Department of Chemical Engineering

In academic year 2004, the Department of Chemical Engineering at MIT maintained its usual high productivity and visibility in teaching and research. For the 15th consecutive year, both our graduate and undergraduate programs garnered the number-one ranking among the nation's chemical engineering departments by *US News and World Report.* The department also had a tremendous year fiscally, with research expenditures of $23.3 million.

During the academic year, 28 doctoral degrees (PhD and ScD) were awarded, along with 36 SM and/or master's-level degrees, yielding a total of 64 advanced degrees conferred. Forty-one SB degrees were conferred as of June 2004, with 70 percent awarded to women.

The department's undergraduate enrollment stands at 140 students. The graduate student enrollment is stable at 258 students, with 232 in the doctoral program and 26 master's-level degree candidates. The graduate programs include 91 foreign, 75 female, 28 Asian American, and 10 self-identified minority students. This year, we received 335 applications for our doctoral program and offered admissions to 75 individuals, of which 53 accepted our admissions. Among the incoming class for 2004, 14 are female and 8 are minority or Asian American graduate students.

Edwin R. Gilliland Auditorium Lecture Hall 66-110 MIT (© 2004 Walter Silver/Boston).

Renovation of the Edwin R. Gilliland Auditorium, on the first floor of the Ralph Landau Building, has added updated audiovisual, networking, and digital media technology to the lecture hall. This has substantially improved both the teaching environment for several key departmental undergraduate and graduate courses and the functionality of the space for various lectures events. Modernized lighting and finishes in the first floor corridor effectively link the renovated auditorium to an earlier renovation on the second floor. In January, a feasibility study to address the facility needs of the Department of Chemical Engineering was completed. The Ralph Landau Building is nearly 30 years old, and much of its infrastructure is approaching the end of its service life. In addition, the nature of chemical engineering has changed, becoming more diverse in its research and teaching mission, as well as expanding ties to materials, biology, and computational sciences. The purpose of this forward-looking study was to assess the facility and program requirements of the department and to study the feasibility of several options for accommodating these requirements. One notable determination of this study was that the current space available to Chemical Engineering is 30 percent below standard benchmarks for comparable use elsewhere at MIT. One way to meet these requirements would be to construct a new building as the "home" of the department, with an area of 244,000 gross square feet.

The department hired one new junior faculty member this year, Dr. Narendra Maheshri, who will be joining us in the spring of 2006. Dr. Maheshri received the bachelor of science degree in chemical engineering and biology from MIT, where he was a Phi Beta Kappa scholar. He received a PhD in chemical engineering from the University of California–Berkeley. Before joining the faculty here, Dr. Maheshri will do postdoctoral research with Professor Erin O'Shea at the University of California–San Francisco. Dr. Maheshri's focus area is cell signaling, and his addition to the faculty bolsters our already accomplished group of teaching and research staff.

We are also delighted with the additions of Richard Smith, web developer; Mary Keith, graduate student coordinator; Timothy Doyle, administrative assistant to professors Kenneth J. Beers and Robert E. Cohen; Esther Estwick, ASO coordinator; and Marketa Valterova, SRS technical assistant.

Undergraduate Education

Undergraduate Enrollment over the Last 10 Years

Class Level	94–95	95–96	96–97	97–98	98–99	99–00	00–01	01–02	02–03	03–04
Sophomores	108	118	87	97	88	71	67	47	56	56
Juniors	104	101	121	90	90	85	76	66	49	43
Seniors	100	103	110	130	94	103	89	84	65	41
Total	**312**	**322**	**318**	**317**	**272**	**259**	**232**	**197**	**170**	**140**

Department undergraduate enrollment stands at 140 students. The enrollment of women remains around 56 percent, and student quality remains excellent.

A major addition to the undergraduate education in Chemical Engineering is the new SB degree in chemical-biological engineering: Course 10-B, approved by the Institute Faculty in 2003 and offered for the first time in fall 2004. The educational opportunity afforded by the new 10-B degree reflects the long-standing recognition of the importance of biology as a fundamental science in biomedical and industrial applications by the Chemical Engineering Department at MIT, dating back 35 years to the first biomedical engineering class at MIT, taught by professor emeritus Edward W. Merrill. Interest in biology has been growing among the undergraduate chemical engineering students in recent years, as reflected by a significant number of 10/7 double majors and students completing the biomedical engineering (BME) minor. The new 10-B program provides clear acknowledgment of the education students receive in both chemical engineering and biology within the units required for a single SB degree.

The structure of the Course 10-B degree parallels that of the traditional Course 10 program. In addition to the General Institute Requirements, both programs have three areas of emphasis: (1) fundamental education in chemistry and biology; (2) education in the triad of core chemical engineering sciences: thermodynamics, transport, and kinetics, with an emphasis on quantitative methods of analysis; and (3) integration and synthesis of fundamental science and engineering science principles for solving engineering problems and understanding complex systems. To reflect this change, existing core classes in the chemical engineering undergraduate curriculum (thermodynamics, kinetics) have been revised—and several new labs have been added—to reflect the increasing emphasis on life sciences applications. The senior capstone design subject, Integrated Chemical Engineering, is modular and already reflects a selection of biologically oriented modules in such areas as drug delivery and bioprocessing. Students graduating with the 10-B degree will be well prepared for industrial employment in the life science industries, engineering graduate studies, and professional degrees in medicine.

Graduate Education

Graduate Enrollment over the Last 10 Years

Degree Level	94–95	95–96	96–97	97–98	98–99	99–00	00–01	01–02	02–03	03–04
Master's	64	56	64	51	59	54	40	38	36	26
Doctoral	166	169	162	167	140	145	166	209	245	232
Total	**230**	**225**	**226**	**218**	**199**	**199**	**206**	**247**	**281**	**258**

Completing their third year of additional responsibilities are Professor Daniel Blankschtein as graduate officer and Professor K. Dane Wittrup as the head of the Graduate Admissions Committee. Because of their efforts, in coordination with the faculty advisors of the department, 100 percent of the past year's rising class passed both the written and oral qualifying examinations and have thus been promoted to candidacy for the PhD/ScD. The incoming graduate class is entering with an average undergraduate GPA of 4.92 (5.0) and, on average, scored in the 81st percentile on the Graduate Record Examinations.

Faculty Notes

Professor emeritus János Béer, on January 30, 2004, was presented the US Department of Energy's Lowry Award by the US secretary of energy. The Lowry Award is the highest honor given by the Energy Department for outstanding contributions to fossil energy science and technology. The citation of the award reads as follows: "For pioneering research and development in fossil fuel technology, inspirational teaching, and service to the government and industry; for contributions in combustion science exemplified by development of a fundamental understanding of heat transfer, NOx formation, and mineral matter transformation in flames; and for leadership that continues to be critical to the design and commercialization of high efficiency, low NOx combustion systems widely used in the fossil-fuel power industry."

Professor Daniel Blankschtein was on sabbatical leave in the Boston area during 2003 and continued to serve as graduate officer in the department. His research group conducts fundamental theoretical and experimental research in the area of colloid and surfactant science, with an emphasis on practical and biomedical applications. Professor

Blankschtein delivered a plenary talk at the 12th International Conference on Biopartitioning and Purification held in Vancouver and gave an invited talk at the Gordon Research Conference on "Barrier Function of Mammalian Skin" held in Bristol, Rhode Island. Professor Blankschtein and his students also presented talks and posters at meetings of the American Institute of Chemical Engineers (AIChE), the Society of Cosmetic Chemists, the Gordon Research Conference on "Chemistry and Physics of Liquids," and the 7th US–Japan Symposium on Drug Delivery Systems held in Maui. Professor Blankschtein continues to serve on the editorial board of Marcel Dekker's *Surfactant Science Series.*

Professor Howard Brenner prepared a paper, taught an advanced topics course entitled Fluid Mechanics Revisited, and presented numerous seminars and lectures on this topic. The underlying theme of this controversial work asserts that the basic foundations of continuum fluid mechanics and thermodynamics should, in the case of compressible fluids, be based upon the transport of volume rather than of mass, as is currently assumed. Brenner received an honorary doctorate from Clarkson University and spoke at its graduate ceremonies.

Dr. William H. Dalzell continued as the environmental, health, and safety (EHS) coordinator for the Chemical Engineering Department. His primary efforts this year have been to insure that all people working with chemicals or biological materials have participated in appropriate EHS training and that all laboratories are in compliance with EHS regulatory requirements. He was director of the Chemical Engineering Practice School Station at Plug Power in Latham, New York, during the month of August 2003. He gave a presentation at Tokushu Kika Kogyo Co., Ltd., in Tokyo, Japan, entitled "Evaluation of Novel Mixing Technology" on November 6, 2003.

Professor William M. Deen was an invited speaker at the First International Symposium on Albuminuria in New York City in May 2004, and papers from his research group were presented at the annual meeting of the AIChE in San Francisco in November 2003. In the 50th anniversary issue of the *AIChE Journal,* one of his papers was recognized as the 15th most-cited paper in the history of that journal. As an invited speaker at the Tufts Workshop on the Integration of Chemical and Biological Engineering in April 2004, he shared his ideas on the teaching of transport phenomena with faculty from a number of participating universities. He was the corecipient of this year's Outstanding Faculty Award from the graduate students in the Department of Chemical Engineering in recognition of his teaching. His group continued its investigations of physiological transport phenomena, which are supported by the National Institutes of Health. Their research topics centered on the hindered transport of macromolecules in biological hydrogels, water and protein filtration in kidney capillaries, and the reaction and diffusion of nitric oxide in cell culture systems used for toxicity studies.

Professor William H. Green Jr. gave invited plenary lectures at the Foundations of Molecular Modeling and Simulations conference in Colorado and at the International Bunsen-Discussion of Dynamics of Molecular Phenomena in Supercritical Fluids in Germany. He will receive the American Chemical Society Fuel Division's Richard A.

Glenn Award at the ACS National Meeting in Philadelphia in August 2004. Green was promoted to associate professor with tenure.

Professor Karen K. Gleason completed her third year as executive officer for the department, gaining institute approval for a new bachelor's degree program, 10-B Chemical and Biological Engineering. Professor Gleason also oversaw several space renovations, including the refurbishment of the Gilliland Auditorium (66-110), which serves as the department's main lecture hall. Her group's research on chemical vapor deposition to create ultrahydrophobic surfaces was featured in the November 2003 issue of *Technology Review* and on NBC television news in August 2003. Professor Gleason gave presentations at the University of California–Berkeley, Cornell University, Rensselaer Polytechnic Institute, Honeywell, Dupont, Wright Patterson Air Force Base, and at the International Society for Plasma Chemistry in Taormina, Italy. Professor Gleason also continues as chief scientific advisor for GVD Corporation, a company she cofounded in 2001.

Professor Paula T. Hammond was awarded the Mark A. Hyman associate career development chair, administered through the Office of the Provost, in the summer of 2003. She also completed her sabbatical, which was begun at Caltech during the first half of 2003, as a Radcliffe Institute fellow during the fall of 2003. The Radcliffe Institute, formerly known as the Bunting Institute, provided the opportunity to interact with scholars from around the world in diverse disciplines on Harvard's campus; Professor Hammond spent much of her time in the Division of Engineering and Applied Science with professors Howard Stone and David Weitz investigating polymer self-assembly using microfluidics. Dr. Hammond's work on dendritic block copolymers was recently featured on the covers of the *Journal of Polymer Science* and *Polymer Chemistry,* while new research efforts in the area of ultrathin film electrochromics were featured on the cover of *Advanced Functional Materials.* Research developments in flexible thin film solid state electrolytes and related energy applications have also led to new patents in the Hammond research group. Dr. Hammond has given invited talks at the Organic Thin Films Gordon Conference in Italy, the Gordon Research Conference on Polymers, and at the 9th annual German-American Beckman Frontiers of Science Symposium (sponsored by the US National Academy of Sciences and the Alexander Von Humboldt-Stiftung). She was also a coorganizer of the National Science Foundation–sponsored German-American Frontiers of Polymer Science, held in Bayreuth, Germany. Dr. Hammond was an invited speaker at several companies and universities as well, including Caltech, Harvard University, Carnegie-Mellon University, and Proctor and Gamble Corporation.

Robert S. Langer's achievements in 2003 include receiving the Heinz Award for Technology, Economy, and Employment; the Harvey Prize, election to Academy of Achievement; and the John Fritz Award (given previously to inventors such as Thomas Edison and Orville Wright). He was also honored as the Founders lecturer (University of Wisconsin), the Rohm and Hass lecturer (Stanford University), the Tripathy Endowed Memorial lecturer (University of Massachusetts, Lowell), the Skinner Memorial lecturer (Northwestern University), the Maurice and Yetta Glicksman lecturer (Brown University), the FMC lecturer (Princeton University), the Seymour J. Kreshover lecturer (National Institutes of Health), and the Whitaker lecturer (American Society of Artificial

Organs), and he received an honorary doctorate from the University of Liverpool, England. Dr. Langer also received the General Motors Kettering Award for Cancer Research (2004). *Parade* magazine (2004) selected Langer as one of six "heroes whose research may save your life." He also joined the Board of Directors for Wyeth Pharmaceuticals, Inc., in 2004.

Professor Gregory Rutledge has continued to serve in his role as director of the Interdepartmental Program in Polymer Science and Technology at MIT, as a team leader of the Institute for Soldier Nanotechnologies, and as editorial board member and special editor for the journal *Polymer.* In July 2004 he assumed the role of executive officer for the Department of Chemical Engineering. Over the past year, he organized the third ACS workshop on Modeling of Macromolecules in Hilton Head, South Carolina. He delivered invited talks at the International Workshop on Thermodynamics and Complex Fluids and at several other conferences and universities. In November 2003, he took part in an international discussion of curriculum development in molecular engineering and taught a new undergraduate elective in chemical engineering by the same title. His research entails the molecular engineering of soft matter through the development of molecular simulations, materials characterization, and electrospinning of nanofibers.

Professor George Stephanopoulos presented the 2003 AIChE Institute Lecture at the annual meeting in San Francisco in November 2003. The title of his lecture was "Invention and Innovation in a Product-Centered Chemical Industry: General Trends and a Case Study." He received the 2003 William H. Walker Award for outstanding contributions to the literature of chemical engineering. He was reelected to the Board of Directors of Mitsubishi Chemical Corporation. He made six presentations in international workshops and symposia on the "Reformation and Rejuvenation of the R&D in Mitsubishi Chemical Corporation."

Professor Gregory Stephanopoulos continued his service on the advisory boards of five academic institutions and on the Board of Directors of the AIChE, where he spearheaded the formation of the new Society for Biological Engineering. In October he was inducted into the National Academy of Engineering for his pioneering contributions in defining and advancing metabolic engineering as well as leadership in incorporating biology in chemical engineering research and education. Professor Stephanopoulos also gave the Cary lectures at Georgia Tech, the Holtz lectures at Johns Hopkins University, and the Centennial lecture at Clarkson University. He was also distinguished lecturer at the University of Utah. He continued his educational and research activity in bioinformatics and metabolic engineering and his work as editor-in-chief of the journal *Metabolic Engineering,* published by Elsevier. In addition, he continued to serve on the editorial board of seven other scientific journals. He cochaired the Gordon Research Conference on Bioinformatics held at Queen's College, Oxford, and delivered keynote lectures at the International Symposium of Chemical Reaction Engineering in Chicago and at the ASM IMAGE Conference in Montreal. At MIT, he continued his teaching of courses on bioinformatics and kinetics of chemical and biological reactions.

Professor Jefferson W. Tester continues to be active in the energy and environmental area with both his teaching and research. He is the chair of the National Advisory

Council of the Department of Energy's National Renewable Energy Laboratory and cochair of the Governor's Advisory Board for the Massachusetts Renewable Energy Trust. Professor Tester also continued as a member of the advisory groups for the Paul Scherrer Institute, Eidgenossische Technische Hochschule (Swiss Federal Institute of Technology) in Zurich, Switzerland; the Energy and Environmental Systems Division of the Idaho National Engineering and Environmental Laboratory; the Governing Board of the Midwest Research Institute and the Division of Earth and Environmental Sciences at the Los Alamos National Laboratory. He gave invited lectures at Virginia Polytechnic Institute, the Council for Chemical Research, and at MIT on various energy topics, including methane and carbon dioxide gas hydrates, transitioning to a hydrogen economy, universal heat mining, advanced drilling methods, and hydrothermal conversion of hydrocarbons and biomass. A new 850-page textbook, *Sustainable Energy: Choosing among Options,* coauthored by Professor Tester, professors Driscoll and Golay of Nuclear Engineering, Dr. Drake of the Laboratory for Energy and the Environment, and Dr. Peters of the Institute for Soldier Nanotechnology, will be released by MIT Press this coming fall. Professor Tester received this year's Outstanding Faculty Award from the graduate students in the Department of Chemical Engineering.

Professor Jackie Y. Ying delivered 15 invited lectures at various international conferences and national meetings during the past year, including keynote lectures at the 10th International Conference on Composites/Nano Engineering, the International Conference on Materials for Advanced Technologies, the TMS annual meeting, and the 7th International Conference on Nanostructured Materials. She served as a symposium organizer for the 18th North American Catalysis Society, and is the conference chair for the 1st Society of Bioengineers International Conference on Bioengineering and Nanotechnology. Professor Ying was an invited seminar speaker at the University of California–Berkeley and the National University of Singapore and delivered the Lindsay Lecture at Texas A&M University. She serves on the editorial boards of eight journals/book series, as well as on the advisory boards of the Leibniz-Institut für Festkörper-und Werkstoffforschung, Dresden (Germany), the University of Queensland Nanomaterials Centre (Australia), the National Research Council Steacie Institute for Molecular Sciences (Canada), and the Institute of Materials Research and Engineering (Singapore). Professor Ying is an honorary professor of chemistry of Jilin University (China) and serves on the Canvassing Committee of the American Chemical Society Award for Creative Research in Homogeneous or Heterogeneous Catalysis. Professor Ying is currently on professional leave in Singapore as the executive director of the Institute of Bioengineering and Nanotechnology, a new national research institute under the Agency of Science, Technology, and Research.

Research Highlights

Energy and the Environment (Professor Jefferson W. Tester)

Several important problems face us in trying to transition to a more sustainable energy system. One set of problems relates to the environmental impacts created by the current approach, which relies heavily on fossil fuels. These range across scales from local to regional effects caused by particulate, sulfur, and nitrogen oxide emissions from combustion to global concerns over carbon dioxide. Another important aspect is the maldistribution and depletion of fossil resources (oil, natural gas, and coal). All of this suggests that we should diversify our energy supply options while we seek to minimize the environmental effects associated with fossil fuel use. So far, progress has been slow, in part because the technologies associated with renewable energy capture and recovery cannot compete economically with today's low-cost fossil fuels. A significant fraction of research in the Chemical Engineering Department is addressing many of these problems. For example, several investigations are aimed at producing cleaner fuels and renewable biomass and geothermal energy systems, while others are focused on processes to remediate environmentally contaminated areas.

Professor Tester's research group, in collaboration with other faculty in chemical engineering, nuclear engineering, and materials science, has been developing a range of experimental and theoretical methods to probe kinetics and transport phenomena in compressed and supercritical media. For example, measurements of reaction rates and product distributions have successfully been linked to ab initio quantum chemical calculations to quantify the effectiveness of reforming and oxidation processes in supercritical water to detoxify chemical and military wastes. Improved fundamental understanding of the role of supercritical water both as a solvent and reactant has been obtained for a number of model wastes, ranging from methylene chloride to methyl tert butyl ether to methyl phosphonic acid.

Synthetic pathways are also being pursued, using mixtures of compressed and supercritical fluids in a collaborative program with Professor Danheiser in Chemistry and Professor Andrew Holmes at Cambridge University. The key idea involves a green chemistry approach where environmentally benign solvents, such as water and carbon dioxide, are used as media to carry out selective carbon-carbon bond-forming cyclo-addition reactions for producing pharmaceutical intermediates and specialty chemicals. So far we have been successful in demonstrating the use of power ultrasound to produce emulsified bi-phasic mixtures of near critical carbon dioxide and water that enhance reaction rates between model Diels-Alder reactants.

In separate studies, Professor Tester, in collaboration with Professor Trout, has developed a refined statistical mechanical model for solid gas hydrates or water clathrates. The basic idea has been to develop a physically consistent model that can be used to predict the properties of important hydrate systems such as those involving carbon dioxide and methane that have direct applications to carbon sequestration in the deep ocean and natural gas recovery from permafrost and marine sediments. Ab initio calculations are coupled to a statistical mechanical model to capture the effects of intermolecular interactions between water host molecules and enclathrated guest molecules. This first-principles approach has successfully predicted equilibrium and transport properties in multiphase systems containing solid hydrates and fundamentally differs from earlier work, which has relied heavily on fitting parameters to robust experimental data.

The third area under investigation is the development of a new approach to drilling ultradeep holes in the earth using thermal spallation and fusion rather than the conventional cutting and grinding approach.

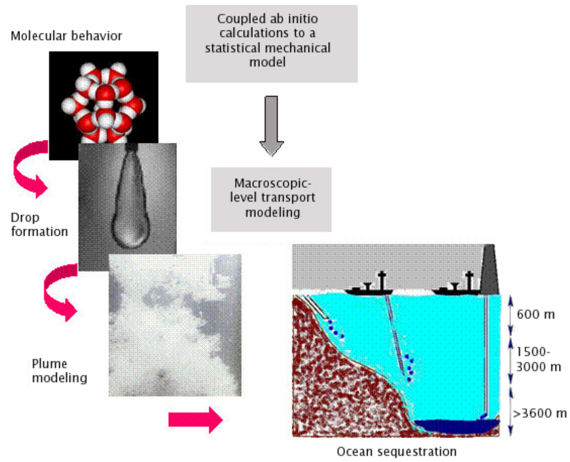


Illustration of the multiscale nature of the investigation of carbon dioxide sequestration. A key question is whether the rate of nucleation of carbon dioxide hydrates can be controlled.

Earlier work in our group has quantitatively characterized rock spallation phenomena using supersonic combustion flame jets at low pressures and fluid densities in shallow hole drilling to show that they will penetrate very hard rock at about 5 to 10 times the rate of conventional bits with little or no wear. Ultradeep drilling to 10+ km will require having an intense heat source at high pressures of 1 kbar or more. Building on our experience operating in high pressure, supercritical water environments, we are analyzing the feasibility of using hydrothermal flames as a heat source to spall and melt rock in confined bore holes. Using conventional drilling technology, an exponential dependence of drilling cost on well depth results in part from the inherent wear to drilling equipment and the need for drill bit replacements.

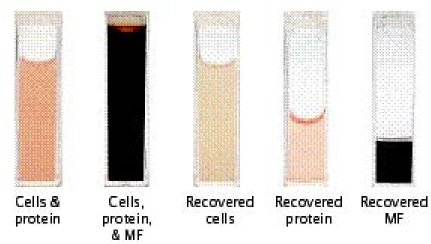
If the thermal method works, we are optimistic that the current exponential dependence would be replaced with a linear dependence of cost on depth. Such technology would drastically improve the economics of geothermal energy recovery from very deep reservoirs, thus making heat mining from the deep earth a universally accessible energy source.

Stimuli-Responsive Colloids for Chemical and Biological Processing and Enhanced Functionality (T. Alan Hatton)

Developments in biotechnology over the past 10 years have been attributed primarily to basic research in the life sciences, although it is the many enabling technologies (e.g., polymerase chain reaction, DNA and protein sequencing, bioinformatics, monoclonal antibodies, mass spectrometry, etc.) that have allowed the biotechnology industry to grow rapidly. Much less can be claimed for the contributions of engineering and engineering science to the development of biotechnology during the same period, however. This is mainly due to the “high-value-added” nature of human health care products, which have been the primary focus of this industry and for which engineering process improvements do not alter the price structure; thus, they have not been a focus of research and development in recent years. Future biobased materials—particularly those produced from renewable resources—will have cost structures for manufacturing that will be totally different from those for human therapeutics, however. In such cases, novel engineering concepts and technologies will be required in order to attain economic viability for such larger volume and lower cost biobased materials.

Our overall research in this area, funded by the DuPont–MIT Alliance and in collaboration with Professor Daniel Wang, has focused on addressing this need through the development of new concepts for alleviating a number of critical bioprocess-related bottlenecks in the production of materials from renewable resources. The primary focus of the work to date has been on developing new functionalized magnetic nanoparticles (~10–20 nm) to increase mass transfer rates (oxygen) in bioreactors for increased cell and product concentrations and for the purification of macromolecules (proteins). The driving force for these technologies is the coupling of the extremely large interfacial areas afforded by these nanoparticles, the ease with which they can be functionalized, and their responsiveness to magnetic field gradients that allows them to be recovered using high-gradient magnetic separation technology.

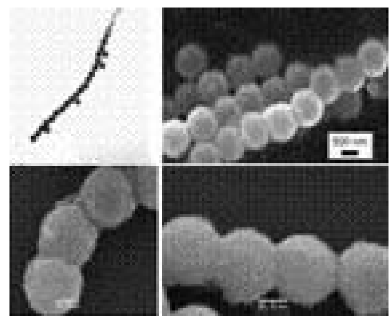
Our group has advanced the prospects for this technology considerably by developing facile new methods for the optimization of the particle preparation, including the synthesis and stabilization of particle clusters of controlled size to ensure high surface areas for effective utilization in fermentation processes and sufficient size to be captured by high-gradient magnetic separation (HGMS) techniques.



The cell and protein solution mixture is combined with the magnetic fluid and passed through an HGMS column. The protein-laden nanoparticles are trapped in the HGMS column and cells recovered in the effluent. Protein is recovered from the trapped particles themselves are recovered by flushing with water with the magnets deactivated.

We have formulated predictive models for the tuning of the sizes of the clusters in terms of the chemical nature and molecular weight of the polymers used to provide both stabilization of the particle suspension and specificity for the targeted protein products. Models have also been developed for the a priori prediction of the performance of HGMS columns, which are of great importance in establishing the parameters required for the particle cluster synthesis and capture. To test the purification capabilities in a real system, fermentations with *Pichia pastoris* have been performed, producing the cationic, antifungal protein drosomycin. Magnetic fluids were added without any prior treatment of the broth, resulting in significant purification of drosomycin. A preliminary analysis indicates that magnetic nanoparticle recovery of proteins from fermentation processes could have significant benefits over conventional separation technologies, with as much as one to two orders of magnitude enhancement in productivity and capacity over the best fixed and expanded bed chromatographic results reported to date.

In other work on magnetically responsive fluids (supported by the Institute for Soldier Nanotechnologies), in conjunction with professors McKinley (Mechanical Engineering) and Doyle (Chemical Engineering), we are exploring new concepts for the enhancement of soldier survivability through the development of tailored magnetorheological (MR) fluids to be used within an integrated, nano-enabled battle suit, both to provide on-demand armor capability and for the prescriptive distribution of energy and materials throughout the battle suit via microchannels, microvalves, micropumps, and microcontrollers. To this end, Professor Hatton’s group has developed synthetic procedures for the preparation of MR particles of novel morphologies to enhance their performance. Specifically, hollow magnetic nanoshell particles of defined size have—through the use of microfluidic technologies and sol-gel chemistry—been linked together permanently to form rigid chains of any desired length. "Large-scale" processes have been developed using microfluidics to enable the production of rigid chains with finely controlled diameters and lengths in sufficient quantities that they can be incorporated in new formulations of nanoMR fluids with high yield stresses and substantially lower composite density. The potential applications of these nanoMR fluids are in responsive, dynamic armor, where the normally flexible battle suit would harden on application of a magnetic field through built-in circuitry, or in other applications such as splints, for medical purposes. Other areas of potential application for these chains are as microvalves and micropumps in microfluidic devices for the controlled, on-demand distribution of materials throughout the integrated battle suit.



Sol-gel chemistry is used to bond superparamagnetic beads aligned in a microchannel of a fixed height to form rigid chains of defined length and diameter. These superparamagnetic beads were prepared by adsorbing magnetic nanoparticles on the surfaces of of the polystyrene beads modified by the layer-by-layer polyelectrolyte adsorption technique.

Along the same lines, together with Professor Greg Rutledge's research group, we have fabricated magnetically responsive nanofibers in which the magnetic nanoparticles are incorporated into the fibers during the electrospinning process. We anticipate that the responsiveness of the fibers and fabrics made there will be improved dramatically if we use monodisperse nanoparticles of about 15–16 nm in diameter where the Neel relaxation time is on the order of seconds; current particles are ~8 nm in diameter and are highly polydisperse. Their relaxation times are on the order of nano- to microseconds, and their dipoles reorient rapidly to follow the direction of the applied magnetic field. With the longer relaxation times of the larger particles, we anticipate that we can absorb additional energy as the more permanent (on the time scale of interest) dipoles are oriented away from and against the restoring force of the applied magnetic field during the deflection of the fibers. We are currently optimizing an alternative synthesis route that will allow the controlled formation of monodisperse particles up to 18 nm in size. These particles may also confer similar properties to the hollow core/shell magnetic chains discussed above. At the same time, we are working on developing nanofibers and particles with chemical functionality to destroy (e.g., chemical warfare agents); this functionality is implicit in the synthesis procedure and will not require postmodification of the fibers or particles. Other areas of interest, in collaboration with Professor Kenneth Smith, include the use of light to control the conformations of photoresponsive surfactants and thereby to control such important properties as surface tension, gel formation, and the folding and unfolding of proteins. In this latter case, we have used shape reconstruction methods in the analysis of small-angle neutron scattering spectra to show clearly that the different stages of unfolding of BSA in the presence of these surfactants can be controlled readily using light; these observations may provide new directions for the controlled processing of proteins, and so on. We are also exploring other aspects of stimuli-responsive materials, in particular light, pH- or temperature-sensitive gels for the dynamic in situ control of separation environments for fine protein purifications, or for new drug delivery applications.

Annual Lectures, Seminars, and Symposium

The department once again hosted a very successful series of four major annual lectures: Frontiers in Biotechnology Lecture, delivered by Phillip Sharp, director of the McGovern Institute for Brain Research; the Hoyt C. Hottel Lecture, delivered by Charles E. Kolb, president of Aerodyne Research, Inc.; the 10th Alan S. Michael Lecture, delivered by Noubar Afeyan, senior managing director and CEO of Flagship Ventures; and the Warren K. Lewis Lecture, delivered by Frank S. Bates, distinguished McKnight University professor and head of Chemical Engineering and Materials Science, University of Minnesota.

Our departmental seminar series featured academic and industry leaders from the University of Wisconsin–Madison, Harvard University, the University of California–Santa Barbara, the University of Minnesota, Merck Research Laboratories, the University of Alberta, the University of Missouri–Columbia, Pennsylvania State University, Rensselaer Polytechnic Institute, and the University of Texas.

Departmental Awards

The department awards ceremony took place on May 10, 2004, in the Gilliland Auditorium of the Ralph Landau Building. We are pleased to recognize this year's recipients of the Outstanding Faculty Awards: Professor William M. Deen and Professor Jefferson W. Tester tied for the graduate students' choice, and Jean-François P. Hamel was selected by the undergraduate students.

The Edward W. Merrill Outstanding Teaching Assistant Award was presented to Saeeda Jaffar for her work in 10.302 Transport Processes.

Chemical Engineering Special Service Awards were conferred to the members of the Graduate Student Council: Hal Alper, Ryan Bennett, Malancha Gupta, Joel Moxley, Jane Rempel, and Benjamin Wang. In addition, Mark Styczynski was awarded the Chemical Engineering Rock for outstanding athleticism and Cindy Chung was recognized for her year as president of the student chapter of the AIChE. All third-year graduate students are required to present a seminar on the progress of their research, and the two recipients of the Award for Outstanding Seminar were Brian Baynes and Andre Ditsch.

Our undergraduates also earned numerous accolades over the course of the year. Henry Bergquist received the Dow Chemical Company Outstanding Junior Award for a balanced record of achievement in academics, campus professional and social organizations, and work experience on or off campus. The Merck Fellowship Award was presented to Wei Chan and Hana Oh in recognition of scholastic excellence, and the National Goldwater Scholarship went to Peter Miller, also in recognition of scholastic excellence. The Ronald E. McNair Scholarship Award went to Nnennia Ejebe, an undergraduate who has demonstrated a strong academic performance and who has made a considerable contribution to the minority community. The Robert T. Haslam Cup, which recognizes outstanding professional promise in chemical engineering, went to Sudha Amarnath. Finally, the Roger de Friez Hunneman Prize—the oldest prize in the department, which is awarded to the undergraduate who has demonstrated outstanding achievement in both scholarship and research—went to Sonali Rudra.

The department is quite pleased to recognize Ms. Gwen Wilcox, assistant to professors Jefferson W. Tester and Bernhardt L. Trout, as the department's Outstanding Employee of the Year for her dedication and outstanding service to faculty, staff, and students.

The Department of Chemical Engineering at MIT has certainly had a very fruitful and rewarding year, and it is poised for even bigger and greater successes for the upcoming year.

Robert C. Armstrong, Department Head and Chevron Professor of Chemical Engineering
Gregory C. Rutledge, Executive Officer and Professor of Chemical Engineering

More information about the Department of Chemical Engineering can be found on the web at http://web.mit.edu/cheme/index.html.