The Department of Chemical Engineering at Carnegie Mellon University (ChemE) invites you to learn about its faculty, areas of research, facilities, research centers, graduate programs and graduate student life. ChemE at CMU originated over a century ago from the School of Applied Sciences within the Carnegie Technical Schools. The Technical Schools evolved into Carnegie Mellon University and the Department of Chemical Engineering issued from the School of Applied Sciences; both are now internationally respected centers of knowledge and research. ChemE at CMU has been home to major names in chemical engineering such as McCabe, Berl, Toor, Brenner and Westerberg.

Today, ChemE has a faculty of 21 internationally known professors, some holding joint appointments with other departments. ChemE awards about 70 B.S., 50 M.S. and 20 Ph.D. degrees each year. The department's research interests fall into six general areas: Bioengineering, Catalysis and Surface Science, Complex Fluids Engineering, Envirochemical Engineering, Process Systems Engineering and Energy Science and Engineering. Research in all of these areas has achieved world-class stature over the past 30 years. In particular, the Complex Fluids group has been renowned for decades for its strength in colloid and polymer science, and the Process Systems group is the strongest of its kind anywhere. We have also formed the super-group called Energy Science and Engineering to focus attention on the depth and breadth of ChemE's engagement with a leading challenge of our time. Our research collectives and their associated faculty are the principal focus of this brochure.

ChemE's home at Carnegie Mellon is Doherty Hall, a historic building at the center of campus. Renovated in 2008/9, the research space is unique in its philosophy of large multi-faculty spaces where the strong community and collegiality in the department find their full expression, fostering creativity in its research. We hope this brochure helps you get to know ChemE at CMU. For more details and the latest information, please visit www.cmu.edu/cheme/.
The Department of Chemical Engineering at Carnegie Mellon hosts a wide variety of research programs, including some of the strongest anywhere. The department’s many research projects are grouped by facilities, shared interests and shared laboratories, into the following areas:

- Biomolecular Engineering
- Catalysis and Surface Science
- Complex Fluids Engineering
- Energy Science and Engineering
- Envirochemical Engineering
- Process Systems Engineering

A general description of each of these research areas appears in the following pages. These groups reflect the traditional areas of interest in the department.
Biotechnology and biomolecular engineering are important areas in the Department of Chemical Engineering. The faculty focus on: metabolic engineering, the production, processing and delivery of nucleic acids, proteins and vaccines; bioanalytical technology development; the structure and mechanics of the cell nucleus and corresponding implications for mechanotransduction; and the development of safe and efficacious drug and nucleic acid delivery systems with unique transport properties. In these areas, faculty apply principles of fundamental biology, biophysics, physical chemistry and synthetic chemistry in addition to traditional chemical engineering concepts of transport phenomena, kinetics, thermodynamics, colloid and interfacial science and modeling.

The faculty have created novel optical and spectroscopic tools to probe the structure and function of proteins at interfaces, such as those presented by chromatographic media and drug delivery vehicles. Novel affinity ligands, including surfactants that hybridize to specific DNA targets for chromatographic purification, and nucleic acid delivery vehicles are also under development via synthetic and combinatorial chemistry approaches. Quantitative imaging methods, including nuclear magnetic resonance, fluorescence and nanoscale mechanical measurements, are brought to bear on intact cells and organelles to better understand metabolic pathways, stem cell differentiation, the progression of cancer and diseases of the nuclear lamina. Robotic technologies for cell proliferation and drug discovery studies are being explored in collaboration with the Robotics Institute; highly adaptable biosensors, rapid DNA sequencing platforms and micro-scale cell sorting schemes are under development. New unit operations, process analytical technologies and entire processes for the efficient production of vaccines, recombinant proteins and other products of the biotechnology industry are being developed.

Other chemical engineering faculty also have significant efforts in the bioengineering and biotechnology domains including efforts in the Process Systems Engineering group to develop practical algorithms for rapid protein structural alignment, metabolic flux optimization and product development for pharmaceuticals. Expertise in the Complex Fluids Engineering group is being leveraged to design more effective drug delivery systems.

Bioengineering faculty and students maintain close interactions with Carnegie Mellon’s Department of Biomedical Engineering, where research expertise is found in biomechanics, tissue engineering, regenerative medicine, medical device development, drug delivery, bioimaging and bioinformatics. Collaborative activities also extend to the Departments of Biological Sciences and Chemistry as well as to the University of Pittsburgh School of Medicine and the West Penn Allegheny Health System.

Carnegie Mellon is one of the founding members of the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL), a federal Manufacturing USA institute aimed at accelerating the pace of innovation in the manufacturing processes used by the biotechnology industry. The BIO and PSE faculty partner to lead Carnegie Mellon’s activities in this program, which also involves faculty members from other engineering departments as well as from the Mellon College of Science and the School of Computer Science.

### Participating Faculty

<table>
<thead>
<tr>
<th>Faculty Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kris Noel Dahl</td>
<td>12</td>
</tr>
<tr>
<td>Michael M. Domach</td>
<td>13</td>
</tr>
<tr>
<td>Todd M. Przybycien</td>
<td>24</td>
</tr>
<tr>
<td>Alan J. Russell</td>
<td>25</td>
</tr>
<tr>
<td>James W. Schneider</td>
<td>27</td>
</tr>
<tr>
<td>Robert D. Tilton</td>
<td>29</td>
</tr>
<tr>
<td>Kathryn A. Whitehead</td>
<td>32</td>
</tr>
</tbody>
</table>
The Catalysis and Surface Science group within the Department of Chemical Engineering engages in a wide range of research areas including catalytic properties of surfaces, enantioselectivity on chiral surfaces, transport in solids, molecular simulation and high throughput study of alloys, adsorption and electrochemistry. The group expertise includes both advanced experimental methods for materials characterization and synthesis as well as advanced theoretical and computational methods for simulation and understanding of novel solid and surface properties. The group benefits from a well-equipped surface science laboratory described on p. 40. The faculty members have backgrounds and degrees in chemical engineering, chemistry, mathematics, physics and materials science, bringing an extremely diverse set of disciplines and expertise to the group.

The interests in catalysis of the CSS group overlap strongly with the Energy Science and Engineering super-group described later, largely based on a collaboration with the DOE National Energy Technology Laboratory located in Pittsburgh. Projects include the development of high throughput catalytic reactor systems for rapid screening of alloy catalysts and optimization of catalytic alloy compositions. A second direction is the use of machine learning and data science with high throughput computations to complement those experiments.

The CSS group is one of the leaders in the application of high throughput methods for experimental and theoretical study of alloy catalysis. Specialized instrumentation has been developed for synthesis of Composition Spread Alloy Films (CSAFs), thin film libraries that contain all possible compositions of a ternary alloy in the space of 1 cm$^2$. A suite of tools has been assembled for spatially resolved characterization to map their surface properties across the entire composition space. Finally, a unique 100 channel microreactor array is used for parallel measurement of steady state catalytic reaction kinetics at 100 different alloy compositions. The CSS group is developing new machine learning based methods to aid in identifying new catalytic materials, as well as to model catalysis across alloy composition, surface structure and reaction condition space. Using these complementary computational modeling methods, the CSS group can develop an unparalleled understanding of the impact of alloy composition on catalysis, and help to design new alloy materials with superior performance.
Complex fluids take diverse forms for diverse applications. Occurring in everyday products and advanced technologies, they span a broad spectrum of the chemical and materials processing industries. We encounter them in our daily lives as personal care and cleaning products. We consume them as foods, which are produced with the aid of complex fluid fertilizer and pesticide applications. When faced with poor health, we rely on complex fluid pharmaceutical formulations and benefit from nano-enabled drug delivery and medical diagnostics. Complex Fluids Engineering is critical to nanotechnology and nanomaterials, where it provides the basis for nanomaterial morphology control, and it enables sustainable chemical engineering strategies to replace organic solvents with aqueous liquids.

Complex fluids can be colloidal nanoparticle suspensions, emulsions, foams, self-assembling surfactant solutions, entangled polymer solutions, gels or other more exotic fluids such as particle-stabilized emulsions or suspo-emulsions with independently dispersed liquids and solids. Some complex fluids behave as “soft materials” that exhibit both fluid and solid characteristics. Complex Fluids Engineering research is motivated by the great variety of functional and rheological characteristics that can be designed into a fluid to meet wide-ranging technological needs. The utility of complex fluids stems from their unusual responsiveness to variations in composition and conditions. In special cases, small changes in conditions trigger a high gain response. “Smart materials” exploit this tendency to adapt to external stimuli, perhaps to change from an elastic solid-like state to a freely flowing liquid, to actuate a mechanical response or to release a cargo molecule. Understanding and controlling highly adaptive fluid characteristics is the essence of Complex Fluids Engineering.

This adaptability derives from delicate enthalpy-entropy balances that permit complex organized structures to exist within the fluid. Macroscopic fluid properties are controlled by hierarchies of structures, forces and dynamic processes that span orders of magnitude in length and timescales. Individual research groups address a wide variety of fundamental and applied research topics, but the over-arching goal in each case is to understand and control the interactions that act across these hierarchical scales and govern applicable complex fluid behaviors. The research portfolio is diverse. It includes fundamental topics in complex fluid structure and dynamics, such as the influence of surfactant and particle adsorption dynamics on the mechanics of fluid interfaces. Linking this fundamental understanding to the origins of emulsion stability supports the development of industrial complex fluid formulation strategies. Some research connects with biotechnology, as when novel nucleotide-binding surfactants are exploited to rapidly sequence DNA or to detect circulating microRNA disease markers. Other research reveals fundamental cellular biomechanical insights by discovering the link between cell stiffness and molecular details of protein network self-assembly. There is a close coupling not only of theory and experiment but also of mechanistic analysis and chemical synthesis. In this way, novel molecular structures are designed and synthesized to produce surfactants or hybrid nanoparticles that deliver prescribed interfacial behaviors. This approach is used, for example, in studies of the origins of surface charge in nonpolar liquids and the development of high efficiency nanoparticulate emulsifiers.

The Complex Fluids Engineering group has a rich tradition at Carnegie Mellon. Students take advantage of the well-equipped, multi-user PPG Industries Colloids, Polymers and Surfaces Laboratory and share specialized instrumentation maintained by individual research groups who collaborate across departments in both the Engineering and Science Colleges. The group develops and makes routine use of state-of-the-art experimental tools and modeling for the investigation of complex fluid bulk and interfacial structure and rheology, intermolecular and surface forces, bulk and interfacial transport phenomena, electrokinetics and surface chemistry driven flows, interfacial charging and dielectric properties.
Energy-related research in ChemE at CMU has been the fastest growing segment of our research portfolio. Energy research spans many technologies including environmental impacts, electrochemical energy systems such as fuel cells, catalysis, solar cell production, energy system modeling, scheduling and optimization. A wide range of approaches are used including computational molecular simulations, high throughput study of alloy catalysis, applied electrochemical studies, materials preparation and optimization and stochastic modeling techniques in systems research. More than half the faculty in ChemE are involved. Reflecting the volume of energy research and the cross-cutting range of energy related work, the department has a grouping of faculty called Energy Science and Engineering.

Much of the department’s energy-related research is funded by various programs of the U.S. Department of Energy, by the National Science Foundation and by corporate sponsors. Our connections with energy research activities across the campus are facilitated by the Wilton E. Scott Institute for Energy Research co-directed by Professor Andy Gellman. The Scott Institute supports energy research spanning the range from energy technology to energy systems to policy. Through the Scott Institute, we are members of the DOE National Energy Technology Laboratory’s University Consortium for Fossil Energy Research.
The Envirochemical Engineering group includes professors Neil Donahue, Coty Jen and Spyros Pandis as well as approximately 30 doctoral students and researchers along with the groups led by professors Peter Adams (Civil and Environmental Engineering, Engineering and Public Policy, courtesy in Chemical Engineering), Albert Presto (Mechanical Engineering), Allen Robinson (Mechanical Engineering and Engineering and Public Policy), Satbir Singh (Mechanical Engineering) and Ryan Sullivan (Mechanical Engineering and Chemistry). They constitute the Carnegie Mellon University Center for Atmospheric Particle Studies (CAPS).

Emissions of gases and particles by industrial and other anthropogenic sources produce a variety of atmospheric pollutants. These often have adverse effects on human health, ecosystems, materials and climate. Fine particles comprise three of the top 10 sources of mortality globally and cause the largest uncertainties in climate forcing. CAPS focuses on identifying and answering critical questions limiting our understanding of atmospheric pollution and on developing the tools needed to reduce harmful air pollutants. The primary emphasis is on using an integrated approach to solve air-quality problems, considering source emissions, atmospheric transport and chemistry and the ultimate removal of the pollutants from the atmosphere by deposition. The group is currently working on problems ranging from smog formation in large urban centers to global climate change.

One area of research involves the development of detailed state-of-the-art computer models describing various components of the atmospheric system as pollutants move from sources to receptors. Another area involves carefully controlled laboratory studies to study fundamental processes related to the formation of pollutants and their properties. The CMU Air Quality Laboratory located in
The department features the largest PSE academic research group in the United States, and consists of five faculty members, and approximately 60 graduate students and 15 post-doctoral researchers. Our research in the PSE area is supported by funding in excess of $4.5 million per year from sources that include — among others — the National Science Foundation, the Department of Energy, Pennsylvania Infrastructure Technology Alliance and the industrial partners of the Center of Advanced Process Decision-making (see pg. 42). Our research goal is to provide intellectual leadership in complex decision-making issues faced by process industries. Our underlying approach is based on developing and advancing systematic modeling and solution methods for multiscale process systems engineering, covering the full spectrum from the molecular to the enterprise level.

The research work of the PSE group is focused in four major areas: Optimization, Design, Operations and Control. Research in Optimization includes theoretical and methodological advances in large-scale nonlinear programming, mixed-integer and disjunctive programming, global optimization, the optimization of differential-algebraic systems, stochastic programming and the optimization of data-driven models and analytics. Topics in Design involve applications in areas such as shale-gas facilities, biofuel plants, reaction/separation systems, energy and process water integration, process intensification, carbon-capture systems, fuel cells, solar cells and power systems, materials design (e.g., catalysts, solvents, performance fluids), metabolic networks and bioinformatics. Topics in Operations include enterprise-wide optimization, supply chain management and optimization under uncertainty, planning and scheduling of batch and continuous process systems, real-time optimization and electric power grids (smart grid). Finally, topics in Control include adaptive control and online parameter estimation, self-learning control, model predictive control, thermodynamics-based control, passivity theory, the design and verification of process operating systems and real-time data analysis.

PSE faculty members have authored the classic textbook, Systematic Methods of Chemical Process Design (Prentice-Hall), and developed state-of-the-art optimization software (e.g., BARON, DICOPT, IPOPT, LOGMIP, rSQP). There has been widespread adoption of Carnegie Mellon-developed research strategies among a large number of academic departments. The PSE faculty have also assumed leadership positions in AIChE and its CAST division,

The PSE group is involved in a number of research interactions with other Carnegie Mellon departments and centers, as well as numerous interactions and research collaborations with prominent universities around the world. Furthermore, our research is heavily integrated with the activities of the Center for Advanced Process Decision-making (see pg. 42), and our students enjoy the opportunity to present their work and meet with the industrial researchers during regular review meetings and workshops. These interactions also facilitate opportunities for our graduate students to engage in summer industrial internships, and generally make them attractive candidates for placement after graduation. Several of our students have taken academic positions at world-renowned institutions (e.g., Georgia Tech, Imperial College, McMaster University, Northwestern University, Oxford University, Princeton University, Purdue University, University of Edinburgh, University of Wisconsin) or have been employed by companies such as Aspen Technology, AT Kearney, Bank of America, British Petroleum, Chevron, Dow Chemical, ExxonMobil, Facebook, Google, McKinsey & Co., Microsoft Research, Royal Dutch Shell, OSIsoft, United Technologies, and many other companies.

Our vision for PSE: Integrative solutions from the molecular to the enterprise level
Shelley L. Anna p. 10
Lorenz T. Biegler p. 11
Kris Noel Dahl p. 12
Michael M. Domach p. 13
Neil M. Donahue p. 14
Andrew J. Gellman p. 15
Chrysanthos E. Gounaris p. 16
Ignacio E. Grossmann p. 17
Annette M. Jacobson p. 18
Coty Jen p. 19
Myung S. Jhon p. 20
Aditya Khair p. 21
John R. Kitchin p. 22
Spyros N. Pandis p. 23
Todd M. Przybycien p. 24
Alan J. Russell p. 25
Nikolaos V. Sahinidis p. 26
James W. Schneider p. 27
Susana C. Steppan p. 28
Robert D. Tilton p. 29
Zachary W. Ulissi p. 30
Lynn M. Walker p. 31
Kathryn A. Whitehead p. 32
B. Erik Ydstie p. 33

**EMERITUS**
Dennis C. Prieve p. 34
Paul J. Sides p. 35
Arthur W. Westerberg p. 35
Professor Anna's research interests are in the areas of interfacial fluid mechanics and transport in multiphase fluids. Prof. Anna is an experimentalist who devises innovative methods to probe and control fluid interfaces. Beyond empirical observations, she also uses scaling analysis, theory and numerics to separate intertwined and competing contributions to interfacial and bulk flow behavior.

Fluid interfaces are ubiquitous in chemical engineering processes and everyday life, arising in food and consumer product production, respiration, cloud formation and oil spill mitigation. The entangled nature of phenomena in these processes often hinders determination of their relative contributions and prevents estimation of relevant process parameters. Lack of relevant parameters hinders translation of new technology to industrial application by preventing accurate design and optimization of processes.

Professor Anna has made a number of important contributions that use microscale geometries to interpret fluid interfacial phenomena. For example, she developed a microtensiometer that has enabled the quantification of interfacial transport and mechanics, facilitating independent, reliable determination of previously inaccessible parameters. She has also contributed to the emerging field of droplet microfluidics via new methods of generating droplets and bubbles with controlled size, interfacial composition, and shape, enabling previously unimagined applications in biological and chemical analysis.

Prof. Anna initially developed the microtensiometer (in collaboration with Lynn Walker) to access kinetic constants for surfactant-oil-water systems by measuring interfacial tension of spherical interfaces. Kinetics controls numerous high-speed emulsification and spray processes, but reliable parameters are largely unavailable. Conventional diffusion-limited analyses do not correctly account for interface curvature, yielding unphysical diffusivities and kinetic constants. Recognizing that smaller bubbles could be used to separate diffusion and kinetic timescales, Prof. Anna developed a new scaling analysis for diffusion in spherical geometries, and devised an elegant method to determine whether experiments are diffusion or kinetic controlled. Her analysis connects two previously recognized limits, allowing curvature to be accounted for at intermediate radii where many experiments operate. Her group conducted the first reliable measurements of kinetic constants for surfactant-oil-water systems. Beyond surfactants, her analyses of oscillating microtensiometer bubbles enabled the decoupling of thermodynamic and mechanical contributions to the dilational interfacial modulus. This analysis allowed her to demonstrate that particle-laden interfaces exhibit significant extra stresses that profoundly impact the stability of foams and emulsions. The microtensiometer has garnered significant interest from academics and industry for its broad uses to characterize interfacial behavior.

Professor Anna is also a leader in droplet-based microfluidics. One of her seminal contributions to this field is a method of continuously producing uniform submicron droplets via “tipstreaming,” a microscale fluid dynamical phenomenon. She showed that tipstreaming occurs when convection and adsorption kinetics timescales are comparable. This observation allows control of the process and was made possible in part by microtensiometer measurements of the kinetic constants. More recently, Prof. Anna has applied similar transport principles to the production of persistent non-spherical microbubbles, which do not relax to equilibrium spherical shapes due to densely packed particle-coated surfaces. Prof. Anna's most recent work focuses on using droplets to control concentration phenomena in complex fluids including phase separation, partitioning and crystallization.
Professor Biegler’s research centers on concepts, algorithms and applications of optimization and numerical methods for process design, analysis, operations and control.

Advanced algorithms for process simulation, optimization and sensitivity analysis. The focus is on the development of numerical methods for simulation and optimization of challenging process applications. This work includes the development of interior point and active set algorithms for nonlinear programming and nonlinear complementarity problems, as well as efficient decomposition strategies for these problems. These algorithms form the core solvers for many areas in process design, control and operations. Emphasis is on efficient methods for large-scale optimization problems that arise in chemical engineering applications and energy systems.

Development of large-scale nonlinear programming methods for optimization of systems of differential and algebraic equations (DAEs). Projects include analysis of stability and accuracy for approximate DAE solutions, algorithms for optimal control problems and methods for large-scale nonlinear programming. These problem types are addressed through large-scale nonlinear programming formulations that can be solved efficiently for large-scale systems. Applications include batch processes, fuel cells, complex dynamic separations, biological fermentations and polymerization reactors.

Real-time algorithms for nonlinear estimation, control and optimization. These methods include the application of maximum likelihood and optimization concepts for parameter estimation, data reconciliation and gross error detection for steady and dynamic problems. In addition, supported by stability analysis for nonlinear dynamic models and based on fast sensitivity-based decompositions, efficient optimization strategies are being implemented for nonlinear control and real-time optimization, and demonstrated on large-scale chemical and energy processes.

Design and optimization of multi-scale processes. Multi-scale optimization strategies address the incorporation of complex models drawn from computational fluid dynamics, molecular modeling and multi-phase distributed systems within an integrated system and aided by reduced order models. A key goal is convergence to the rigorous optimum in computationally efficient ways. Applications include periodic adsorption processes such as pressure swing adsorption, simulated moving beds, power plants with embedded CFD models and complex polymer processes.

LORENZ T. BIEGLER
BAYER UNIVERSITY PROFESSOR AND HEAD
biegler@cmu.edu

RECOGNITION

Lectureship Award for Outstanding Achievement in Chemical Engineering Fundamentals, Chemical Engineering Division, American Society of Engineering Education, 2017
Qiushi Visiting Professorship, Department of Control Science and Engineering, Zhejiang University, Hangzhou, China, 2015
William H. Walker Award for Excellence in Contributions to Chemical Engineering Literature, AIChE, 2015
Fellow, Society of Industrial and Applied Mathematics (SIAM), 2014
Member, National Academy of Engineering, 2013
Honorary Doctorate of Engineering Sciences (Dr.-Ing. E.h.), Technische Universität Berlin, January, 2013
Nordic Process Control Award, Copenhagen, 2012

PUBLICATIONS

Recognitions
Max Planck Institute Science of Light, Societas Physico-Medica Presentation, 2016
National Science Foundation CAREER Award, 2010
Young Investigator Award Gold from the World Congress of Biomechanics, 2010
Ruth L. Kirchstein National Research Service Award: Post-doctoral research fellowship from the NIH, 2004

Publications

Professor Dahl uses rheological, biophysical and optical techniques to understand the structure and organization of the cell nucleus.

Diseases of the nuclear lamina. Many diseases result from the loss or mutation of lamins and other structural proteins at the nuclear envelope and in the nuclear interior. Prof. Dahl's studies compare normal cells with cells in which structural proteins are either chronically absent or rapidly down-regulated (as by RNAi-mediated gene silencing). These studies reveal the adaptations made by nuclei to altered mechanostuctural environments in order to restore function.

Stem cell differentiation and cancer progression. Nuclear shape and chromosome positioning change dramatically during stem cell differentiation and cancer progression. Fluorescence techniques are being combined with quantitative biophysics to track recruitment of transcription factors or cell cycle regulators to differentiation specific or cancer-specific genes while cells or nuclei are under well-defined imposed forces.

Mechanotransduction. Mechanotransduction allows cells to sense mechanical forces and adapt by changing gene expression. In 2010 Prof. Dahl received an NSF CAREER Award to work on the hypothesis that mechanical force reorganizes the nucleus and thereby regulates gene expression.

HeLa cells overexpressing GFP-spectrin and labeled for emerin (red) and DNA (blue) show enhanced spectrin at the nuclear envelope. Nucleoskeletal spectrins are responsible for a balance of mechanical forces and resilience after deformation.
Professor Domach studies fundamental and applied aspects of biomedical engineering to metabolic engineering and cell biology. He concentrates on cellular processes, cell physiology/energetics, enzymology and novel biomedical devices.

**DNA products.** Through a collaboration at the University of Pittsburgh, we strive to create engineered production platforms that produce very large quantities of vaccine-grade, plasmid DNA. This work entails redesigning plasmid vectors as well as host strains. Also pursued are assessing the impact of producing large amounts of DNA via proteomics and other methods in order to develop additional cell engineering insights. Finally, process level work is explored such as boosting titer by metabolically consuming the selection agent at end of the fermentation.

**Cellular processes.** The goal is to understand the behavior of cells in bioreactors and, thus, reactor performance in terms of biochemical reaction and control mechanisms. Current work entails developing in situ NMR and fluorescent spectroscopic methods for observing intracellular reaction processes. Coupling the experimental investigations to mathematical model development also is a key component of this work.

**ReCOGNITION**

Editor-in-Chief of Biotechnology Progress  
Fellow, American Institute of Biological and Medical Engineers  
Presidential Young Investigator Award

**PUBLICATIONS**


Research in Professor Donahue’s laboratory focuses on three interrelated topics: the oxidation pathways of reduced compounds throughout the atmosphere, measurement of atmospheric compounds, including free radicals and stable molecules, and the fundamental quantum mechanics and dynamics controlling reactivity and causing variation in reactivity among related chemical systems. Special attention is paid to reactions causing phase changes (condensation and nucleation).

Atmospheric Oxidation Mechanisms. Reduced compounds react in the atmosphere with oxidants including hydroxyl (OH), ozone (O₃) and nitrate (NO₃). Their oxidation products include oxygenated organics (aldehydes, ketones, peroxides, organic acids, carbon monoxide and carbon dioxide), ozone and organic aerosols. Prof. Donahue’s students observe the mechanisms connecting these reactants and products by initiating the oxidation in flow tubes and smog chambers. The time scale of flow-tube experiments permits observation of mechanisms step-by-step while studying interactions typical of the real atmosphere. This chemistry in the CMU smog chambers occurs over longer timescales (minutes to hours), allowing observation and constraint of secondary aerosol formation as well as the chemical processing of condensed-phase organics by gas-phase oxidants. Collaborative experiments in the CLOUD experiment at CERN permit observation of particle nucleation under extremely clean and precisely controlled conditions. The broad objective is to understand how oxidation mechanisms and their products, including ozone and aerosols, change with changing atmospheric composition.

Fundamental Reactivity. Chemical reactivity can evolve dramatically among a series of related reactions. Reactivity can differ by a factor of a million or more, and similar reactions can have qualitatively different reaction products. This has profound consequences for atmospheric chemistry, combustion and all other systems involving complex mechanisms. It also indicates that observation without fundamental understanding is dangerous. A major objective of our work is to understand the fundamental quantum mechanics and reaction dynamics describing this evolution.

Organic Phase Partitioning. We are developing methods to treat the coupled oxidation chemistry and mixing thermodynamics that control the levels and properties of organic particulate matter in Earth’s atmosphere. Organic aerosol consists of millions of individual compounds, many of them uncharacterized, but we are able to identify key bulk properties of the particulate organic phase and then describe the dynamics and solution thermodynamics in terms of these measurable properties.
Professor Gellman’s group uses a wide variety of experimental methods to study surface chemical processes such as the bonding of molecules to metal surfaces, surface structure, reaction kinetics, adsorption and catalysis.

Prof. Gellman’s group investigates fundamental problems in heterogeneous catalysis and surface chemistry using the experimental methods of surface science. A primary focus area is the enantioselective surface chemistry of chiral metal surfaces. Because most pharmaceuticals are chiral, enantioselective chemical processing is the key challenge to preparation of the vast majority of pharmaceuticals. Gellman was the first to realize that single crystal metal surfaces can be chiral, in spite of the fact that the bulk structures of metals are always achiral. His group pioneered efforts worldwide to study and understand enantioselectivity of reactions on naturally chiral metal surfaces.

Recent efforts have developed high throughput methods for study of surface and materials science. These are rapidly accelerating the study of alloy surface chemistry and structure sensitive surface chemistry. Gellman’s group has developed tools for the preparation and characterization of Composition Spread Alloy Films (CSAFs), thin film alloy libraries that contain all possible compositions of alloys such as PdxCuyAu1-x-y (x = 0 g 1, y = 0 g 1-x) in the space of 1 cm2 (Figure). In addition, his group has developed a unique, 100-channel microreactor array for parallel measurement of catalytic reaction kinetics at 100 different alloy compositions across a CSAF. Gellman’s group is also developing the use of Surface Structure Spread Single Crystals (S4Cs) which expose single crystal surfaces of all possible orientations on one 1 cm2 sample. These high throughput methods will increase by a couple of orders of magnitude the rate at which one can study the effects of alloy composition and surface structure on catalytic surface chemistry.

Left panel: Illustration of a Composition Spread Alloy Film prepared such that the interior of the triangle contains all possible composition of a ternary alloy A,B,C1-x-y. The edge regions span the three binary alloy composition spaces and the vertex regions are pure component films. Right panel: Photograph of a CuAuPd CASF.

ANDREW J. GELLMAN

LORD PROFESSOR OF CHEMICAL ENGINEERING, CHEMISTRY (COURTESY), MATERIALS SCIENCE AND ENGINEERING (COURTESY)
CO-DIRECTOR OF THE WILTON E. SCOTT INSTITUTE FOR ENERGY INNOVATION
gellman@cmu.edu
www.cmu.edu/cheme/people/faculty/andrew-gellman.html

RECOGNITION

AVS Fellow, American Vacuum Society, 2012
ACS Fellow, American Chemical Society, 2011
Ipatieff Prize, American Chemical Society, 1998
Alfred P. Sloan Research Fellow, A.P. Sloan Foundation, 1991-1993

PUBLICATIONS

M.A. Payne, J.B. Miller, A.J. Gellman, “High-Throughput Screening Across Quaternary Alloy Composition Space: Oxidation of (AlxFeyNi1-x-y)~0.8Cr~0.2” ACS Combinatorial Chemistry 18(9), (2016), 559–568 (10.1021/acscmbcs.6b00047)
Research in the Gounaris group contemplates the development of theory, quantitative methodologies and software implementations to address problems of industrial and scientific interest that involve complex decision-making. The research pertains to a wide spectrum of application areas, ranging from how process industries conduct their operations in a lean and efficient manner to how advanced materials are synthesized for optimal performance to how utility networks are developed in ways that minimize overall energy consumption.

Process Operations. Many decision problems arise in the context of managing a process industrial enterprise. Typically, these problems involve the selection of the best investments (e.g., selecting the site to build a new plant) or the reduction of variable costs (e.g., minimizing energy consumption during production, optimizing supply-chain operations). The group develops mathematical models and associated optimization algorithms to address questions of this nature. Example areas of focus include production scheduling and the distribution of finished goods, interim products and raw materials. From a methodological perspective, the focus is on both exact and metaheuristic algorithms, including innovative hybrid schemes that exploit the strengths of both approaches, while significant effort is spent on addressing the effect of operational uncertainty so as to enable rigorous risk management in these contexts.

Materials Design. The technological explosion in Materials Science has set the stage with a number of interesting decision-making problems. The continuous discovery of new materials as well as the compilation of large computer-generated databases of hypothetical structures has created the need for computational tools that can quickly screen the various options and match materials to processes. At the same time, advances in our ability to fabricate materials with finely-tuned microstructures has created the need for rigorous design tools to select the specific microstructures that maximize material performance. The group focuses on developing accurate correlations between the structure of materials and their functionality and stability in an application setting, as well as on how to effectively use these correlations in designing optimal structures and the processes to fabricate them. Material classes of interest include microporous materials, which are used abundantly in the process industry as adsorbents and membranes, as well as metallic and metal-oxide surfaces and nanoparticles for use in various catalysis, chemical looping, semiconductor and optics applications.

Networks Optimization. Large and complex networks arise in a multitude of fields; from cell metabolism and epidemiology to traffic management and the internet, to name but a few. Understanding network behavior via detailed mathematical modeling and simulation has traditionally helped us elucidate how a network’s structure affects its performance. However, little work has been done in identifying the very network topologies that shall enable the network to behave in a most desirable manner. To further compound the complexity of the task, at the time a network is designed there usually exists significant uncertainty about how the network shall be operated in practice. In this context, the group develops rigorous quantitative techniques to design networks that exhibit satisfactory performance across the envelope of expected operational conditions. Applications of interest include the design of optimal pipeline networks that retain their economic viability and environmental sustainability over a wide range of potential demand profiles and over their operational lifetime, as well as the generation of small “in-silico” model networks that mimic the behavior of large existing networks (e.g., the U.S. electricity grid) in order to aid us in studying the latter.
The goal of Professor Grossmann’s work is to develop novel mathematical programming models and techniques for a variety of problems in process systems engineering.

Logic-based and Global Optimization. New modeling and solution methods are being developed for linear and nonlinear discrete-continuous optimization problems. These are based on generalized disjunctive programming in which equations and symbolic logic relations are formulated as part of the optimization problem. Based on recent connections with disjunctive programming theory by Balas, new convex mixed-integer nonlinear programming reformulations based on a hierarchy of relaxations are being investigated that exhibit tighter relaxations. These ideas are being translated into algorithms for automatic reformulation and for cutting plane algorithms. Global optimization techniques are also being investigated that exploit the mathematical structure of disjunctions of nonconvex functions.

Optimization of Water, Process and Shale Gas Production Systems. Models and solution techniques based on mixed-integer nonlinear programming are being developed for the synthesis of integrated process water networks, superstructures of process flowsheets and energy systems and design of biofuel processes. For process flowsheets, effective global optimization techniques are being investigated. The strategic design of infrastructure, drilling operations and water management for shale gas production is being addressed. In addition, we are addressing the optimal long-term planning of electric power systems involving fossil and renewable sources of energy.

Planning, Scheduling and Enterprise-wide Optimization. Mixed-integer and disjunctive optimization models and solution techniques are being developed for the planning and scheduling of batch and continuous process systems, as well as for supply chain optimization of process networks. Major applications include production and distribution of industrial gases, design and planning of supply chains, inventory management and reliability of process systems. The handling of uncertainties and disruptions is being handled through novel multistage stochastic optimization methods, which involve decomposition methods based on Lagrangean relaxation, Benders decomposition and bi-level decomposition.

Recognition

ETH Zürich Chemical Engineering Medal, 2017
Hougen Lectureship, University of Wisconsin, Madison, 2017
Honorary Doctor, Kazan National Research Technological University, Kazan, Russia, 2016
Doctor Honoris Causa, Universidad de Cantabria, Santander, Spain, 2016
One of the Most Influential Scientific Minds, Thompson Reuters, 2015
Chemical Engineering Division’s Lectureship Award, ASEE, Seattle, 2015
Sargent Medal, Institution of Chemical Engineers, U.K., 2015

Publications

ANNETTE MOFF JACOBSON

TEACHING PROFESSOR OF CHEMICAL ENGINEERING
DIRECTOR COLLOIDS, POLYMERS, AND SURFACES PROGRAM
ASSOCIATE DEAN OF UNDERGRADUATE STUDIES
jacobson@cmu.edu
www.cmu.edu/cheme/people/faculty/annette-jacobson.html

RECOGNITION

Academic Advising Award, Carnegie Mellon University, 2003

PUBLICATIONS


Research Interests: Surfactant micellization, solubilization and adsorption phenomena; polymer and colloid characterization.

Colloids, Polymers and Surfaces (CPS) Program. Professor Jacobson is director of the CPS Program, an interdisciplinary educational program providing coursework and an M.S. degree in the study and applications of nanoparticles, macromolecules, interfaces and the complex fluids formed by these materials. The program includes the PPG Industries CPS Laboratory, a facility used for teaching and research for graduate and undergraduate students. The laboratory houses equipment for conducting more than 30 experiments for the physical characterization of nanomaterials, polymers and complex fluids. CPS staff provide extensive training for student researchers in the use of equipment.

The educational mission of the program includes sponsorship of annual outreach events for K-12 educators and students to support and promote STEM education and careers. A key goal of the program involves the creation and dissemination of innovative curricula about consumer product manufacture of complex fluids to engage K-12 students, with a specific focus on hands-on experience for the student.

Solubilization Phenomena. Solubilization is the incorporation of compounds into the aqueous phase in excess of their water solubility, accomplished through the formation of aqueous micelles of surfactant. Characterizations of these materials include the measurement of critical micelle concentrations by a number of techniques including dye solubilization, surface tension, light scattering and conductivity measurements.

Colloid and Polymer Characterization. Colloidal characterization methods include for example microelectrophoresis, surface area analysis and particle sizing. Polymer characterization is accomplished through measurement of thermal, rheometric and mechanical properties as well as light scattering for molecular weight and size.
Professor Coty Jen examines the life cycle of aerosol particles in the atmosphere and how these particles ultimately affect air quality and the environment. Specifically, she researches how gaseous compounds emitted from various sources react to form and grow aerosol particles in the atmosphere.

**Development of Nanoparticle Instrumentation.** Freshly nucleated atmospheric aerosol particles are ~1 nm in diameter, consist of several molecules clustered together and exist in parts per quadrillion level concentrations. Prof. Jen is developing new instrumentation to measure the chemical composition and concentration of these nanoparticles in the atmosphere. These instruments include chemical ionization mass spectrometers and high-resolution particle sizers/counters.

**Chemical Reactions behind Atmospheric Nucleation and Growth.** Prof. Jen has conducted field measurements to determine which compounds are responsible for atmospheric nucleation, the process that produces the majority of seed particles for cloud formation. Specifically, she has studied how sulfuric acid, the product from SO2 emissions, and amines react to form and grow particles. She has developed a heuristic model to predict nucleation rates that can be generalized to more complex mixtures such as the atmosphere.

**Organic Nitrogen Speciation.** Biological processes, like decomposition of proteins, emit organic nitrogen compounds (e.g., amines and amides). These compounds have previously been shown to adversely affect human health and the environment. Prof. Jen’s research has shown that these compounds are prevalent in the atmosphere at concentrations high enough to not only participate in nucleation but also other aerosol chemistry. She is now working to develop the tools to speciate organic nitrogen compounds in aerosols and map out their chemical reactions in the atmosphere.

**Recognition**

National Science Foundation AGS Postdoctoral Fellowship Award, 2015
UMN Best Dissertation Honorable Mention, 2016
University of Minnesota Doctoral Dissertation Fellowship, 2014
National Science Foundation Graduate Research Fellowship, 2011
Achievement Rewards for College Scientists Scholarship, 2010

**Publications**


C. N. Jen, J. Zhao, P. H. McMurry, D. R. Hanson, “Chemical Ionization of Cluster Formed from Sulfuric Acid and Dimethylamine or Diamine,” Atmos. Chem. Phys., 16, 12513–12529 (2016)


RECOGNITION

Guest Editor, Journal of Nanoparticle Research, 2013

Founding Organizer, U.S.-Korea Forums on Nanotechnology, 2003-present

World Class University Visiting Professorship, Sungkyunkwan University, Korea, 2008-2013

Fellow, Korea Academy of Science and Technology, 2004-present

PUBLICATIONS


Professor Jhon’s research focuses on the fundamentals in engineering science and their application to the state-of-the-art engineering problems. He is particularly interested in the convergence of nanotechnology to manufacturing and sustainability areas.

Prof. Jhon developed novel mathematical models to understand the macroscopic properties in complex engineering systems from first principles using a multiscale framework (combining atomistic, molecular, mesoscale and continuum approaches), via integration of broad range of time and length scale processes across multiphysical phenomena in a parallel computing scheme. His main research objective is to develop an optimized holistic multiscale model using state-of-the-art modeling tools.

Prof. Jhon is investigating mechanical and reliability issues in information storage devices at the Data Storage Systems Center (DSSC). Mathematical software suitable for designing next-generation drives, including heat assisted magnetic recording, is being developed in collaboration with industrial partners at the DSSC. Transport processes of oligomeric films in nanoscale confined geometries are investigated. Experimental and theoretical studies on nanotribology, nanorheology and nanomechanics are being performed.

In conjunction with the Institute for Complex Engineered Systems (ICES), he is pioneering the modeling of nanoscale devices and graphene and graphene oxide materials, which is extremely important for the next generation silicon-on-insulator transistors and sensors.

He is exploring the design and manufacturing of deposition equipment for organic light-emitting devices, large area scanning atomic force microscopes as well as chemical mechanical planarization equipment, which is used extensively in the semiconductor device manufacturing industry.

Prof. Jhon is also interested in traditional engineering disciplines including fluid mechanics, polymer and suspension rheology, interfacial dynamics, turbulent drag reduction, transport in porous media and statistical mechanics. He is developing a unified theory descriptive of yield stress for electrorheological (ER) & giant ER fluids and magnetorheological fluids by combining both polarization and conduction models. In addition, he is examining rheological properties of complex fluid systems including perfluoropolyethers, polymer/clay nanocomposites and polymer/carbon nanotube composites. He is constructing a novel mesoscale model for thermo-capillary and thermo-osmosis phenomena which are key design factors for better performance in polymer electrolyte membrane fuel cells.

He is investigating the superior thermo-mechanical properties of large graphene sheets and novel atomic layer etching methodologies that are used in a variety of applications in transistors, energy storage and high strength composite materials. He is also developing multiscale models in lithium ion batteries to develop composite cathode materials used for next generation storage devices with high capacity.

Prof. Jhon is further developing new research projects on nano-convergent technologies that are critically important to human interface systems as well as policy studies in nanotechnology, green energy, defense and remanufacturing areas.
Professor Khair uses the tools of modern applied mathematics and engineering sciences — scaling theory, asymptotic analysis and numerical computations — to investigate problems in fluid dynamics, colloid science, electrochemistry and electrokinetics.

The research in Prof. Khair’s group covers a broad array of topics, from charge transport in organic electronics to the fluid mechanics of swimming organisms. However, the unifying philosophy of Prof. Khair’s work is to rigorously quantify the dynamics of a physical phenomenon, with the aim of leveraging the knowledge gained for novel technologies and applications. The latter is aided through close collaboration with experimentalists. Vignettes of selected projects are below.

**Electrophoresis of Colloidal Particles.** Current work involves prediction of the phoretic drift of colloidal particles under electric fields in concentrated electrolytes and ionic liquids, which is of relevance to energy storage and transport in high salt media.

**Nonlinear Viscoelasticity of Complex Fluids.** Current work involves analyzing the dynamics of complex fluids (e.g., colloidal dispersions and polymer solutions) under large-amplitude, time-dependent flows.

**Swimming Across Reynolds Numbers.** Current work involves quantifying the locomotion of self-propelled organisms across a range of length scales, and the impact thereof on mixing by suspensions of swimmers.

**Stress dynamics of a colloidal suspension of slightly nonspherical colloidal particles under a large-amplitude oscillatory shear flow, from ref. 4.**
Professor Kitchin's research group uses computation to study chemical reactions on metal alloy and oxide surfaces.

Professor Kitchin has been investigating how mixtures of metals, also known as alloys, can be better at catalyzing chemical reactions than pure metals. His group uses quantum chemical calculations to model alloy surfaces and to relate their electronic and crystal structures to their reactivity. An outstanding challenge in the field has been how to model these materials across the entire composition and structure space. The lattice constants, crystal structures and reactivities of alloys depend on their composition. Prof. Kitchin's group has developed new approaches to approximate these dependencies, enabling the simulation of alloy catalyst surfaces across composition space under reaction conditions. This approach enables one to design and optimize alloy catalysts for specific reaction conditions.

Many catalyst properties that we are interested in require tens of thousands of calculations to be performed. Typical molecular force fields are not sufficiently accurate to use for simulating chemical reactions on surfaces, but quantum chemical calculations are too expensive to use directly for these kinds of simulations. Prof. Kitchin's group is using quantum chemical calculations to train neural networks for these simulations. His group then uses the trained networks to efficiently perform molecular dynamics and Monte Carlo simulations with the underlying accuracy of the quantum chemical calculations. This allows us to simulate dynamic properties such as diffusion, and reactions, as well as properties like alloy segregation. This work is an essential step to expanding the utility of quantum chemical calculations to larger systems and longer time scales in a broad range of applications.
Professor Pandis’s research areas include the study of multiphase atmospheric chemistry as it relates to photochemical smog and acid deposition, as well as topics related to global climate change.

Control strategies for atmospheric ozone, particulate matter and acidity air pollution problems have been traditionally treated separately from each other, often resulting in suboptimal choices of emission control strategies. The air pollution group is developing comprehensive mathematical models describing the interplay of pollutant emissions, atmospheric homogeneous and heterogeneous chemistry, dispersion and removal processes leading to major air pollution problems. After evaluation against observations, these tools are used for the identification of cost-effective emission controls for the reduction of damages caused by multiple pollutants.

**Atmospheric Chemistry and Global Climate Change.** The interactions between the anthropogenic perturbations of the atmospheric chemical composition and climate are investigated in a number of projects. These include studies of the role of atmospheric aerosols in the earth’s radiative balance, changes in the oxidative capacity of the atmosphere, the anthropogenic perturbations in the remote marine atmosphere and the long-range transport of atmospheric trace components.

**Properties of Atmospheric Aerosols.** The partitioning of semivolatile atmospheric aerosol components between the gas and particulate phases is investigated. The role of the organic aerosol components in the ability of atmospheric particles to absorb water is a major focus of this research.

**Air Quality and Climate Change.** The interactions between climate and anthropogenic perturbations of atmospheric chemical composition are investigated in a number of projects. These include studies of the role of atmospheric aerosols in the earth’s radiative balance, changes in the oxidative capacity of the atmosphere, the anthropogenic perturbations in the remote marine atmosphere and the long-range transport of atmospheric trace components. We are developing a comprehensive modeling system that can describe air quality and climate at the global scale, but also at the regional and urban scales. This system is used to address questions about the changes in air quality and the emission control strategies that can both improve local air quality and help reduce climate change.

---

**SPYROS N. PANDIS**

RESEARCH PROFESSOR OF CHEMICAL ENGINEERING AND ENGINEERING & PUBLIC POLICY
spyros@andrew.cmu.edu
www.cmu.edu/cheme/people/faculty/spyros-pandis.html

---

**RECOGNITION**

American Institute of Chemical Engineers, Lawrence K. Cecil Award, 2016
American Association for Aerosol Research, David Sinclair Award, 2016
Thomson Reuters Highly Cited Researcher, 2014
Fellow, American Association for Aerosol Research, 2012
European Research Council, Advanced Investigator IDEAS Award, 2011
Book of the Year, American Meteorological Society, 2006

**PUBLICATIONS**


Professor Przybycien's group focuses on research questions in the areas of bioprocessing, applied biophysics, drug delivery and biosensing. A common theme is the application of optical, spectroscopic and simulation tools to connect molecular-level behavior to engineering-level system design and operation spaces.

**Bioprocessing.** Work in this area deals with systems, processes and fundamental molecular phenomena associated with the purification, formulation and storage of recombinant proteins and other biologics generated by the biotechnology industry. Current topics include the use of PEGylation technology to enhance the performance of affinity chromatography media, the development of new platform downstream processes for high titer recombinant proteins based on continuous precipitation, the propagation of process variance in downstream processing operations and the incorporation of process analytical and systems engineering tools into the design and operation of continuous downstream processes.

**Applied Biophysics.** This area is based on fundamental studies of protein adsorption, aggregation and denaturation phenomena. Current topics include the determination of the morphology of protein-polymer conjugates including PEGylated proteins and the adsorption of proteins on sand for water purification applications (both in collaboration with Prof. Tilton).

**Drug Delivery.** Here the emphasis is on using molecular-level insights to improve drug-based therapies. Current topics include enhancing spreading, mucolysis and antimicrobial activity in pulmonary drug delivery by incorporating surfactants into liquid and solid aerosol formulations (a collaboration with Profs. Tilton and Garoff as well as faculty at the University of Pittsburgh School of Medicine).

**Biosensors.** Current topics include the development of a hand-held tissue reflectance spectrometer for the detection of incipient pressure ulcers regardless of skin pigmentation and the modeling of light propagation in skin.
The goal of our work is to harness the power of biology to solve important problems of global significance by exploiting the rich interface between chemical, biological and material sciences to build multifunctional materials.

Polymer-Enhanced Biomacromolecular Systems. Our Center for Polymer-Based Protein Engineering at CMU works to advance the science of how to rationally tailor the structure-function-dynamics of proteins and enzymes through biomolecule-polymer hybrid synthesis. Using atom-transfer radical polymerization, we are working to develop protein-polymer conjugates with predictably tuned activity under diverse operational conditions. In full partnership with Professor Krzysztof Matyjaszewski, we collaborate with many faculty at CMU and beyond in this rapidly emerging field. The great diversity of both polymer and protein structure and functionality are used to produce protein-polymer conjugates that have utility in bio-therapeutics proteomic analysis, bioenergy, protein structural analysis, molecular detection, cancer therapy and industrial catalysis.

Enzymatic Biosensors and Biofuel Cells. We are working to develop an increased understanding of enzymatic biosensors and biofuel cells through a combination of enzyme modification and materials science approaches. Biofuel cells have the potential for continuous powering of implantable devices, while biosensors can be used to sensitively and selectively detect target substances in physiological or industrial applications. We are using carbon nanotube-based materials and polymer-based protein engineering methodologies to modify the activity, stability and electron transfer efficiency of electroactive enzymes. Development of these enzyme-polymer conjugates and enzyme-modified surfaces with tailorable characteristics has the capability to help promote enzyme-based bioelectronics with enhanced performances.

Membrane Engineering of Red Blood Cells. We are combining polymer-based protein engineering with polymer modification of cell surfaces to convert red blood cells into therapeutic delivery vehicles. We have developed a platform technology that can either target drug-loaded red blood cells to specific sites or convert them into specific toxin or bimolecular scavengers. We are also exploring how protein-cored nanoparticulate antimicrobials can be carried on erythrocyte surfaces as a treatment for sepsis.

RECOGNITION
Honorary Professor, Nanjing Tech University, 2017
ESWP President's Award for Engineering Excellence, 2014
Founding International Fellow, TERMIS, 2012
TERMIS Lifetime Achievement Award, 2012
Ladies Hospital Aid Society Doctor of Distinction Award, 2011
Carnegie Science Center Award of Excellence in Advanced Materials, 2011
American Institute for Medical and Biological Engineers, Chair, College of Fellows, 2011
American Chemical Society, Pittsburgh Award, 2010
Rolling Stone Top 100 People Who Will Change America, 2009

PUBLICATIONS
Professor Sahinidis’s research interests are at the interface between computer science and operations research, with applications in a variety of engineering and scientific systems.

**Informatics Problems in Chemistry, Biology and Medicine.** With the recent accumulation of vast amounts of chemical, biological and clinical data, many scientific fields are becoming increasingly data-driven as opposed to model-driven. This paradigm shift has brought about many challenging computational problems. Even though these problems originate from very disparate fields, they have very similar mathematical structures. In particular, they involve the use of a merit function to evaluate alternatives from very large, typically combinatorial, search spaces. Prof. Sahinidis’s work in this area provides comprehensive and rigorous solutions to thermodynamic property prediction, inverse imaging problems in X-ray crystallography, modeling and estimation of reaction pathways, structural bioinformatics, medical diagnosis and prognosis, and the design of novel chemicals that are environmentally benign. A recent focus of data-centric work in Prof. Sahinidis’s group has been the ALAMO project, which addresses the problem of discovering algebraic relationships that are hidden in a set of data, an experimental process or a simulation model.

**Optimization Theory, Algorithms and Software.** A plethora of problems in science and engineering require the solution of nonlinear optimization problems with multiple local solutions. Since the early 1990s, Prof. Sahinidis’ research pioneered the development of an all-purpose, rigorous global optimization methodology. His results have included powerful domain reduction strategies, sharp relaxations for nonconvex optimization problems, an entirely linear outer-approximation scheme for global optimization, finite branching schemes for certain continuous optimization problems, and the global optimization software BARON. Scientists and engineers have used BARON in many application areas, including the development of new Runge-Kutta methods for partial differential equations, energy policy making, modeling and design of metabolic processes, product and process design, engineering design and automatic control. The ultimate goal of this research is to provide precise and valuable computational optimization tools that will make possible the solution of problems that are currently considered intractable. Toward this end, current projects pursue fundamental research in convexification, linear and nonlinear optimization, and optimization without algebraic models. While general in purpose, the algorithms are developed and validated through several applications, including critical problems in energy process modeling and optimization.
Professor Schneider uses surfactant self-assembly concepts to design faster, more sensitive DNA and RNA analysis and purification methods along with improved particle stabilization schemes for use in nonpolar liquids. These goals are achieved by the synthesis of biomimetic peptide amphiphiles and development of novel colloidal force measurement techniques.

Rapid, Gel-Free DNA Electrophoresis using Micelle Tags. We have developed a series of electrophoresis techniques that give rise to fast electrophoretic separations. The “micelle-ELFSE” method has nonionic surfactant micelles transiently attached to a 5'-alkyl group on DNA oligomers, retarding their electrophoretic mobility slightly and in a length-dependent way. Micellar self-assembly gives rise to rapid size fluctuations, so that micelle tags provide a highly uniform mobility shift for equal-length oligomers during the run. This ensures that peaks are very sharp as required for high-resolution analytical separations. Micelle-ELFSE gives 10-100x improvements in run time compared to polymer-based systems, and we are working to extend the method to kilobase DNA and in microfluidic systems for ultrafast separations. Applications for micelle-ELFSE include forensic analysis, sequencing, genotyping and DNA stretching.

Plasmid and miRNA Purification using y-Peptide Nucleic Acid Amphiphiles. In collaboration with the Center for Nucleic Acids Science and Technology (CNAST), we have designed libraries of surfactant materials derived from y-peptide nucleic acids (yPNAs). Invented by CNAST faculty, yPNAs are synthetic DNA analogs that bind DNA and RNA targets with great selectivity and stability. When attached to surfactants, yPNAs tag desired sequences for removal by hydrophobically driven separation methods, including various forms of chromatography and electrophoresis. Additionally, the crucial hybridization event occurs in solution, with more favorable kinetics and thermodynamics than encountered when using surface-bound probes, and with minimal interference by contaminants. Current efforts focus on the ultrasensitive isolation of microRNAs from biological samples, with applications in early detection of cancer, and the larger-scale purification of plasmids as required for DNA vaccine development.

Self-Assembly and Charging in Nonpolar Liquids. The low dielectric environment of nonpolar solvents generally prevents the dissociation of ion pairs. In applications where electrical conductivity is required, including display devices and fuel processing and transport, nonpolar solvents can be charged by the addition of surfactants. However, charging mechanisms are not well understood due to a lack of synthetic control over the chemical structure and purity of surfactants. We have created a flexible synthetic scheme to better identify the role of chain architecture and headgroup chemistry on the morphology of micelles formed in nonpolar liquids, and their effectiveness as charging agents. In collaboration with Dennis Prieve and Paul Sides, the extent of charging and the identity of charge carriers are examined using powerful colloidal characterization methods, including total internal reflectance microscopy (TIRM), electrochemical impedance spectroscopy and the ZetaSpin device. We are also using these methods to study surfactant-assisted electrostatic stabilization of particles in nonpolar liquids.

Wetting Dynamics using Atomic Force Microscopy (AFM). The dynamics of liquid film formation play a critical role in enhanced oil recovery methods and many other applications. We have developed new AFM techniques to interrogate the formation and breakage of liquid bridges formed between AFM probes and chemically modified surfaces over millisecond time scales. These techniques are currently applied to study film stabilization using nanoparticles, both as emulsifiers and agents for enhanced oil recovery.

JAMES W. SCHNEIDER

PROFESSOR OF CHEMICAL ENGINEERING

schneider@cmu.edu
www.cmu.edu/cheme/people/faculty/

RECOGNITION

Fellow, American Institute of Medical and Biological Engineering (AIMBE), 2014
Kun Li Award for Excellence in Education, 2012, 2005
Beckman Young Investigator Award, 2002
NSF CAREER Award, 2001

PUBLICATIONS

Structure-Property Relationships; Advanced Characterization of Complex Materials

Advanced characterization of complex materials. Professor Steppan's research interests include the characterization of complex materials and their fundamental structure-property relationships, such as the rheological behavior of dilute polymer solutions and the effect of flow on the molecular conformation of polymer chains. Her extensive industrial experience encompassed the development and physical testing of a wide range of polymeric materials including coatings, elastomers, foams and thermoplastics. Typical materials engineering applications require a balance between chemistry and physical properties. For example, polyurethane elastomers used for skateboard wheels are carefully formulated to result in an optimal blend of hardness, resilience (bounce) and resistance to abrasions and tears with an automotive clear coating, and have outstanding chemical resistance and mechanical properties while exhibiting superb appearance.

Colloids, Polymers and Surfaces (CPS) Program. Prof. Steppan is assistant director and an integral member of the CPS program, an interdisciplinary educational program providing coursework and an M.S. degree in the study and application of nanoparticles, macromolecules, interfaces and the complex systems formed by these materials. The program includes the PPG Industries CPS Laboratory, a facility used for teaching and research for faculty, graduate and undergraduate students.

Recognition

Kun Li Award for Excellence in Education, 2016

Publications


Research in Professor Tilton’s group emphasizes the use of colloid and interface science fundamentals to engineer complex fluid and particulate systems.

**Interfacial Engineering with Nanoparticulate Polymer Brushes.** A polymer brush is an assembly of highly stretched polymer chains anchored at one end. When those chains are anchored to a nanoparticle core of a size comparable to the brush thickness, the structure, called a nanoparticulate polymer brush, provides unique interfacial performance properties. This group has developed these nanomaterials for high efficiency emulsification and boundary lubrication. Ongoing investigations emphasize how the brush structure and composition control their equilibrium and dynamic properties at solid/liquid, liquid/liquid and liquid/vapor interfaces and how these in turn dictate their application performance.

**Colloidal Forces in Polymer/Surfactant Mixtures.** Commercial complex fluid formulations generally take advantage of strong interactions among multiple components to achieve desired performance traits. The forces that act between dispersed colloids are fundamental to complex fluid formulation. This group is investigating complexation of water-soluble polymers and surfactants and how it can be used to manipulate long range structural forces between colloids.

**Potential Nanoparticle Ecotoxicity.** Much uncertainty exists, but the toxicity of certain nanomaterials indicates a potential for some nanoparticles to disrupt ecosystems. The potential impact depends on their interactions with natural materials. This group is investigating nanomaterial interactions with natural organic matter and its effect on microbial toxicity.

**Exploiting Interfacial Transport for Enhanced Drug Delivery.** Patients with obstructive lung disease often suffer from persistent bacterial infections that are inaccessible to aerosolized antibiotics. This group is developing aerosolized surfactant formulations that harness surface tension-driven Marangoni flow to maximize drug spreading over the lung airway surface to treat mucus-sheltered infections. This is aided by studying fundamental Marangoni flow mechanisms at complex fluid interfaces.

---

**ROBERT D. TILTON**

**PROFESSOR OF CHEMICAL ENGINEERING AND BIOMEDICAL ENGINEERING**

tilton@andrew.cmu.edu

www.cmu.edu/cheme/people/faculty/robert-d-tilton.html

---

**RECOGNITION**

Editor, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2017 – present

Fellow of the American Institute for Medical and Biological Engineering, 2013

Fellow of the American Chemical Society, 2010

Chair of the American Chemical Society Division of Colloid and Surface Chemistry, 2008

National Science Foundation CAREER Award, 1996

Victor K. LaMer Award, American Chemical Society Division of Colloid and Surface Chemistry, 1993

---

**PUBLICATIONS**


Professor Ulissi's research focuses on using molecular simulations and systems engineering approaches to understand and design nanoparticle/solution interfaces.

Chemical, mechanical, electronic and thermal properties of materials all change at the nanoscale. Entropic fluctuations become more important and materials confined in 1- or 2-dimensions (tubes, wires, sheets) behave differently. Capturing these effects in real devices and applications requires a range of modeling approaches, from hard theory (DFT and kinetics), to soft theory (continuum, statistical mechanics and molecular dynamics), and up through systems engineering approaches. Applications include biomedical sensors (nanotube-based optical sensors) and energy (CO₂ to fuels, fuel cells, thermal catalysis).

Machine-learning approaches to accelerate materials discovery. Density functional theory (DFT) is the tool of choice for studying reactions on chemical surfaces. However, it is prohibitively expensive to use full-accuracy DFT to identify catalyst surface with optimal properties due to the sheer number of possible materials, facets and active sites. The search process can be greatly accelerated by using flexible surrogate models that learn from previous DFT calculations to predict interesting materials. This process can be accelerated with deep-learning methods from the computer science community. Applications include both thermal and electrochemical catalysis.

High-throughput calculations for materials informatics. Developing new structure-property relationships or machine learning regression methods requires large self-consistent datasets that are rare in literature. We use and develop modern workflow tools like fireworks and luigi to organize, distribute, and analyze many thousands of DFT calculations. These methods drive down the cost of investigating new chemistries and materials while simultaneously making the results accessible and searchable. This approach also allow for online material optimization or active learning approaches to be applied and tested quickly.

Nanoscale selectivity. Interfacial selectivity is central to catalysis and biomedical imaging. Nanoparticles with desirable properties (optical, electronic, catalytic) are often available, but face challenges in complex chemical environments with a variety of analytes or reactants in solution. Restricting access to these surfaces using soft functionalizations (polymers, DNA, surfactants) has been successful in developing selective carbon-nanotube sensors, but designing the selectivity a priori remains a challenge. These properties can be studied using classical molecular simulations and thermodynamic models to study interfacial packing and selectivity at these interfaces.
Behavior of Complex Systems with Fluid-Fluid Interfaces. Fluid-fluid interfaces deform readily in external fields and are sensitive to molecular transport from the bulk. Molecular adsorption to interfaces changes the interfacial tension and constitutive behavior of those interfaces. The response of a system containing fluid-fluid interfaces (emulsions, foams, bubbly liquids) to mechanical or other deformation is dependent on these interfaces. Earlier work on sprays, atomization, microfluidic droplet formation and polymer blends convinced us that there needs to be improved understanding of the details of the interfaces and mechanics. We have been developing devices and approaches to the characterization of complex interfaces and interfaces in contact with complex (i.e., non-Newtonian) bulk phases. Tools include microscopy, device development, soft lithography, and rheology.

Impact of Nanoscale Structure on Rheology. Relatively weak forces at the molecular level dictate the macroscopic properties, particularly the flow properties, of complex fluids. To effectively process and control these fluids, we need to understand the flow-structure relationship for different types of structured fluids and how molecular structure influences this coupling. While the intermolecular forces of importance act over nanometers, the structures formed span nanometers through microns; the timescales associated with response of these structures fall in the range of most processing flows. Work in the group combines rheology with scattering techniques to tackle and quantify the flow-structure coupling. A number of structured fluids have been considered by the group; liquid crystal polymers, polymer blends, surfactant mesophases, wormlike micelles and block copolymers.
The research interests of the Whitehead Lab lie at the interface of chemistry, molecular biology and medicine. The group’s goal is to engineer safe and effective drug delivery systems capable of achieving therapeutic outcomes in biological models and, ultimately, in humans.

Professor Whitehead’s work in drug delivery has two major thrusts: 1) Developing patient-friendly delivery systems for therapeutics that must be administered by injection (e.g., protein drugs like insulin and vaccines), and 2) Engineering nanoparticle delivery systems for gene-based drugs, the “medicines of tomorrow.” Her work in these two areas has garnered broad recognition.

**Oral Delivery of Macromolecular Drugs.** Although oral delivery is the most patient-friendly route of drug administration, it cannot be utilized for proteins and other macromolecules because of their susceptibility to enzymatic degradation in the GI tract and low permeability across the intestinal epithelium. The Whitehead Lab is designing small molecule, polymeric and plant-derived delivery systems that reversibly open up the tight junctions of the small intestine, facilitating high levels of protein bioavailability.

**Nanotechnology for RNA Medicines.** RNA drugs such as messenger RNA (mRNA) and short interfering RNA (siRNA) have the potential to treat every disease in existence via a personalized medicine approach, but only if delivery vehicles can be designed that escort delicate RNA drug molecules into the right organ and cell targets throughout the body. The Whitehead Lab has addressed this challenge through the development of lipid nanoparticles using high throughput approaches. Current efforts focus on understanding how lipid nanoparticle chemistry affects RNA delivery efficacy and on treating several diseases, including inflammatory bowel disease and Non-Hodgkin lymphoma.
Professor Ydstie’s group develops methods for stable and robust control and optimization of chemical processes that combine physical models and online learning.

**Design and control of particulate processes with application to Solar Cell production.** Prof. Ydstie develops models and control strategies for solar grade silicon production. Solar grade silicon is in high demand due to the very rapidly growing interest in using solar cells to generate electricity for domestic uses, telecommunications and distributed power generation in the third world. This investigation is aimed toward design and control of fluidized bed reactors for decomposition of silane.

**Dynamics and Control of Complex Process Networks.** Prof. Ydstie introduced a framework for studying dynamics, distributed control and optimization of complex networks. These networks represent self-organizing structures so that stability and optimality follow as a consequence of how the networks are put together and how they are connected with other networks. The class is sufficiently broad to cover process networks, biochemical networks, reaction networks and supply chains.

The study has led to a decomposition of the business decision-making processes, optional behaviors and decentralized decision making. The formalism of irreversible thermodynamics and the passivity theory of nonlinear control is a basis for this theory.

**RealTime Adaptive Control and Optimization.** Online optimization techniques for constrained and unconstrained optimization using input/ output data are being developed. The aim is to make stand alone optimization modules that gather information by simulation and/or experimentation and adaptively control the process so that over time, the optimizer converges to tile optimal decision maker. The optimizer is based on a method referred to as Q learning which was developed in the area of computer science for optimal control of discrete and continuous Markov decision problems. Prof. Ydstie’s group adapted the method for real-time process control and developed a theoretical foundation for online decision making using adaptive control theory. The advantages of the adaptive methods over other traditional optimization approaches are that it uses current process models to develop policies and that they are self-learning in the sense that they adapt as process conditions change.

**B. ERIK YDSTIE**

PROFESSOR OF CHEMICAL ENGINEERING
PROFESSOR OF ELECTRICAL ENGINEERING (COURTESY)
PROFESSOR OF ELECTRICAL ENGINEERING
AT NUST, TRONDHEIM, NORWAY
ydstie@cmu.edu
www.cmu.edu/cheme/people/faculty/erik-ydstie.html

**RECOGNITION**
Dowd Fellow CIT, 2012
Best Paper Computers and Chemical Engineering, 2012
CAST Award of the AIChE, 2007
13th RWH Sargent Lecture Imperial College, London, 2006
Automatica, Associate Editor, 1993-1999

**PUBLICATIONS**
Although officially retired as of June 30, 2017, Professor Prieve will continue research and writing for the foreseeable future. Currently he has two on-going projects. The first concerns charge effects in nonpolar media which tries to identify charge carriers and how they are formed in highly nonpolar media like alkanes. This work is currently being performed by Ph.D. candidate Keyi Xu, co-advised by Profs. Schneider and Sides. Ultimately, this will lead to understanding how charges are formed at solid/liquid interfaces such as carbon black in motor oil. Surfactants are routinely added to motor oil to suppress sludge formation; electrostatic repulsion between particles has been identified as being important. Other applications include the formulation of complex fluids applied as sprays in agricultural products such as fertilizers or pesticides.

The second project concerns diffusiophoresis in high-salinity environments. Diffusiophoresis is the migration of a colloidal particle that is driven by the gradient in concentration of some molecular-size solute that interacts with the particle. In this case, the solute is an electrolyte like NaCl and the particle is charged in aqueous solutions. The motivation for this came from Dr. Mazen Kanj at Saudi Aramco who asked whether diffusiophoresis might be exploited to transport functionalized nanoparticles into porous rock during enhanced oil recovery. Unlike existing applications (e.g., the Autophoretic® deposition of the primer coat of paint on automobile frames), enhanced oil recovery involves very high salinity (near saturation) where rates of electrokinetic phenomena like diffusiophoresis are expected to vanish. The collaborator on this project is Prof. Aditya Khair.

In addition to publishing results from the above research, Prof. Prieve plans to write a textbook based on his course notes, several of which are available on ResearchGate.net.

RECOGNITION

ACS National Award in Colloid and Surface Science, 2011
President of the International Association of Colloid and Interface Scientists, 2009-2012
Lectureship Award, Division of Colloid and Surface Chemistry, Chemical Society of Japan, 2007
Fellow of the American Institute of Chemical Engineers, 2004
Editor of Colloids and Surfaces A, 1999-present
AIChE Alpha Chi Sigma Award for Chemical Engineering Research, 1995

PUBLICATIONS

Professor Sides became an emeritus faculty member of the Department of Chemical Engineering in July 2017. He is continuing research in collaboration with Professors Dennis Prieve and James Schneider. The subject of the project is electrically charged species in nonpolar liquids. Surfactants added to nonpolar liquids dope them to impart ionic conductivity to the liquid and to charge solid surfaces such as particles or planar solids. Sides and Prieve have pioneered the use of impedance spectroscopy to determine the concentration of charged species and their hydrodynamic radius. Comparison of the size of the charged species to an average size obtained from light scattering measurements has revealed that they are not necessarily the same and perhaps even rarely so.

Prof. Sides will continue to develop the ZetaSpin™ instrument for determination of the zeta potential of solid samples and will focus more attention on his company, ZetaMetrix Inc., spun off from CMU to make and market the instrument. The sample is a disk mounted coaxially on the end of a rotating cylindrical support. The instrument is a convenient method for determination of the zeta potential of planar surfaces, based on the fluid dynamics near a rotating disk. The technique does not suffer from problems of surface conductivity encountered by other methods. Also, the ZetaSpin™ can be used to investigate adsorption of particles or molecules and to determine the zeta potential of porous samples. Recent advancements include determining the zeta potential of porous samples and samples immersed in nonpolar liquids. This instrument is employed at Dow, Applied Materials, Penn State and the University of South Australia, among other sites.

RECOGNITION
Hitachi HIVIP Scholar, 1990
Fulbright Scholar, 1989
Dupont Young Faculty Award, 1981

PUBLICATIONS

Professor Art Westerberg retired in 2004 after an academic career that spanned four decades. His research contributions include algorithms and frameworks for equation-based simulation and optimization, synthesis of energy and separation networks and forerunners of collaborative design and information tools. Also, as Swearingen University Professor, former department head and director of the Engineering Design Research Center, Prof. Westerberg left a lasting legacy of research and leadership that helped define the field of Process Systems Engineering. Moreover, as founder of the ASCEND project, he continues to participate in the development of this advanced modeling platform, along with a worldwide community of collaborators.

RECOGNITION
Warren K Lewis Award, AIChE, 2009
William H. Walker Award, AIChE, 1988
CAST Computers in Chemical Engineering Award, AIChE, 1983

PUBLICATIONS
AWARDS AND HONORS

2017

LORENZ BIEGLER – ASEE Lectureship Award
NEIL DONAHE – ACS Gustavus John Esselen Award
IGNACIO GROSSMANN – ETH Zurich Chemical Engineering Medal
TODD PRZYBYCIEN – Fellow, ACS
ALAN RUSSELL – ESWP President's Award
ROBERT TILTON – Editor, Colloids & Surfaces A: Physicochemical & Engineering Aspects
LYNN WALKER – Fellow, Society of Rheology
KATHRYN WHITEHEAD – Carnegie Science Center Emerging Female Faculty Award

2016

SHELLEY ANNA – Associate Editor, Physical Review Fluids
CHRYSANTHOS GOULARIS – Glover-Klingman Prize
IGNACIO GROSSMANN – ACS, Pittsburgh Award
IGNACIO GROSSMANN – Reuters, World’s Most Influential Minds
IGNACIO GROSSMANN – Honorary Doctor, Kazan National Research Technological University, Russia
IGNACIO GROSSMANN – Doctor Honoris Causa, Universidad de Cantabria, Spain
ADITYA KAHR – Camille Dreyfus Teacher-Scholar Award
SPYROS PANDIS – AIChE Lawrence K. Cecil Award
SPYROS PANDIS – AAAR Sinclair Award
NIKOLAOS SAHINIDIS – HELORS National Award and Gold Medal
SUSANA STEPPAN – Kun Li Award for Excellence in Education
LYNN WALKER – Fellow, AIChE
LYNN WALKER – Editor-in-Chief, Rheologica Acta
LYNN WALKER – Barbara Lazarus Award for Graduate Student and Junior Faculty Mentoring
KATHRYN WHITEHEAD – DARPA Young Faculty Award
KATHRYN WHITEHEAD – Cellular and Molecular Bioengineering Young Innovator

2015

LORENZ BIEGLER – William H. Walker Award for Excellence in Chemical Engineering
LORENZ BIEGLER – Qiushi Visiting Professorship, Zhejiang University, Hangzhou, China
NEIL DONAHE – Thomas Lord Professor of Chemical Engineering, Chemistry, and Engineering and Public Policy
IGNACIO GROSSMANN – Sargent Medal, Institution of Chemical Engineers, UK
IGNACIO GROSSMANN – Constantin Carathéodory Prize
IGNACIO GROSSMANN – American Publisher's Award for Scholarly Excellence
IGNACIO GROSSMANN – ASEE Chemical Engineering Division Lectureship Award
CODY JEN – NSF AGS Postdoctoral Fellowship Award
ADITYA KAHR – Dean's Early Career Fellowship
NIKOLAOS SAHINIDIS – Constantin Carathéodory Prize
LYNN WALKER – Chair, Fluid Mechanics Program, AIChE
LYNN WALKER – AIChE Women's Initiatives Committee Mentorship Award
KATHRYN WHITEHEAD – Popular Science Brilliant 10 Award
KATHRYN WHITEHEAD – Kun Li Award for Excellence in Education

2014

SHELLEY ANNA – Fellow, American Physical Society
NIKOLAOS SAHINIDIS – Fellow, INFORMS
resources

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curricula and Courses of Study</td>
<td>p. 38</td>
</tr>
<tr>
<td>Laboratories</td>
<td>p. 40</td>
</tr>
<tr>
<td>Research Centers</td>
<td>p. 42</td>
</tr>
<tr>
<td>Application Process</td>
<td>p. 44</td>
</tr>
<tr>
<td>Graduate Student Life</td>
<td>p. 45</td>
</tr>
<tr>
<td>Opportunities to Support che@cmu</td>
<td>p. 45</td>
</tr>
</tbody>
</table>
The Department of Chemical Engineering at Carnegie Mellon University grants the doctoral degree and a number of master's level degrees. Ph.D. students are fully supported by fellowships or by the department; however, master's students must have independent sources of financial support.

**PH.D. PROGRAM**

The Ph.D. program cultivates a deep foundation in coursework and leads to the completion of a research-based thesis. The Ph.D. requires years to earn because the student must learn fundamentals, assimilate the current knowledge in a focused area, create new knowledge and communicate that knowledge to peers in a variety of venues. The typical student in the chemical engineering department at Carnegie Mellon University, called Direct Entry, arrives with a B.S. in chemical engineering and emerges 4.7 years later with the Ph.D. degree. Students entering the Ph.D. program with an M.S. degree usually complete the degree in 4 years.

**COURSEWORK**

Direct Entry students take 4 core chemical engineering courses from a menu of six courses: Mathematics, Fluid Mechanics, Thermodynamics, Reaction Engineering, Heat and Mass Transfer, and Process Systems Engineering. Direct Entry students also take 4–5 technical electives offered inside and outside the department. Students entering with an M.S. take 4–6 courses.

**RESEARCH**

Students begin their research during the first year of residence, which commences with the selection of their research advisor before the end of the first semester. The matching of a student with an advisor considers student preferences, faculty availability and project funding. New graduate students meet each faculty member to discuss research projects under way or planned. The student indicates three choices for a thesis advisor. The department head assigns advisors based on the input from students and faculty.

**ASSESSMENTS**

Ph.D. students must pass an oral Qualifying Exam at the end of the first year. Focused on research progress, this test consists of a presentation followed by questions from an exam committee. Ph.D. students must also pass a Ph.D. proposal in the third year of residence; here, the student presents the main themes and methods of their proposed thesis to the student's Thesis Committee. This committee ultimately will hear the defense of the dissertation, the third major assessment and capstone test of the student's readiness to graduate.

**TEACHING ASSISTANT (TA) DUTIES**

All Ph.D. students must participate as teaching assistants for three semesters. The typical expectation is approximately five hours per week during those semesters. The department does not use TA status to close funding gaps. Funding is guaranteed when the student's progress is satisfactory. All Ph.D. students complete the same TA requirements.

**MASTER DEGREE PROGRAMS IN CHEMICAL ENGINEERING**

The master's programs in chemical engineering take advantage of the specialties of Carnegie Mellon University and prepare students with skills and technical depth relevant for a variety of careers. A core curriculum has been developed by the faculty of chemical engineering to prepare students for the types of complex engineering problems faced by today's chemical engineer. The focus is on developing confidence and familiarity with modern engineering tools and applying these to larger and more complex problems than are typically feasible for a B.S. chemical engineering curriculum. Graduates of the master's programs are familiar with numerical methods for solving engineering problems, computational fluid mechanics and transport, process simulation and optimization. Graduates will also have access to the cutting-edge research programs at CMU through project work and graduate-level courses.

The department offers two different degree programs. The **Master of Chemical Engineering (M.Ch.E.)** is a two semester course work degree that is designed to be completed in two academic semesters. The **Master of Science (M.S.) in Chemical Engineering** involves both course work and project work and is designed to be completed in four academic semesters. Both degrees offer technical depth, an opportunity to develop the computational skills that CMU is known for. The M.Ch.E. allows for breadth through additional courses taken while the M.S. provides depth and specialization though an independent project.

The core curriculum is made up of four courses. The core courses are offered each year with focus on technical depth and software aptitude:

- 06-623 Mathematical Modeling of Chemical Engineering Processes
- 06-625 Chemical & Reactive Systems
- 06-663 Analysis & Modeling of Transport Phenomena
- 06-665 Process Systems Modeling

Elective courses are chosen by students in the program to fit their interests and career goals. Sampling the diverse course offerings at a world class research institution is done with the advice of the faculty in chemical engineering.

Students in the M.S. program complete a three semester independent project working closely with a research group in the
department. These projects are designed to provide students with exposure to one of the sub-disciplines of chemical engineering that is a strength of the department. Students are required to prepare a final report of the project work to develop written communication skills.

**M.S. IN COLLOIDS, POLYMERS AND SURFACES (CPS) PROGRAM**

*COURSE REQUIREMENTS FOR THE M.S. CPS DEGREE*

Coursework required for the M.S. in Colloids, Polymers and Surfaces (CPS) is relevant to many industries, as chemical product manufacture and process development often require applications involving complex fluids that include nanoparticles, macromolecules and interfaces. Examples include industries working with nanotechnology, coatings and pigments, pharmaceuticals, surfactant-based products, cosmetics, pulp and paper, ink, food science, environmental science, agricultural products, polymers/advanced materials and biomaterials.

The College of Engineering and Mellon College of Science jointly offer an interdisciplinary M.S. degree in Colloids, Polymers and Surfaces. Students electing this option must complete 96 units including the following minimum coursework:

- 06-705 Advanced Chemical Engineering Thermodynamics, or
- 09-611 Chemical Thermodynamics (mini)/09-603 Math Analysis for Chemistry (mini)
- 06-607 Physical Chemistry of Colloids and Surfaces
- 06-609 Physical Chemistry of Macromolecules
- 39-801 CPS Lab I: Colloids and Surfaces
- 39-802 CPS Lab II: Polymers

Students may elect to do an independent project (and submit a satisfactory written report) and/or other advanced technical electives with approval of the CPS program director to complete the 96 unit minimum requirement.

**M.S. IN ENERGY SCIENCE, TECHNOLOGY AND POLICY**

The College of Engineering offers a Master’s in Energy Science, Technology and Policy program intended for students who seek a master’s program that emphasizes both engineering and a broader perspective in economics and public policy. Students enroll in the program independent of a department but can select a disciplinary concentration within chemical engineering. Requiring 8 - 10 courses to complete, the degree is designed to be finished in one academic year. Students in this program acquire a unique education focused on energy and incorporating strengths from other engineering departments.

For details about the MESTP program, see neon.materials.cmu.edu/energy.
AIR QUALITY LAB

The Air Quality Laboratory supports the Center for Atmospheric Particle Studies with state-of-the-art facilities and equipment. Work modes include both laboratory-scale studies of atmospheric chemistry as well as field campaigns. Equipment can be easily moved from one experiment to another as needs dictate. Facilities include: two 16 cubic meter temperature-controlled smog chambers, three mobile laboratories for field measurements (one with dual 7 cubic meter smog chambers), an aerosol flow reactor and a high-pressure discharge flow reactor. The laboratory houses several pieces of state-of-the-art instrumentation including: two high-resolution aerosol mass spectrometers, a single-particle laser ablation mass spectrometer, two chemical ionization mass spectrometers, a proton transfer reaction mass spectrometer, several scanning mobility particle size spectrometers, two cloud condensation nucleus counters, several thermal denuders for particle volatility measurement, two Fourier transform infrared spectrometers and several gas chromatograph-mass spectrometers.

BIOMOLECULAR ENGINEERING LAB

This facility is well equipped for laboratory scale production/synthesis, manipulation and characterization of biologics ranging from metabolites to recombinant proteins, nucleic acids and cells.

Microbial cell culture capabilities include 1- and 5-liter batch fermenters with monitoring and control of pH and dissolved oxygen and mass-spectroscopy monitoring of fermentation off-gas. A 10-liter incubator shaker is also available. Mammalian cell culture and live cell imaging are available in BSL-2 designated facilities. Separate areas equipped with CO₂ incubators and laminar-flow biosafety hoods are available for recombinant DNA manipulation of cells and for cell-artificial material interaction work. Harvest, isolation and purification capabilities include a 6-liter capacity centrifuge, several ultracentrifuges, a Speed-Vac concentrator, a French press, an Akta Crossflow filtration workstation, Akta Explorer and Prime low-pressure chromatography workstations, a Waters Alliance preparative high pressure chromatography system, a Buchi spray drying system for the controlled production of micron sized powders and a lyophilizer. These capabilities are supported by a large-scale automated autoclave, glass washing equipment, a 4°C cold room, multiple -80°C and -20°C freezers. Linked molecular biology facilities include several PCR thermocyclers and a ViiA 7 real-time PCR system.

Characterization work with cells is supported with a tabletop flow cytometer, a Coulter counter, and three inverted epifluorescence microscopes. The live cell imaging facility includes a fully automated microscope enclosed in an environmental chamber (temperature and CO₂). Microscopy capabilities include bright field, phase, polarization, fluorescence imaging, time lapse, and deconvolution. Biophysical cellular characterization attachments include parallel plate flow chambers, micropipette aspiration, TIRF (total internal reflection fluorescence), FRAP (fluorescence recovery after photobleaching) and microinjection.

CATALYSIS AND SURFACE SCIENCE LAB

The Department of Chemical Engineering houses one of the best equipped catalysis and surface analysis laboratories in the U.S. for use by the Catalysis and Surface Science group. The CSS lab has six versatile ultrahigh vacuum, surface preparation and analysis chambers equipped with state-of-the-art instrumentation. Many of these chambers and ancillary equipment were constructed at Carnegie Mellon; some of their capabilities are unique. The instrumentation in the laboratory includes: five X-ray photoemission spectrometers (XPS), two ultra-violet photoemission spectrometers (UPS), five low energy
electron diffraction (LEED) optics, a high resolution electron energy loss spectrometer (HREELS), a variety of mass spectrometers, two Fourier transform infrared (FTIR) spectrometers, and two low energy ion scattering spectrometers (LEIS). One of chambers is capable of spatially resolved XPS, UPS and LEIS to allow mapping of surface properties. In addition, the lab houses a secondary electron microscope equipped with energy dispersive X-ray analysis (EDX) and electron backscatter diffraction (EBSD). A Raman microscope is used for spatially resolved acquisition of Raman spectra.

The chambers all have equipment for surface preparation including exposure to gases, organic vapors and Knudsen cells for exposure to high molecular weight organics such as amino acids. In addition, the lab houses three UHV chambers designed specifically for the preparation of Composition Spread Alloy Films (CSAFs), thin alloy films with lateral composition gradients that span the entire composition space of a ternary alloy (see p. 15). These CSAFs serve as alloy libraries for high throughput studies of their surface and catalytic properties. The CSS lab is also well equipped with catalytic reactor systems. Two commercial systems are used for study of steady state catalytic reaction kinetics and for exposure of various materials to catalytic reaction conditions. In addition, the CSS lab has three unique multichannel micro-actor array systems for spatially resolved study of catalytic reaction kinetics across CSAFs. These high throughput reactors allow concurrent measurement of catalytic reaction kinetics at 100 different alloy compositions.

Finally, the CSS lab is fully equipped for electrochemical research with potentiostats, a rotating disk electrode, a range of electrochemical cells, a fuel cell test stand, an electrochemical quartz crystal microbalance, and a gas chromatograph and mass spectrometer for analysis of head space gas composition.

**GARY J. POWERS EDUCATIONAL COMPUTER LAB**

The Gary J. Powers Educational Computer Lab is the department’s state-of-the-art computer lab and serves as a collaborative workspace that undergraduate students utilize for carrying out their coursework and research activities. The lab doubles as an instructional space for faculty and teaching assistants to deliver lectures and tutorials.

Initially established in 1991, the lab has been supported by many companies and foundations in order to ensure that students continue to have the top of the line equipment available to them.

Past contributors have included Dell, Intel, Air Liquide and the Center for Advanced Process Decision-Making.

In 2013, the computer lab was dedicated in memory of Professor Gary J. Powers, who had passed away in 2007. In honor of this dedication, the Center for Advanced Process Decision-Making (of which Gary was a member) committed funds in Gary’s name toward further upgrades.

Gary was extremely dedicated to education and learning on the undergraduate level and he often visited with students in the computer lab. His commitment to education and learning is truly a legacy that has touched the lives of many students.

Today, the lab features 30 workstations on which students can run a suite of productivity and specialized course-related software. The lab also features shared printing and scanning equipment for student use and is augmented by an array of server resources available for advanced computation and remote access.

In addition to the Gary J. Powers lab, a small casual study space, the Undergrad Lounge, houses additional computer and printer resources.

**PPG INDUSTRIES COLLOIDS, POLYMERS AND SURFACES (CPS) LAB**

The Colloids, Polymers and Surfaces (CPS) educational program includes the PPG Industries Colloids, Polymers and Surfaces Laboratory, a unique 2,200 square foot facility supporting the complex fluids research group, is used both for instruction and research. The CPS lab provides the capability for characterization of fine particles, macromolecules, interfaces and the complex fluids formed by combinations of these materials.

Lab courses in colloid and polymer characterization are offered at both the undergraduate and graduate levels. The hands-on laboratory experience features 27 experiments and demonstrations. Offering laboratory courses every semester to 25–30 students, CPS lab personnel train about 40 students per year including undergraduate, master’s and doctoral students working on independent research projects in most of the engineering and science departments at Carnegie Mellon.

Physical property measurement capabilities in the lab include surface and interfacial tension, particle sizing, contact angle, rheology, static and dynamic light scattering, differential scanning calorimetry, UV-VIS spectrophotometry, mechanical property testing, conductivity, critical micelle concentration measurements, powder surface area, electrophoretic mobility of colloids and dynamic surface tension. The laboratory is also used for outreach events that provide hands-on science experiences for K-12 students and teachers to promote science and engineering.
The Center for Advanced Process Decision-making (CAPD) is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.

The CAPD is a unique research group that deals with the development of methodologies and computer tools for process design, analysis and operations. Major goals of the CAPD are to do basic research in Process Systems Engineering (PSE), produce students with unique skills in PSE, and interact with industry through mutually beneficial projects.
An enabling discipline, complex fluids engineering applies fundamental principles of intermolecular and surface forces to advance technology in fields as diverse as coatings, polymeric materials, pharmaceutical and biopharmaceutical manufacture and drug delivery, consumer and personal care products and environmental engineering. Key to the CCFE are the numerous collaborations among faculty and students that create synergistic combinations of science and engineering knowledge bases and problem-solving strategies, focused both on industrially motivated and fundamental science.

NATIONAL ENERGY TECHNOLOGY LABORATORY — REGIONAL UNIVERSITY ALLIANCE

FACULTY: Biegler, Gellman, Grossmann, Kitchin, Matyjaszewski, Sahinidis, Siirola

www.cmu.edu/cheme/research/research-centers/index.html

The Department of Chemical Engineering at Carnegie Mellon has spearheaded the formation of a collaborative energy research program including faculty from a variety of departments across Carnegie Mellon, five other universities and the Department of Energy – National Energy Technology Laboratory (NETL). Professor Gellman leads the effort of the NETL – Regional University Alliance (RUA) at Carnegie Mellon.

The NETL is a U.S. DOE national laboratory with campuses in Pittsburgh, Pa., Morgantown, W. Va and Albany, Ore. and with the U.S. R&D mandate in fossil energy utilization. The NETL-RUA was initially established in 2007. The goal of its energy research portfolio is to address the problems associated with the socially and environmentally responsible use of existing fossil energy sources and the development of alternative sources for the future. The NETL-RUA research portfolio is funded at a level of ~$20 M/yr. The research portfolio covers the full range of problems related to fossil fuel energy generation, distribution, utilization and environmental impact and is aligned with the research focus areas of the NETL:

1. Computational and basic science
2. Energy system dynamics
3. Geological and environmental systems
4. Materials science and engineering

Departmental faculty members, postdocs and students work in highly integrated, collaborative teams with NETL scientists to tackle energy problems of national importance that will shape the evolution of the U.S. energy portfolio over the coming century.

WILTON E. SCOTT INSTITUTE FOR ENERGY INNOVATION

FACULTY: Biegler, Donahue, Gellman, Gounaris, Grossmann, Kitchin, Pandis, Sahinidis, Ulissi, Ydstie

https://www.cmu.edu/energy/

The Wilton E. Scott Institute for Energy Innovation was established by Carnegie Mellon in the fall of 2012 as a university-wide initiative to foster work on improved energy efficiency and energy sources that are clean, sustainable and affordable. The institute was established with a generous gift from ChE alum Sherman Scott and his wife Joyce Bowie Scott and is named in honor of Mr. Scott’s father. The activities of the institute have been expanded since then with generous gifts from many alumni, industry and a $30M award from the R.K. Mellon Foundation. Prof. Jay Whitacre (MSE) serves as the institute’s director and Professor Andy Gellman (ChE) serves as co-director. The faculty membership in the Scott Institute spans all of Carnegie Mellon’s seven colleges.

The Wilton E. Scott Institute for Energy Innovation is focused on developing and demonstrating the technologies, systems and policies needed to make the transition to a sustainable energy future. Using Carnegie Mellon University’s expertise in integrated systems and an understanding of the intersection between energy and public policy, the institute concentrates on energy efficiencies and reliability, as well as smart operations, materials and processes. Functionally, the institute serves to represent the broad set of energy related research activities that have developed at Carnegie Mellon over the past few decades. These include some 30 research centers with focuses spanning all aspects of energy technology, policy and impact. The institute serves to foster synergy among these previously existing activities by seeding research efforts and supporting activities that cross technological and disciplinary boundaries. In addition, its role is to incubate the growth of new activities that expand the scope of Carnegie Mellon’s research activities into new and emerging fields of energy science and engineering.
APPLICATION PROCESS

APPLYING TO OUR MASTER’S AND PH.D PROGRAMS

Carnegie Mellon enjoys an international reputation as a leading research university, while offering the benefits of a collaborative and collegial academic community. We uphold a long-standing tradition of world-class, interdisciplinary research with particular strengths in process systems engineering, complex fluids engineering, solid-state materials engineering, bioengineering, environmental engineering and energy engineering.

In order to apply to our graduate programs, prospective students must have completed a regular four-year course of study in chemical engineering or related discipline at a recognized university with better than a B average. Admission is based on overall academic performance, recommendation letters, statement of purpose, Graduate Record Examination (GRE) scores and Test of English as a Foreign Language (TOEFL, score of 100 or better preferred) or International English Language Testing System (IELTS, score of 7.0 or better preferred) scores (if applicable). Admission to the Ph.D. program is further based on a demonstrated commitment to a research-based career via prior research experience. Ph.D. program applicants do not need to have a master’s degree to be considered for admission.

Please note that TOEFL/IELTS scores are required for all applicants whose native language is not English, and who are not documented U.S. citizens or U.S. permanent residents. This requirement cannot be waived, even for applicants who have completed a degree in the U.S.

FINANCIAL AID AND COSTS

Master’s-level students provide their own financial support for their studies either from their own resources, employer programs, foundations or governmental agency sources.

Ph.D.-level students are provided with tuition and stipend support via governmental agency, foundation, employer, research grant, research contract and/or college and departmental sources as long as they remain graduate students in good standing.

APPLICATION DETAILS AND CONTACT INFORMATION

Details about the graduate application process are available at: cmu.edu/cheme/education/index.html.

To contact the Director of Graduate Admissions or the Graduate Recruiting and Admissions Manager for questions about our graduate study programs or about the application process, please email: chegrad@andrew.cmu.edu.

APPLICATION DEADLINES

<table>
<thead>
<tr>
<th>Application windows for</th>
<th>FALL program start:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ph.D. program:</td>
</tr>
<tr>
<td></td>
<td>Master’s programs:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SPRING program start:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ph.D. program*:</td>
</tr>
<tr>
<td>Master’s programs:</td>
</tr>
</tbody>
</table>

*Contact the director of Graduate Admission before applying as spring Ph.D. slots may or may not be available.
ChemE graduate students at CMU automatically become part of ChEGSA. ChEGSA is a student organization for all graduate students in the Chemical Engineering Department. It serves as the liaison between the graduate students and the faculty, staff and undergraduates. ChEGSA hosts social and professional events aimed at improving the graduate student experience at CMU. Students may participate as much or as little as they like; ChEGSA is a community available to graduate students from their first day on campus.

Master's students also become part of the master students' association ChEMSA. Organized in 2012, the group participates in student orientation activities and organizes social events throughout the year. Visit the ChEMSA website (chemsacheme.cmu.edu/) for more details.

To aid in students’ professional development, ChEGSA hosts an annual research symposium. Started in 1979, this two-day event features graduate research presentations, a poster session and a keynote speaker. Students have the opportunity to interact and present to their peers as well as to representatives from industry. The symposium is funded through the generous support of corporate and individual donors. To contribute, please visit the ChEGSA website (chegsacheme.cmu.edu/) and click on the Symposium tab for more details.

Supporting ChemE

Become involved with the Carnegie Mellon Chemical Engineering Department’s mission by contributing to the department fellowship and scholarship funds and by collaborating with faculty in their innovative research.

Work with the department and the Career and Professional Development Center by hiring ChemE graduates and by hiring students in internships.

Contact Janet Latini at jlatini@andrew.cmu.edu or 412-268-2230 to discuss your contribution.

www.cmu.edu/cheme/supporting-cheme/index.html