Department of Chemical Engineering

Overview

The Department of Chemical Engineering (ChemE) continues to be ranked as the world's number-one chemical engineering program, a position it has held for the past 26 years. Many of our faculty received major honors and awards this year. Despite this continuity, there have been some significant changes in the physical space that the department has occupied for almost 40 years and a recent change in leadership.

Research volume in the department continues to be strong, increasing by 7% this year to $57.6 million. Of these funds, $23.6 million were handled directly through the department, and the rest was handled by different cost centers at MIT, including the Koch Institute for Integrative Cancer Research, the MIT Energy Initiative, the Institute for Soldier Nanotechnologies, and the Ragon Institute. The strong engagement with these interdisciplinary centers continues to provide a robust basis for innovation, and provides our students with experience solving important and difficult real-world problems.

Professor Klavs F. Jensen stepped down as department head in July 2015, after leading the department for eight years. Among his many accomplishments are significant space renovations, including the modernization of Building 66 and new faculty laboratories in buildings E17 and E18; successful recruiting 10 new faculty members; and exemplary leadership. His many years of service are greatly appreciated by the faculty and staff of the Department of Chemical Engineering.

Paula T. Hammond, the David H. Koch professor in engineering, became the new head of the Department of Chemical Engineering, effective July 13, 2015. Professor Hammond is an accomplished researcher with a strong record of service to MIT and the department. Her many awards and honors include the Alpha Chi Sigma Award for Chemical Engineering Research in 2014, the American Institute of Chemical Engineers (AIChE) Charles M. A. Stine Award in Materials Engineering and Science in 2013, the Junior Bose Faculty Award for Excellence in Teaching in 2000, a National Science Foundation (NSF) CAREER Award in 1997, and the MIT Karl Taylor Compton Prize in 1992. The department looks forward to Professor Hammond's new ideas and vision for the future.

William Green stepped down as executive officer in January 2015 and was replaced by Patrick Doyle. In turn, Patrick Doyle stepped down as graduate officer and was replaced by Richard Braatz. Barry Johnston serves as undergraduate officer, and Paula Hammond served as postdoctoral officer but will be succeeded by William Green at the start of this academic year. Chemical Engineering continues to claim two Institute Professors as primary faculty members—Daniel I.C. Wang and Robert S. Langer. Several Chemical Engineering faculty play important leadership roles on campus: Robert C. Armstrong is director of the MIT Energy Initiative, Arup K. Chakraborty is director of the Institute for Medical Engineering and Science, Dane Wittrup is associate director of the Koch Institute for Integrative Cancer Research, and Karen Gleason is associate provost.

Space Changes and Renovations

Renovations to Building 66, home of the Department of Chemical Engineering for close to 40 years, were recently completed. The much-needed modernization of Building 66 was a $45 million project of which more than $26 million was secured from the Institute and private donor funding. The remaining fundraising goal is roughly $19 million, and the department is in active conversations with select alumni and friends about gifts to support laboratory and teaching spaces. The renovations encompass more than half of the building's total footprint, including every floor and all building operations. The completed improvements include:

- Modernization of the laboratories to reflect the experimental and design-oriented range of research conducted by today's faculty and students
- Offices for graduate students distinct from the laboratory areas
- Elevated safety standards building-wide through new design and upgraded infrastructure and equipment
- Redesigned faculty offices for more efficient use of space
- Undergraduate lounge and meeting space, along with informal lounge areas to encourage the formal and informal interactions that support a strong learning community
- Tinted exterior windows that reduce solar load, which will stabilize interior climate and working conditions throughout the day
- Fully upgraded building systems, including heating, lighting, and ventilation

The department is especially thankful to Professor Green (executive officer during the renovations) and Steve Wetzel (Chemical Engineering facilities coordinator), who were both deeply involved in executing and managing this important project.

Arrivals and Promotions

Professors Bradley Olsen and Yuriy Roman were promoted from assistant professor to associate professor without tenure. Heather Upshaw was hired as the Chemical Engineering Leadership Giving Officer. Upshaw previously served as Wellesley College's director of parent and family giving. Faika Weche was promoted to the SRS Program, and Bonnie Jean MacEachern was promoted to financial coordinator.

Research and Recognition

Many senior Chemical Engineering faculty members received major awards for their research achievements. Robert Langer received the Queen Elizabeth Prize for Engineering. A complete list of Langer's awards is given below. Richard Braatz received the AIChe Computing in Chemical Engineering Award. Karen Gleason was elected to the National Academy of Engineering, became a fellow of AIChE, and received the AIChE Charles M.A. Stine Award (2014). Paula Hammond received the AIChE Alpha Chi Sigma Award (2014). Emeritus professor Edward W. Merrill was elected to the Institute of Medicine. Gregory Rutledge received the 2014 Fiber Society Founder's Award. Gregory Stephanopoulos received the AIChE Walker Award and was elected president of AIChE in 2015.

Three junior faculty won National Science Foundation CAREER Awards: Brad Olsen, Yuriy Roman, and William Tisdale. Kwanghun Chung became a Searle Scholar. In addition, Brad Olsen was awarded an Alfred P. Sloan Fellowship.

Undergraduate Education

Current Status of the Undergraduate Program

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, Family Weekend, and other activities. Sixty-six SB degrees were conferred in June 2015, 51% of which were awarded to women. Student quality remains high. The distribution of undergraduate students by class over the last 10 years is shown below.

Undergraduate Enrollment over the Last 10 Years

Class Year	05–06	06–07	07–08	08–09	09–10	10–11	11–12	12–13	13–14	15–16
Sophomores	100	95	96	87	87	80	72	61	67	57
Juniors	83	75	67	77	68	71	73	63	63	66
Seniors	53	83	77	75	73	75	75	69	58	64
Total	236	253	240	239	228	226	220	196	188	187

The 10-ENG program leading to the engineering bachelor of science 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 have recently received ABET accreditation for 10-ENG as a degree in engineering. The initial specialization tracks include energy, materials, biomedical, and environmental. Student response has been cautious (fall 2014 enrollment of nine).

The average starting salary for graduates of the Department of Chemical Engineering is $85,516 (2015 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 and to the continued high demand for our students. The senior survey indicates that for 2014, 37% of our students continued their studies in graduate or professional schools.

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 are president Julia Sun, vice president for administration and financial officer June Park, vice president for public relations Anthony Concepcion, vice president for internal relations

Whitney Loo, vice president for external relations David Hou, freshman and alumni committee members Kali Benavides and Spencer Wenck, intercollegiate chairs Joyce Zhang and Robbie Shaw, industrial affairs committee member Githui Maina, webmaster Allen Leung, 2015 regional conference chair Kelsey Jamieson, sponsorship chairs Allison Hallock and Shahrin Islam, Class of 2015 representatives Michael Fu and Joel Schneider, Class of 2016 representatives Pam Cai and Nancy Lu, and Class of 2017 representatives Dheevesh Arulmani and Sophia Liu.

Graduate Education

Current Status of the Graduate Program

The graduate program in the Department of Chemical Engineering offers master's of science degrees in chemical engineering (MS) and in chemical engineering practice (MSCEP), the doctor of philosophy (PhD) and doctor of science (ScD) degrees in chemical engineering, and the doctor of philosophy degree 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 237, with 222 in the doctoral program and 15 master's-level degree candidates. In the doctoral program, 213 students are in the PhD/ScD track and nine in the PhDCEP track. In the master's-level program, 14 are in the MSCEP track. Thirty-two percent of our graduate students are women, and five percent are members of underrepresented minority groups. Thirty-eight of our graduate students were recipients of outside fellowship awards, including from the National Science Foundation, the National Institutes of Health, and the Department of Defense. The distribution of graduate students by degree is shown in Table 2. During AY2015, 68 advanced degrees were conferred, including 38 doctoral degrees and 30 master's degrees. Thirty-four students passed the written portion of the doctoral qualifying exams and are thus one step closer to being promoted to candidacy for the PhD/ScD or PhDCEP. The department received 457 applications for admission to the doctoral program, offered admission to 58 individuals, and received 40 acceptances, or a 69% acceptance rate. Out of 96 applications for master's-level degrees, the department made eight offers and received eight acceptances, a 100% yield. Among the incoming graduate class, 17 are women. The average undergraduate grade point average of the incoming graduate class was 4.95.

Graduate Enrollment over the Last 10 Years

Degree level	**05–06**	**06–07**	**07–08**	**08–09**	**09–10**	**10–11**	**11–12**	**12–13**	**13–14**	**14–15**
Master's	16	18	26	32	38	28	20	10	11	15
Doctoral	203	217	212	228	203	212	224	212	211	222
Total	**219**	**235**	**238**	**260**	**241**	**240**	**244**	**222**	**222**	**237**

Research Centers

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

Biologically Derived Medicines on Demand

This DARPA-sponsored program (Defense Advanced Research Projects Agency) successfully entered into a second phase of work in June 2015. The program aims to establish an end-to-end manufacturing system for making small numbers of doses of biologic therapeutics at point-of-care in approximately one day. The MIT-led team emphasizes small-scale continual production and purification, incorporating concepts of quality-by-design, process analytics, plant-scale control, and real-time release

Over the past two years, the team has successfully enabled a "breadboard" prototype that produced tens to thousands of doses of two different biologic drugs (a hormone and a cytokine used to treat certain cancers). The biophysical attributes and bioactivity of the drugs were comparable to reference materials of currently approved versions of these medicines. The team also made advances in new technologies for measuring the identity, quality, and bioactivity of small quantities of produced proteins using a range of modalities, including Raman spectroscopy, electrokinetic separation in nanofluidic channels, and modulation of fluorescence signals from carbon nanotube arrays. The ability to make biologic drugs at small scales anywhere opens up new opportunities to improve health care in battlefield medicine, global health, orphan diseases, and ultimately personalized medicine.

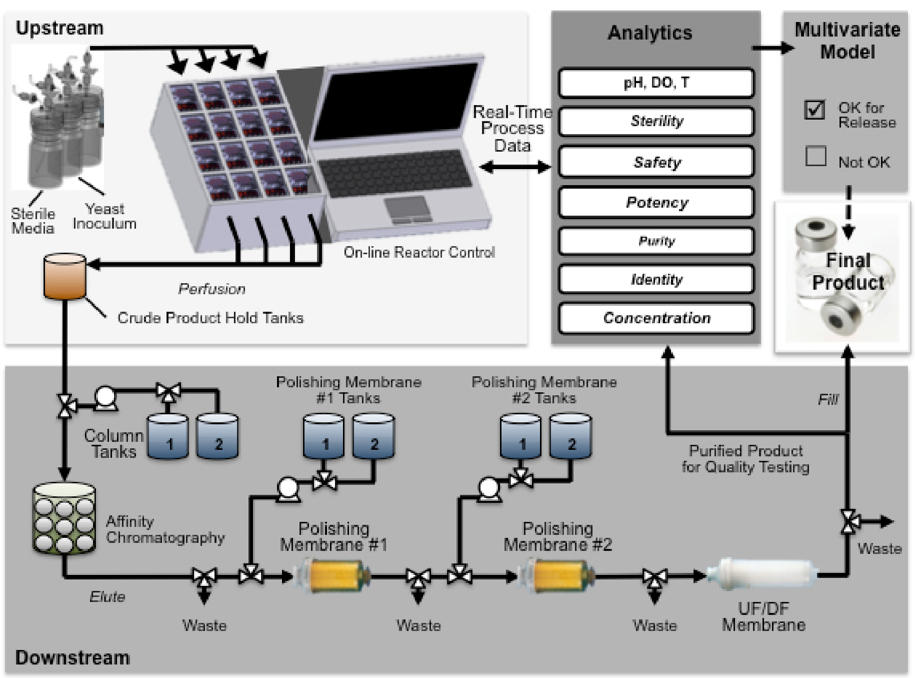

Figure 1. Schematic of prototype Integrated, Scalable Cyto-Technology (InSCyT) for the flexible manufacturing of biologics on demand.

The objectives of this project are ambitious. Today, manufacturing biologics requires weeks to months to produce and release, using many separate operations, often spread physically over a large facility and the world. To envision something akin to a 3-D printer in capability—a manufacturing facility that is fully portable and flexible to make many different products—is to press the limitations of what is possible in biomanufacturing for producing high-quality therapeutics for patients.

The interdisciplinary research team comprises six labs spanning Chemical Engineering, Electrical Engineering, and Biological Engineering at MIT, as well as labs from the Barnett Institute at Northeastern University, Rensselaer Polytechnic Institute, and Pall Corporation. Research topics include small-scale perfusion fermentation of a yeast host, synthetic biology approaches to controlling production and providing flexibility in products, novel purification strategies and cutting-edge technologies for affinity capture and polishing of products, nanometer-scale and optical systems for evaluating product quality and potency, and systems control strategies. The integration of technologies is an essential element of the program to realize an efficient and small manufacturing platform that could be portable to reach remote locations. Advances in the technologies evaluated and developed in this program will help to inform new strategies for integrated and continuous manufacturing of biologics at commercial scales. As part of the program, an active dialogue between the program team, industry experts, and the US Food and Drug Administration continues with the aim of understanding and defining best strategies towards realizing such transformational shifts in manufacturing on demand. The project is led by Professor J. Christopher Love.

Novartis-MIT Center for Continuous Manufacturing

In May 2015, the Novartis-MIT Center for Continuous Manufacturing completed the eighth year of a 10-year research collaboration between Novartis and MIT, aimed at transforming pharmaceutical manufacturing from batch to fully integrated continuous manufacturing. After organizing and hosting the International Symposium on Continuous Manufacturing of Pharmaceuticals at MIT last year, the center remains focused on implementing continuous manufacturing into the pharmaceutical industry.

During the past year, the emphasis has been on advancing the center's numerous projects, which cover a range of activities needed to continuously manufacture pharmaceuticals from end to end. To create active compounds requires a range of reactions that can produce not only the existing drug molecules but also new compounds. Because purification of the active compounds is mainly achieved through crystallization, many of the projects address crystallization and related technologies, and because tableting was selected as the primary method of creating the finished pharmaceutical products, several novel processes to continuously produce tablets were explored. Several technologies developed at MIT have been successfully transferred to Novartis, and many current projects are on track to be finalized and ready to translate over the last two years of the collaboration.

In the past year, researchers produced approximately 50 publications and presented findings at numerous international and national meetings. In addition, the center has filed 10 patent applications for breakthrough technologies.

As a follow-up to the Second International Symposium on Continuous Manufacturing of Pharmaceuticals, eight white papers were published in the March 2015 edition of the *Journal of Pharmaceutical Sciences,* covering all of the major areas of continuous manufacturing of pharmaceuticals. The papers were well received and heavily downloaded. A third symposium being planned for Cambridge/MIT in June 2016 will emphasize the achievements of the past two years and remaining areas that need more work.

The center is led by director Bernhardt L. Trout and Novartis head of continuous manufacturing Markus Krumme. The team also includes associate director Keith D. Jensen and program coordinator Faika E. Weche.

The David H. Koch Institute for Integrative Cancer Research

Five Chemical Engineering research laboratories are housed in the David H. Koch Institute for Integrative Cancer Research: those of faculty members Daniel Anderson, Paula Hammond, Robert Langer, Christopher Love, and Dane Wittrup. The Koch Institute brings together scientists and engineers with appointments spanning the campus to collaborate on research aimed at new cancer therapies. Dane Wittrup serves as the Koch Institute's associate director.

Faculty Notes

Robert C. Armstrong served as director of the MIT Energy Initiative (MITEI), which continues to grow rapidly in its research, educational, and outreach components. Twelve companies sponsor research as founding and sustaining members of MITEI; altogether, the energy initiative has about 71 industrial and public partners across four continents. MITEI has helped to bring in nearly $600 million in support over its first eight years of operation and 350 energy graduate fellowships spread over 22 departments. Professor Armstrong serves on the Scientific Commission of the Eni Enrico Matteo Foundation, the PULSE Award selection committee for EDF, the external advisory board of the National Renewal Energy Laboratory, and the advisory boards of chemical engineering departments at Northwestern University and Washington University and the Energy Institute at Texas A&M University. He gave numerous lectures on energy around the world during the past year.

Martin Z. Bazant continued research in electrochemistry, transport phenomena, and applied mathematics. His lab achieved control of metal dendritic growth in porous media by surface conduction and modeled Marcus-Hush electrode kinetics, solid oxide fuel cell impedance, and Li-ion battery phase transformations. He published 15 papers and gave 10 invited talks. Enrollment in 10.626 Electrochemical Energy Systems tripled. He was awarded the Global Climate and Energy Project Chair for his sabbatical at Stanford. He became chief scientific advisor for Saint Gobain Ceramics and Plastics's Northboro research and development center and helped create a practice school station there for MIT.

Daniel Blankschtein's research group conducts fundamental theoretical and experimental research in the area of colloid and interface science, with emphasis on industrial and biomedical applications. Recent research advances included molecular dynamics simulation and kinetic modeling of the dispersion and stabilization of 2D materials like graphene, MoS2, and phosphorene in various solvents, molecular modeling of the wetting behavior of water on graphene and other 2D materials, molecular-thermodynamic modeling of the formation and stabilization of reconfigurable multiple emulsions, oral drug delivery using an ingestible microneedle pill (mPill), ultrasound-assisted delivery of drugs to the colon to treat ulcerative colitis, and ultrasound-assisted transdermal vaccination. Blankschtein's group interacts closely with several companies that make use of software developed by his group to facilitate surfactant formulation design. His teaching responsibilities included the core graduate course 10.40 Chemical Engineering Thermodynamics in fall 2014 and the interdisciplinary graduate course 10.43 Introduction to Interfacial Phenomena in spring 2015. In May 2015, Professor Blankschtein received the Outstanding Teaching Award from graduate students in the Department of Chemical Engineering for the ninth time. He and his students delivered talks and presented posters at the International Ultrasonics Symposium in Chicago, the 2014 AIChE annual meeting in Atlanta, the 9th InVacs in Boston, the 5th International Colloids Conference in Amsterdam, Digestive Disease Week in Washington, and the 7th Brazilian Symposium in Medicinal Chemistry in São Paulo. Professor Blankschtein continues to serve on the editorial board of Marcel Dekker's Surfactant Science Series.

Richard D. Braatz received the AIChE Computing in Chemical Engineering Award, the top senior award in process systems engineering, "for fundamental contributions to control theory/algorithms for molecular, multi-scale, and large-scale systems with applications to chemicals, microelectronics, and pharmaceuticals manufacturing." As the department's graduate admissions officer, he led a successful recruiting year and was appointed as graduate officer. He gave numerous invited talks, including plenaries at major conferences, continued to lead systems research in many (bio)pharmaceutical manufacturing projects on campus, and served on numerous advisory and editorial boards, including as senior editor of *IEEE Life Sciences Letters.*

Fikile R. Brushett, the Raymond (1921) and Helen St. Laurent Career Development Professor of Chemical Engineergin, and his research group continued to advance the science and engineering of electrochemical energy storage and conversion. This work is supported by the Joint Center for Energy Storage Research (JCESR), the US Department of Energy (DOE) Energy Innovation Hub, MITEI, MIT-Kuwait, MITEI-Bosch, and the MIT Center for Materials Science and Engineering. Brushett published seven papers, filed two patents, and gave four invited lectures, including a plenary talk at the Barcelona Energy Challenges Symposium. He is the principal investigator of grids cell design and prototyping thrust in JCESR. He served as an instructor for 10.492 (fall 2014) and 10.301 (spring 2015).

Kwanghun Chung is a member of the core faculty of the Institute for Medical Engineering and Science (IMES) and is the Helmholtz Career Development Assistant Professor of Chemical Engineering. He is also a principal investigator at the Picower Institute for Learning and Memory. His interdisciplinary research team is devoted to developing and applying novel technologies for integrative and comprehensive understanding of large-scale complex biological systems. Professor Chung has continued to improve and develop CLARITY, a tissue-clearing technology he invented during his postdoctoral training at Stanford. CLARITY is widely recognized for providing new capacity in comprehensively studying large-scale biological systems.

Recent research advances by Chung include active transport of charged molecules within and/or from a charged matrix, an invention that has been filed with the US Patent Office. Chung was named a 2014 Searle Scholar and was selected as one of *Cell* magazine's 40 Under 40. Since July 2014, Professor Chung has traveled extensively to speak about CLARITY imaging, including at Baylor College of Medicine, Case Western Reserve School of Medicine, and Stanford University. He also taught a short course on advancements in brain-scale and automated anatomical techniques for the Society for Neuroscience. Chung taught HST.562 Imaging and Sample Processing, and has been responsible for IMES's Distinguished Lecture Series. He also served on the IMES Committee on Academic Programs and the Department of Chemical Engineering's Graduate Admissions Committee.

Robert E. Cohen was elected a fellow of the American Academy of Arts and Sciences in spring 2015. In summer 2014 he assumed the position of chairman at MatTek Corporation, which he cofounded in 1985 with emeritus chemical engineering professor Raymond F. Baddour. He gave invited lectures at Princeton University and at Stevens Institute. These lectures provided updates on the evolution of his research program that connects fundamental wetting phenomena to the solution of important engineering problems. A publication in *Physical Review Letters* PRL 114, 014501 (2015) provides a model and experimental results to support the premise that robust superhydrophobic surfaces significantly reduce skin friction drag in the regime of turbulent flow. In June 2015, Cohen and his research group hosted a delegation of students and postdocs from Princeton University for the 22nd rendition of a two-day MIT-Princeton microsymposium on polymers.

Charles L. Cooney, Robert T. Haslam (1911) Professor of Chemical and Biochemical Engineering, Emeritus, continues to teach the capstone subject 10.491 Integrated Chemical Engineering, which introduces all Chemical Engineering seniors to batch process design and pharmaceutical manufacturing. He also continues as advisor to the Singapore-MIT Alliance for Research and Technology (SMART) Innovation Center in Singapore, as a member of the Masdar MIT executive committee, and as a member of the steering committee for the Deshpande Center for Technological Innovation. He is faculty director of the summer course Downstream Processing, held through MIT's Professional Institute, and co-faculty lead on a custom Sloan executive education program for Takeda Pharmaceuticals. Professor Cooney is also an overseer of the Boston Symphony Orchestra and a trustee emeritus of the Boston Ballet.

Patrick S. Doyle is the executive officer of the Department of Chemical Engineering. He continues to advance his work on DNA polymer physics and microfluidic synthesis of functional microparticles using stop flow lithography. He received a Deshpande Center grant to commercialize his barcoded particle technologies for anticounterfeiting applications. He is actively involved in SMART. He delivered a lecture at the Gordon Conference on Microfluidics. Professor Doyle serves on the scientific advisory board of Firefly Bioworks, Lariat Biosciences, and Achira Labs. This year he was appointed the Robert T. Haslam (1911) Chair in Chemical Engineering.

Karen K. Gleason was elected to the National Academy of Engineering, received the AIChE Charles M.A. Stine Award, and was selected for the 2015 International Union of Pure and Applied Chemistry (IUPAC) Distinguished Women in Chemistry or Chemical Engineering Award. She continues in her second year as associate provost. In this role, she provides oversight of space planning, allocation, and renovations across the Institute. She is also responsible for the oversight of MIT's industry-facing offices and is co-chair of MIT's Information Technology Governance Board. In this role, Professor Gleason led the establishment of a new $25M MIT-Philips alliance. She serves on numerous boards, including those of the Ragon Institute, the Dupont-MIT Alliance, the Hong Kong University of Science and Technology-MIT Research Alliance Consortium, and the Massachusetts Competitive Partnership Academic Board. She published 18 peer-reviewed journal papers and was sole editor for the book *CVD Polymers: Fabrication of Organic Surfaces and Devices*, published by Wiley. Speaking engagements included the MIT Ideas Lab presentation at the World Economic Forum, the Adel Sarofim named lectureship at the University of Utah, and the keynote address for the MIT ILP Brazil Symposium.

William H. Green served as the department's executive officer through January 2015. Research highlights include development of detailed models for organosulfur chemistry relevant to fuel desulfurization processes, for the combustion of the synthetic jet fuel JP-10, and for the cracking of oil to gas under geological conditions. He also elucidated which reactions dominate in each of the stages of preignition chemistry, important for fuel performance in engines. Experiments in his lab corrected order-of-magnitude errors in literature values for reaction rates important in combustion and atmospheric chemistry, and demonstrated a new gas-to-liquids process.

Paula T. Hammond presented in the Brown university-wide colloquium lecture series, *Thinking Out Loud*, on her research in targeted delivery systems for cancer. She also gave invited talks at the RNA Nanotechnology Gordon Conference in February and the Polymers Gordon Conference in June, and lectures at multiple universities, including the University of California at Berkeley, the University of Florida, and the Univesity of North Carolina at Chapel Hill. She gave a plenary lecture at the International Nanomedicine Conference in Sydney, Australia, and a seminar at Nanyang Technological University in Singapore. Professor Hammond is a co-founder and member of the scientific advisory board and board of directors of LayerBio, a startup that is translating her lab's layer-by-layer drug delivery developments. She continues to serve as an associate editor of the American Chemical Society (ACS) journal *ACS Nano.* She is a board member for the Society of Biological Engineering and is in the final year of her term as a member of the AIChE's board of directors. Her research continues to expand in the areas of targeted cancer nanotherapies, release of therapeutics to address soft tissue wound healing and bone regeneration, and other biomaterials systems.

T. Alan Hatton continued to serve as director of the David H. Koch School of Chemical Engineering Practice, where he has placed student teams at host companies in the US and in Ireland, and has secured commitments for Practice School stations in fall 2015 and spring 2016 in Abu Dhabi, Canada, Ireland, and Australia, in addition to a number of US sites. He has advised the Masdar Institute Cooperative Program on the establishment of a Practice School–like program in Abu Dhabi. He is a member of the scientific advisory boards of the Particulate Fluids Processing Center at the University of Melbourne and he chaired the external review committee of the University of Melbourne's chemical engineering department. He is on the editorial advisory board of *Colloid and Interface Science Communications* and the advisory board of the Engineering Conferences International in New York. He was recently appointed an honorary professorial fellow at the University of Melbourne.

In addition to his responsibilities as department head, **Klavs F. Jensen** continued his research on functional micro- and nano-structured materials and devices for chemical and biological applications. With Professors Stephan Buchwald and Timothy Jamison in Chemistry, he explored a wide range of flow systems for chemical applications, with particular emphasis on systems for which continuous processing provides unique performance advantages. These systems also formed the basis for continuous flow synthesis and separation developments as part of the Novartis-MIT Center for Continuous Manufacturing and the DARPA-sponsored Pharmacy on Demand (PoD) program. The PoD effort expanded beyond the initial demonstration of continuous synthesis of four common pharmaceuticals in a small, integrated, reconfigurable, and transportable system. The ability of small systems to operate at high pressure and temperature conditions was used in the synthesis of nanoparticles for optical applications in collaboration with Professor Moungi Bawendi. Biological applications—specifically devices to facilitate the transport of macromolecules across cell membranes through cell squeezing and electroporation—were pursued in collaboration with Koch Institute researchers. During the past academic year, Jensen gave plenary lectures on microreaction technology at international conferences and at universities. He served on advisory boards to chemical engineering departments, including those at Princeton and Northwestern University, and participated in the governing board of the Technical University of Denmark and on the scientific advisory board for the Singapore A*STAR Institute for Nano and Biotechnology.

Jesse H. Kroll and his group continued their work on atmospheric particulate matter and the oxidation of atmospheric organic compounds. In addition to laboratory work at MIT, he and members of his group took measurements of organic compounds at an ice core facility at Desert Research Institute, cookstove emissions at the Lawrence Berkeley National Laboratory, and volcanic particulate matter on the island of Hawaii. This last effort was carried out with 22 undergraduate students as part of TREX (Traveling Research Environmental eXperience), an Independent Activities Periodsclass that introduces students to environmental fieldwork. In spring 2015 Kroll expanded TREX to include a new follow-up class focused on data analysis, interpretation of results, and scientific communication. He gave several invited talks and seminars on his research, including two at American Chemical Society national meetings and one at the American Geophysical Union fall meeting. In May, Kroll received the Maseeh Award for Excellence in Teaching.

Heather J. Kulik entered her first full year in the Department of Chemical Engineering, where she is currently the Joseph R. Mares Career Development Chair Assistant Professor. Her research group continued advancing high-throughput computational chemistry techniques for the understanding and design of biochemical and materials systems at the nanoscale, leading to four publications this year in *Proceedings of the National Academy of Sciences, Journal of Chemical Physics,* and *Journal of Physical Chemistry.* Kulik delivered three invited talks, including at the American Chemical Society central eastern regional meeting in Pittsburgh in fall 2014. Her work has attracted sponsorship from MITEI, the NSF, and the Royal Society of Chemistry. In January, her group moved into newly renovated lab space on the second floor of Building 66. Kulik introduced a new elective in computational chemistry in fall 2014, 10.637 Quantum Chemical Simulation, and served as a co-instructor for 10.65 Chemical Reactor Engineering in spring 2015.

Robert S. Langer received honorary degrees from the University of Maryland, Hanyang University, the University of New South Wales, Drexel University, and the University of Western Ontario. He was elected a foreign corresponding member of the Austrian Academy of Sciences and received the Queen Elizabeth Prize for Engineering, the Kyoto Prize in Advanced Technology, the Scheele Award, the Breakthrough Prize in Life Sciences, the Biotechnology Heritage Award, the Chemical Pioneer Award, the ETH Zurich Chemical Engineering Medal, and the Mack Memorial Award. Named lectures included the Ørsted Lecture, the Ruckenstein Lecture, the Lerner Lecture, the Barre Lecture, and the Amundson Lecture.

J. Christopher Love continued his research applying new bioanalytical processes to profile immune responses in chronic diseases, including HIV/AIDS, multiple sclerosis, type 1 diabetes, cancer, and food allergies. His lab also worked to advance biomanufacturing research to lower the costs of producing protein therapeutics to promote global access. He continued to lead a team of investigators from MIT, Rensselaer, Pall Corporation, and Northeastern University under DARPA's Biologics Manufacturing on Demand program for end-to-end manufacturing of biologic drugs at point-of-care in approximately 24 hours, which successfully began phase 2 activities. In collaboration with the Center for Biomedical Innovation and the Department of Biology, he also developed the first EdX course from Chemical Engineering, 10.03x Advances in Biomanufacturing, focused on the principles of biomanufacturing. This MOOC, launching July 2015, brings innovations in video segments that include historical documentary, expert interviews, and hands-on interviews with practitioners of biomanufacturing.

Allan S. Myerson continued his research on fundamental and applied problems in crystallization and pharmaceutical manufacturing. He continued his work as a principal investigator in the Novartis-MIT Center in Continuous Manufacturing and the DARPA project Pharmacy on Demand, which involves the development of a tabletop pharmaceutical manufacturing device. Professor Myerson serves as an associate editor of the ACS journal *Crystal Growth and Design.* He serves on scientific advisory boards of Gensyn Technologies, a company devoted to particle engineering applications in pharmaceuticals; BlueSpark, a company that develops novel flexible batteries; and CONTINUUS Pharmaceuticals.

Bradley D. Olsen, the Paul M. Cook Career Development Associate Professor of Chemical Engineering, and his research group continued work in the areas of bioinspired and biofunctional block copolymers, polymer gels, and protein-based materials for applications in defense, sustainability, and human health. Major accomplishments included reporting on a new method of fabricating highly active biocatalysts, engineering a new injectable high-stiffness gel for tissue engineering, discovering superdiffusive behavior for the first time in associative polymer gels, and publishing the invention of new protein sequences that mimic nucleoporins. This research is supported by the Air Force Office of Scientific Research, the ISN, the Department of Energy Office of Basic Energy Science, the National Science Foundation, and the Defense Threat Reduction Agency. Olsen published 12 peer-reviewed papers and presented 15 invited lectures. His group also submitted a patent on nuclear pore mimetic gels and a provisional patent on new bioconjugate brush polymers. Olsen was awarded a 2015 Camille Dreyfus Teacher-Scholar Award and a DuPont Young Investigator Award and was named one of the Talented 12 by *Chemical and Engineering News*. He served as an instructor for 10.569 Synthesis of Polymers and taught a short course at the State University of São Paulo on bioconjugate materials.

During AY2015, **Kristala L. J. Prather** was on sabbatical leave from MIT and in residence at Harvard University as a fellow of the Radcliffe Institute for Advanced Study. She delivered several invited lectures, including the Merck Lecture in Chemical Engineering and the Lloyd N. Ferguson Lecture. She was a featured speaker in the Dr. Bruce J. Nelson ’74 Distinguished Speaker Series at Harvey Mudd College. Her service as co-chair of the Department of Energy/Office of Biological Environmental Research Workshop on Bioenergy culminated in the release of the report “Lignocellulosic Biomass for Advanced Biofuels and Bioproducts” by DOE in February 2015; her service as a member of the National Academies/National Research Council Study Committee on the Industrialization of Biology culminated in the release of the report of the same name in March 2015. Prather continues to serve as co-director of the long-running course Fermentation Technology (founded by Professor Daniel I.C. Wang and offered through the MIT Professional Education program) and as co-director of the Microbiology Graduate Program, an interdisciplinary program with faculty from the Schools of Engineering and Science. Recently, she was appointed bioengineering systems program lead for the MIT-Portugal Program.

Yuriy Roman continued his work on heterogeneous catalysis and materials design for the conversion of alternative feedstock, such as lignocellulosic biomass, natural gas, and carbon dioxide. His work is sponsored by federal and industrial sources, including NSF, DOE, British Petroleum, and Saudi Aramco. His group published 14 papers, including work in *Angewandte Chemie* on C-C coupling strategies with Lewis acids, as well as in *Journal of the American Chemical Society* on the conversion of methane to acetic acid. Professor Roman delivered 12 invited lectures, including keynote lectures at the International Symposium on Zeolite and Microporous Crystals in Sapporo, Japan, and at the International Conference on Materials for Advanced Technologies in Singapore, as well as seminars at the University of Wisconsin, Madison, and the University of Oklahoma. He was awarded a CAREER Young Investigator Award by the National Science Foundation. In addition, Roman was elected president of the New England Catalysis Society, and continues in his role as the program coordinator for the AICHE Catalysis and Reaction Engineering Division. His teaching activities included 10.492, Integrated Chemical Engineering-Catalysis for Energy Applications, and 10.37 Reactor Design and Kinetics. Together with his wife, Professor Roman continued serving as associate housemaster in Ashdown House.

Gregory C. Rutledge, the Lammot du Pont Professor of Chemical Engineering, continued to teach, mentor, and conduct research in the molecular engineering of high-performance polymers and the development of electrospun fibers and membranes. His contributions in these areas were recognized in 2014–2015 by the Founders Award of the Fiber Society, its highest award for research achievement, and by being named a fellow of the Polymeric Materials Science and Engineering Division of the American Chemical Society. He delivered invited lectures at the 3rd Biennial Conference on Electrospinning and the 7th International Conference on Multiscale Materials Modeling. He co-organized the ACS symposium Polymer Modeling: Structure, Dynamics and Function. Professor Rutledge stepped down as member of the governing council of the Fiber Society after a three-year tenure, and became a member of the awards committee. He continues to serve as editor for *Journal of Materials Science* and *Journal of Engineering Fibers and Fabrics*, as well as on several editorial advisory boards. He is chairman of the Committee on Research Computing and serves on the Committee on the Undergraduate Program.

George Stephanopoulos received the 2015 American Society for Engineering Education Chemical Engineering Division CACHE Award for Excellence in Computing in Chemical Engineering Education, and he continued his research activities in two areas: process systems engineering at the nanoscale with a focus on conceptual design, fabrication, and operation of nanoscale processes, and the collaborative integrated design of biorefineries for the production of high-added value chemicals and materials. At the annual AIChE meeting in Atlanta, he and his collaborators presented two papers: "A Framework for the Design and Optimization of Biorefinery Networks" and "A Multiresolution Approach to Optimally Control the Dynamic Directed Self-Assembly of Nanostructures." He published the third part of a series, "Controlled Formation of Nanostructures with Desired Geometries," in *I&EC Research,* and the first paper on a novel framework for the multi-actor, multi-objective optimization of collaborative manufacturing in the proceedings of the 12th International Symposium on Process Systems Engineering and 25th European Symposium on Computer Aided Process Engineering in Copenhagen, Denmark.

Gregory Stephanopoulos, the W.H. Dow Professor of Biotechnology and Chemical Engineering, continued his research program as director of the Metabolic Engineering Laboratory, supervising the efforts of 25 to 30 researchers to engineer microbes in order to convert them into little chemical factories for the production of fuels and chemicals. Notable successes in this area are the engineering of ethanol tolerance in yeast (*Science*), co-culture technology for product synthesis through long biosynthetic pathways (*Nature Biotech*), and an integrated system for biological conversion of gaseous substrate into lipids. In parallel, he continued investigating the metabolic aspects of cancer, with particular focus on the identification of therapeutic metabolic targets. Gregory 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. He was also elected president-elect of AIChE, effective January 2016. He delivered the 2014 Lacey Lectures at the California Institute of Technology and the 2014 Alkiviades C. Payatakes Memorial Lecture in Patras, Greece. He continues to serve as editor-in-chief of the journals *Metabolic Engineering* and *Current Opinion in Biotechnology*, and on the editorial boards of eight other scientific journals. In addition, he delivered plenary and keynote lectures at the 3rd Bioeconomy Forum, São Paulo, Brazil; a plenary lecture at the inaugural conference of the Brazilian Industrial Biotech Association in São Paulo; a plenary lecture on low carbon emissions at the University Alliance Conference in Beijing; and a keynote speech at the 10th Metabolic Engineering Conference in Vancouver.

Michael S. Strano has continued his research focusing on the chemical engineering of low dimensional systems. His work on plant nanobionics was published in *Nature Materials* earlier this year and was featured in several major media outlets, including *Popular Science,* the *Los Angeles Times,* the BBC, and *The Economist.* The Strano laboratory developed a new method for producing nanoparticles that recognize specific molecules called CoPhMoRe (Corona Phase Molecular Recognition), published in *Nature Nanotechnology* and recently shown to extend to protein recognition. Strano has continued his work on infrared fluorescent tattoos to monitor biochemicals in the human body, extending his research to the molecule cortisol, in addition to glucose and insulin. He spent part of the summer of 2014 at Army Research Laboratories in Aberdeen, MD, working on nanomaterial composites as a part of the Army's Open Campus Initiative. Strano was selected as one of 10 finalists in chemistry for the Blavatnik National Award for Young Scientists for 2015. He continues to serve in the Defense Science Study Group, visiting and interacting with scientists and military and policy officials throughout the Department of Defense. He serves on the Defense Science Board's Task Force on Deterring, Preventing, and Responding to the Threat or Use of Weapons of Mass Destruction. He was appointed to the editorial boards of the ACS journal *Langmuir, ChemPhysChem, Advanced Energy Materials,* and *Scientific Reports.* He was recently appointed volume editor for the Materials Research Society's *MRS Bulletin.* Strano continues his service on the American Institute of Chemical Engineers Awards Committee. He delivered invited lectures at the University of Michigan Department of Chemical Engineering's Seminar Series, Northwestern University's International Institute for Nanotechnology, the Physical Chemistry seminar series at the University of Pittsburgh, Kyoto University's Department of Chemical Engineering and the Institut de Biologie Moleculaire at the University of Strasbourg, France. He was also an invited speaker at the Sensor Innovation Workshop at King Abdullah University of Science and Technology in Saudi Arabia. He served on the organizing committee of the 2015 Brazil-US Frontiers of Science and Engineering in Rio de Janeiro, presenting a lecture on nanoengineering and nanomaterials. Strano was recently selected as a Thomson Reuters highly cited researcher for 2014. This spring, he initiated an educational research project called "Assessing the impact of real time, anonymous inquiry during lecture on active learning and educational outcomes."

James W. Swan began his second year in the Department of Chemical Engineering, where he is currently the Texaco-Mangelsdorf Career Development Professor. His research focuses on computation and modeling of colloidal scale self-assembly, working to advance scalable manufacturing of ordered materials with applications to sustainable energy and biomedical technologies. He has developed and begun publishing new algorithms for dynamic simulation of nanoparticle fluid mechanics using graphics processing units. This research has already enabled new studies of materials such as gels and protein solutions, and upcoming publications will demonstrate the important role of fluid mechanics in the assembly of soft materials. The Swan research group consists of five graduate students, one visiting master's student, one undergraduate student, and one postdoctoral associate.

Bernhardt L. Trout continues in his roles as director of the Novartis-MIT Center for Continuous Manufacturing, an $85 million partnership. In addition, he is director of the Benjamin Franklin Project for the Advancement of the Arts and Sciences. The Franklin Project aims at broadening the education of MIT undergraduates in the realms of ethics, foundations of economics, leadership, and the origin of modern science. He has extended this program beyond Chemical Engineering to all of the engineering departments in the School of Engineering. Trout runs a laboratory of 20 graduate students, postdocs, and staff focusing on pharmaceutical small-molecule manufacturing and biopharmaceutical formulation and stabilization. Other recent scientific accomplishments in the Trout group include elucidation of the molecular mechanisms of heterogeneous nucleation of small molecular organics via both computational and experimental methods, and the development of methods to predict viscosity and protein-protein binding of biotherapeutics. These methods and specific algorithms are used by large- and medium-sized pharmaceutical companies around the world. Over the year,Trout gave more than 10 invited talks, including several keynote and plenary talks, and published or submitted more than 20 research papers and five patents. He is on the scientific advisory board of three companies.

Daniel I.C. Wang continues his involvement with the Singapore-MIT Alliance (SMA). He has three PhD candidates at the National University of Singapore, all of whom spent spring term at MIT. He is continuing his SMA research on high-throughput systems for mammalian cells, and has been invited by Genentech, Life Technologies, Momenta Pharmaceutical, and Pfizer to give seminars on this research. He is trying to license this technology to a number of companies, and has presented his research at the AIChE, ACS, and Society for Industrial Microbiology and Biotechnology annual meetings. Professor Wang continues his research with Saudi Aramco on microbial desulfurization of crude oil. One PhD thesis and three papers have been published from this research. Wang was invited to serve as chairman of the scientific advisory board of the Bioprocessing Technology Institute of A*STAR, Singapore. The journal *Biotechnology and Bioengineering* has established the Daniel I.C. Wang Award for Research Excellence for investigators under the age of 35. His former students have endowed the DIC Wang Award for Excellence in Biochemical Engineering, sponsored by three professional organizations, the American Chemical Society, the American Institute of Chemical Engineers, and the Society for Biological Engineering. On June 5, 2014, it was formally announced that two of Wang's former students have endowed the Daniel I.C. Wang Professorship in the Department of Biological Engineering.

Research Highlights

Using Polymerization Reactions to Detect Molecular Recognition (Hadley Sikes)

The goal of molecular diagnostic tools in medicine is to provide reliable, feasible analysis of samples derived from patients for molecules that are associated with health and disease. In principle, molecular diagnostics can be used for a wide variety of purposes: screening for disease or risk of disease, diagnosis of disease, selection of the therapy that is most likely to be effective when several therapies are available, identification of therapies that are contraindicated for a particular patient, monitoring response to therapy, distinguishing aggressive from indolent disease, and providing patients with prognostic information. For a variety of reasons, current understanding of pathogens and disease states on a molecular level far exceeds our ability to make use of this understanding to assist medical practitioners with routine decisions regarding patient care. One such reason is that many analysis techniques that are perfectly feasible in a research laboratory are not well suited to the point-of-care.

Numerous researchers in academic, government, and private-sector laboratories are working to develop methods and technologies to address this feasibility gap and increase the prevalence of molecular analyses at the point-of-care. Considering the needs of users, available resources and context for use are essential for widespread adoption. Expensive and complex instrumentation and higher values of cost-per-test than patients can afford are two barriers to adoption. In recent years, with these barriers in mind, the Sikes Lab has developed a new analysis technique that is conceptually distinct from pre-existing techniques. Rather than using nanoparticle labels to detect molecular recognition, as in pregnancy tests, or enzyme labels, as in the enzyme-linked immunosorbent assays that are ubiquitous in current medical practice, the Sikes Lab is investigating using polymeric hydrogels that form only if the molecular recognition events of interest occur. The lab is particularly interested in the questions of whether the concept of amplification that is inherent in polymer chemistry can be used in a practical manner to lower costs-per-test, improve the performance of molecular diagnostics in the hands of users, and eliminate the need for instrumentation. Figure 2 presents (A) a schematic of the concept and the molecular species that react to form a hydrogel if (and only if) molecular recognition events occur, and (B) cell phone images depicting test results for 10 pinprick samples of blood containing 10 different clinically relevant levels of a protein that indicates a malarial infection.

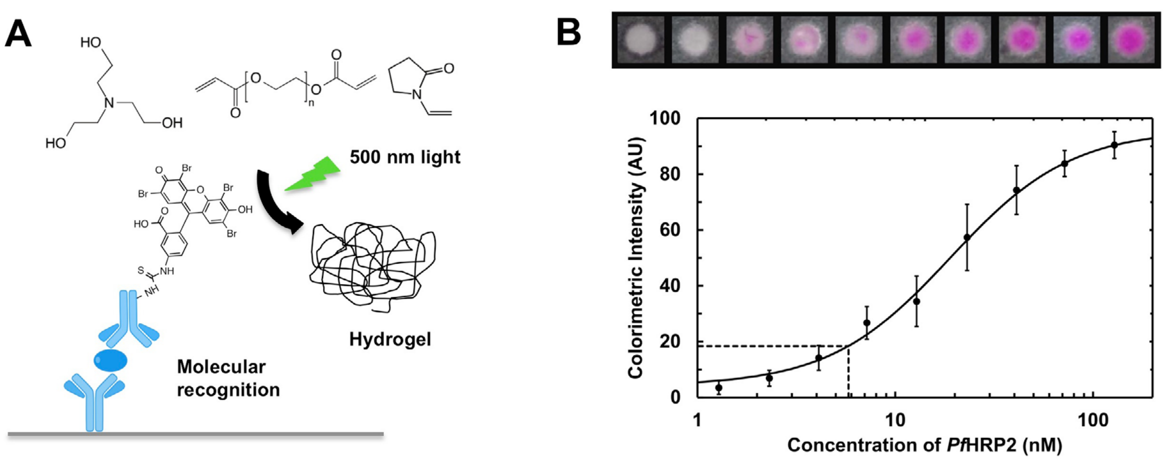

Figure 2. A colorimetric blood test for malaria for <1 cent. The test is fabricated using cellulose and an ordinary solid ink printer. A polymerization reaction produces responses that are easily perceptible by eye, and the reaction proceeds in air in less than one minute. (PfHRP2: histidine rich protein 2 of Plasmodium falciparum)

Figure 3 compares the polymerization readout with that produced by the two other existing categories of reagents that produce visible, amplified signals in immunoassays: nanoparticles and enzymes. Though nanoparticles alone produce colored responses in pregnancy tests, which are fabricated using nitrocellulose, nanoparticles alone do not produce a colored response in tests made of cellulose, which are much less expensive due to both material cost and a simple manufacturing process. In order to generate colored responses using nanoparticles in tests made of cellulose, a silver amplification step is required and was used here.

A comparison between the color of the test of blood that did not contain the protein (the column labeled "0" in Fig. 3A) with all others in the series demonstrates that all three approaches generate a more intense colorimetric response if the protein is present in the clinically relevant range of concentrations and the test is observed at an optimal time. Figure 3B shows only negative samples (blood that does not contain the protein that indicates malaria) and reveals a serious problem for untrained or overburdened users: as time elapses from the optimal time to view results, negative samples that are analyzed using nanoparticle or enzyme labels also develop colored responses. Figure 3 shows that the polymerization approach provides two key functional advantages: positive results contrast unambiguously with negative results, and negative results do not begin to resemble positive results with elapsed time. This work provides solutions to two of the greatest needs identified in the first field trial of cellulose-based diagnostic devices.

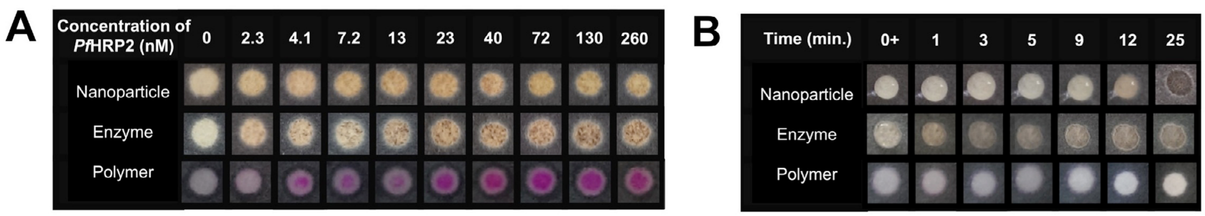

Figure 3. (A) Pinprick-sized samples of blood were analyzed for histidine rich protein 2 of Plasmodium falciparum (PfHRP2), a pathogen that causes malaria. The colored responses generated by nanoparticle/silver staining, enzyme/substrate, and polymerization approaches to signal amplification are compared. Pictures were taken with a cell phone at the optimum endpoint in time for each method. The "0" column represents a blood sample that did not contain PfHRP2. (B) All of the samples shown here are for blood that did not contain PfHRP2. For improved accuracy in the hands of users, these negative samples should remain white with time.

Progressing from initial, proof-of-concept work to the practical achievements depicted in Figures 2 and 3 required a significant investment in fundamental studies. In our proof-of-concept work, polymerization reactions required 8–20 minutes and an atmosphere free of oxygen, which is not practical in the resource-limited settings that are the focus of our research efforts. Identifying chemical reactions and stoichiometries that tolerated air and proceeded in less than a minute was a breakthrough. Proof-of-concept studies used molecular recognition events with unrealistic, extremely high binding affinity. Developing and validating a model that accurately predicted assay performance (sensitivity) for more realistic binding affinities allowed selection of appropriate clinical applications and detection reagents. The chemical details of how to couple polymerization reactions to molecular recognition events greatly impact performance and needed to be elucidated.

Looking forward, in addition to field tests of the chemical technology that will inform the next design cycle, we are particularly interested in gaining a mechanistic understanding of the unique photo-catalytic redox reactions we are using to initiate the polymerization of acrylate monomers in aqueous, air-saturated solutions. Figure 4 shows a comparison of the polymerization reaction used in Figures 2 and 3 with all others that have been investigated for the same purpose. It is unprecedented for such a small number of initiating molecules to start a polymerization reaction that proceeds through a radical mechanism with oxygen, a well-known inhibitor of radical reactions, present in large excess. It is even more puzzling that the reaction proceeds as quickly as it does. To unravel these mysteries and perhaps identify other reactive systems that perform similarly, we are proposing potential mechanisms and using a combination of novel spectroscopic techniques and kinetic modeling to test for consistency between each mechanism and experimental observations. In addition to exciting potential for real-world impact, this project area has proven to be an exceptional training opportunity for students and postdocs whose interests traverse the traditional boundary between engineering and science.

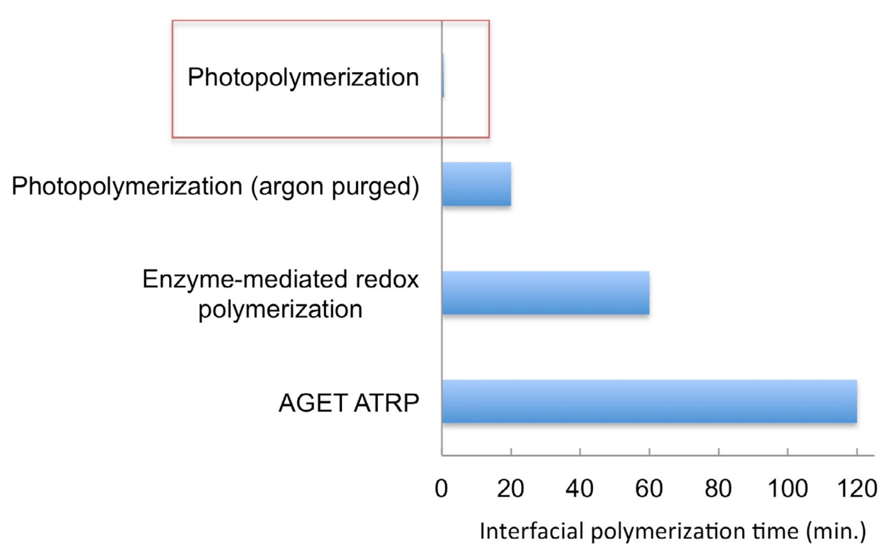

Figure 4. A comparison of reaction times required for production of visible hydrogel films that reveal molecular recognition events.4a Rapid reaction times are preferred. In the years since Ref. 3a appeared, several polymerization chemistries have been investigated. Our current focus is boxed in red. AGET ATRP: activators generated by electron transfer for atom transfer radical polymerization, a popular controlled polymerization technique.

Using Nanoparticles to Modify the Functions of Living Plants (Michael S. Strano)

The Strano Laboratory is interested in the chemical engineering of so-called low dimensional nanomaterials, which are patterned at the nanometer scale and exhibit unusual properties due to quantum confinement. The Strano Lab addresses problems in medicine, energy, water, and food security and novel materials. In recent work, the lab has invented a series of techniques that enable nanoparticles of various sizes and functionalities to be localized within living plants and traffic to specific targets, including plastids such as the chloroplasts. The lab’s vision is to develop engineering techniques and materials capable of transforming living plants into ones with non-native, beneficial functions.

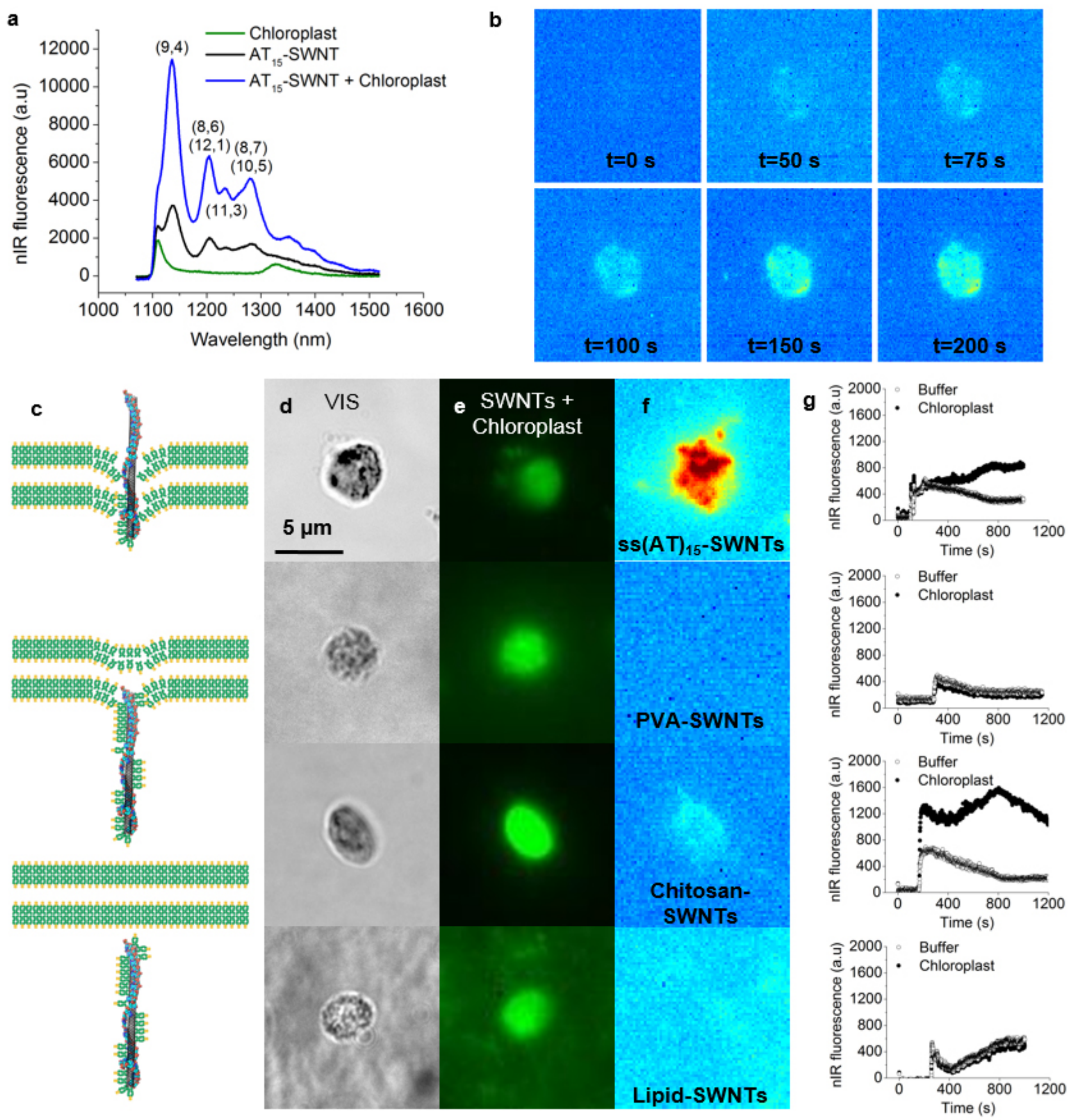

Figure 5.a, Chloroplast autofluorescence was masked from near-infrared images by a long-pass 1,100 nm filter. b, Near-infrared photo still indicating rapid penetration of ss(AT)15–SWNTs through the lipid bilayers of isolated chloroplasts. c, SWNT transport through chloroplast double membrane envelope via kinetic trapping by lipid exchange. d–f, Bright-field (×100; d) and near-infrared (×100; e) images of isolated chloroplasts indicating uptake of SWNTs coated in ss(AT)15 DNA and chitosan, but not of PVA- and lipid-coated SWNTs (×100; f). g, Change in average SWNT fluorescence in cross-sections of chloroplasts versus external buffer solution. Laser excitation 785 nm at 75 µW.

In a recent paper in *Nature Materials*, we explored the use of nanoparticles and specific nanomaterials to "engineer" new features and functions in extracted chloroplasts (Giraldo et al., 2014) and whole plants. The lab showed that single-walled carbon nanotubes (SWNTs) passively transport and irreversibly localize within the lipid envelope of extracted plant chloroplasts (Figure 5), promote over three times higher photosynthetic activity than that of controls, and enhance maximum electron transport rates. The SWNT-chloroplast assemblies also enable higher rates of leaf electron transport *in vivo* through a mechanism consistent with augmented photoabsorption. Concentrations of reactive oxygen species inside extracted chloroplasts are significantly suppressed by delivering poly(acrylic acid)–nanoceria or SWNT–nanoceria complexes. In subsequent work, we have extended additional findings to living plants themselves, designing attractive applications and outlining a new field that the lab tentatively calls "plant nanobionics."

Establishing design principles for the delivery of nanoparticles into chloroplasts has enabled the development of a wide variety of promising applications. For instance, the Strano Lab is developing the first nanobionic chemiluminescent plant (Figure 6a). Through the delivery of specifically functionalized silica and other nanoparticles into plant tissues, the plant's own adenosine triphosphate (ATP) can be utilized to generate visible photons, making it possible to indirectly utilize the energy stored by the plant's photosynthetic machinery and channel it towards powering a series of nanoparticle types to make plants luminescent in visible wavelengths in the dark. Having ambient background lighting generated from plants' own ATP might establish new paradigms of scaled illumination, where less energy is needed to bring our environment to an adequate brightness.

The Strano Lab is interested in further exploring the use of novel SWNT-based plant-imbedded sensors to replace sensors in habitable spaces. As pre-concentrators of their immediate environment, SWNT-plant hybrids could essentially act as self-powered chemical/biological sensors utilizing natural mechanisms of preconcentration and bioaccumulations, groundwater filtration, and processing. Detection of pollutants, hazardous chemicals, and nitroaromatics can also be accomplished in this manner. Plant pre-concentration of these compounds will enable us to detect very small quantities that are present in the plant's immediate environment, and recent advances allow the lab to communicate with the living plant using infrared signaling. Figure 6b shows the first nanobionic explosives-detecting plant, where a series of nanoparticles embedded in the plant leaf lamina responds to nitroaromatics delivered to it from transpiration of surrounding groundwater. A collection of different sensors embedded in plants will enable the surreptitious and self-powered real-time monitoring of our environment.

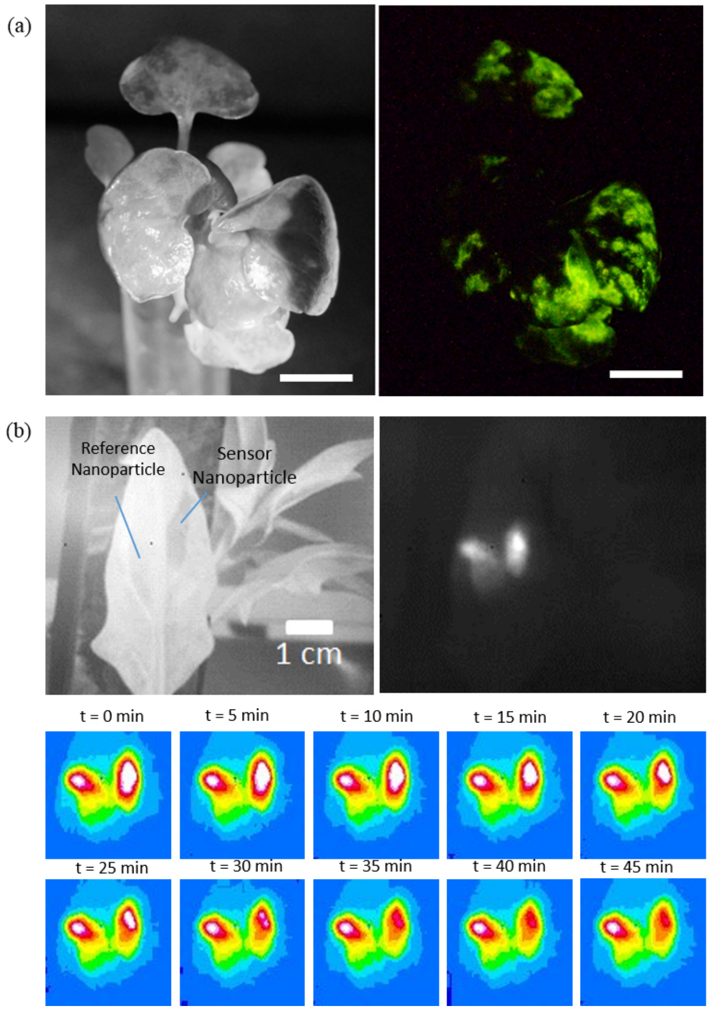

Figure 6. (a) Chemiluminescent Plant. Watercress (three-week-old, lab grown), luminescent watercress (left), brightfield image (right). Photo was taken by Nikon D5300, 1 min exposure, ISO 6400, f/4.5. scale bar=1 cm. (b) Explosive Detector Plant. Brightfield image of leaf (top left). Leaf under excitation (top right) — two spots are seen: one is the reference nanoparticle, and the other is the sensor nanoparticle, which quenches in response to nitroaromatics. (Bottom) False colored images of leaf under excitation. The right spot shows sensor nanoparticle quenching with time in response to nitroaromatics, while the left spot shows relatively constant intensity of reference nanoparticle.

Lectures and Seminars

During 2014–2015, the Chemical Engineering Department hosted a distinguished group of academic and industry leaders, speaking on topics highlighting cutting-edge research addressing today's energy and health-related challenges. Webcasts for all major lectures can be accessed at http://web.mit.edu/cheme/news/webcast.html.

12th Daniel I.C. Wang Lecture on the Frontiers of Biotechnology (formerly Frontiers in Biotechnology Lecture) (September 26, 2014): "Expanding the Enzyme Universe by Evolution and Design." Frances H. Arnold, Dick and Barbara Dickinson Professor at California Institute of Technology, discussed her research at this inaugural Wang Lecture, honoring the accomplishments and legacy of Institute Professor Daniel I.C. Wang. Professor Arnold's research focuses on directed evolution and protein engineering, with applications to alternative energy, chemicals, and medicine. At Caltech, Dr. Arnold pioneered the “directed evolution” of proteins, mimicking Darwinian evolution in the laboratory to create new biological molecules. Her laboratory has developed methods of laboratory evolution and structure-guided recombination that are used widely in industry and basic science to engineer proteins with new and interesting properties.

29th Hoyt C. Hottel Lecture (November 21, 2014): “Energy and the Industrial Revolution: Past, Present, and Future.” Professor Arun Majumdar, Jay Precourt Professor at Stanford University, discussed the evolution of alternative energy. Professor Majumdar serves on the faculty of the department of mechanical engineering at Stanford and is a senior fellow of the Precourt Institute for Energy. Prior to joining Stanford, he was the vice president for energy at Google, where he created several energy technology initiatives and advised the company on its broader energy strategy. He continues to be a consultant to Google on energy. In October 2009, Dr. Majumdar was nominated by President Obama and confirmed by the Senate to become the founding director of the Advanced Research Projects Agency-Energy (ARPA-E), where he served until June 2012. Between March 2011 and June 2012, Dr. Majumdar also served as the US acting under secretary of energy, and as a senior advisor to the secretary of energy.

21st Alan S. Michaels Lecture (April 10, 2015): “Reengineering the Tumor Microenvironment to Enhance Cancer Treatment: Bench to Bedside.” Professor Rakesh K. Jain, Andrew Werk Cook Professor of Tumor Biology and director of the Edwin L. Steele Laboratories for Tumor Biology at Harvard Medical School and the Massachusetts General Hospital, discussed his current research. Dr. Jain is regarded as a pioneer in the area of tumor microenvironment and is widely recognized for his seminal discoveries in tumor biology, drug delivery, in vivo imaging, bioengineering, and bench-to-bedside translation. These include uncovering the barriers to the delivery and efficacy of molecular and nano-medicines in tumors, developing new strategies to overcome these barriers, and then translating these strategies from bench to bedside. He proposed a new principle—normalization of vasculature—or treatment of malignant and non-malignant diseases characterized by abnormal vessels that afflict more than 500 million people worldwide. This concept has fundamentally changed the thinking of scientists and clinicians about how antiangiogenic agents work, and how to combine them optimally with other therapies to improve the treatment outcome in patients.

37th Warren K. Lewis Lecture (May 8, 2015): “Challenges and Opportunities in the Production of Renewable Chemicals and Fuels in Brazil and the US.” Bernardo Gradin, chief executive officer (CEO) of Brazil’s GranBio, discussed how his company is changing the alternative energy industry. In 2011, Mr. Gradin founded and became CEO of GranBio, an industrial biotechnology company, as well as becoming president of Inspirare Instituto, a nonprofit organization dedicated to fostering basic education in Brazil. Gradin is a board member of ABIQUIM (the Brazilian Chemical Association), a board member of CNPEM (Brazilian National Laboratories), leader of the CNI (Brazilian National Confederation of Industry) Bioeconomy Commission, and chairman of the Chemistry and Advanced Material Community of the World Economic Forum.

Departmental Awards

The Department Awards Ceremony took place on May 11, 2015, in the Gilliland Auditorium of the Ralph Landau Building. We are pleased to recognize this year's recipients of the Outstanding Faculty Awards: Professor Daniel Blankschtein was the graduate students' choice, and Professor William Tisdale was selected by the undergraduate students.

The Edward W. Merrill Outstanding Teaching Assistant Award was presented to undergraduate student Whitney Loo for her work in 10.26 Chemical Engineering Projects Laboratory class. The Outstanding Graduate Teaching Assistant Award was presented to PhD student Joel Paulson for his service to 10.34 Numeric Methods. 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 Ray Smith and Sue Zanne Tan.

Chemical Engineering Special Service Awards were conferred to the members of the Graduate Student Council: Matt Ashner, John Barton, Stephen Brown, Kameron Conforti, Nabeel Dahod, Leia Dwyer, Andrew Fiore, Lisa Guay, Tim Ioannidis, James Kaczmarek, Eric Miller, Carolyn Mills, Dan Salem, Zach Sherman, and Zsigi Varga. Members of the Graduate Student Advisory Board were also recognized: Garrett Dowdy, Kristen Severson, Ankur Gupta, Jose Gomez, Rosanna Lim, Ray Smith, Kaja Kaastrup, and Sayalee Mahajan. In addition, Justin Kleingartner was awarded the Chemical Engineering Rock Award for his contributions to athletics within the department. The following undergraduate students were also recognized for their service to the student chapter of the American Institute of Chemical Engineers: Julia Sun, Anthony Concepcion, Whitney Loo, David Hou, June Park, Robbie Shaw, Githui Maina, Kali Benavides, Spencer Wenck, Joel Schneider, Michael Fu, Pamela Cai, Nancy Lu, Sophia Lu, Dheevesh Arulmani, Kelsey Jamieson, Allison Hallock, Shahrin Islam, and Allen Leung.

Our undergraduates earned numerous accolades over the course of the year. The Robert T. Haslam Cup, which recognizes outstanding professional promise in chemical engineering, went to Akerek Wu. The department's oldest prize, the Roger de Friez Hunneman Prize, awarded to an undergraduate who has demonstrated outstanding achievement in both scholarship and research, went to Anisha Gururaj. The Wing S. Fong Prize, awarded to a chemical engineering senior of Chinese descent with the highest cumulative GPA, was awarded to Catherine Liou, Xingyi Shi, and Derek Wu. The BP award for outstanding academic achievement by sophomore women chemical engineers went to Zi-Ning Choo, Alexandria Miskho, and Anni Zhang. Kiara Cui received the BP award for outstanding academic achievement by a junior woman chemical engineer. The BP award for outstanding performance in the projects laboratory course by a junior woman chemical engineer was awarded to Kelsey Jamieson. Sydney Hodges earned the BP award for outstanding performance in research by a junior woman chemical engineer.

The department is pleased to recognize Joel Dashnaw as the department's Outstanding Employee of the Year for his dedication and exceptional service to faculty, staff, and students. Two Chemical Engineering Individual Accomplishments Awards were conferred: Brian Smith received an award for his work in the field of safety for the department, and Fran Miles received an award for her dedication and service to the undergraduate community. Two members of the Chemical Engineering staff, Rebecca Hailu and Marwan Cheguenni, received Infinite Mile awards.

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