Materials Processing Center

The Materials Processing Center (MPC) was established as an interdisciplinary center within the School of Engineering in response to a recognized national need to improve the materials processing knowledge base and to streamline the process of translating materials research results into industrial innovations and applications.

Following a science-to-systems approach, MPC assembles faculty resources and leverages existing knowledge to help companies and federal agencies address challenges and create opportunities. More than 60 faculty and senior research staff have active research accounts in MPC, and the center organizes events for the broader materials research community at MIT, which includes more than 195 faculty. MPC is now in its 32nd year.

In the past year, MPC's research volume reached an all-time high of $20 million, representing an increase of 19% over the previous year, and a total increase of 48% over the past two years. While this growth occurred across the interdisciplinary scope of the center's research, it included continued significant growth in research on materials for energy. MPC continued to support its two subcenters—the Solid State Solar Thermal Energy Conversion Center (S^3TEC) and the Microphotonics Center (MPhC)—as well as professor Harry Tuller's large multi-faculty program in chemomechanics of far-from-equilibrium interfaces, and professor Donald Sadoway's Advanced Research Projects Agency–Energy (ARPA–E) program, Electroville.

Four new research thrusts were intiated in the MIT–International Iberian Nanotechnology Laboratory (MIT-INL). The center worked with the Microsystems Technology Laboratories (MTL) to organize the second MIT-INL workshop, titled "Nanostructured Materials, Devices, and Systems," which featured presentations given by MIT-INL staff members as well as MIT faculty, and included a student poster session. All events were promoted and open to the MIT community.

Industry Collegium and Industrial Advisory Board

The MPC Industry Collegium consists of 10 companies that provide direct financial support for the center's discretionary activities through annual donations. Representatives from these companies work with MPC throughout the year to identify opportunities for collaboration and participate in MPC's annual Materials Day and related activities. Current collegium members include: Belgium Consortium, Corning, Hitachi, Ishikawajima-Harimi Heavy Industries, Merck KGaA, Michelin, Raytheon, Siam Cement Public, Toyota, and Varian Semiconductor Equipment Associates. Growth of collegium membership is a high priority for MPC.

The MPC Industrial Advisory Board meets for a full day after the Materials Day event each year. MPC's director and staff report on the prior year's activities and describe planned initiatives and goals for subsequent years. In addition, several new faculty present their planned research, and selected senior faculty discuss major new programs. The board provides valuable advice on program development and management. It also

assists in identifying opportunities for interactions with industry. The board meeting culminates in an oral and written report to the dean of the School of Engineering or a designated representative. Current board members represent 3M, Bell Laboratories North America, Compaq Computer Corporation, Draper Laboratory, General Motors, Harmonic Inc., Lockheed Martin, Lord Corporation, Norton, Novartis Pharmaceuticals, Saint-Gobain, Solvay Advanced Polymers, Varian Semiconductor Equipment Associates, and WiPower Inc.

New faculty who spoke at this year's board meeting were associate professor Nicholas Fang, Department of Mechanical Engineering (DME); assistant professor Bilge Yildiz, Department of Nuclear Science and Engineering (NSE); associate professor Wojciech Matusik, Department of Electrical Engineering and Computer Science (EECS); assistant professor Kenneth Kamrin (DME); and assistant professor Katharina Ribbeck, Department of Biological Engineering (BE).

Solid State Solar Thermal Energy Conversion Center

MPC completed its third year supporting the Solid State Solar Thermal Energy Conversion Center (S^3TEC), a US Department of Energy (DOE) Basic Energy Sciences–sponsored Energy Frontier Research Center. Led by professor Gang Chen (DME), the center is a multidisciplinary effort that includes leading researchers from physics, chemistry, materials sciences, and electrical and mechanical engineering. The center's research focus has application in the use of solar and other heat sources in conversion to electrical energy.

Research is based on three major areas: the study and control of photons for solar thermoelectric and thermophotovoltaics, the understanding of electron and phonon transport, and high-temperature reliability. The core activities of the center are focused on the investigation and development of thermoelectric materials, the collection and conversion of heat energy into electrical energy, and thermophotovoltaics for high-efficiency energy conversion of solar energy into electricity. Key to the energy conversion process is the ability to understand phonon transport processes in these materials, combined with the design and fabrication of highly selective surfaces to serve as efficient photon emitters in the case of thermophotovoltaic systems. Investigation of the materials systems requires use of unique and adapted characterization tools, such as thermoreflectance, acoustic wave, and phonon tomography (at Oak Ridge National Laboratory).

Based at MIT, S^3TEC supports the research efforts of 12 principal investigators, multiple academic disciplines, and student and postdoctoral members assigned from their research teams. Partnerships and collaborating organizations include Boston College, Rensselaer Polytechnic Institute, and Oak Ridge National Laboratory. The center was officially launched in August 2009 for a five-year period, based on meeting annual reporting requirements; its goals are to enable highly efficient harvesting of heat energy from multiple high-temperature processes, such as power plants, chemical plants, and engines (e.g., turbines and automobiles), in addition to realizing more efficient collection of the full solar energy spectrum into usable, sustainable green energy.

Microphotonics Center

The Microphotonics Center is supported by a 21-member industry consortium. Members include Advanced Micro Devices, Alcatel-Lucent, Analog Devices, Advanced Photonic Integrated Circuits (APIC) Corporation, Corning, Electronics and Telecommunications Research Institute, Fujitsu, Hewlett Packard, International Business Machines, Intel Corporation, Kotura, LioniX, National Semiconductor, Nippon Electronics Corporation, Optitec, and Silicon on Insulator Technologies. MPhC features the Communication Technology Roadmap (CTR) program and its industry-led Technology Working Groups. The consortium is directed by MIT staff and one representative from each member company, forming the board of directors.

Organization of the roadmapping effort originated with the formation of three Technology Working Groups: cross-market applications, complementary metal-oxide-semiconductor (CMOS) platform, and integration, packaging, and interconnect. Working group activities helped to support the funding of three CTR fellows, who worked closely with each working group, resulting in the authorship of white papers under the diligent direction of industry-based working group leaders.

The CTR program is in its third phase, with a growing membership and a new structure for engagement and deliverable work products. Phase III working groups are currently focusing on baseline optical PCIe3.0+, the next-generation data signaling bus ideally suited for high performance graphics cards, and dimensions of computational scaling within an open architectures forum dealing with the challenges of multicore processing. Consortium members are working to form a consensus on identifying the parameters, needs, and distinctions between short-term and long-term communication links. Shifting from a four-year, 200-page document, CTR III is publishing shorter, more frequent white papers on a revolving timeline to better match the industry cadence of a typical product cycle. Recent white paper titles include “Scaling Limits and Energy” and “The Limit of Copper Interconnect Scaling.”

Selected Faculty Highlights, Honors, and Awards

MPC faculty have had significant research accomplishments and have received numerous awards and honors, as individually reported in the reports of their home academic departments. Of special note are:

Lionel Kimerling, the Thomas Lord professor of materials science and engineering, and his Electronic Materials Research Group (EMAT), in a team led by senior research associate Jurgen Michel, achieved another milestone this past year in the area of silicon-based active photonic devices with the design and demonstration of an electrically pumped germanium-based laser on silicon operating at room temperature. The Ge-on-Si device emission exhibited a gain spectrum of 1590–1610nm, making it ideally suited with single mode telecom and datacom applications. The more important property of the design is it’s compatibility with Si CMOS technology as a monolithically integrated laser on SI, and it provides the first real step at achieving chip-chip communications and intrachip communications. News of this achievement was quickly recognized and reported by the *New York Times* and other national media. Additional information can be found on the EMAT website.

Donald Sadoway, John F. Elliott professor of materials chemistry, has earned recognition this year for his pioneering work on an entirely new type of battery, one based on floating layers of high-temperature molten metal and salt. The battery could provide electricity storage on a scale useful to major electric utilities—allowing them to store energy whenever it is' available and cheap, and then pump it back into the grid when it is' most needed. Such storage capability could be the key to making intermittent sources of power—such as sun, wind, and tides—a reliable part of the world's energy supply. The innovative approach earned Professor Sadoway a coveted spot at this year's TED (Technology, Entertainment, and Design) talks; a video of his remarks garnered more than 440,000 views in its first three weeks and is now up to 772,353 views online. *Time* magazine included him in its annual list of the 100 most influential people in the world. Finally, Sadoway's liquid battery project has garnered more than $13 million in government and industry funding, partly from the French energy company Total, provided through the MIT Energy Initiative (MITEI) (not including money raised by a company founded to commercialize the technology—half of which came from Bill Gates, Microsoft cofounder and current chairman, who watched Professor Sadoway's lectures via MIT OpenCourseWare).

Christopher Schuh, the Danae and Vasilios Salapatas professor of metallurgy and a MacVicar Faculty Fellow, was appointed the new head of the Department of Materials Science and Engineering (DMSE), assuming his new responsibilities October 12, 2011. Professor Schuh succeeds professor Carl V. Thompson, who was the interim department head since July 2011. There are 34 faculty members in DMSE, and both its graduate and undergraduate programs were ranked first in the nation in the latest *US News and World Report* rankings. Professor Schuh's research focuses on experiments, analytical theory, and computer simulations that explore the processing-structure-property relationships in structural metals. Schuh's research covers many length scales, from long-range disorder in grain boundary networks to the nanoscale disorder in amorphous and nanocrystalline alloys.

Harry Tuller, professor of ceramics and electronic materials, DMSE, and Bilge Yildiz, assistant professor of nuclear science and engineering, were among the 2012 recipients of the International Union of Materials Research Societies (IUMRS) Somiya Award, along with three international collaborators. The team was honored for its work on" the design of ionic and mixed conducting ceramics for fuel cell application". Professors Tuller and Yildiz have been actively collaborating on chemo-mechanical coupling in mixed ionic electronic conducting oxides in energy conversion devices such as solid oxide fuel cells. Their collaborative research has been supported by US-DOE Basic Energy Sciences and MITEI. The awards ceremony will be held at the IUMRS International Conference on Electronic Materials, hosted by the Materials Research Society of Japan, on September 27, 2012, in Yokohama, Japan.

Pablo Jarillo-Herrero, the Mitsui career development assistant professor in the Department of Physics, was recently awarded the Presidential Early Career Award for Scientists and Engineers. This is the highest honor bestowed by the US government on science and engineering professionals in the early stages of their independent research careers. Awardees are selected for their pursuit of innovative research at the frontiers of science and technology, and their commitment to community service as demonstrated through scientific leadership, public education, or community outreach. Professor Jarillo-Herrero, who was nominated by the Department of Energy, was cited for his pioneering research on quantum transport phenomena in graphene and topological insulators, which has expanded understanding of the fundamental electronic structure and laid the foundation for future energy applications. He was also cited for his outreach to the public through the popular press.

Bilge Yildiz was the winner of the 2012 Charles W. Tobias Young Investigator Award. Established in 2003 by the Electrochemical Society, the biennial Tobias Award recognizes outstanding scientific or engineering work in fundamental or applied electrochemistry or solid-state science and technology by a young scientist or engineer. The award ceremony will take place in Hawaii in October 2012, at the joint international meeting of the Electrochemical Society and the Electrochemical Society of Japan, where Professor Yildiz will also present a keynote lecture. The focus of 'her research is understanding the response of the surface physical chemistry of ionic solids when driven by dynamic environments of chemical reactivity and mechanical stress. Her goal is to advance quantitative understanding of how surface activity and charge transport kinetics are driven by the environment, and to apply this knowledge to enable the design of novel surface chemistries for highly efficient solid oxide fuel/electrolysis cells and for corrosion-resistant materials.

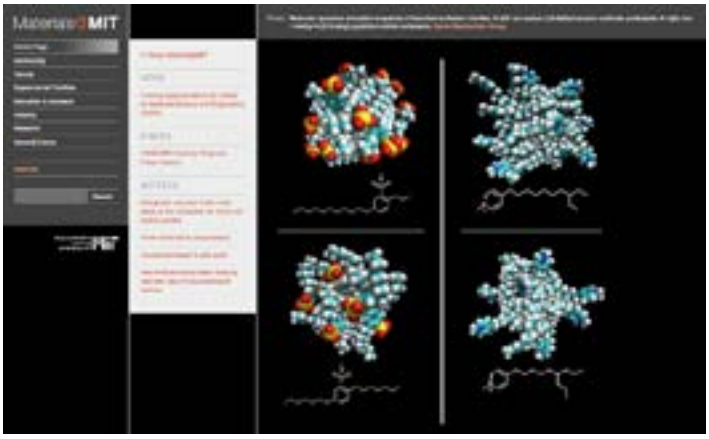
Promoting Exchange of Knowledge

As part of the MIT community, MPC's first priority is the education of the next generation of materials processing research scientists, engineers, and leaders. To this end, MPC initiates programs to enhance the intellectual vitality of the materials processing community.

Materials@MIT Gateway

MPC continues to expand its collaborations with other materials-related centers across campus to provide a common and guided gateway to the current maze of possibilities faced by outside visitors when approaching MIT with a materials interest. The Materials@MIT gateway web initiative—cosponsored by MPC, the Center for Materials Science and Engineering (CMSE), and DMSE—actively encourages the participation of all campus organizations involved in materials research.

The increasing shift to online information transfer has catalyzed a more focused initiative utilizing this site as a campus-wide materials reporting resource. Materials@MIT has become a highly successful portal for materials news and events within the MIT community. Faculties from several disciplines have availed themselves of the website's popularity, advertising well-received journal publications. The website has become a comprehensive repository of contact information for MIT startup companies, MIT materials research centers, and shared experimental user facilities. A comprehensive listing of academic programs, K–12 outreach programs, and campus-wide research reports is available at this site, in addition to a cross-departmental directory of faculty engaged in materials research.



Screen capture of the Materials@MIT homepage

Screen capture of Materials Processing Center website homepage, featuring a news and announcements segment, a materials news articles segment, and worldwide and MIT materials news feeds

Summer Research Internship Program

MPC does not limit its educational outreach to the MIT community. For 29 years, it has sponsored (now cosponsored with CMSE) a summer internship program for promising undergraduate researchers from other colleges and universities nationwide. The nine-week MPC Summer Research Internship Program is a National Science Foundation Research Experience for Undergraduates program that brings the best science and engineering undergraduates in the country to MIT for graduate-level materials research in laboratories of participating faculty. The program culminates in a poster session held in Lobby 13, where students present their research to the MIT community.

The 2012 program involved 15 faculty and 15 students from schools including Brown University; the University of California, Berkeley; Florida State University; the University of Kansas; the University of Minnesota; Ohio University; Universidad of del Turabo (Puerto Rico); Mount Holyoke College; St. Olaf College; and the University of Utah.

2011 Summer Scholars

More information about the MPC/CMSE Research Experience for Undergraduates summer internship in materials science can be found at http://mpc-web.mit.edu/.

Materials Day

Sharing knowledge and insight with others in the materials science and engineering field can lead to new ideas, collaborations, and breakthroughs. Once a year, the materials community is invited to Materials Day, a celebration to recognize and honor the many important accomplishments and achievements of the past year and to talk about the future.

Held in the fall, Materials Day is a daylong symposium on a featured topic, followed by a graduate student/postdoctoral associate poster session. The Materials Day 2011 Symposium focused on computational materials and looked back at the 32-year legacy of MPC and how its widening focus has come to define an interdisciplinary hub of activity today. Seven presentations were made over the course of the day, from both faculty and industry professionals, drawing a crowd of more than 110 attendees.

Invited speakers and their talk titles included: Dr. Sadasivan Shankar, Intel Corporation ("The Yin and Yang of Computational Materials Design"); professor Jeffrey Grossman, DMSE ("Atomic-scale Modeling for the 21st Century Energy Challenges"); Dr. Jerry Young, Boeing ("Atoms to Airplanes: Simulation, Testing, and the Future of Design"); associate professor Markus Buehler, Department of Civil and Environmental Engineering (CEE) ("From Atoms to Structures—Turning Weakness into Strength"); Dr. Yue Qi, General Motors Research and Development/Planning ("Computational Materials Design—From Hard Coatings to Soft Membranes"); professor Gerbrand Ceder, DMSE ("The Materials Genome Project: Accelerated and Large-scale Materials Discovery through Computation"); and assistant professor Alfredo Alexander-Katz, DMSE ("Soft Materials in Silico: Opening New Frontiers in Materials Science"). Professor Thompson, DMSE and MPC director, led the opening welcome presentation.

The poster session that followed the panel presentations included over 65 posters presented by graduate students and postdoctoral associates from departments including Chemical Engineering, Chemistry, CEE, EECS, Aeronautics and Astronautics (AeroAstro), DMSE, DME, NSE, BE, and Physics. The posters were judged by a panel of representatives from industry as well as members from the MPC advisory board. Winners received award certificates and $500 prizes. Poster session winners were:

Roberto Guzman de Villoria, AeroAstro:
"Continuous Growth of Vertically Aligned Carbon Nanotubes"
Sponsor: Nano-engineered Composite Aerospace Structures Consortium (NECST)
Faculty advisor: Professor Brian Wardle

Sunny Wicks, AeroAstro
"Hierarchical Structural Materials with Aligned Carbon Nanotubes for Multifunctional Applications"
Sponsor: NECST
Faculty advisors: Professors Brian Wardle and Michael Rubner

Adam Jandl and Roger Jia, DMSE
"III-V Semiconductors for Thermoelectric and Thermophotovoltaic Applications"
Sponsor: S^3TEC
Faculty advisor: Professor Eugene Fitzgerald

Materials Day 2012 is scheduled for October 17, 2012.

Materials Day 2011 Poster Session winners, from left to right: Roberto Guzman de Villoria (Department of Aeronautics and Astronautics); Ernest Littauer, advisory board chair; Sunny Wicks (Department of Aeronautics and Astronautics); Carl V. Thompson, director, MPC; Adam Jandl and Roger Jia (Department of Materials Science and Engineering); Mark Beals, associate director, Materials Processing Center

International Partnerships with Industry and Government

MPC continues to collaborate with the Microsystems Technology Laboratories in managing the MIT-INL program. Research thrust areas are:

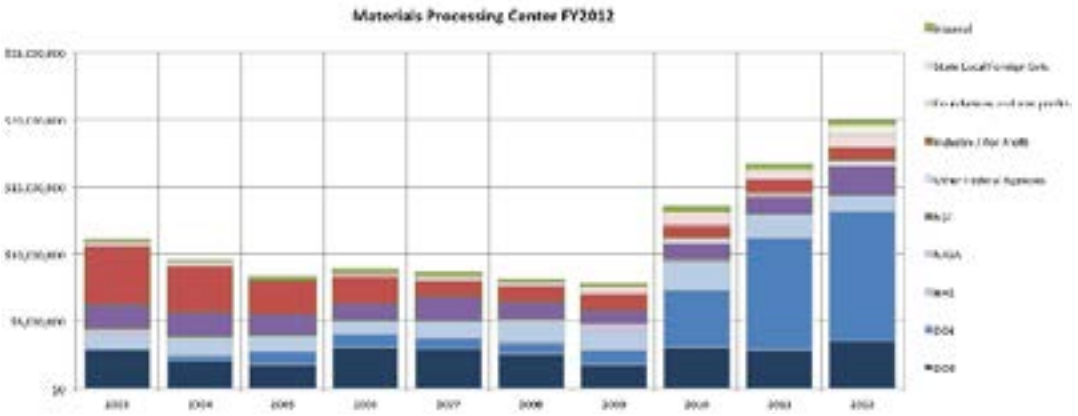
- graphene-based microsystems for environment and food-quality monitoring
- nanomaterial arrays for integrated energy storage devices, supercapacitors, and sensors for autonomous sensor systems
- piezoelectric microelectromechanical systems for energy harvesting and actuation
- top-down templating of protein assembly: complex molecular self-assembly routes to biological device fabrication

Two of the four thrust areas are centered in MPC and two in MTL. Faculty supported in the program include Tomas Palacios, Pablo Jarillo-Herrero, Sang-Gook Kim, Martin Schmidt, Carl V. Thompson and Karl Bergrenn. The second annual workshop for the MIT-INL program was held at MIT and included presentations from MIT faculty already involved in the program, as well as INL collaborators and potential future participants. A new research thrust area has been proposed to INL on the subject of nanotechnology for water treatment; professors Evelyn Wang and Jongyoon Han have submitted proposals.

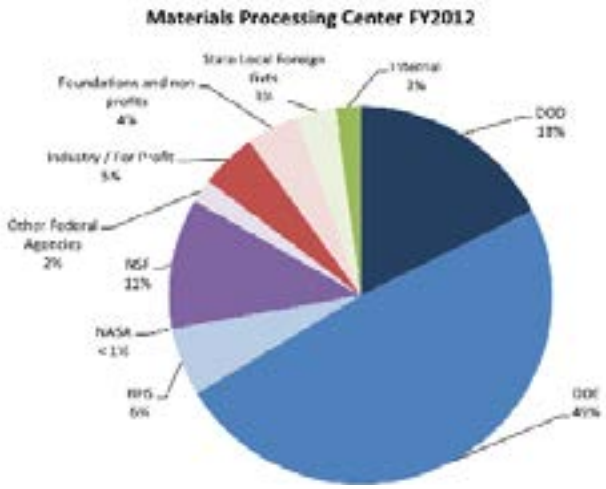
Research Volume

MPC's five priority research areas are medical materials, photonics, energy, environment, and nanotechnology. Total expenditures under MPC totaled $20 million in FY2012 (+11%). Major program expenditures included: Professor Sadoway's ARPA–E program on liquid metal batteries; professor Alexander van Oudenaarden's National Institutes of Health (NIH) funding on stochastic gene expression and signal transduction in single cells; Professor Chen's S^3TEC DOE Energy Frontier Research Center work on solar-thermal energy; Professor Fitzgerald and seven co-PI's' work on "Lattice Engineering Substrates for Disruptive Electronics" by Singapore's National Research Foundation; Professor Thompson's INL research collaboration on nanoscience and nanotechnology, co-shared with MTL; and Professor Kimerling's MPhC Multidisciplinary University Research Initiative (ended 12/2011) and APIC Corporation program on silicon-based photonic integration (ended 2/2012). Campus materials research volume across MPC, CMSE, the Institute for Soldier Nanotechnologies, and DMSE reached nearly $53.9 million (+11.2%) for FY2012.

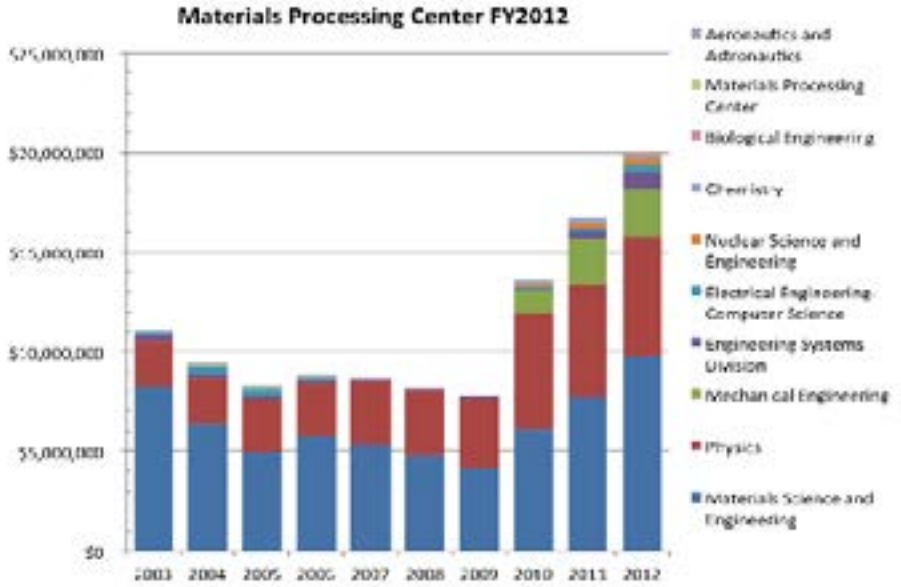
MPC researchers are sponsored not only by a variety of companies but also by nearly every major federal research–sponsoring agency, including the National Science Foundation, DOE, NIH, Defense Advanced Research Projects Agency, Air Force Office of Scientific Research, Office of Naval Research, and US Army Research Laboratory.



MPC sponsored research volume, FY2002–FY2012



Material Processing Center major sponsors, FY2012



Materials Processing Center academic affiliations, FY2012

Outlook

MPC will continue to be active in international programs. The center kicked off the new Singapore–MIT Alliance for Research and Technology Centre program in low-energy electronic systems, and it continues to manage the MIT-INL program. In the past year, MPC faculty also submitted proposals for SkTech Center–MIT Research Centers. A group led by professor Marc Baldo and co-PI Professor Kimerling proposed a "Seed Concepts in Low Energy" center, which was awarded seed funding. A group led by Professor Thompson proposed formation of a Center for Electrochemical Energy; this proposal is among the finalists for full funding.

Research on materials for energy continues to be a growing focus within MPC. In addition to the proposal for an energy-focused SkTech Center, professor Yang Shao-Horn led the development of a proposal for a DOE Research Hub on battery technology. If the proposal is successful, this major center will involve collaborations with Oak Ridge National Laboratory and the University of Texas.

Because of MPC's expanding research portfolio and the new services to centers and programs that it provides, it is expanding its staff. This year, Gilbert Cordova joined the center as a senior financial administrator. Mr. Cordova was the fiscal officer for the Department of Physics for five years before joining MPC. The center has also initiated a search for a new science writer, who will develop content for the MPC website and for a new newsletter. Despite the recent expansion of the MPC staff, the center will be able to reduce the MPC allocation rate from 4% to 3%, while significantly expanding its services to faculty.

MPC activities, such as Materials Day and the Summer Research Internship Program, are supported by MPC Industry Collegium membership fees. The center would like to develop new outreach and community building activities. However, collegium membership has been constant over the last three years, and is also significantly lower than it has been in the past. During the past year, MPC has focused on development of new collegium member benefits and mechanisms for recruiting new members. It has collaborated with the Industrial Liaison Program in doing this. The addition of a science writer will help in its efforts to expand the collegium. MPC is also developing new mechanisms for generating revenue by providing companies new services.

The Materials Processing Center looks forward to continuing its work with individual faculty and teams of faculty to develop and support new interdisciplinary research programs. As always, the center will continue to search for new ways to interact with industry in order to create collaborations that promote the two-way exchange of expertise and lead to the development of new materials and processes that provide a sustainable improvement in the quality of life worldwide.

Carl V. Thompson
Director
Stavros Salapatas Professor of Materials Science and Engineering