clark, Chrysler, Ford, Pharmacia, Shell, UOP, and Conoco. This aspect of the program provides graduate study and research that are relevant to the needs of society and the needs of the chemical and materials processing industries.

The department has 18 faculty, 9 staff, nearly 400 undergraduate students, and more than 50 graduate students (over 75% in the PhD program). The College of Engineering ranks 86th nationally in the 2010 U.S. News and World Report Best Graduate Schools. The department has graduate student cooperative agreements with the chemical engineering program at the Universidad de Sonora, Mexico, and at the University of Lappeenranta, Finland. Michigan Tech's Office of International Programs arranges similar opportunities with other universities around the world.

Our facilities include a full-time computer staff and more than 120 computers with powerful chemical engineering modeling and analysis programs.

**Program**
The Department of Chemical Engineering offers a friendly, educationally stimulating environment, and it has an outstanding record of educating world-class engineers. Beyond technical knowledge, the program emphasizes critical thinking, resourcefulness, problem solving, teamwork, and research skills. Graduate students have the opportunity to identify the course selection and research direction that match their interests.

**Degrees**
MS in Chemical Engineering
PhD in Chemical Engineering

Researchers in the Biochemical Processing Laboratory

***Research Excellence***
*External funding from industry and government for chemical engineering research is over $1 million annually, with a current level of approximately $3 million.*

***Additional Opportunities***
*Graduate students can participate in interdisciplinary study and research with other units, such as chemistry, environmental engineering, biological sciences, materials science, and mechanical engineering.*

***Financial Assistance***
*Research assistantships, teaching assistantships, and fellowships are available to qualified applicants. All students admitted to the Graduate School are considered for these awards. Some graduate internships are supported by Ford, General Motors, DuPont, 3M, Dow Corning, Conoco, Amoco, Chrysler, and Kimberly-Clark.*

Researchers in the Polymer Extrusion Laboratory


# Gerard T. Caneba

*Professor*

*PhD. University of California-Berkeley, 1985*

*Director, Center for Environmentally Benign Functional Materials*

Carbon nanotube / polymer composites, Controlled chain polymerizations, Enhanced oil recovery and cleanup operations, Mathematical modeling/computer simulation of dynamic systems, Sustainability polymer materials/systems

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## The FRRPP Process

The free-radical retrograde-precipitation polymerization (FRRPP) process was discovered by the G. Caneba at Michigan Tech in the 1990s as a chain polymerization method, whereby phase separation is occurring while reactive sites are above the lower critical solution temperature (LCST). During the early stages of polymerization-induced phase separation, nanoscale polymer domains were found to be persistent in the reacting system, in apparent contradiction with results of microstructural coarsening from constant-temperature modeling and experimental studies. This mass confinement was used for micropatterning and for entrapment of reactive radical sites, for the formation of block copolymers that can be used as intermediates, surfactants, coatings, coupling agents, foams, membranes, hydrogels, etc. FRRPP-based materials and its mechanism have also been proposed to be relevant in energy and environmentally responsible applications. This includes current efforts in the development of new types of polymer surfactants that can be used in mitigating adverse effects of oil spills and in oil recovery/carbon sequestration applications.

## Carbon Nanotube/Polymer Composites

With collaboration and financial support of NASA-Johnson Space Center (Houston, Texas), Dr. Caneba's group embarked on research involving polymer composites with single-wall carbon nanotubes (SWCNTs). Current efforts in this area involve the formulation of SWCNT/ polymer composite films for use as solar energy absorbers in building interior surfaces and lightweight radiation shields.

## Mathematical Modeling/Computer Simulation Efforts

Since 1983, G. Caneba has been involved in pioneering efforts in mathematical modeling and computer simulation of nonlinear dynamic systems. Current activities include efforts in simulation and analysis of flat temperature profiles in FRRPP systems, as well as intermittency behavior in ultrasonic cavitation phenomenon in nanoparticle dispersions.

***Selected Publications***

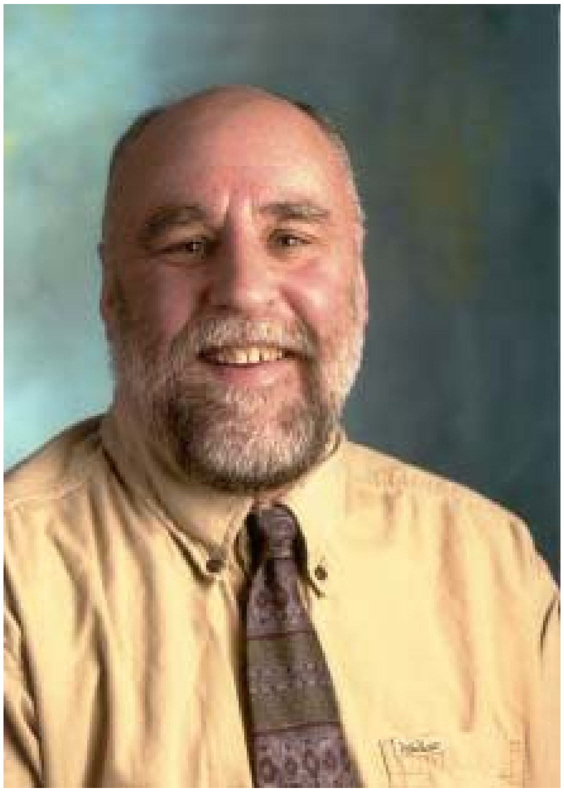

G.T. Caneba, "Free-Radical Retrograde-Precipitation Polymerization (FRRPP): Novel Concept, Processes, Materials, and Energy Aspects", Springer-Verlag, Heidelberg, March, 2010, ISBN 978-3-642-03024-6.

G.T. Caneba, and Y.L. Dar, "Emulsion Free-Radical Retrograde-Precipitation Polymerization (EFRRPP) and Related Topics", Springer-Verlag, Heidelberg, book manuscript under development and to be submitted, December 2010.

G.T. Caneba, C. Dutta, V. Agarwal, and M. Rao, "Novel Ultrasonic Dispersion of Carbon Nanotubes", *Journal of Minerals and Materials Characterization and Engineering,* 9, 165-181 (2010).

V.R. Tirumala, R. Divan, D.C. Mancini, and G.T. Caneba, "Fabrication of High Aspect Ratio Hydrogel Microstructures", *Microsystems Technologies Journal*, 11(4-5), 347-352 (2005).

G.T. Caneba, and J.E. Axland, "Vinyl Acetate-Acrylic Acid-based Copolymers for Enhanced Oil Recovery", The Journal of Minerals and Materials Characterization and Engineering, 1(2), 97 (2002).




# M. Sean Clancey

*Lecturer*

*PhD. Michigan Technological University, 1988*

Technical Communications

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Technical communication is an active and growing sub-field of engineering, as the importance of being able to communicate technical information clearly and concisely is of the utmost importance in business and industry today. The field has expanded over they years to include such topics as engineering communication, writing across the curriculum, writing in the disciplines. Engineering communication focuses on writing and speaking within the engineering field specifically, while the writing across the curriculum/writing within the disciplines expands that study to investigate issues of communication across all degree programs.

My interests incorporate all those areas. I have presented papers at international conferences on such topics as teaching writing style to engineering students, and most recently, types of engineering communication not traditionally covered in communication classes. I have also presented papers on program assessment, including means of incorporating assessment of writing and speaking in engineering curricula. These studies have helped me design educational activities in both my junior-level technical communication classes and my first-year writing classes.

***Selected Publications***

*Engineering Writing as a signifying Practice: The Engineer as Ecrivain*. Proceedings of the Conference in improving Writing in Engineering Design, Michigan Technological University, 1992

*Watching Ourselves Work: A Collaborative Visual Model of Writing Center Research*. With Nancy Grimm and Ruthann Ruehr. Midwest Writing Centers Association Conference (MWCA), St.Cloud, MN, 1990.

*Research Connections in the Writing Center: A Room with a View*. With Nanacy Grimm, Ruthann Ruehr, Betsy Aller, Susan Guitar, and Anne O'Donnell. MWCA Conference, Kansas City, MO, 1991.

*Writing Centers as Social Spaces for Cultural Negotiation*. With Sylvia Matthews, Jeani Behr, Anne O' Donnell, and Shonte Tate. MWCA Conference, St.Paul, MN , 1992

*Engineering Students Writing About Style*. 3rd National Writing Across the Curriculum Conference, Charleston, SC, 1997

*Torn between 'Two Cultures': Negotiations of Administering Programs in Engineering*. With Betsy Aller, Council of Writing Program Administrators Annual Summer Conference, Houghton , MI 1997


**Tomas B. Co**
*Associate Professor*
*PhD. University of Massachusetts, 1988*


Process Integrity
Process Modeling
Plant Wide Control


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I am interested in advanced control strategies and algorithms including the application of artificial intelligence to process control.

**Process Integrity**
As systems undergo operational changes due to equipment degradation, market demands, and other external disturbances, some processes approach failure conditions. To provide appropriate actions to prevent failure, predictive monitoring and control are needed. To this end, we are currently developing a mathematical theory of process integrity. Our study focuses on three major parts: (1) process integrity measure, (2) process integrity control, and (3) plant-wide system integrity. We incorporate existing tools from reliability theory and control theory to assess integrity based on how rapidly recovery can be achieved.

**Process Modeling**

Process models are needed to better analyze and design controllers for chemical processes. We are currently investigating methods for parameter estimation of nonlinear continuous-time systems as well as unstable systems. In particular, we are developing transformation techniques such as modulating functions to model nonlinear systems and relay schemes to model unstable processes. The development of recursive techniques are being explored for use in on-line for process control and failure diagnosis.

***Selected Publications***


T. Co, "Relay-Stabilization and Bifurcations of Unstable SISO Processes with Time Delay", IEEE Transactions on Automatic Control, Vol. 55, No.5, pp 1131 - 1141, 2010.

T. Co, “Relay Stabilization and Identification of Unstable Processes”, Proceedings of the 17th International Federation of Automatic Control, Seoul, South Korea, July 6-11, 2008.

T. Co, "Use spreadsheets to estimate modeling parameters", Chemical Engineering Progress, February, 2008, pp. 45-50.

T. Co, "Modeling Dynamic Processes Using Granular Runge-Kutta Methods", Proceedings of the IEEE International Conference on Granular Computing, Silicon Valley, November 2-4, 2007.

Ungarala, S., Z.-Z. Chen and T. B. Co, "The theory of process integrity and global analysis for process monitoring and diagnosis," Proceedings of the 4th IFAC Workshop on On-Line Fault Detection and Supervision in the Chemical Process Industries (CHEMFAS-4), 2001.

S. Ungarala and T. Co, "Model parameter tracking in microbial growth processes", AIChE J, 44, 2129-2134 (2000)


# Daniel A. Crowl

*Herbert H. Dow Professor for Chemical Process Safety*
*PhD. University of Illinois, 1975*

Chemical Process Safety

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My research interests are in chemical process safety and loss prevention.

**Flammability**

Increased emphasis on the prevention of fires and explosions has led to a need for high-quality flammability data covering a wide range of compositions of fuel/oxygen/nitrogen. The purpose of this project is to 1) improve the experimental methods for characterization, 2) obtain high quality data and 3) improve theoretical methods for predicting flammability and combustion behavior.

**Reactivity**

The chemical industry has a continuing problem with reactive chemical accidents. This problem is due to the complex nature of chemical reactivity. This research will focus on simplified methods to characterize reactivity that can be readily applied in a chemical plant.

***Selected Publications***


D.A. Crowl and J. F. Louvar, Chemical Process Safety - Fundamentals with Applications, 3rd Edition, Prentice-Hall. 2011

D.A. Crowl and J. Louvar, Chemical Process Safety - Fundamentals with Applications, 2nd Edition, Prentice-Hall. 2002

D. A. Crowl, Understanding Explosions, American Institute of Chemical Engineers, NY, 2003

D.A. Crowl, editor of Safety Section, Perry's Chemical Engineers Handbook, 8th ed., to appear in 2007.

D.A. Crowl, Guidelenes for Consequence Analysis of Chemical Releases, American Institute of Chemical Engineers, NY, 1999.

D.A. Crowl, editor, Inherently Safer Chemical Processes A Life Cycle Approach, American Institute of Chemical Engineers, New York, 1996.

# Tim Eisele

*Assistant Professor*
*PhD. Michigan Technological University*

Processing of Industrial Wastes, Particle Separations, Biological Metal Extraction

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**Research and Teaching Interests:**
Particulate processing, chemistry and thermodynamics of metals extraction; physical separation processes, sustainable raw materials production, oxidative and reductive bioleaching of metals.

**Large-scale processing and utilization of industrial wastes.**
Materials such as fly-ashes, scrubber sludges, metallurgical slags, machining wastes, and many other similar materials present a significant disposal problem, which can be much reduced if commercial markets can be developed for them.

**Advanced processing techniques for particulate separations.**
I have an interest in development of improved processing techniques to deal with ever finer and more diverse particulate materials. This includes advanced separation techniques such as column flotation, centrifugally-enhanced particle separators, electromagnetic separations, and improving the energy efficiency of the comminution (crushing and grinding) step, which is generally considered to only be about 1-2% efficient compared to the theoretical energy requirement.

**Bioleaching of Metals.**
A number of metals are currently recovered by hydrometallurgy (dissolution in aqueous solution, leaching from ore, and reprecipitation), frequently using microorganisms that promote metal and sulfur oxidation. In addition to oxidative leaching, I am investigating the use of metal-reducing organisms for hydrometallurgy of metals that are more soluble in their reduced forms, such as iron and manganese**.** Leaching processes for these metals would allow the recovery of metal from much lower-grade ores, while also reducing environmental impact and improving energy efficiency.

***Selected Publications***

Eisele, T. C., and Kawatra, S. K., Production of Iron using Environmentally-Benign Renewable or Recycled Reducing Agents, U. S. Patent No. 7,632,330, December 15, 2009.

Eisele, T. C., and Kawatra, S. K., “Reverse column flotation of iron ore”, Minerals and Metallurgical Processing, 2007, Vol. 24, No. 2, pp. 61.

Eisele, T. C. and Kawatra, S. K., “Causes and Significance of Inflections in Hydrocyclone Efficiency Curves,” Chapter 9, Advances in Comminution, the Society for Mining, Metallurgy and Exploration, Littleton, CO, 2006, pp. 131-147.

Eisele, T. C. and Kawatra, S. K., “Design of Iron Comminution Circuits to Minimize Overgrinding, Chapter 22, Advances in Comminution, the Society for Mining, Metallurgy and Exploration, Littleton, CO, 2006, pp. 309-320.

Eisele, T. C., “Direct Biohydrometallurgical Extraction of Iron from Ore”, U. S. DOE, FG26-03NT41938, DOI 10.2172/877695, 2005.

# Caryn L. Heldt

*Assistant Professor*
*PhD. North Carolina State University, 2008*

Bioseparations, Virus Removal and Detection, and Biosensors

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My research group uses natural and artificial molecular recognition to improve human health. This work includes discovering small peptides or chemicals that bind specifically to proteins and engineering devices that utilize the binding property.

**Virus Removal and Detection**

A biotherapeutic is any product that is made to improve human health and comes from a biological source, including human blood plasma, cell culture or bacterial fermentation. The sources of these products are living organisms, so there is an inherent risk that these products may contain viruses that could infect patients receiving the therapy. The inactivation of enveloped viruses works well with little known contamination, but the breakthrough and contamination of biological products by nonenveloped viruses has been demonstrated. This reveals the need to find better removal techniques for nonenveloped viruses. I am interested in finding methods to improve the removal of nonenveloped viruses from biotherapeutics using precipitation, filtration and affinity techniques.

**Therapeutic Targets for Amyloid Disease Progression**

Many diseases, including Alzheimer's disease and type II diabetes involve the aggregation of small peptides that are naturally found in the body into fibrils and plaques, and are classified as amyloid diseases. It is currently hypothesized that small oligomers of the plaque forming peptides may be the toxic species. Yet it is difficult to isolate these oligomers to determine how they form and to determine their toxicity to cells *in vitro* or *in vivo*. I am characterizing the formation of toxic oligomers using biophysical techniques and then will slow or stop the formation of oligomers using small peptides and chemical molecules.

***Selected Publications***

Heldt, C.L., Zhang, S., and Belfort, G. Asymmetric Amyloid Fibril Elongation: A New Perspective on a Symmetric World. *Proteins* **2010**, Accepted.

Heldt, C.L., Sorci, M., Posada, D., Hirsa, A., and Belfort, G. Detection and removal of microaggregates in insulin preparations. *Biotechnology and Bioengineering* **2010**, Accepted.

Heldt, C. L.; Gurgel, P. V.; Jaykus, L. A.; Carbonell, R. G., Influence of Peptide Ligand Surface Density and Spacer Arm Length on the Capture of Porcine Parvovirus. *Biotechnology Progress* **2009,** 25, (5), 1411-1418.

Heldt, C. L.; Gurgel, P. V.; Jaykus, L. A.; Carbonell, R. G., Identification of trimeric peptides that bind porcine parvovirus from mixtures containing human blood plasma. *Biotechnology Progress* **2008,** 24, (3), 554-560.

Heldt, C. L.; Hernandez, R.; Mudiganti, U.; Gurgel, P. V.; Brown, D. T.; Carbonell, R. G., A colorimetric assay for viral agents that produce cytopathic effects. *Journal of Virological Methods* **2006,** 135, (1), 56.


# S. Komar Kawatra

*Professor and Department Chair*
*PhD. University of Queensland, 1974*

Iron and Steel Making
Particle Technology

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My general research philosophy is to carry out research in close cooperation with industry, and to make sure that all of my students start with fundamental research, and carry it all the way to implementation in operating plants. Some of the most significant projects are listed below.

**Ash Analyzer**

I developed the first on-line slurry ash analyzer based on X-ray backscatter, which has been patented and licensed to Outokumpu Oy, Finland. The analyzer incorporates two sensors: a gamma-ray transmission unit to measure the percent solids of the slurry, and an X-ray backscatter/ fluorescence unit to determine the ash content of the entire slurry. The combined signal from the two sensors provides a means for determining the ash content of the solids in the slurry.

**On-Line Measurement of Rheology**

My research group has developed a technique for rapid on-line measurement of the rheology of particulate processing streams. This method uses standard, off-the-shelf transducers, which are combined with computations using the gas law and the Hagen-Poiseuille equation to calculate the rheological behavior of the particulate suspension over a wide range of shear rates. Unlike existing vibrational and tube viscometers (which operate at fixed shear rates), the stress/ strain data is calculated directly, which allows the viscosity to be determined at whatever shear rates are of most interest for the process.

***Selected Publications***


Kawatra, S. K., Eisele, T. C. and Dilley, H. L., "A procedure for Evaluating Existing Heavy-Media Coal Preparation Circuits to Enhance Sulfur Removal: A case Study", Chapter 4 in High Efficiency Coal Preparation (ed Kawatra), Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 1995, pp. 55-61.

Udupa, A. R., and Kawatra, S. K., "Developments in Gold Leaching," Mineral Processing and Extractive Metallurgy, Vol. 7, 1990, pp. 115-135.

Rose, W.I., Paces, J.B., Chesner, C.A., Pletka, B.J., Hellawell, A., Kawatra, S.K., Pilling, J.E., "New Interdisciplinary Engineering Design Course in Planetary Materials and Resource Utilization" Proc. of Space'90,American Society of Civil Engineers, Aerospace/ASCE/ Albuquerque, NM, 1990, pp., 1413-1422

DeLa'O, K. A., Eisele,T. C., Kasul, D. B., Rose W. I., Kawatra, S. K., "Separation of Lunar Ilmenite: Basalt vs. Regolith", Proc. of Space'90, American Society of Civil Engineers, Aerospace /ASCE/ Albuquerque, NM, 1990, pp. 177-186.

Kawatra, S. K., Eisele, T. C., and Bagley, S. T., "Studies of Pyrite Dissolution in Pachuca Tanks and Depression of Pyrite Flotation by Bacteria," Biotechnology in Minerals and Metal Processing (B. J. Scheiner, F. M. Doyle and S. K. Kawatra, eds.), Society of Mining Engineers, Littleton, CO, 1989, pp. 55-62.


# Jason M. Keith

*Associate Professor*

*PhD. University of Notre Dame, 2001*


Fuel Cells / Alternative Energy
Modeling of Pollution Control / Composite Systems
Engineering Education


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My research interests are in using experiments combined with applied mathematics to solve energy and pollution problems. I am also active in engineering education research and scholarship.

**Polymer Composites for Fuel Cell Bipolar Plates**

Fuel Cells have been proposed as an alternative to fossil fuels for stationary and transportation applications. In order to make this a possibility, several fundamental changes must occur. One particular area is the development of a new bipolar plate material. These plates separate one cell from another within the fuel cell, and have channels etched to allow for reactant and product flows. These plates are currently made from the addition of a graphite powder to a thermosetting polymer. This polymer cannot be remelted and reused in bipolar plate applications.

In this project we are investigating a more sustainable way to develop the bipolar plate material. This involves the use of a liquid crystal polymer. Furthermore, we are attempting to improve the thermal and electrical conductivities of the fuel cell bipolar plate through the addition of multiple carbon fillers (carbon black, synthetic graphite, and carbon fiber) which has been shown to have a synergistic effect on these important material properties.

After extruding the polymer and filler into pellets, they are injection molded into samples, which are tested for thermal conductivity, electrical conductivity, and tensile strength. The rheology is tested on the extruded pellets.

**Chemical Reactor Dynamics**

Tight emissions standards are being developed for diesel fueled vehicles. We are using thermal stability theory to understand the ignition phenomenon within design diesel particulate traps to reduce emission of these harmful particles.

***Selected Publications***


D. Lopez Gaxiola, M. M. Jubinski, J. M. Keith*, J. A. King, and I. Miskioglu, “Effects of Carbon Fillers on Tensile and Flexural Properties in Polypropylene-Based Resins,” *Journal of Applied Polymer Science*, **118(3)**, 1620-1633 (2010).

D. Huang and J. M. Keith*, “Parametric and Sensitivity Analysis of Diesel Particulate Filter Regeneration,” *International Journal of Chemical Reactor Engineering,* **7,** A56:1-24 (2009).

D. Lopez Gaxiola, J. M. Keith*, J. A. King, and B. A. Johnson, “Nielsen Thermal Conductivity Model for Single Filler Carbon/Polypropylene Composites,” *Journal of Applied Polymer Science*, **114**, 3261-3267 (2009).

J. M. Keith*, D. P. Visco, D. L. Silverstein, “Ideas to Consider for New Chemical Engineering Educators: Part 1 (Courses Offered Earlier in the Curriculum),” *Chemical Engineering Education*, **43(3)**, 207-215 (2009).

H. Zheng and J. M. Keith (by invitation), “Thermal Stability of Chemical Reactors,” Encyclopedia of Chemical Processing, Sunggyu Lee, editor; vol. 4, pp. 2997-3008 (2005).


**Julia A. King**

*Professor*

*PhD. University of Wyoming, 1989*


Thermally and electrically conductive resins / composites


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My research interests are in the area of composite materials. Specifically, my interests often focus on adding various carbon fillers to typically thermoplastic polymers to produce electrically and thermally conductive resins.

Increasing the thermal and electrical conductivities of typically insulating polymers, such as polyethylene terephthalate (PET) and nylon, has the potential of greatly increasing the market for these materials. A thermally conductive material is useful as a heat sink in applications such as lighting ballasts and transformer housings. An electrically conductive material can be used in static dissipative, slightly electrically conductive (e.g., fuel gages, etc.), or EMI (Electromagnetic Interference)/RFI (Radio Frequency Interference) shielding applications (computer and cellular phone housings, etc).

One approach to improving the thermal and electrical conductivities is through the addition of a conductive filler material. For example, adding synthetic graphite particles to nylon 6,6 increases the thermal conductivity from approximately 0.3 W/mK to 1.8 W/mK and decreases the electrical resistivity from approximately $10^{15}$ ohm-cm to 20 ohm-cm. Another application for thermally and electrically conductive resins is for a bipolar plate for a fuel cell.

For more information see Dr. King's website at: http://www.chem.mtu.edu/org/ctc

***Selected Publications***


J. A. King, D. Lopez Gaxiola, B. A. Johnson, and J. M. Keith, "Thermal Conductivity of Carbon Filled Polypropylene Based Resins", Journal of Composite Materials, Vol. 44, No. 7, pp. 839-855, April 2010.

J. A. King, M. D. Via, J. M. Keith, and F. A. Morrison, "Effects of Carbon Fillers on Rheology of Polyproylene Based Resins", Journal of Composite Materials, Vol. 43, No. 25, pp. 3073-3089, December 2009.

J. A. King, B. A. Johnson, M. D. Via, and C. J. Ciarkowski, "Electrical Conductivity Modeling of Carbon-Filled Polypropylene Based Resins", Journal of Applied Polymer Science, Vol. 112, No. 1, pp. 425-433, April 2009.

R. A. Hauser, J. A. King, R. M. Pagel, and J. M. Keith, "Effects of Carbon Fillers on the Thermal Conductivity of Highly Filed Liquid Crystal Polymer Based Resins", Journal of Applied Polymer Science, Vol. 109, No. 4, pp. 2145-2155, August 2008.

J. A. King, R. L. Barton, R. A. Hauser, and J. M. Keith, "Synergistic Effects of Carbon Fillers in Electrically and Thermally Conductive Liquid Crystal Polymer Based Resins", Polymer Composites, Vol. 29, No. 4, pp. 421-428, April 2008.


# Wenzhen Li

*Assistant Professor*
*PhD. Chinese Academy of Sciences 2003*

Electrocatalysis, Electrochemical Energy, Fuel Cells, Nanomaterials

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My research interest is in the areas of nanostructured materials for electrochemical energy conversion and storage applications.

Energy issues have been identified as a primary research challenge for the next fifty years. With major raw oil reserves declining and the world's population rapidly growing, people will be forced to seek clean, affordable, flexible, technically-viable and sustainable energy resources. Low temperature fuel cells have been very attractive for future power sources for automobile, homes and portable electronics. Compared to hydrogen fuel, ethanol is a renewable energy source, because the energy is generated using a huge, naturally replenished resource - Sunlight. Because the kinetics of both the ethanol oxidation at the anode and the oxygen reduction at the cathode can be greatly facilitated in a high pH medium, and non-Pt catalysts are viable in alkali, direct ethanol alkaline membrane fuel cells (DEAMFCs) are very promising as next-generation sustainable electrochemical energy devices, and they are our current research focus.

Our current research interests include: 1) nanostructured precious group metal (PGM) catalysts with high intrinsic electrocatalytic activity to reduction reaction of oxygen, and oxidation reaction of biomass-derived alcohols . We will focus on reducing the PGM loading and improving the catalyst durability. 2) Pd-based nanostructures for ethanol oxidation in alkaline electrolyte, we will design novel Pd-catalysts with high selectivity (to $CO_2$) and long-term high performance in alkaline electrolyte. 3) Inexpensive non-PGM catalysts and novel support materials, such as Ag, carbide, carbon nanotubes, graphene, and their composites. Besides activity, we are specially interested in their stability and durability in 'real' low temperature fuel cell operations.

In addition, we are also interested in rational design, precise synthesis and electrochemical *in-situ* characterization of multi-metallic nanostructures, such as nanotube, nanocube, nanowire, nanocable (1-D axial core-shell structure), etc. for potential electrochemical energy conversion and storage applications.


Our research is currently supported by ACS-PRF and NSF.


**Selected Publications** (40+ papers, 2000+ total citations, h index: 45, highest single paper citation = 384, 6 papers > 100 citations/paper,16 papers > 50 citations/paper )


**Wenzhen Li**, Changhai Liang, Weijiang Zhou, Jieshan Qiu, Zhenhua Zhou, Gongquan Sun, Qin Xin, Preparation and characterization of multi-walled carbon nanotube-supported platinum for cathode catalyst of direct methanol fuel cells, Journal of Physical Chemistry B, 2003, 107, 6292-6299. (SCI: 384, the No.2 highest cited among > 28800 research articles in fuel cell area published after 2003)

**Wenzhen Li**, Weijiang Zhou, Weijiang Zhou, Huanqiao Li, Zhenhua Zhou, Bing Zhou, Gongquan Sun, Qin Xin, Nano-structured Pt-Fe/C as cathode catalyst in direct methanol fuel cell, Electrochimica Acta, 2004, 49, 1045-1055.

**Wenzhen Li**, Xin Wang, Zhongwei Chen, Mahesh Waje, Yushan Yan, Pt-Ru supported on double walled carbon nanotubes as high performance anode catalysts for direct methanol fuel cells, Journal of Physical Chemistry B, 2006, 110, 15353-15358.

**Wenzhen Li***, Pradeep Haldar, Supportless PdFe Nanorods as Highly Active Electrocatalyst for Proton Exchange Membrane Fuel Cell**,** Electrochemical Communications, 2009, 11, 1195-1198.

**Wenzhen L**i*, Lianbin Xu, Zhongwei Chen, Yushan Yan*An organic phase synthesis route to high performance PtCo alloy electro-catalysts for PEMFC, Journal of Power Sources, 2010, 195, 2534-2540.

Olumide Winjobi, Zhiyong Zhang, Changhai Liang, **Wenzhen L**i*, Carbon nanotube supported platinum-palladium nanoparticles for formic acid oxidation, Electrochimica Acta, 2010, 55, 4217-4221.


## Adrienne R. Minerick

*Associate Professor*
*Medical microDevice Engineering Research Laboratory (M.D.-ERL)*
*www.MDERL.org*
*Ph.D. Univ. of Notre Dame, 2003*


- Microdevices
- Medical diagnostics
- Nonlinear electrophoresis


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The mission of M.D. - ERL is to explore electric fields to elicit cellular responses at the micron length scale. Applications include the development of portable medical diagnostic devices to detect blood diseases and quantify infected / unhealthy cells relative to healthy cells - all within a single drop of blood.

**Microdevices:** Lab-on-a-Chip devices have the potential to perform multiple complicated lab procedures with nanoliters of fluid in portable, integrated chips. In M.D.-ERL, our custom-designed devices handle biofluid samples in contact with electrodes. Microfabrication occurs via photolithographic methods in the Microfabrication Facilities (MFF) at Michigan Tech.

**Electrokinetics:** Microfluidic devices require pressure driven flow or applied electrical fields to move liquids through the microchannels. We use dielectrophoresis - non-uniform alternating current (AC) electric fields to polarize cells. Our lab has demonstrated that the cell's polarization is also dependent on membrane molecular expression. Experiments indicate that O+ red blood cells can be distinguished with >95% confidence [Srivastava 2008, Minerick 2008]. This enables the potential for portable blood typing devices for use in emergency situations or remote field locations.

**Medical Diagnostics:** Versatile medical microdevices could significantly improve diagnostics – at a fraction of the costs. This technology could compress many blood tests into a 5-minute test in the doctor's office and provide the patient with a positive or negative result and quantify disease progression. Further uses could include disease management (think blood glucose meters).

***Selected Publications***


Minerick, A.R., "The Rapidly Growing Field of Micro and Nanotechnology to Measure Living Cells," Invited Perspective with Cover Figure, *AIChE Journal,* Volume 54, Issue 9, Pages 2230-2237, 2008.

Srivastava, S. K.; Minerick, A. R.; "DC Dielectrophoretic Applications in Microdevice Technology", in press, *Analytical & Bioanalytical Chemistry,* 2010.

Srivastava, S. K.; Minerick, A. R.; "Insulator-based Dielectrophoretic characterization of polystyrene particles", under review, *J. Chromatography,* 2010.

Minerick, A.R., "Particles in Microfluidic Systems", Chapter in *Microfluidic Devices in Nanotechnology: Current Status and a Future Perspective*, Edited by Challa Kumar Wiley, 2010.

Gencoglu, A and A.R. Minerick, "Chemical and Morphological Changes on Platinum Microelectrode Surfaces in AC and DC fields with Biological Buffer Solutions," *Lab on a Chip*, Volume 9, Issue 13, 2009. DOI: 10.1039/B820126A

Srivastava S.K., P.R. Daggolu, S.C. Burgess, and A.R. Minerick, "Dielectrophoretic Characterization of Erythrocytes: Positive ABO Blood Types," *Electrophoresis,* Volume 29, Issue 24, Pages 5033-5046, 2008.

Minerick, A. R. "DC Dielectrophoresis in Lab-on-a-Chip Devices." In: Li, Dongqing (ed). *Encyclopedia of Micro- and Nanofluidics*. Springer, Berlin Heidelberg New York, 2008.


# Faith A. Morrison

*Associate Professor*
*PhD. University of Massachusetts, 1988*

Rheology of Complex Systems
Chemical Engineering Education

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Our research is centered around using rheological techniques to probe the behavior of flowing liquids. For us, the interesting systems are those with structure, including filled polymers, high-molecular-weight polymers, and block copolymers, as described below.

**Filled Polymers**

Adding filler to a polymer increases the viscosity, but may bring desirable changes as well, such as enhanced thermal and electrical conductivity. We are involved with investigating the rheological properties of highly filled polymer-carbon systems.

**Better Educational Materials**

Educational research of the last decade can be employed to produce better textbooks that improve student learning. Following up on *Understanding Rheology*, a new undergraduate fluid mechanics textbook is in preparation. This textbook is a thorough redesign of the traditional chemical engineering undergraduate textbook in fluid mechanics.

**Block Copolymers**

Copolymers are macromolecules that are made up of different chemical units bonded together to make one long chain. When the chemical units are arranged in long blocks, the polymer may undergo microphase separation. One of our goals is to understand the flow mechanism of microphase-separated block copolymers.

***Selected Publications***


Morrison, Faith A., Drawing the Connections: Engineering Science and Engineering Practice," Chemical Engineering Education, 110-115, Sprnig 2005.

Morrison, Faith A., *Understanding Rheology* (Oxford University Press, 2001), ISBN 0-19-514166-0.

King, Julia A., Faith A. Morrison, Jason M. Keith, Michael G. Miller, Ryan C. Smith, Mariana Cruz de Jesus, Amanda M. Neuhalfen, and Rodwick L. Barton, “Electrical Conductivity and Rheology of Carbon –Filled Liquid Crystal Polymer Composites,” Journal of Applied Polymer Science, 101(4), 2680-2688 (2006).

A. Nakatani, F. Morrison, C. Jackson, J. Douglas, J. Mays, M. Muthukumar, and C. Han, Shear-Induced Changes in the Order-Disorder Transition Temperature and the Morphology of a Triblock Copolymer, Journal of Macromolecular Science-Physics Edit4ion, B35 (3/4), 489 (1996).

P. Manjeshwar, F. Morrison, and J. Mays, Test of the Constitutive Hypothesis of Melt Fracture: Large Amplitude Step-Shear of Polyisoprenes, Proceedings of the XIIth International Congress on Rheology, Quebec City, Canada, August 18 23, 1996, A. Ait-Kadi, J. Dealy, D. James, and M. Williams, eds., 123.

# Michael E. Mullins

*Professor*
*PhD. University of Rochester, 1983*

Environmental Kinetics and Thermodynamics
Engineered Nanostructures
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**Ceramics, fine particles, and engineered nanostructures**
In the area of ceramics and particle technology, we are learning to make novel nanoscale structures for use as electrodes, catalysts, biomaterials, and membranes. Specific current research includes the development of polymer/inorganic nanofibers for tissue scaffolds, electrosynthesis of new hybrid materials, porous carbon electrodes for battery and fuel cell applications, the development of zeolite membranes for gas phase separations and reactions, the production of nanometer scale polymer/ceramic particles, and the synthesis of polymer inorganic nanocomposites for biomedical, electronic and photonic applications.

The treatment of ceramic, polymer, and particulate surfaces fits into the mix of new technologies for these advanced materials. We employ sol-gel, vapor, and plasma techniques to modify surfaces to achieve the desired catalytic, electronic, or physical properties. Our group uses a variety of spectroscopic techniques including FTIR, Raman, electrochemistry, and X-ray analysis to characterize the chemistry and structure of the materials. For physical analysis we employ electron microscopy, thermal analysis, gas adsorption, and cyclic voltametry among other methods.

**Environmental thermodynamics and kinetics**
An understanding of the partitioning and reaction of contaminants in the environment is crucial to the design of clean industrial processes and for fate assessment studies. Whether these contaminants end up in groundwater, soil, air, or even in humans is a function of their thermodynamic behavior in each of these compartments. Since most environmental contaminants are dilute, we have spent the past decade studying dilute solution thermodynamics and partitioning experimentally and theoretically. We are currently involved in measuring vapor-liquid equilibria for mixed solvent/electrolyte systems, and developing models to predict the behavior of such systems.

***Selected Publications***

KenHeng See, Michael E. Mullins, and Patricia A. Heiden. “A Reactive Core-Shell Nanoparticle Approach to Prepare Hybrid Nanocomposites: Effects of processing variables.” *Nanotechnology 16*, (9), 1950-1959 (2005).

Bovornlak Oonkhanond and M.E. Mullins, “Electrical double-layer effects on the deposition of zeolite A on surfaces.” *Journal of Colloid and Interface Science 284*, 210-215 (2005)

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M. E. Mullins, T. N. Rogers, and A. Loll. "Estimation of Henry’s Constants for Aqueous Systems at Elevated Temperatures", Fluid Phase Equilibria, 150, 245 (1998).

Y. Choi, J. K. Lee, and M.E. Mullins. "Densification Process of TiCx-Ni Composites Formed by Self-Propagating High-Temperature Synthesis Reaction", Journal of Material Science, 32, 1717 (1997).

A. A. Kline, T.N. Rogers, M.E. Mullins, B.C. Cornilsen, and Lj. M. Sokolov, "Sol-Gel Kinetics for the Synthesis of Multi-component Glass Materials", Journal of Sol-Gel Science and Technology 2, 269-272 (1994).


# Ching-An Peng

Professor
James and Lorna Mack Chair in Bioengineering
PhD. University of Michigan 1995


Drug Delivery
Nanobiotechnology
Tissue Engineering


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My research interests are in drug delivery, nanobiotechnology, and tissue engineering

**Drug Delivery**
The potential of ultrasonic standing wave fields to facilitate viral transduction rate has been demonstrated. Under acoustic exposure, suspended cells move to the pressure nodal planes first and form cell clusters. Then, viruses circulated between nodal planes use the pre-formed cell clusters as the nucleating sites to attach on. As a result, this system enhances gene delivery efficiency. The same apparatus were used to increase the gene delivery efficiency of nonviral vectors such as polyethyleneimine. Further modification of acoustic setup and optimization of operating parameters are undergoing to augment both viral and nonviral gene delivery efficiency.

**Nanobiotechnology**
Unlike bacteria-based infection which can be controlled by antibiotics, viruses fully relying on host cells for their replication are not so readily dealt with. The emergence and spread of viral diseases worldwide, particularly HIV/AIDS, outbreaks of severe acute respiratory syndrome virus, and the scares of pandemic avian influenza virus seriously raise the concern that any virus strain has the potential evolving into a life-threatening pathogen. In this regard, developing fast and efficient screening technology has its merits of identifying potential drugs against viral diseases that still lack of effective prevention or treatment. Quantum dot (QD), an emerging probe for biological imaging and medical diagnostics, has been employed in my lab to form complexes with virus and used as fluorescent imaging probes for exploring potential antiviral therapeutics. Since preservation of viral infectivity after tagging virus with QDs is of utmost importance, various strategies are currently investigated to assure constructed QD-virus imaging modality is capable of providing meaningful information. In addition, various multifunctional bionanohybrids are fabricated for the field of cell therapy and tissue engineering.

**Selected Publications**


Lee, Y-H and **Peng, C-A**, Enhanced retroviral gene delivery in ultrasonic standing wave fields, Gene Therapy 12: 625-633, 2005..

You, J-O, Liu, Y-S, Liu, Y-C, Joo, K-I, **Peng, C-A**, Incorporation of quantum dots on virus in polycationic solution, Inter. J. Nanomedicine 1: 59-64, 2006.

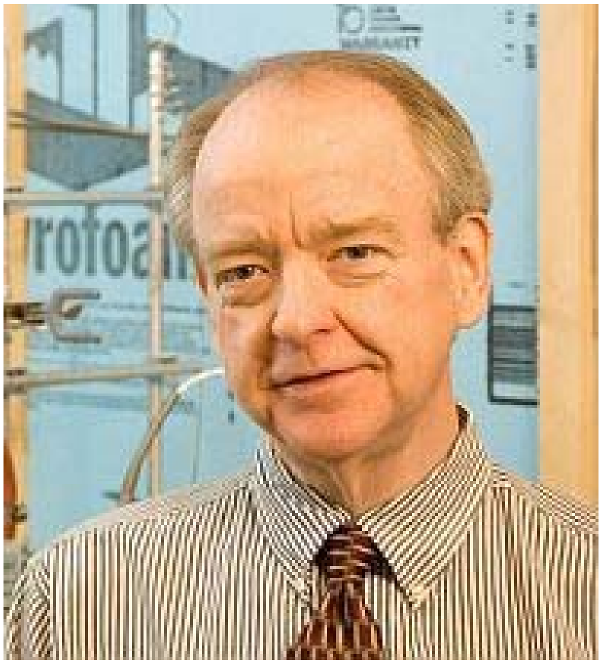
Don, T-M, King, C-F, Chiu, W-Y, Peng, C-A, Preparation and characterization of chitosan-g-poly(vinyl alcohol)/poly(vinyl alcohol) blends used for the evaluation of blood-contacting compatibility, Carbohydrate Polymers 63: 331-339, 2006.

Lee, Y-H, **Peng, C-A**, Nonviral gene transfer of suspension cells in ultrasound standing wave fields, Ultrasound Med Biol 33: 734-742, 2007.

Yacobi, NR, Phuleria, HC, Demaio, L, Liang, CH, **Peng, C-A**, Sioutas, C, Borok, Z, Kim, K-J, Crandall, ED, Nanoparticle effects on rat alveolar epithelial cell monolayer barrier properties, Toxicology in Vitro 21: 1373-1381, 2007.

Kwon, YJ, **Peng, C-A**, Differential interaction of retroviral vector with target cell: quantitative effect of cellular receptor, soluble proteoglycan, and cell type on gene delivery efficiency, Tissue Eng Part A 14: 1497-1506, 2008

Wang, C-H, Hsu, Y-S, **Peng, C-A**, Quantum dots encapsulated with amphiphilic alginate as bioprobe for fast screening anti-dengue virus agents, Biosens Bioelectron, in press, http://dx.doi.org/10.1016/j.bios.2008.08.009




# Tony N. Rogers

*Associate Professor*
*PhD. Michigan Technological University, 1994*

Process Simulation and Improvement
Physical Property Measurement
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**PROCESS SIMULATION:** Dr. Rogers has research and teaching experience with the ASPEN Plus®, UniSim®, and SuperTarget® simulation software. As a member of the U.S. EPA Center for Clean Industrial and Treatment Technologies (CenCITT), Dr. Rogers is experienced in design calculations for a variety of environmental unit operations: air and steam stripping, carbon adsorption, catalytic oxidation, activated-sludge wastewater treatment, and others.

**PROCESS & PRODUCT IMPROVEMENT:** Dr. Rogers is advancing environmentally conscious process design in two areas: (1) integrating pollution prevention concepts into chemical processes, and (2) developing new tools and strategies for process evaluation. He has created software tools to evaluate processes by criteria such as economics, safety, toxicity, and environmental impact. Dr. Rogers serves as faculty advisor to Consumer Product Manufacturing (CPM), a client-sponsored enterprise in which students develop new consumer products, manufacturing equipment, and packaging/shipping options.

**PHYSICAL PROPERTY RESEARCH:** A major focus of Dr. Rogers' research is to address the need for reliable physical property data for process design and simulation. Under the direction of AIChE/DIPPR® (Design Institute for Physical Properties), Dr. Rogers has worked since 1991 to provide property data to industry in the environmental, safety, and health areas. He has also conducted experimental VLE and LLE studies for air-water-organic systems and measured distribution ratios of organic chemicals between water and ionic liquid phases at equilibrium.

**ELECTRICAL ENERGY STORAGE:** Research sponsored by the U.S. DOE and the Michigan Universities Commercialization Initiative (MICU) has resulted in the development of a rechargeable asymmetric battery consisting of a nickel-carbon foam positive electrode and an electrolytic capacitor negative electrode.

### *Selected Publications*


Lau, K.A., T.N. Rogers, D.J. Chesney (2010). "Measuring the Aqueous Henry's Law Constant at Elevated Temperatures Using an Extended EPICS Technique.“ *Journal of Chemical & Engineering Data*. In press.

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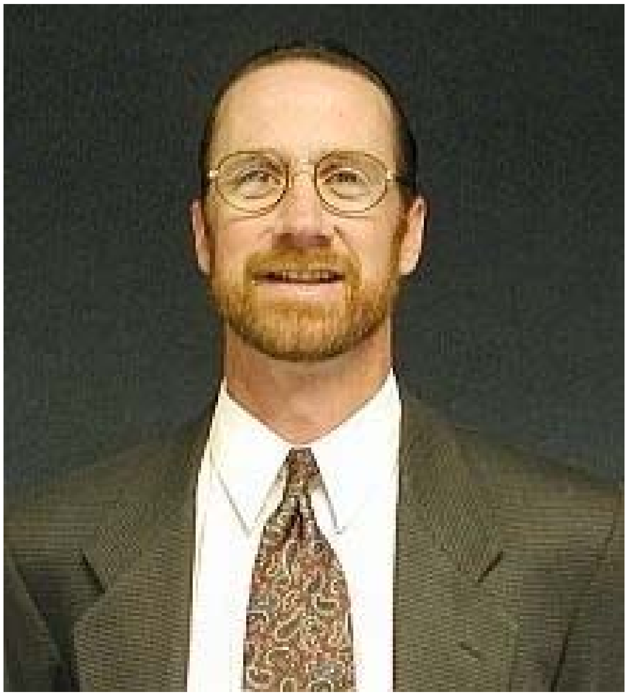
Raymond, J.W., T.N. Rogers (1999). “Molecular Structure Disassembly Program (*MOSDAP*): A Chemical Information Model to Automate Structure-Based Physical Property Estimation.” *Journal of Chemical Information and Computer Sciences*. Vol. 39, pp. 463-474




# John F. Sandell

*Associate Professor*
*PhD. Michigan Technological University, 1995*

Fire Protection and Environmental Engineering

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My research interests include researching issues related to engineering pedagogy, alternative materials utilization, fire protection, fire safety, and chemical process safety.

***Fire Protection***
The development of innovative fire suppression systems is an on-going problem especially in the chemical process industries. Specifically new advances in technology related to fire protection systems for processes and process structures is currently needed. New materials used in today's manufacturing facilities require advanced fire protection techniques and technologies. This will include the use of materials microscopy techniques including the development of novel uses of electron beam analytical techniques for engineering applications (electron microprobe and SEM focused).

***Engineering Education***
With the use of new technologies in today's classroom, students are now exposed to a wide variety of multimedia approaches to teaching. As a result, there is a continuous need for college instructors to develop new and effective teaching techniques. This requires a comprehensive study focused on student behavior in a classroom setting.

***Selected Publications***

Sandell, J.F., "Chemical Engineering Technician: Profile". Materials provided for this article published in *Tech Directions* (February 2003).

Sandell, J.F., G.R., Dewey, L.L., Sutter, J.A., Willemin, "Evaluation of Lead Bearing Phases in Municipal Waste Combustor Fly Ash". ASCE Journal of Environmental Engineering, January 1996 Vol. 122 (1), pp. 34 40.

Sutter, L.L., G.R., Dewey, J.F. Sandell, "Characterization of Lead Bearing Phases in Municipal Waste Combustor Fly Ash", The Proceedings of the Microscopy Society of America, August 1996.

Dewey, G.R., L.L., Sutter, J.F., Sandell, "Reactivity Based Approach for Classifying Fly Ash", The Proceedings of the American Power Conference, April 1996, Chicago, IL.

# David Shonnard

*Professor and Robbins Chair in Sustainable Use of Materials*
*PhD. University of California-Davis, 1991*

Bioprocess Engineering, Alternative Energy, Sustainability
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Research interests are in the areas of sustainability, life-cycle environmental assessments, environmental transport processes, and forest-based biofuels.

**Life Cycle Assessment / Sustainability**

Life Cycle Assessment (LCA) is a method that allows for a comprehensive assessment of environmental impacts for a product or process. The scope of the assessment is over the entire life cycle; starting with extraction of raw materials from the environment, manufacturing, transportation, use in society, recycle, reuse, and final treatment or disposal in the environment. Multiple indicators of environmental impacts are used; for example air greenhouse gasses, water emissions, toxicity, and resource consumption. The purpose of LCA is to compare alternative products or processes that meet the same function. An example might be alternative fuels to meet a specific transportation requirement (conventional gasoline versus ethanol). Studies conducted thus far include a comparison of regional cellulosic feedstocks for ethanol production, green jet from numerous plant oils, pyrolysis-based biofuels and biopower, and forest feedstock supply chain.

**Bioproccess Engineering / Renewable Bio-Based Fuels**

Research in these areas employ a range of conversion approaches, including molecular biology techniques for enzymatic hydrolysis of lignocellulosic biomass and acid-catalyzed hydrolysis of woody biomass, forest products wastewater streams, and residuals from the agricultural sector.

***Selected Publications***

Allen, D.T. and Shonnard, D.R. (and other contributors), “Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice-Hall, Upper Saddle River, NJ, 2002, pp. 552, ISBN 0-13-061908-6.

Jensen, J.R., Brodeur-Campbell, M., Morinelly, J., Gosson, K., Shonnard, D.R., (2010), Effects of Dilute Acid Hydrolysis Conditions on Enzymatic Hydrolysis of Aspen, Balsam, and Switchgrass, *Bioresource Technology*, **101**(7), 2317-2325.

Morinelly, J.E., Jensen, J.R., Browne, M., Co, T.B., Shonnard, D.R., (2009), Kinetic Characterization of the Formation and Degradation of Xylose Monomer and Oligomer during Dilute Acid Pretreatment of Lignocellulosic Biomass from Forests and Switchgrass, *Industrial and Engineering Chemistry Research*, **48**, 9877-9884.

Holman, P.A., Shonnard, D.R., Holles, J.H., (2009), Using Life Cycle Assessment to Guide Catalysis Research, *Industrial & Engineering Chemistry Research*, **48**, 6668-6674

Kalnes, T., Marker, T., Shonnard, D.R., 2007, Green Diesel: A Second Generation Biofuel, *International Journal of Chemical Reaction Engineering*, **5**(article A48), http://www.bepress.com/ijcre/vol5/A48 .

Zhang, Q., J.C. Crittenden, D. Shonnard, and J.R. Mihelcic, 2003, "Development and evaluation of an environmental multimedia fate model CHEMGL for the Great Lakes region,“ *Chemosphere*, **50**(10), 1377-1397.


**Wen Zhou**
*Assistant Professor*
*PhD. University of California, Los Angeles, 2006*

Systems Engineering and Biology / Biofuel production / Bioinformatics

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My research is focused on using and advancing computational systems biology and engineering to better understand and further improve complex chemical and biochemical processes to address problems related to bioenergy production and environment protection. The complexity of processes involved in these problems necessitates systematical approaches. The ultimate goal is to generate computational tools that can be used to aid the analysis and design of corresponding biochemical systems.

**Bioenergy production from lignocellulosic biomass**

Lignocellulosic biomass has long been recognized as a renewable carbohydrate source for human energy use and is available in large quantities. The success of converting lignocellulosic biomass into biofuel cost-efficiently will not only solve the current energy demand crisis, but will also create a clean sustainable energy cycle that offers environmental advantages unequalled by other feedstocks or fuels. Processing of lignocellulosic biomass is estimated to be the key factor impeding current establishment of a cellulosic biofuel industry, which is achieved mainly in two ways: 1) thermochemical approach and 2) biochemical approach. My interests are focused on the biochemical approach, and I am also interested in its possible coupling with the thermochemical approach.

***Selected Publications***


Zhou, W.; Xu, Y. and Schuttler, HB. Cellulose hydrolysis in evolving substrate morphologies III: time scale analysis. *Biotechnology and Bioengineering.* 107, 224-234, 2010.

Zhou, W.; Hao, Z.; Xu, Y. and Schuttler, HB. Cellulose hydrolysis in evolving substrate morphologies II: numerical results and analysis. *Biotechnology and Bioengineering.* 104, 275-289, 2009.

Zhou, W.; Schuttler, HB.; Hao, Z. and Xu, Y. Cellulose hydrolysis in evolving substrate morphologies I: a general modeling formalism. *Biotechnology and Bioengineering.* 104, 261-274, 2009.

Zhou, W. and Manousiouthakis, V. I. Automating the AR Construction for Non-isothermal Reactor Networks. *Computers and Chemical Engineering.* 33, 176-180, 2009.

Zhou, W. and Manousiouthakis, V. I. Global capital/total annualized cost minimization of reactor network. *Industrial and Engineering Chemistry Research.* 47, 3771-3782, 2008.

Zhou, W. and Manousiouthakis, V. I. On dimensionality of Attainable Region construction for isothermal reactor networks. *Computers and Chemical Engineering.* 32, 439-450, 2008.

**About Michigan Tech and Houghton**

Michigan Tech, founded in 1885, has gained world-wide recognition for innovative education and scholarship.
Our graduate students receive intensive, advanced instruction and the opportunity to pursue wide-ranging research.
Houghton lies in the heart of Upper Michigan's scenic Keweenaw Peninsula. The campus overlooks Portage Lake and is just a few miles from Lake Superior. The area's expansive waters and forests, including the University's 600-acre recreational forest adjoining campus, offer students unparalleled opportunity for outdoor recreation.

Houghton has a population of 7,400 residents. The University's more than 6,600 students from many states and foreign countries make the area a vibrant multicultural community.

Houghton is rated the safest college town in Michigan and the eighth-safest in the nation. It also has been called one of the nation's top-ten summer sports areas, and one of the top-ten best places in the country to live.

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