Department of Chemical Engineering

During the 2011–2012 academic year, the MIT Department of Chemical Engineering continued to shine, being rated the number one chemical engineering program at both the graduate and undergraduate levels by US News and World Report for the 23rd year in a row. Our faculty received many awards and honors and our new undergraduate degree program, 10-ENG, is off to a good start.

Sponsored research volume in the department increased once again to a total of $53.9 million over the past year. Of this amount, $32 million is directly handled through the department, with the remainder handled by different cost centers at the Institute. These centers include the MIT Energy Initiative (MITEI), the Koch Institute for Integrative Cancer Research, the Ragon Institute, and the DuPont-MIT Alliance, among several others. The high level of interdisciplinary work and collaboration across fields continues to provide a strong basis for innovation in the department, as well as for the development of new investigative tools and computational approaches.

Professor Klavs Jensen continued his term as department head. Professor Paula Hammond stepped down as executive officer in December 2011 and was replaced by professor William Green. Professor William Deen announced his retirement and stepped down from his role as the department's graduate officer; he has been succeeded by professor Patrick Doyle. Barry Johnston continues to serve as undergraduate officer. Professor Richard Braatz remains the chair of our graduate admissions program. Chemical Engineering continues to claim two Institute Professors as primary faculty members: Daniel I.C. Wang and Robert S. Langer.

New Faculty Arrivals

This year we welcomed William Tisdale to our Chemical Engineering faculty as a new assistant professor. He obtained his bachelor's degree in chemical engineering from the University of Delaware (magna cum laude) in 2005 and a PhD in chemical engineering from the University of Minnesota in 2010; he did postdoctoral research at the Organic and Nanostructured Electronics Lab within the Department of Electrical Engineering and Computer Science (EECS) before joining the faculty. For his doctoral research, Professor Tisdale pioneered the use of a surface nonlinear optical technique for probing charge transfer at interfaces in nanostructured solar cells and then leveraged this ability to demonstrate a possible pathway toward solar cell devices surpassing conventional efficiency limits. As an assistant professor at MIT, his research program will be focused on understanding and optimizing the flow of energy in nanostructured materials and drawing the connection among processing, morphology, and dynamics. To meet these goals, Professor Tisdale's group will rely heavily on state-of-the-art optical spectroscopy and microscopy techniques.

We continue to await the arrival of Fikile Brushett as an assistant professor. Dr. Brushett is completing his postdoctoral stay at Argonne National Laboratories, where he is developing (under the supervision of Dr. John Vaughey and Dr. Dennis Dees) new electrochemically active materials and novel chemistries for room-temperature non-aqueous flow batteries with high energy efficiency and operating voltage.

Research and Recognition

Professor Langer received many awards in 2011–2012. He received both the Priestley Medal and the Perkin Medal, two of the highest awards in the chemical sciences. He was also elected as a fellow of the American Chemical Society (ACS) as well as the American Institute of Chemical Engineers (AIChE). Langer received the Terumo International Prize, the Wilhelm Exner Medal, the Feodor Lynen Award from *Nature Biotechnology*, the Innovation Award for Bioscience from *The Economist*, the Warren Alpert Foundation Prize, the Boston Museum of Science's Walker Prize, the Apple Award from the American Spinal Injury Association, and the Society of Cosmetic Chemists' Frontier of Science Award. Professor Langer also gave an extraordinary number of major lectures and commencement addresses this year (as detailed below).

Professor Wang received the rare honor of having a major award named after him. The D.I.C. Wang Award for Excellence in Biochemical Engineering is cosponsored by ACS, AIChE, and the Society for Biological Engineering.

Professor George Stephanopoulos received the AIChE Founders Award in fall 2011 and was elected a fellow of the American Academy of Arts and Sciences. Professor Jensen received the AIChE William H. Walker Award for Excellence in contributions to chemical engineering literature in fall 2011. Jensen was also the first recipient of the International Union of Pure and Applied Chemistry (IUPAC) ThalesNano Prize in Flow Chemistry. Professor Paul I. Barton received the AIChE Computing in Chemical Engineering Award in fall 2011, while professor Bernhardt Trout received the AIChE Impact Award. Professor Karen Gleason will receive the AIChE Process Development Research Award at the upcoming 2012 national meeting. Professor Greg Stephanopoulos received the Eni Prize in Renewable and Non-Conventional Energy and the inaugural *Biotechnology Progress* award for outstanding publications in biotechnology. Associate professor J. Christopher Love was named a Camille Dreyfus Teacher-Scholar. Professor K. Dane Wittrup was elected into the National Academy of Engineering and was named a fellow of the American Academy of Arts and Sciences.

In addition to these major awards, many of our faculty gave important invited lectures. For example, professor Robert Armstrong presented the Johansen-Crosby Lecture (Michigan State) and the Ohanian Lecture (University of Florida). Professor Patrick Doyle was awarded the Soft Matter Lectureship by the Royal Society of Chemistry. Professor Hammond will be the plenary lecturer for the American Chemical Society's POLY/PMSE Division at the upcoming national meeting. Professor Jensen presented the Robert Pigford Memorial Lecture (University of Delaware), and Professor Love gave the keynote lecture at the Engineering Conferences International (ECI) Vaccine Technology IV meeting. George Stephanopoulos held the Alkis Payatakes Lectureship (University of Houston) as well as the Basore Distinguished Lectureship at Auburn, and Greg Stephanopoulos presented the Chancellor's Distinguished Lecture at Louisiana State University.

Some of our more exciting research breakthroughs this year include Greg Stephanopoulos' discovery of the key pathway by which cancer cells make lipids under hypoxia, Michael Strano's invention of an all-carbon photovoltaic that uses near-infrared light, Paula Hammond's self-assembled hemostatic coating for soldier wound remediation, Martin Bazant's development of shock electrodialysis, and Arup Chakraborty's design of immunogens that could lead to an HIV vaccine. More details about the work and professional efforts of our faculty are included in the Faculty Notes section.

Undergraduate Education

Since 2004, the Department of Chemical Engineering has offered bachelor of science (SB) degrees in both chemical engineering (Course 10) and chemical-biological engineering (Course 10-B). In fall 2011, we introduced the 10-ENG flexible SB degree in engineering. Department undergraduate enrollment has been gradually declining since AY2007. Chemical Engineering continues to have one of the highest student-to-faculty ratios in the School of Engineering. The department advises students about career paths in chemical and chemical-biological engineering through active participation in freshman advising seminars, fall and spring term open houses, parents' weekend, and other activities. Seventy-five SB degrees were conferred in June 2012, 56% to women. Student quality remains high. The distribution of undergraduate students by class over the last 10 years is shown in Table 1.

Table 1. Undergraduate Enrollment over the Last 10 Years

Class Year	02–03	03–04	04–05	05–06	06–07	07–08	08–09	09–10	10–11	11–12
Sophomores	56	56	95	100	95	96	87	87	80	72
Juniors	49	43	55	83	75	67	77	68	71	73
Seniors	65	41	55	53	83	77	75	73	75	75
Total	**170**	**140**	**205**	**236**	**253**	**240**	**239**	**228**	**226**	**220**

The 10-ENG program leading to the engineering SB degree was introduced in response to demand from our students for a curriculum that would allow specialization in particular topics. The program features some flexibility in that requirements of the department, the Institute, and the profession may be met in some cases by categories of subjects rather than particular subjects. We will seek ABET (Accreditation Board for Engineering and Technology) accreditation of 10-ENG as a degree in engineering rather than chemical engineering. The initial specialization tracks are energy, materials, biomedical, and environmental. Student response has been cautious (a fall 2013 enrollment of seven students), but two 2012 seniors immediately transferred to 10-ENG; they were both double majors who had been seeking a 10-C degree.

The average starting salary for graduates of the Department of Chemical Engineering is $71,100 (2012 senior survey), which is among the highest in the School of Engineering. This attests to the success of the graduates of the 10 and 10-B programs in the department and to the continued high demand for our students. The 2012 senior survey indicates that 33% of our students are going on to graduate or professional school.

Undergraduates in the Department of Chemical Engineering maintain an active student chapter of the American Institute of Chemical Engineers, with invited speakers, presentations at national meetings, and visits to company sites. The student officers of AIChE were Tim Chang (president), Saloni Jain (vice president), Ksenia Timachova (secretary), Molly Kozminsky (treasurer), Allison Hinckley (social chair), Michelle Lu (publicity chair), Lauren Kazmierski and Kelechi Nwosu (Class of 2012 representatives), Mark Kalinich (Class of 2013 representative), and Paige Finkelstein and Charlotte Kirk (Class of 2014 representatives).

Graduate Education

The graduate program in the Department of Chemical Engineering offers master of science degrees in chemical engineering (SM) and in chemical engineering practice (MSCEP), doctor of philosophy (PhD) and doctor of science (ScD) degrees in chemical engineering, and PhD degrees in chemical engineering practice (PhDCEP). The PhDCEP track was established in 2000 in collaboration with the Sloan School of Management. The total graduate student enrollment is currently 244, with 224 in the doctoral program and 20 master's-level degree candidates. In the doctoral program, 213 students are in the PhD/ScD track and 11 are in the PhDCEP track. In the master's-level program, 20 are in the MSCEP track. Thirty-two percent of our graduate students are women. Two percent are underrepresented minority students. Fifty-one of our graduate students were recipients of outside fellowship awards from the National Science Foundation, the National Institutes of Health (NIH), the Department of Defense, and others. The distribution of graduate students by degree for the last 10 years is shown in Table 2. During the 2011–2012 academic year, 37 doctoral degrees (35 PhD or ScD, 2 PhDCEP) were awarded, along with 31 master's-level degrees (26 MSCEP, 5 SM), for a total of 68 advanced degrees conferred. Thirty-seven students passed the doctoral qualifying exams and were promoted to candidacy for the PhD/ScD or PhDCEP. The department received 432 applications for admission to the doctoral program, offered admission to 63 individuals, and received 35 acceptances of offers, for an acceptance rate of 56%. Of 73 applications for master's-level degrees, the department made eight offers and received seven acceptances of offers, for a yield of 88%. Among the incoming graduate class for 2012, 16 are women and four are underrepresented minorities. On average, the incoming graduate class held an undergraduate grade point average (GPA) of 4.95 (out of 5.0).

Table 2. Graduate Enrollment over the Last 10 Years

Degree Level	02–03	03–04	04–05	05–06	06–07	07–08	08–09	09–10	10–11	11–12
Master's	36	26	19	16	18	26	32	38	28	20
Doctoral	245	232	216	203	217	212	228	203	212	224
Total	**281**	**258**	**235**	**219**	**235**	**238**	**260**	**241**	**240**	**244**

Research Centers

The Department of Chemical Engineering is actively involved and takes a leadership role in several Institute-wide education and research programs. A few of these are highlighted here.

DuPont-MIT Alliance

The DuPont-MIT Alliance (DMA) has entered its 12th year as a successful partnership. The amended and restated agreement underscores the research collaboration in chemical, biochemical, and material sciences on campus and at the DuPont Experimental Station in Wilmington, DE.

Governance

A steering committee is responsible for the direction of research and educational activities. The committee meets biannually. The current steering committee members on the MIT side of the board include director Claude Canizares, vice president for research and associate provost, and Bruce Tidor, professor of biological engineering and computer science. The daily supervision of the program is managed on campus by Patricia Reilly, assistant director.

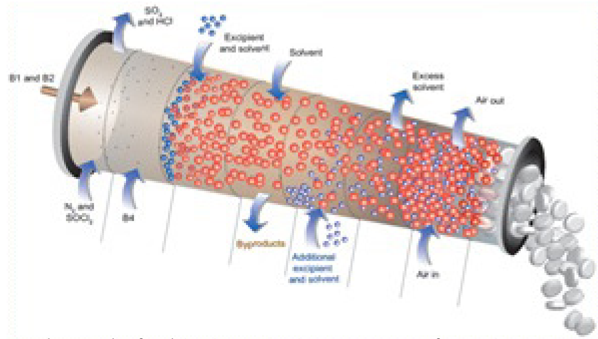
The DuPont director is Dr. Doug Muzyka, supported by the DuPont associate directors, Drs. Henry Bryndza, Steven Freilich, and Nandan Rao, with the assistance of the project director, Dr. William Provine.

Research Focus

Partnering with MIT continues to bring new research and technologies to DuPont. The direction of the research projects is determined by the unanimous vote of the steering committee. The current portfolio of projects engages research activities in several departments. The 2012 annual budget for research activities was $690,000.

The research collaboration between DuPont and MIT will encompass technologies such as fermentation engineering, energy storage, energy generation, and enzyme catalysis. The new programs should have a broad impact and should be able to lay foundational elements for new business enterprises.

Novartis-MIT Center for Continuous Manufacturing



The goal of achieving continuous manufacturing, represented by the "wind-pipe" vision.

The Center for Continuous Manufacturing, now entering the second phase (2012–2017) of a 10-year collaboration between Novartis and MIT, was formed with the goal of transforming pharmaceutical manufacturing from batch to fully integrated continuous manufacturing. This goal, represented by the "wide-pipe" vision illustrated in Figure 1, requires end-to-end integration of the entire process, from synthesis of active ingredients to production of the finished dosage form; continuous flow of material; and 24-hour-per-day operations.

The center's vision is transformational: rather than considering each process step as a separate entity, it takes a holistic view of the entire value stream from chemical raw materials to the finished dosage form. All processes are intimately interlinked, and the need for corrective processing steps is eliminated. This vision offers the potential for leaner processing, higher quality, more flexibility, and, in the end, cost savings.

In the center's first phase (2007–2012), researchers published 200 publications, including 15 theses, and they presented findings at numerous international and national meetings. The center filed and has been awarded provisional patent applications for seven breakthrough technologies. In addition, in 2011–2012 a core team of researchers translated the vision to practice and successfully demonstrated fully integrated continuous manufacturing operations of a pilot plant designed and built by MIT. This plant has been a very useful tool for understanding the complexities of integrated continuous manufacturing.

The second phase of the collaboration will focus on continued research and translation of novel technologies into integrated manufacturing tools. These new technologies will be developed by a team of approximately 50 to 60 researchers who are being led by 11 faculty members from three departments (Chemical Engineering, Mechanical Engineering, and Chemistry). Research activities will focus on the entire spectrum of pharmaceutical manufacturing processes, including chemical reactions, reactors, separations, final finishing steps, and process modeling and control.

The center is led by Bernhardt L. Trout, MIT center director, and Markus Krumme, Novartis head of continuous manufacturing. Other members of the center team are Stephen Sofen, MIT executive director; James Evans, MIT associate director; Stephanie Bright, MIT program coordinator; and Salvatore Mascia, strategic project manager.

David H. Koch Institute for Integrative Cancer Research

Course 10 has a major presence in the exciting new Koch Institute for Integrative Cancer Research (KI), with five faculty members located at the institute: Dan Anderson, Paula Hammond, Bob Langer, Chris Love, and Dane Wittrup. The Koch Institute brings together cancer biologists and engineers from across departments at MIT to conduct interdisciplinary research focused on improved diagnosis and treatment of cancer. Opportunities provided by the institute include interactions with cancer clinicians, key cancer centers such as the Dana Farber Cancer Institute, the Boston hospitals, and industry partners. Anderson, Hammond, and Langer's programs feature a world-class concentration of expertise in nanostructured vehicles for drug delivery at KI. On the basis of her creative work in synthesis of nanostructured materials, Hammond was recently named by the Boston Globe as one of "12 Bostonians Changing the World." Love and Wittrup join Darrell Irvine and Jianzhu Chen to constitute an immune engineering group with unusual strengths in both the analysis and manipulation of the immune system's response to cancer. Wittrup serves as associate director of KI.

Faculty Notes

Professor Armstrong served as deputy director of the MIT Energy Initiative, which continues to grow rapidly in its research, educational, campus, and outreach components. Sixteen companies and public institutions sponsor research as founding and sustaining members of MITEI; all together, the energy initiative has about 65 industrial and public partners across four continents. MITEI has helped to bring in approximately $400 million in support over its first five years of operation and around 200 energy graduate fellowships spread over 20 departments. Professor Armstrong serves on the AIChE Board of Directors, the Scientific Commission of the Eni Enrico Matteo Foundation, and the External Advisory Board of the National Renewal Energy Laboratory. During the past academic year, he gave the plenary lecture at the Agence Nationale de la Recherche French Conference on Energy in Lyon and spoke at the EmTech Conference in Colombia. He serves on the advisory boards of the chemical engineering departments at Georgia Tech; Northwestern University; the University of Colorado, Boulder; and Washington University.

Professor Bazant continued research in chemical engineering physics through mathematical modeling and theoretically motivated experiments. His lab focused on electrochemical systems for energy conversion and water purification. He published a general theory of driven phase separation in nanoparticles (in *Nano Letters* and *ACS Nano*) that helps to explain the high rate capability of iron phosphate nanoparticles for Li-ion batteries (commercialized by A123 Systems), as well as water sorption hysteresis in concrete (in a project for the MIT Concrete Sustainability Hub). He also published a theory of overlimiting current and deionization shocks in porous media (in *Physical Review Letters*) that is the basis for a new approach to water deionization in his lab (shock electrodialysis). Still active in mathematics, he published central limit theorems for power-law distributions (in the *Journal of Theoretical Probability*) and joined the editorial board of the *SIAM Journal of Applied Mathematics*. He delivered keynote lectures at the ACS Colloids and International Society of Electrochemistry meetings, co-organized a major conference on electrokinetics at ICREA (Institució Catalana de Recerca i Estudis Avançats) in Barcelona, and held the Joliot chair at ESPCI (École Supérieure de Physique et de Chimie Industrielles) in Paris. He continued teaching 10.50 Analysis of Transport Phenomena (with Professor Deen) and his own class 10.626 Electrochemical Energy Systems, which was offered to undergraduates for the first time as 10.426 and listed in the MIT energy curricula. He served on the Environmental Research Council, Committee on Graduate Admissions, and Committee on Discipline, and coached undergraduates for the Mathematical Contest in Modeling.

Professor Daniel Blankschtein's research group conducts fundamental theoretical and experimental research in the area of colloid and surfactant science, with an emphasis on industrial and biomedical applications. Recent research advances include molecular-thermodynamic modeling of surfactant micelles of varying curvature, molecular dynamics simulations of branched surfactant systems, molecular modeling of surfactant/polymer-induced stabilization of carbon nanotubes and grapheme sheets in aqueous media, oral drug delivery using an ingestible ultrasound-emitting pill, and ultrasound-assisted transdermal vaccination. Professor Blankschtein's group interacts closely with several companies that make use of software developed in the group to facilitate surfactant formulation design. His teaching responsibilities included the core polymer science and technology course 10.55 Colloid and Surfactant Science (fall 2011) and the newly developed interdisciplinary course 10.56 Advanced Topics in Surfactant Science (spring 2012). Professor Blankschtein and his students delivered talks and presented posters at the 242nd American Chemical Society national meeting, the 2011 American Institute of Chemical Engineers annual meeting, the DuPont Experimental Station (Wilmington, DE), and Procter & Gamble (Cincinnati, OH). In addition, Professor Blankschtein and his students hosted representatives of DuPont and Procter & Gamble at MIT to deliver tutorials on recent advances in surfactant research. Professor Blankschtein continues to serve on the editorial board of Marcel Dekker's Surfactant Science Series.

Professor Braatz continued research on control systems engineering with pharmaceuticals, materials, and energy applications. He also redesigned lectures in 10.551 Systems Engineering. In February, he was inducted into Oregon State University's Academy of Distinguished Engineers. He gave numerous invited talks, including a semiplenary presentation on systems nanotechnology at the American Control Conference. Professor Braatz served on numerous award committees and advisory and editorial boards, and he was editor-in-chief of *IEEE Control Systems* magazine.

Professor Chakraborty continued his research at the convergence of physical science, engineering, and medicine. Perhaps the most important finding emerging from his laboratory this year is the development of a general method that allows the translation of virus sequences into a quantitative fitness landscape. The availability of viral fitness landscapes makes possible the rational design of immunogens for vaccines against scourges such as HIV. Chakraborty's laboratory has designed such an immunogen based on the Gag polyprotein of HIV, and it is being moved to animal trials in laboratories at MIT and Massachusetts General Hospital. Chakraborty also taught a mandatory subject for graduate students (10.40 Chemical Engineering Thermodynamics) and received the outstanding faculty award for graduate teaching by a popular vote of the graduate students. In addition, Chakraborty accepted the job of founding director of the Institute for Medical Engineering and Science at MIT, and since February has been working on launching this new institute. Chakraborty continues to serve the National Academy of Engineering, the American Academy of Arts and Sciences, and the Dreyfus Foundation in numerous ways.

Professor Charles L. Cooney, Robert T. Haslam (1911) professor of chemical and biochemical engineering, continued as the faculty director of the Deshpande Center for Technological Innovation and assumed the additional role of faculty lead for entrepreneurship and innovation activities associated with the MIT Skolkovo Institute of Science and Technology. Professor Cooney was awarded the degree of doctor honoris causa of our Ramon Llull University, where he gave the 2012 commencement address. He serves on the NIH Engagement Committee, the Knight Science Journalism Fellowships Advisory Board, the Advisory Committee for Regional Engagement, the MIT Sanofi Aventis Joint Scientific Steering Committee, the executive committee of the Masdar Institute of Science and Technology (Abu Dhabi), the Center of Biomedical Innovation steering committee, the steering committee of the bioengineering section of the MIT Portugal Program, the steering committee of the Novartis-MIT Center for Continuous Manufacturing, the executive committee of the Legatum Center, and the advisory committee to the Singapore-MIT Alliance for Research and Technology (SMART) Innovation Centre. He is co-chair of the MIT-India Strategy Group. He is the faculty director of the downstream processing summer course held through MIT's Professional Institute. His research focuses on pharmaceutical manufacturing technology and technological innovation. He was named a fellow of the American Chemical Society. Professor Cooney is also an overseer of the Boston Symphony Orchestra and a trustee emeritus of the Boston Ballet.

Professor Doyle continued to advance his work on single-molecule DNA physics and microfluidic synthesis of functional microparticles. He was promoted to the rank of full professor and recently became the department's graduate officer. He continues to serve as an editorial board member for the journal *Biomicrofluidics*. He delivered invited lectures at the Gordon Research Conference on Microfluidics, Georgia Tech, ETH Zurich, the Nanobiotech Conference, and the Asia Pacific Confederation of Chemical Engineering Congress. As noted above, the Royal Society of Chemistry awarded him the Soft Matter Lectureship, which honors a younger scientist who has made a significant contribution to the soft matter field.

Professor Gleason was the inaugural lecturer at the Pall Corporation's Center for Applied Material Science in Port Washington, NY. She also presented invited lectures at the 14th International Conference on Organized Molecular Films (Paris), IUPAC's MACRO2012 World Polymer Congress (Blacksburg, VA), the Canadian Society of Chemistry (Calgary), Instituto Químico Sarriá (Barcelona), Printed Electronics USA 2011 (Santa Clara, CA), the University of Connecticut, and the PerkinElmer NanoSymposium (Boston). Professor Gleason continues to serve as chief scientific advisor to the GVD Corporation, a technology company she cofounded to commercialize inventions from her laboratory. GVD is headquartered in Cambridge, MA, with a commercial manufacturing facility in Greenville, SC.

Professor Green became the department's executive officer in January 2012. He plays several roles at MITEI, in both research and education, and spoke at the MITEI Europe conference in March. Professor Green was a co-author of the National Research Council's report *Transforming Combustion Research Through Cyberinfrastructure*. He elucidated the detailed reaction steps involved in steam methane reforming on multifaceted nickel catalysts (the main method for producing hydrogen) and in the combustion of butanol and JP-10 (two synfuels). He and his group developed new methods for solving large systems of differential equations using graphics processing units, predicting the pressure dependence of chemical reaction rates, and solving reacting flow computational fluid dynamics simulations, and they applied these new capabilities to solve energy problems. Professor Green continues as editor-in-chief of the *International Journal of Chemical Kinetics*.

Professor Hammond was recently named a fellow of the ACS Division of Polymer Chemistry. She is a co-organizer and co-author of the National Science Foundation's biomaterials report and associate editor of the American Chemical Society journal, *ACS Nano*. She presented invited seminars at several venues, including Johns Hopkins University, Case Western Reserve University, the Eindhoven University of Technology in the Netherlands, the Gordon Conference on Biomaterials, and the Gordon Conference on Drug Carriers in Medicine and Biology. Professor Hammond continues to serve as scientific advisor for Svaya Nanotechnologies, a company based on her patent for spray layer-by-layer techniques. She recently stepped down from her role as the department's executive officer after three and a half years of service; she has remained engaged in the Undergraduate Committee and other departmental Institute service, including the MIT Presidential Search Committee. New research developments in her lab include a self-assembled hemostatic coating for soldier wound remediation and a new means of synthesizing a macromolecular form of self-packaging RNAi for delivery (the latter work was published in *Nature Materials*).

Professor T. Alan Hatton continued to serve as the director of the David H. Koch School of Chemical Engineering Practice, where he has maintained the international flavor of the program by placing student teams at host companies in Switzerland, Belgium, and the United Kingdom in addition to the United States. He is an active participant in the Singapore-MIT Alliance (SMA) program on chemical and pharmaceutical engineering. Professor Hatton has served as a member of the scientific/technical advisory boards of the Particulate Fluids Processing Center at the University of Melbourne, the GSK-Singapore Partnership for Green and Sustainable Manufacture in Singapore, and Vale Energia Limpa (a joint venture between Vale and SGC Energia). Over the past year, he has given a number of invited lectures at ACS meetings in Denver and San Diego, the Glaxo GSM Symposium in Singapore, the Chemical Heritage Foundation, the University of Washington, the University of Massachusetts at Lowell, Tsinghua University (Beijing), and the Pacific Northwest National Laboratory; he also presented the Andrew Main Lecture in the D.B. Robinson Distinguished Speakers Series at the University of Alberta. He is on the editorial advisory board of *Langmuir* and is an advisory board member of the Engineering Conferences International in New York.

In addition to his responsibilities as department head, Professor Jensen served as chair of the School of Engineering Committee on Diversity while continuing his research on functional micro- and nanostructured materials and devices for chemical and biological applications. With collaborations in chemistry, he has explored a wide range of miniaturized flow systems for chemical applications with particular emphasis on systems for which continuous processing provides unique performance advantages. These systems also form the basis for continuous flow synthesis and separation developments as part of the Novartis-MIT Center for Continuous Manufacturing. The ability of small systems to operate at high pressure and temperature conditions not easily achieved in batch is being exploited in the synthesis of nanoparticles for optical and catalytic applications relevant to energy conversion through MITEI-sponsored projects. Biological applications, specifically the devices to facilitate the transport of macromolecules across cell membranes, are being pursued in collaboration with Koch Institute researchers. During the past academic year, Professor Jensen gave several plenary lectures on microreaction technology at international conferences and universities. He served on advisory boards to chemical engineering departments for North Carolina State University, Princeton, and the University of Wisconsin. He also participated in the governing board of the Technical University of Denmark and the scientific advisory board of the Singapore A*STAR Institute for Biotechnology and Nanotechnology.

Professor Jesse Kroll continued his research on the multiphase organic chemistry of the atmosphere. His group's research includes laboratory studies of the reactions important to the formation and evolution of fine particulate matter, development of new instruments for measuring atmospheric constituents, and field studies to better understand the composition of the atmosphere. In July 2011 members of the group participated in a major multi-institution field campaign, held in the Colorado Rockies, aimed at better constraining the organic carbon budget of forested environments; other collaborative studies were carried out at MIT's Sloan Automotive Laboratory and the Lawrence Berkeley National Laboratory's Advanced Light Source. During Independent Activities Period (IAP), Professor Kroll led a group of undergraduates on a field study to measure the chemistry of volcanic smog ("vog") on the big island of Hawaii. During the spring semester, he codeveloped a new freshman course aimed at introducing students to engineering challenges associated with sustainability and the environment. In fall 2011 he was awarded the Gilbert W. Winslow career development professorship.

In 2012, Professor Langer received an honorary degree from Bates College. He presented the Eliahu Caspi Memorial Lecture (University of Massachusetts Medical School), the Gladstone Distinguished Lecture (University of California, San Francisco), the Kavli Foundation Innovation in Chemistry Lecture (American Chemical Society), the Kroc Lecture (Joslin Diabetes Center), the Knight Lectures (University of Akron), the Bullard Lecture (Uniformed Services University), and the University of Maryland's Dean Lecture. He also presented commencement addresses at Bates College; the School of Chemistry at the University of California, Berkeley; the Johns Hopkins Business School; and Buckingham Browne and Nichols High School.

Professor Love continued to develop and apply new bioanalytical processes to profile immune responses in chronic diseases and conditions including HIV/AIDS, multiple sclerosis, type 1 diabetes, and food allergies. His lab also continued to assess clonal variation in biomanufacturing processes using single-cell analysis and pursued strategies to lower the costs of producing protein therapeutics that may enable biomanufacturing in developing countries. As noted above, he was selected as a Camille Dreyfus Teacher-Scholar in recognition of his contributions in research and the classroom. He delivered a lecture to the general public as part of the Broad Institute's Midsummer's Night Lecture Series. In spring 2012, he introduced a new course on advances in biomanufacturing with Department of Biology colleague Anthony Sinskey and MIT's Center for Biomedical Innovation. Professor Love also remained active as a member of the Koch Institute and an associate member at both the Broad Institute and Ragon Institute.

Professor Allan S. Myerson continued his research on fundamental and applied problems in crystallization and pharmaceutical manufacturing. He also continued his work as a principal investigator at the Novartis-MIT Center for Continuous Manufacturing and began a new project ("Pharmacy on Demand"), sponsored by the Defense Advanced Research Projects Agency, that involves the development of a tabletop pharmaceutical manufacturing device. Professor Myerson offered a new pharmaceutical engineering course for graduate and undergraduate students. He serves as an associate editor of the ACS journal *Crystal Growth and Design* and as a scientific advisor to the Pharmaceutical Solid State Cluster in Ireland. In addition, he was named chair of the Scientific Advisory Board of GenSyn Technologies, a small company devoted to particle engineering applications in pharmaceuticals.

During the 2011–2012 academic year, Bradley Olsen served as the St. Laurent career development assistant professor in the Department of Chemical Engineering. His group's research focused on the chemistry and physics of new polymers derived from or inspired by biological systems. The materials being developed in Olsen's lab are attracting interest for applications in biomaterials, defense, and energy conversion. His group filed two patent applications and one provisional patent application and published three peer-reviewed papers on the topics of tissue engineering hydrogels, polymer dynamics, and block copolymer templated self-assembly of proteins. Olsen was awarded a 2012 Air Force Office of Scientific Research Young Investigator Award. He also served as a co-instructor for 10.40 Chemical Engineering Thermodynamics (fall 2011) and 10.10 Introduction to Chemical Engineering (spring 2012).

Professor Kristala L.J. Prather continued her research activities, primarily in the areas of metabolic engineering and synthetic biology. This work is sponsored by the federal government (National Science Foundation and US Army Research Office), industry (Shell Global Solutions and GlaxoSmithKline), and international sponsors (MIT Portugal Program). In addition to several presentations at professional conferences, she gave 20 invited lectures, including four presentations at international meetings, and made three visits to corporate research centers. Prather was invited to serve on the editorial board of a new, well-received journal, *ACS Synthetic Biology*, as well as the well-respected journal *Biotechnology & Bioengineering*. Last summer, she became co-director of the 10.48s

Fermentation Technology course founded and directed by Professor Wang and offered through the MIT Professional Education Program. She is currently serving as co-chair of the 2013 International Conference on Biomolecular Engineering, sponsored by the Society for Biological Engineering. On July 1, 2011, Prather became the Theodore T. Miller career development associate professor.

Professor Yuriy Roman continued his work on the development of catalytic strategies for the production of chemicals and fuels from biomass. He published three articles in peer-reviewed journals on a new class of catalysts for low-temperature hydrogenations, as well as a technoeconomic analysis of hydrogen utilization during biofuel upgrading. He presented his work at three national meetings and delivered four invited lectures, including lectures at the University of Massachusetts at Amherst and Albemarle. He was a founding panelist of the Initiative for a Carbon Negative Economy consortium. In fall 2012, he taught 10.492 Heterogeneous Catalysis for Energy Applications and was a co-instructor in 10.291. In spring 2012, Professor Roman taught a new graduate course, 10.S95 Modern Concepts in Heterogeneous Catalysis.

Gregory C. Rutledge is the Lammot du Pont professor of chemical engineering. Professor Rutledge's research involves the molecular engineering of soft matter. The synergistic combination of molecular simulation and experimentation as practiced by the Rutledge group to accelerate discovery of new materials is reflected in the principles of the *Materials Genome Initiative for Global Competitiveness*, a report recently issued by the National Science and Technology Council. The Rutledge group developed process-structure-property relationships for advanced plastics by molecular simulation. In the lab, they are pioneering the technology of "electrospinning" for the fabrication of novel nanofibers and membranes for a variety of applications. Over the past year, Professor Rutledge delivered invited, plenary, or keynote lectures at a variety of international venues including Canada, China, Korea, Thailand, Tokyo, and the United States; in China, he was the guest of the vice-governor of Jiangsu Province and the president of Jiangnan University. He is co-editor of the *Handbook of Polymer Crystallization* and associate editor of the *Journal of Engineering Fibers and Fabrics*, and on the editorial boards of the journals *Macromolecules* and *Polymer*. He is co-chair of the Committee on Research Computing at MIT and coordinator of ABET accreditation for the Department of Chemical Engineering.

Professor Hadley Sikes and her research group continued their work in the areas of polymer reaction engineering and protein engineering with the overarching goal of improving human health. One of the lab's specialties is polymerization-based amplification, a technique co-invented by Professor Sikes for use in low-cost molecular diagnostics. This year, the Sikes lab published two papers about dramatic improvements to the technique and one paper on the topic of a protein reagent for use in epigenotyping tests. Professor Sikes served the American Institute of Chemical Engineers by organizing all of the content related to biosensors at the upcoming annual meeting, including a sensors topical conference and several sessions in the materials and bioengineering divisions.

Professor George Stephanopoulos received the Founders Award for Outstanding Contributions to the Field of Chemical Engineering from the American Institute of Chemical Engineers. Along with his colleague Professor Barton, he received a National Science Foundation grant for proposed research titled “Directed Assembly of Nanoscale Process Systems.” In January, he presented a plenary lecture (“Systems Thinking in the Management of Process Operations”) at the joint session of FOCAPO 2012 and CPC VIII and presented an outline of “Revamping Goals and Content of a Process Dynamics and Control Course” in a panel discussion at the same session.

Professor Gregory Stephanopoulos is the W.H. Dow professor of biotechnology and chemical engineering and director of the Laboratory of Bioinformatics and Metabolic Engineering. His research focuses on two areas: the advancement of metabolic engineering as the enabling technology for biosynthesis of biofuels and biobased products from renewable resources and the investigation of the metabolic aspects of cancer with a particular focus on the identification of therapeutic metabolic targets. In the latter area, a major breakthrough published in the journal *Nature* was the identification of reductive carboxylation as a key pathway supplying carbon nutrients for lipid synthesis by cancer cells under hypoxia. Professor Stephanopoulos continued his service on the advisory boards of four academic institutions and as chair of the managing board of the Society for Biological Engineering, which promotes the integration of biology and engineering to provide enabling technologies for industrial and medical applications. He continued to serve as editor-in-chief of the journal *Metabolic Engineering* and on the editorial boards of eight other scientific journals. In addition to numerous research presentations at professional society meetings (AIChE, ACS, American Society for Microbiology), he delivered a lectio magistralis on the occasion of his receiving the 2011 Eni award; he also presented plenary and keynote lectures at the Symposium of the Protein Society (Boston), the Gordon Research Conference on Plant Metabolic Engineering, the 10th Lactic Acid Bacteria Conference (the Netherlands), Academia Nazionale dei Lincei (Milan), the 1st International Conference on Electrofuels (Providence, RI), the Academy of Athens, the Hougen Symposium (Madison, WI), the Conference on Regulation of Metabolism in Cancer (Cold Spring Harbor Lab), and the 9th Metabolic Engineering Conference (Biarritz, France). He was elected as a fellow of AIChE and a corresponding member of the Academy of Athens.

Professor Strano continued his research focusing on the chemical engineering of low-dimensional systems. He was promoted to full professor in the Department of Chemical Engineering in July 2012. His work on the theory and experimental realization of thermopower wave power sources was featured on the cover of *IEEE Spectrum* and in *Physics World*. The Strano laboratory invented an all-carbon photovoltaic capable of harvesting the near infrared portion of the solar spectrum neglected by most photovoltaic devices; this work was published in *Advanced Materials* and recently featured in *The Economist*. Professor Strano’s elective course 10.585 Engineering Nanotechnology continues to enroll to maximum capacity each fall, attracting students from physics, chemistry, and nearly every engineering discipline at MIT. The Strano lab has published a series of papers (in *Nanoletters* and the *Journal of the American Chemical Society* and featured on Nanotechweb) demonstrating label-free detection of single proteins using nanosensor arrays. This past year, Professor Strano joined the editorial advisory board of *Advanced Energy Materials* and served as guest editor for *Proceedings of the National Academies of Sciences*. He began his five-year term on the American Institute of Chemical Engineering Awards Committee and also advises the US government on national awards in science and engineering. Recent Strano group alumni have accepted prestigious, tenure-track academic positions at the Memorial Sloan-Kettering Cancer Center (Daniel Heller), the Ulsan National Institute of Science and Technology (Chang Young Lee), Hanyang University (J.H. Kim), the Gwangji Institute of Science and Technology (M.H. Ham), and Kyungwon University (Jae Hee Kim).

William A. Tisdale began his position in the Department of Chemical Engineering in January 2012, where he is currently the Roddey career development assistant professor. Tisdale's research interests lie in understanding and controlling the movement of energy in nanostructured materials. The Tisdale research group currently consists of three graduate students and one postdoc, and the group is awaiting completion of renovated lab space in Building 66.

Professor Trout continued in his role as director of the Novartis-MIT Center for Continuous Manufacturing. Together with colleagues at MIT and Novartis, he has renewed the center for another five years. He has also continued his role as co-chair of the SMA program on chemical and pharmaceutical engineering, in addition to running a laboratory of 25 graduate students and postdocs focusing on pharmaceutical small-molecule manufacturing and biopharmaceutical formulation and stabilization. Recent scientific accomplishments include licensing a new algorithm to predict and engineer out instability (now used in over 20 companies), developing new insights into heterogeneous nucleation and using that information to engineer surfaces for the desired effect, and inventing new equipment for small-molecule pharmaceutical manufacturing. He gave more than 10 invited talks and published or submitted over 30 research papers. Last fall, he was presented the Annual Impact Award from AIChE's Computational Molecular Science and Engineering Forum.

Professor Wang continued his research and teaching activities in the SMA program. He is co-advisor to four PhD candidates in the program. In 2011, two of his SMA students received their PhD degrees. He has two PhD students at MIT, and in 2011 one of the candidates graduated. He continued to direct and teach in the 10.48s Fermentation Technology annual summer course. In August 2011, this course was offered at MIT for the 48th consecutive year, making it the longest-running summer course at MIT. He recently turned over the directorship to Professor Prather. In March 2012 he traveled to Nanjing, China, to initiate a $50 million, five-year research collaboration with the city of Nanjing. In April, he was in San Diego to inaugurate the D.I.C. Wang Award for Excellence in Biochemical Engineering.

Professor Wittrup was inducted into the National Academy of Engineering this year, as noted above, for "developments in protein engineering, protein expression, and quantitative pharmacology." Wittrup group alumni news included the following: Greg Thurber (PhD '08) accepted a position as assistant professor of chemical engineering at the University of Michigan; Jennifer Cochran (postdoctoral '04) was recommended for tenure in the Bioengineering Department at Stanford University; Anne Robinson (PhD '94) was named department head of chemical engineering at Tulane University; and Margie Ackerman (PhD '09) received large grants from the Gates Foundation and NIH to support her research on HIV as an assistant professor of bioengineering at Dartmouth.

Research Highlights

Advanced Control of Pharmaceutical Crystal Manufacturing (Richard D. Braatz)

The global pharmaceutical industry is facing increased pressure to improve efficacy, safety, and manufacturing efficiency, with the latter especially important for making drug compounds available for treating life-threatening diseases such as malaria or AIDS in the least economically developed countries. Most pharmaceutical manufacturing processes include a series of crystallization processes to achieve high purity and to produce the desired final crystal form. The operating conditions of the crystallizations determine the physical properties of the products, including crystal purity, shape, and size distribution. These properties in turn determine the efficiency of subsequent manufacturing operations and product effectiveness, such as bioavailability and shelf life. For pharmaceuticals that exhibit multiple polymorphs (that is, multiple crystal lattice structures), the crystallization process operations also affect the polymorph produced. The polymorphic phase affects the drug crystal's properties such as dissolution and toxicity, which are important from a consumer and regulatory point of view (see Figure 2 for photographs of two polymorphic forms of the same molecule). Improved control of crystallization processes offers possibilities for better crystal product quality, shorter process times, and reductions in or elimination of compromised batches.

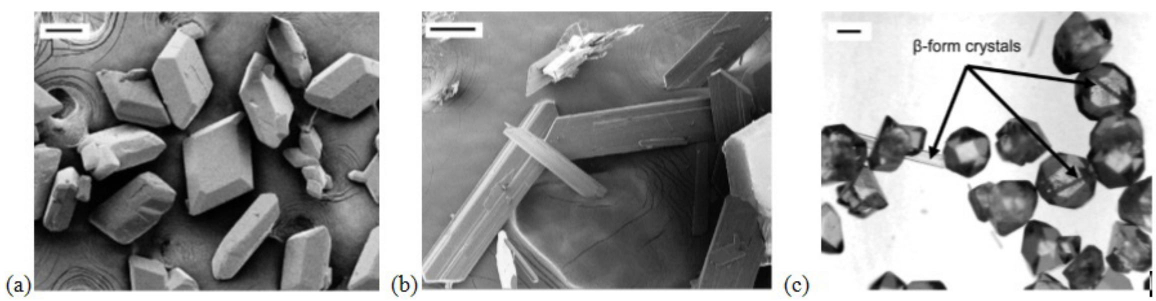


Figure 2. Scanning electron micrographs of (a) alpha-form and (b) beta-form L-glutamic acid crystals (scale bars = 100 microns) and an optical microscopy image of stable beta-form crystals growing uncontrollably from the surfaces of metastable alpha-form crystals (scale bar = 180 microns).

Due to increasing structural complexity, multiple polymorphs (different crystalline arrangements of the same compound) are more frequently encountered in the pharmaceutical industry. Manufacturing of a specified metastable polymorph in a controlled and repeatable manner is extremely challenging due to the need to prevent nucleation of a more stable form from the surface of the metastable form (Figure 2). Once crystals of the stable polymorphic form are nucleated, they will continue to grow and will induce the dissolution of the metastable crystals. Methods developed for selective crystallization of the metastable form include identifying a critical level of seed loading necessary to suppress the nucleation of any crystal forms and using molecular additives to stabilize the metastable form. These approaches are system specific with uncertain applicability to other polymorphic systems.

Richard Braatz's laboratory has developed technologies for the manufacturing of pharmaceutical crystals to control their shape, size distribution, and polymorphic form. Regardless of which product characteristic is desired, the underlying strategy is to employ control technology to kinetically operate the pharmaceutical crystallization process to manufacture the desired product, rather than allowing the product's crystal characteristics to be specified by thermodynamics. Employing mathematical models and systems analysis, the Braatz laboratory developed and predicted the success of the technologies theoretically and confirmed them experimentally by application to several model organic compounds including pharmaceuticals and amino acids.

For example, crystals of highly uniform size with a narrow size distribution were manufactured by inducing crystal nucleation and growth within two impinging jets operating under high velocity, to form a highly turbulent fluid region between the jets (Figure 3). This operation resulted in very large and spatially uniform driving forces that produced highly uniform crystal nuclei (Figure 4a) that subsequently grew in a spatially uniform flow. It was shown theoretically and confirmed experimentally that these crystals could be continually added to a controlled crystallizer to produce nearly any specified size distribution.

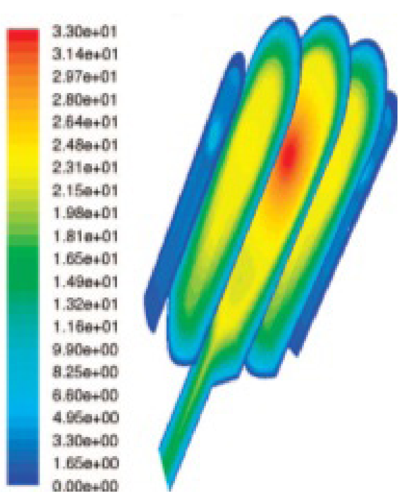


Figure 3. Local turbulent Reynolds numbers in a confined chamber with two impinging jets (one at the left and one at the right, about one third from the top of the chamber). Simulations combined computational fluid dynamics with spatially varying population balance modeling of the evolution of the crystal size distribution as a result of nucleation and growth. Such simulations are useful in process understanding and to ensure that the inlet jet velocities are high enough to ensure rapid mixing.

Crystal shape was shown to be controllable (Figure 4b) by creating alternating operations of crystal growth and dissolution in a mixed turbulent fluid environment. Mathematical modeling indicated that this approach resulted in much faster changes in the crystal shape relative to the predictions of past studies by exploiting the length-scale dependencies of the dissolution rates during the manufacturing process.

Technology for the control of the polymorphic crystal form was developed that employed an in-situ infrared spectroscopy, multivariate statistical analysis, in-situ laser backscattering, and nonlinear feedback control. A fully automated system determined phase equilibria and metastable limits that define an operating region that suppressed the nucleation of any crystals, and a feedback control algorithm ensured that the states moved along a specified trajectory in the operating region in the presence of disturbances. Experimental validations demonstrated the selective growth of large metastable crystals of uniform size (Figure 4c). The laboratory’s current research is employs mathematical modeling and theoretical analysis to develop continuous-flow variations of the technologies and to demonstrate these technologies in the laboratory.

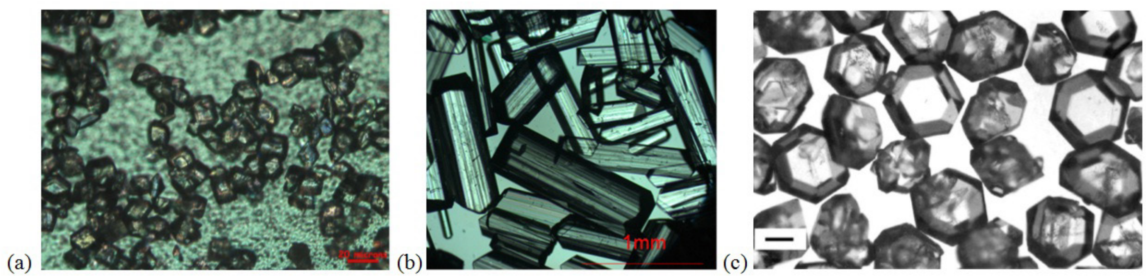


Figure 4. Exquisite kinetic control of the size, shape, and polymorphic form of pharmaceutical crystals: (a) uniformly sized crystals of L-asparagine monohydrate manufactured using a dual-impinging jet mixer (scale bar = 20 microns), (b) optical microscopy image of large organic crystals manufactured by cycling growth and dissolution, and (c) optical microscopy image of large metastable crystals of alpha-form L-glutamic acid, manufactured without the use of molecular additives under conditions in which crystals of a different polymorphic are thermodynamically stable (scale bars = 180 microns).

Pretargeted Radioimmunotherapy: Precise Delivery of Ionizing Radiation to Tumors (K. Dane Wittrup)

A goal of many cancer therapeutic strategies is to deliver a cell-killing compound specifically to tumors while sparing vulnerable healthy tissue to the greatest extent possible. This problem is made extremely difficult by the inherently passive nature of drug biodistribution: drugs are injected intravenously and then distributed everywhere throughout the body by convection and diffusion. By binding to tumor cells via specific macromolecular recognition, new drugs such as antibodies may be retained in tumor tissue while the systemic circulating drug pool is drained by excretion through the kidneys or metabolism by the liver. Unfortunately, the high systemic exposure necessary to drive adequate drug retention in tumors often leads to unacceptably high toxic effects on healthy organs.

The Wittrup group has developed a highly optimized strategy for maximizing the localization of radiometals in tumor tissues by a method known as pretargeted radioimmunotherapy (PRIT), illustrated schematically in Figure 5.

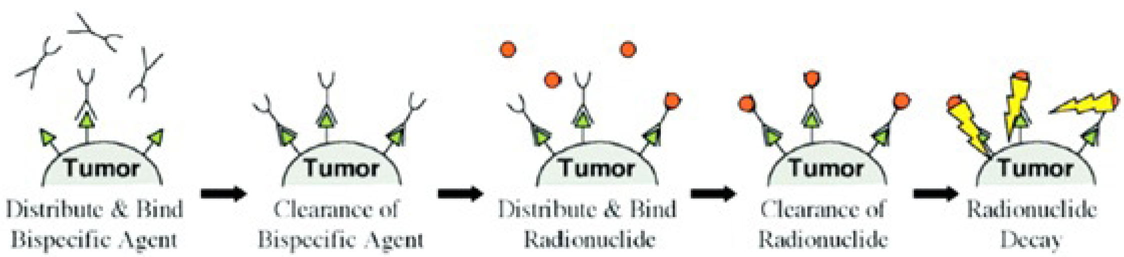


Figure 5. Pretargeting involves breaking the therapeutic agent into two parts: a bispecific antibody and a small toxic payload. The bispecific antibody can be dosed at high levels without toxic side effects, driving diffusive uptake in the tumor and retention by specific binding to the tumor cell surface. Residual bispecific antibody in the blood pool is cleared by addition of a clearing agent, and then the small toxic payload is administered. Its small size leads to both rapid diffusion into the tumor and rapid excretion through the kidneys, which minimizes systemic exposure. The bispecific antibody on tumor cell surfaces captures the payload and holds it close to the tumor cells until ionizing radiation is released, killing the cell.

In a thesis that included protein engineering, pharmacokinetic modeling, and animal studies of biodistribution, Kelly Davis Orcutt (PhD '09) developed a PRIT method that delivers radiation with unprecedented specificity to tumor tissues. First, Kelly developed a novel bispecific antibody topology with an scFv fused to the C terminus of the light chain, which modularly allows addition of a radiometal chelate-binding domain to essentially any therapeutic antibody. She then performed biodistribution studies of alternative forms of the chelated radiometal to find the most rapidly clearing version that would not be retained in healthy tissues. Following a simple pharmacokinetic model to guide the affinity goal, she performed affinity maturation by directed evolution to create a binding domain that binds to metals in the DOTA chelator with extremely high affinity. Finally, she brought all of the pieces together to demonstrate the capabilities of this system for pretargeting and described the results with another simplified pharmacokinetic model. The performance of the system is shown in Figure 6.

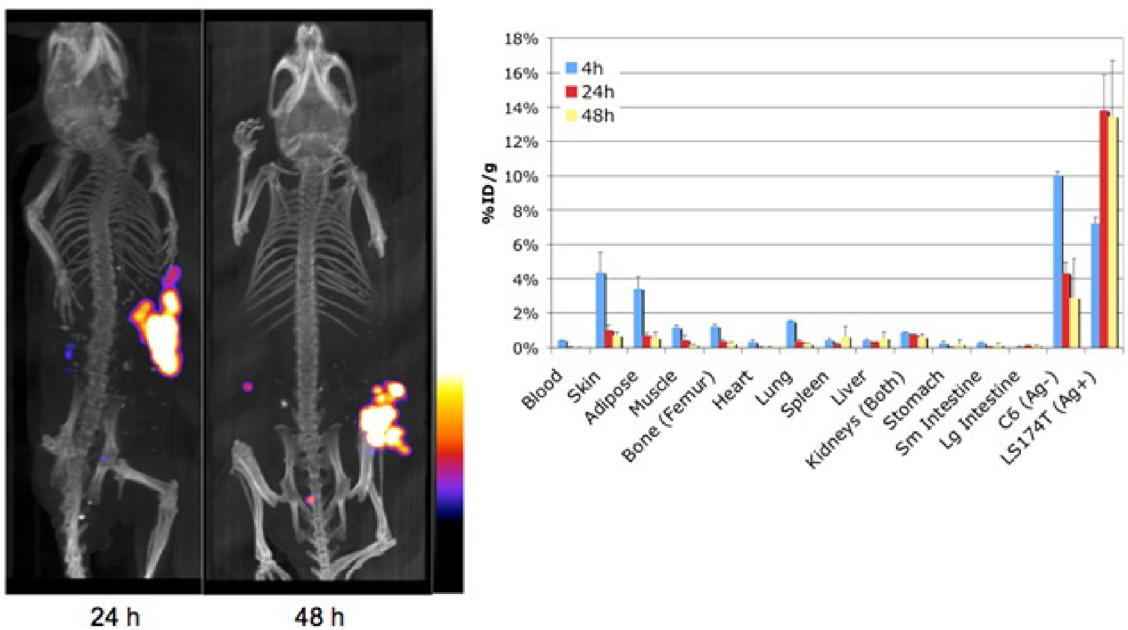


Figure 6. Left: SPECT/CT image of pretargeted radioimmunotherapy. The skeletal anatomy of the mouse is determined by CT, and the localization of radiation in the tumor is determined by SPECT (single-photon emission computed tomography) imaging of gamma emissions and depicted by the heat color scale. Highly specific tumor localization is clearly achieved. Right: quantitative biodistribution as determined by necropsy and scintillation counting of individual organs. At 24 and 48 hours, the tumor:blood and tumor:kidney tissues attain unprecedentedly high values.

The components of this pretargeting system are now being tested, with plans for clinical trials, with collaborators at Memorial Sloan-Kettering (Steve Larson), City of Hope (Paul Yazaki), and the Fred Hutchinson Cancer Research Center (Ollie Press). Dr. Orcutt is working at inviCRO, a consulting firm in the area of preclinical and clinical imaging consulting and research.

Annual Lectures, Seminars, and Symposia

During 2011–2012, the Chemical Engineering Department hosted a distinguished group of academic and industry leaders, as well as a memorial symposium for professor emeritus Adel F. Sarofim, who passed away in December 2011. Highlights are noted below. Webcasts for all major lectures can be accessed at http://web.mit.edu/cheme/news/webcast.html.

11th Frontiers of Biotechnology Lecture (October 14, 2011): "Development of Liquid Fuels from Lignocellulose." Chris Somerville of the Energy Biosciences Institute at the University of California, Berkeley, is a biochemist who has been recognized for his work on the biochemistry, cell biology, genomics, and genetics of various aspects of plant and microbial growth and development. He was one of the early advocates for the development of Arabidopsis as a model system to dissect plant growth and development and was the first chairperson of the Arabidopsis Genome Initiative, an international collaboration that completed the sequence of the first plant genome. The majority of his research contributions have concerned the synthesis and modification of membrane and storage lipids and the synthesis of polysaccharides. His lecture covered the efficient production of cellulosic fuels by biochemical routes, which will require innovation in three main areas: sustainable production of feedstocks that do not compete with food production, depolymerization of feedstocks, and conversion of feedstocks to liquid fuels.

26th Hoyt C. Hottel Lecture (April 13, 2012): "Sunlight-Driven Hydrogen Formation by Membrane-Supported Photoelectrochemical Water Splitting." Nathan S. Lewis (PhD '81) of the California Institute of Technology and the Beckman and Kavli Nanoscience Institutes discussed his current ("unsolved") research. His research group is developing an artificial photosynthetic system that will use only sunlight and water as the inputs and will produce hydrogen and oxygen as the outputs. They are taking a modular, parallel development approach in which the three distinct primary components—the photoanode, the photocathode, and the product-separating but ion-conducting membrane—are fabricated and optimized separately before assembly into a complete water-splitting system.

18th Alan S. Michaels Lecture (April 27, 2012): "Lessons in Biomedical Innovation and Biotechnology." John Maraganore, CEO of Alnylam Pharmaceuticals, discussed the biotechnology industry and its emergence as the world's major source of new innovative medicines, delivering profound impact in the treatment of human disease. At its best, biotechnology recognizes disruptive discoveries in basic research that can be harnessed as a platform for drug discovery and development. RNA interference (RNAi) represents one such research discovery, and Alnylam represents an example of an entrepreneurial effort to advance this science toward new drugs. Important lessons in the story of RNAi and Alnylam and their broader implications were shared.

34th Warren K. Lewis Lecture (May 4, 2012): "'Simplicity' as a Component of Invention." George M. Whitesides of Harvard University discussed general simplicity, examples of simplicity through the evolution of the Internet, and issues in his own research that illustrate the principles of simplicity. Whitesides's scientific contributions come from such diverse areas as nuclear magnetic resonance spectroscopy, materials and surface science, microfluidics, and nanotechnology. He is best known for his insights into surface chemistry, understanding how molecules arrange themselves on a surface. The discovery laid the groundwork for advances in nanoscience that led to new technologies in electronics, pharmaceutical science, and medical diagnostics. His recent research interests include energy, the origin of life, and science for developing economics.

Adel F. Sarofim Memorial Symposium (May 11, 2012): On December 4, 2011, the department and the chemical engineering industry lost a dear friend and innovator, Adel F. Sarofim. The department hosted a memorial symposium to remember his career and life. The symposium included talks from his former students and colleagues. Speakers included:

- Jim Noble '68, Sarofim student and former professor, MIT Chemical Engineering
- János Béer, professor emeritus of chemical and fuel engineering, MIT
- Ahmed Ghoniem, Ronald C. Crane (1972) professor of mechanical engineering, MIT
- John Heywood, professor emeritus of mechanical engineering and Sun Jae professor, MIT
- Mike Modell '60, Sarofim student and former professor, MIT Chemical Engineering
- David Marks, Goulder family professor emeritus of civil and environmental engineering and engineering systems, MIT
- Roberto Ruiz, president and COO, OnQuest Inc.
- Simon Hanson '74, chief engineering officer, Fuel & Furnace Consulting
- Leon Glicksman, professor of building technology and mechanical engineering, MIT
- JoAnn Lighty, professor and chair of chemical engineering, University of Utah

Figure 7. Klavs Jensen, head of the Department of Chemical Engineering, discusses the legacy of professor emeritus Adel Sarofim during the symposium in Professor Sarofim's honor on May 11, 2012.

A webcast and photos from the Sarofim Symposium can be found at http://web.mit.edu/cheme/news/2012/sarofim-symp.html.

Departmental Awards

The department awards ceremony took place on May 14 in the Gilliland Auditorium of the Ralph Landau Building. We are pleased to recognize this year's recipients of the Outstanding Faculty Awards: Professor Deen and Professor Chakraborty were the graduate students' choice, and professor Narendra Maheshri was selected by the undergraduate students.

The Edward W. Merrill Outstanding Teaching Assistant Award was presented to PhD student Cary Opel for his work in 10.37 Chemical and Biological Reaction Engineering. The Outstanding Graduate Teaching Assistant Award was presented to PhD student Karthik Shekhar for his service to 10.40 Thermodynamics. 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 Karthik Shekhar and Muzhou Wang.

Chemical Engineering Special Service Awards were conferred to the members of the Graduate Student Council: Irene Brockman, Noemie-Manuelle Dorval Courchesne, Connie Gao, Justin Kleingartner, Aditya Kunjapur, Mark Molaro, Stephen Morton, Sven Schlumpberger, Carl Schoellhammer, Stephanie Schulze, and Zack Ulissi. In addition, Stephen Morton was awarded the Chemical Engineering Rock Award for his contributions to athletics within the department.

Our undergraduates also earned numerous accolades over the course of the year. The following undergraduate students were recognized for their service to the student chapter of the American Institute of Chemical Engineers: Tim Chang, Saloni Jain, Molly Kozminski, Mary Boyd, Allison Hinckley, Michele Lu, Lauren Kazmierski, Kelechi Nwosu, Mark Kalinich, Paige Finkelstein, Charlotte Kirk, and Ksenia Timachova. The Xi Chapter of Phi Beta Kappa voted to invite one member of the Chemical Engineering Class of 2012, Yunxin Jiao, to become a member of the society in recognition of her excellent academic record and commitment to the objectives of a liberal education. Joshua Cohen and Allison Hinkley were the recipients of the Gates Cambridge Scholarship for 2012. Nikita Consul was recognized as an Amgen Scholar. The Merck Fellowship Award was presented to Tejas Navaratna and Jared Forman in recognition of their scholastic excellence. The Robert T. Haslam Cup, which recognizes outstanding professional promise in chemical engineering, went to Mengfei Yang. The department's oldest prize, the Roger de Friez Hunneman Prize, is awarded to an undergraduate who has demonstrated outstanding achievement in both scholarship and research; this year it went to Shawn Pan. This year was the second year that we presented the Wing S. Fong Award. It is awarded to the chemical engineering senior of Chinese descent with the highest cumulative GPA, in honor of Wing S. Fong for his hard work and dedication to his adopted home, university, and country. This year's price was awarded to two equally worthy students: Yunxin Jiao and Yuewei Ji.

The department is quite pleased to recognize Gwen Wilcox as its outstanding employee of the year for her dedication and exceptional service to faculty, staff, and students. PhD student Rachel Howden was presented with a Chemical Engineering Individual Accomplishment Award for her contributions to making Chemical Engineering a welcoming and familial department through her hospitality and incredible baked goods. Gracie Dorneus was also presented with a Chemical Engineering Individual Accomplishment Award for her contributions to the Administrative Services Office. The School of Engineering Infinite Mile Award was given to systems administrator James Hardsog for his exceptional support of the entire department's information technology needs. The Administrative Services Office (Phoebe Spence Biagiotti, Ximena Forero-Irizarry, David Kubiak, Richard Lay, Renee LeBlanc, and Christine Rodriguez) received a team Infinite Mile Award from the School of Engineering for their extremely professional and capable financial management.

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

Klavs F. Jensen
Department Head
Warren K. Lewis Professor of Chemical Engineering

William H. Green
Executive Officer
Hoyt C. Hottel Professor of Chemical Engineering