Materials Science and Engineering
2015-2019 Strategic Plan

Mission statement

> ***The Mission of the Department of Materials Science and Engineering is to provide our graduates with a well-rounded engineering education with specific emphasis on materials science and engineering in order to meet the needs of industry, academia, and government; to conduct research at the frontiers of the field; and to provide an integrating and leadership role to the broad multi-disciplinary materials community.***

Vision statement

> ***Through its actions MatSE strives for international preeminence in materials science and engineering as indicated by highly-cited scholarly publications, outstanding leadership in the profession, and the education of a diverse group of highly-qualified graduates.***

The materials landscape at Penn State has undergone significant transformation in the last five years. In 2011 the Millennium Science Complex (MSC) opened its door as the new home for the Materials Research Institute. About 1/3 of the MatSE faculty have their offices and research laboratories in this facility. MRI provides a centrally located state-of-the-art nanofabrication facility and houses state-of-the-art analytical equipment in materials characterization. We have already seen that MSC is a magnet for recruiting top faculty and graduate students to the department and Penn State.

The remaining faculty members of MatSE are housed in Steidle Building – an historic Klauder Building built in 1929. The University approved the renovation plan to reconstruct Steidle Building by removing the middle section and replacing it with 28,267 sq. ft. of modern graduate and undergraduate laboratories. When completed in 2016 the graduate laboratory spaces will be shared by faculty involved in bio-nanomedicine, materials processing, structural materials, advanced polymer synthesis, computational materials science, and polymer membranes and electrochemistry. The renovated spaces in Steidle Building will also house new analytical equipment and additive manufacturing facilities to support hands-on undergraduate education, and a state of the art computation facility for both undergraduate and graduate instruction in computational materials science and engineering. While the university has made a significant investment to renovate the 105,036 GSF (65,635 NSF) in Steidle, we have a long way to go to equip the building with new state of the art equipment. In 2016, MatSE faculty, staff, and students will be equipped with the most modern materials research facilities of any university in the U.S.

During the Steidle re-construction the faculty, staff and students are distributed in 6 different buildings with most research being located in the newly constructed modular laboratory (Mod Lab) complex between Research Unit A and the Forest Resources Laboratory on the East campus. During this time the department is challenged to maintain the strong sense of community that exists today and which is so important for recruiting new students, faculty and staff.

In 2010 the University's Core Council underscored the need to address low enrollment options in MatSE. Partly as a result of that report, as well as the need to modernize and increase flexibility in the undergraduate materials science and engineering curriculum, we transformed the undergraduate program and replaced options with specializations effective fall 2012. In doing so we increased academic rigor by adding a required course in computational materials science and engineering, added a communications-intensive course on materials selection and sustainability to significantly improve the oral and written communication skills of MatSE juniors, and now require all students to take organic chemistry and an introduction to polymer science and engineering course. Partly as a result of the above changes MatSE undergraduate enrollments have almost doubled from 143 in 2009 to 261 in 2014. B.S. graduates numbered 20 in 2009/2010 and we are poised to exceed 60 B.S. graduates in 2014/2015. At the same time enrollments in 9 MatSE core course have more than doubled from 30 – 40 students per class to an average of 80 students as more engineering and science departments add materials options, in addition to our enrollment increases. With the increased flexibility of the degree and the renewed Steidle Bldg. we expect to see further growth in student enrollments. At the same time the percentage of women faculty and student has remained reasonably steady at 20-25% and MatSE graduate undergraduate and graduate students from underrepresented groups has been <4% over the last 5 years.

The field of materials continues to rapidly expand as materials form a critical interface with society's ever-increasing thirst for new technology in medicine, communications, electronics, transportation, energy and water. Engineering solutions involving materials are at the forefront of meeting the demands for sustainability solutions and advanced manufacturing. Recent decisions by the federal government to expand research funding for Big Data, the Materials Genome, Energy, and Additive Manufacturing will play a role in future plans for MatSE. MatSE faculty members fill important leadership roles in cross-cutting and interdisciplinary research centers and institutes focused on these emerging areas. An increasingly important direction is to investigate and evolve new research and education paradigms to support the infrastructure investments in MRI, PSIEE and the Huck Institute.

A Special Goal – The Materials Legacy on Display

A special goal of the 2015-2019 plan is to finalize the renewal of Steidle Building with state of the art equipment and undergraduate laboratories, examples and displays of how "Materials

Change Our World", and to capture the materials legacy at Penn State. In this way we plan to make renewed Steidle a showcase for EMS and MatSE education and research.

Materials education and research is a major success story at Penn State. The Department of Materials Science and Engineering was created in 1967 through a number of mergers involving Metallurgical Engineering (founded in 1907), Ceramic Technology (1923) and Fuel Science (founded in 1934). In 1972 polymers was added to create one of the most comprehensive materials science and engineering departments in the country. In 1962 The Materials Research Laboratory was created and subsequently merged with The Materials Research Institute in 2001.

The Department of Materials Science and Engineering at Penn State is recognized as one of the premier materials programs in the world. The legacy of materials is directly tied to the commitment to excellence and success of numerous faculty and alumni over the last 100 years. With the transformation of Steidle Building to a modern, state-of-the-art teaching and research facility in 2016, we have a unique opportunity to recognize and highlight those individuals who are responsible for our legacy. We propose to commemorate them by naming offices, meeting rooms, and laboratories in their honor. Funds to name these spaces will be used to purchase state-of-the-art equipment that will reflect the quality of the new facilities and will ensure the continuation of our success.

A directed development plan has been initiated to display the department's legacy so our students, faculty and visitors will understand and be made aware of our history each and every day. The "Legacy on Display" initiative will name Research Labs, Meeting Rooms, the Department Convocation Room (the rotunda room), Distinguished Faculty Offices, Faculty Offices and undergraduate research laboratories such as the Advanced Materials Processing Lab, The 3D Printing Lab, The Interactive Computer Learning Lab, the Analytical Labs and the Metallography Lab.

Based on numerous retreats and committee meeting, the MatSE faculty and staff set the following goals to guide the department in the coming years. The department's goals for 2015-2019

- **Goal 1 - Maximize the growth of all MatSE students through expanded use of electronic tools in the classroom, state of the art equipped laboratories, and expanded opportunities for graduate student teaching**

- **Goal 2 - Transform and grow the department's research portfolio in cutting-edge research directions to address society's needs for sustainable technologies**

- **Goal 3 – Communicate and promote departmental diversity and community**

- **Goal 4 – Re-invent infrastructure support and increase discretionary funds to enhance departmental success**

Goal 1 - Maximize the growth of all MatSE students through expanded use of electronic tools in the classroom, state of the art equipped laboratories, and expanded opportunities for graduate student teaching

Undergraduate performance has been characterized by a bi-modal grade distribution for many years. Students who enroll in MatSE as freshmen have a clear advantage relative to students arriving from the campuses or by transferring from other departments. To alleviate the difference in educational background that often leads to lower levels of achievement, we are committed to ensuring all students have maximal access to educational materials. We plan to use digital, e-learning tools and other electronic means to ensure that all MatSE students can access MatSE courses independent of their location, background or when they join MatSE.

Industry has shown an increasing need for MatSE M.S. graduates and an M.S. education for employees with a non-MatSE background. In the last year 433 applicants were turned away from the i-MatSE graduate degree program. We envision establishing alternative programs for these candidates by offering new options in the i-MatSE graduate program.

The strategic initiatives to support Goal 1 are:

Undergraduate performance:

- Diversify and modernize the delivery of course content both inside and outside the classroom
- Require e-devices of all UG students
- Significantly upgrade and broaden undergraduate teaching laboratories to include an Additive Manufacturing Lab, Analytical Labs and an Interactive Learning Lab
- Develop initiatives to enable all students to maximize their potential to attain higher levels of achievement
- Recruit outstanding students with an honors program to include international experience, co-op/internship, and/or UG research, and professional society participation

Graduate education:

- Create a one-year non-thesis professional masters degree in materials
- Diversify classroom teaching opportunities for graduate students

Goal 2 - Transform and grow the department's research portfolio in cutting-edge research directions to address society's needs for sustainable technologies

To maintain our leadership and reputation for excellence in materials research it is important to constantly innovate and to push the frontiers of materials. The programs outlined below will require significant investments in infrastructure and personnel. With retirements and new university-wide funding initiatives, the department will be able to respond to many of the opportunities for innovation outlined below. Some of the areas envisioned can be organized under a theme of Materials by Design which incorporates principles of sustainability and life cycle design. We expect that partnerships with the Huck Institute, MRI, and PSIEE will be instrumental in organizing these areas for success.

The following research areas, which are more fully described in Appendix I, will require significant departmental, college and university investments:

- Create a research cluster in the development of, and access to, *in-situ* and *in-operando* tools by hiring faculty in *in-situ* and *in-operando* characterization of materials and devices, e.g. *in-situ* spectroscopy, diffraction, and microscopy, and hire faculty experts in *in situ* characterization of dynamic processes, and the modeling of many-body electronic structure theory/computation
- Use additive manufacturing to (1) enhance human health by linking with Hershey Medical School and the Huck Life Science Institute to advance 3-D bio-printing, and (2) create a new research thrust on AM of electronic devices by hiring at least one faculty expert in additive manufacturing engineering/science
- Develop a new research thrust at the water-materials interface based on polymer membranes, aqueous electrochemically-driven systems (e.g., corrosion) and add a faculty member in metals processing for the development of alloys for aggressive environments
- Lead a research thrust in electronic, photonic, and magnetic materials for sensors for monitoring human health, agriculture, efficient combustion, nuclear waste storage, nuclear power generation, and/or homeland security by working with the Center for Dielectrics and Piezoelectrics and by hiring a faculty member expert in magnetic and electronic material systems
- Position Penn State as a leader in ionically-driven devices and systems by developing cross-cutting efforts with Penn State's Energy Institute and the Battery Center

Goal 3 – Communicate and promote departmental diversity and community

Today MatSE is composed of a diverse community but we could do better to increase the number of students from underrepresented groups. There are a number of new programs within EMS and the University to increase the number of students, faculty and staff from underrepresented groups. We plan to partner with the EMS Associate Dean's office to recruit outstanding students in STEM fields.

Community and culture have always been critical to MatSE. As the department enrollments grow and the percentage of international students increases, it will be more difficult to maintain the sense of community that the department enjoys today. The issue is further complicated by the Steidle Building renovation and the lack of a centralized "home" for the students, faculty and staff of MATSE during the renovation. In the coming years we must redouble our efforts to ensure that we continue to build and maintain a student-centered community and culture through the Steidle renovation process. To instill and retain a sense of community, we envision a concerted effort to celebrate our legacy while at the same celebrating student and faculty successes.

Our strategies to achieve this goal include:

- Create a summer school/REU-type program with the College to directly connect and recruit prospective undergraduate and graduate students into materials
- Develop recruiting program to Increase the percentage of students from underrepresented groups in MatSE.
- Develop a "Women in MatSE" campaign to increase the percentage of women students and faculty in the department.
- Develop initiatives to facilitate richer interactions and community between faculty, staff, graduate, and undergraduate students
- Better incorporate campus students into the department before they arrive at UP
- Put "materials on public display" in the new Steidle Building (periodic table, materials obelisk)
- Promote the use of common spaces in new Steidle Bldg for student/staff/faculty interactions
- Celebrate departmental accomplishments and legacy
    - Display and highlight student and faculty successes in new Steidle Bldg
    - Display the MatSE legacy in Steidle (named offices, award history, "family tree")
- Develop communication products to market our strengths at Penn State, to our customers, and the external materials community

Goal 4 – Re-invent infrastructure support and increase discretionary funds to enhance departmental success

Growth of the department in the new directions proposed above will require a significant investment in personnel training, hiring staff with new skills and infrastructure costs. The strategies below are designed to align staff responsibilities with these plans. Also, we envision a number of strategies to increase discretionary revenue needed to support the goals of the Strategic Plan.

Infrastructure enhancements:

- Realign and hire staff around new responsibilities and needs such as the safety coordinator position, technical laboratory manager, and undergraduate analytical facilities manager in Steidle Bldg
- Create a formal staff-supported program for large proposal and innovative research initiatives. Sponsor faculty-run think tanks to initiate new research directions
- Enhance student education by significantly upgrading the facilities with modern, state of the art equipment in the new Steidle Building labs and classrooms through a Steidle-naming sponsorship program (e.g. 3D Printing Lab, Undergraduate Analytical Labs, Advanced Materials Processing Laboratory, Interactive Learning Lab) ($600,000), as described in Appendix II.
- Endow graduate "top-up" support to recruit outstanding women and students from underrepresented groups
- Endow each position in the Undergraduate Research Fellows program (e.g., $25K/student)
- Endow the MatSE Safety Program ($50,000)
- Endow International Internship in Material Scholarships ($50,000/student)
- Increase the number of endowed faculty chairs and professorships
- Make more assistantships available to first-semester PhD students to aid recruiting and increase availability of students mid-year for new research projects

Potential Discretionary Revenue Streams:

- Create a non-thesis professional masters degree with a clear revenue sharing plan
- Increase summer semester offerings to generate discretionary funds for faculty and the department
- Create a materials e-certificate through the World Campus

Appendix I

In-situ Study of Dynamic Processes

Advances in microscopy and spectroscopy have created the opportunity to study materials as they evolve in real time. For example, femtosecond probes allow us to directly observe the formation of crystals and the transformation of materials in ways that were never before possible. Materials scientists are also increasingly studying the evolution of materials in their native, synthetic, or service environment (*in situ*). Processes of interest occur in geological materials, materials synthesis, and the use of materials in extreme environments. Taking this approach one step further, we want to characterize the electronic and atomic processes that occur *in operando* when a material is used in a battery, transistor, or other device. To complement the instrumentation and a faculty member hired in this area, we also propose to hire of a materials theorist to work closely with experimentalists to interpret their findings and predict new phenomena. In particular, a theorist with expertise in many-body theory of non-equilibrium processes is needed.

Additive Manufacturing

Through collaboration between EMS, the College of Engineering, the Materials Research Institute, and the Applied Research Lab, ARL established the Center for Innovative Manufacturing Processes (CIMP-3D). The Center focuses on *materials by design,* and the application of *additive manufacturing science* for manufacturing structural biomaterials (bone, cartilage, ligaments, circulatory systems, etc.), thermostructural components for energy systems, and components for water treatment (filters, membranes, catalytic supports).

Additive manufacturing is a relatively new materials processing technology which enables the production of components with complex geometries, with dimensional fidelity and properties unachievable by conventional materials processing methods. Significant processing efficiencies, the ability to rapidly prototype components, and significant manufacturing cost savings on complex, high performance components for a myriad of applications are the hallmarks of this technology.

The 5 year vision of CIMP-3D is to be the top R&D center for engineered AM components in the U.S. To achieve that status the Center will focus on six key goals:

- Lead Basic Research of AM Science & Technology
- Expand AM Infrastructure at Penn State
- Grow AM Education for Penn State Students

- Transition & Commercialize AM Research & Technology
- Expand AM Outreach & Engagement with Industry
- Develop a Sustained Communication Plan for CIMP-3D

The Center plans expansion of its activity to include partnerships with Hershey Medical, Huck Life Sciences, Penn State Behrend, the Materials Research Institute, and the Center for Innovative Sintered Products as well as other educational institutions to expand its research portfolio and extend its educational and technology transfer footprint. A faculty hire in this area is critical for MatSE to participate in this vision and growth of AM at Penn State.

Develop a New Research Thrust at the Water-Materials Interface

The interaction of water and materials critically impacts our energy future. Power generation is second only to agriculture in water use. To more efficiently use water in power plants, metal alloys for turbines that can operate at higher temperatures are needed. Alloys resistant to aqueous corrosion are also required for exploitation of the Marcellus shale. A new hire in metallurgy will work with other researchers in the Department of Materials Science and Engineering and across campus to address the critical need for alloys for power generation.

Water is ubiquitous in our daily life, and the pressure for clean water for industrial, agricultural, and human needs continues to increase. Materials are key to water recycling, desalination, and purification. Polymer membranes are recognized as one of the most promising water treatment technologies, and polymer surfaces are routinely used in antifouling and anticorrosion technology. We plan to hire an expert in materials for water purification who can build on existing strengths in polymers science to nucleate new activities on materials for water recycling, reuse, and purification. Photo- and electrically-driven purification technologies, porous materials, and new polymeric materials will be developed. The new faculty member will contribute to a team that is already intensively studying ionic motion in polymers, which is the key step in desalination.

Lead a Research Thrust in Electronic, Photonic, and Magnetic Materials for Sensors

The development of novel materials for sensors is an area ripe for further commitment by the Department of Materials Science and Engineering. Faculty members in the Department are already working on chemical sensing (including environmental monitoring), temperature sensing (including infrared imaging), ultrasound detection, measurement of stresses and stress distributions, and radiation detectors. Applications for new materials and sensors systems can be found in diverse efforts across campus—for manufacturing, medicine, petroleum extraction, efficient combustion, agriculture, and monitoring the environment.

Position Penn State as a Leader in Ionically-Driven Devices and Systems

Ion transport in solids is the fundamental process underlying the performance of a wide spectrum of electrochemical devices. Materials with high ionic conductivity and controlled properties are needed for new battery, fuel cell, capacitor, and other electronic and energy applications. In addition, ion transport controls chemical phenomena such as corrosion of metals and alloys and is key to electrodialysis for water purification. A thorough understanding of ion transport in solids is critical for energy harvesting, conversion, and storage. It is also important for electronics for our digital future.

The Department of Materials Science and Engineering already has leading efforts on many materials in which ion motion is a salient feature. This strength has translated into well-recognized research on dielectric materials in which ionic motion must by deliberately suppressed. Other researchers in the Department have successful programs in polymers for ionic transport. As new applications for materials in energy conversion and storage emerge, the need for new ionically-conductive materials is pressing. Therefore, we will create a new thrust in ionic materials and devices by developing cross-cutting efforts between existing Penn State activities. For instance, the Battery and Energy Storage Technology (BEST) Center, the Center for Dielectrics and Piezoelectrics (CDP), and the Electrochemical Technologies Program in the EMS Energy Institute all have efforts that are complementary to this thrust.

Appendix II

Undergraduate Analytical Laboratories

An important component of the laboratory experiences of our undergraduates is hands-on operation of analytical equipment. This experience complements the theoretical education in these techniques gained in lecture courses. To enhance access of our undergraduates to this type of equipment, decrease costs and the burden on the equipment at MCL, we intend to equip laboratory spaces with table-top XRD and SEM units, AFM and thermal analysis (TGA, DTA, DSC, TMA) equipment. This suite of techniques complements the existing optical microscopy facility within the metallography laboratory.

Advanced Materials Processing Laboratories

An important hub for materials science and engineering students is the Advanced Materials Processing Laboratory. This laboratory houses the equipment and instruments needed to educate undergraduate students in the processing of glasses, metals and ceramics. As a hands-on laboratory, students have first-hand experience in fabricating materials either through their laboratory course work or during an undergraduate research experience. These experiences catalyze young people to further pursue careers in one of the materials specialties. A first rate, state-of-the-art processing laboratory is also critically important for recruiting the best and brightest to the field of materials.

The Advanced Materials Processing Laboratory is equipped with a variety of furnaces for binder burnout, sintering and heat treating of metals. In addition, ceramic processing equipment including multiple types of milling equipment a tape casting machine, warm isostatic laminator and a heated platen press is available. For metal processing, the facilities include a rolling mill, arc melting furnace, welding table and metal casting capability. Additional multi-use equipment includes ambient and vacuum drying ovens, balances, a spin coater and viscometer. Also planned are glass melting and processing equipment acquisitions, including batching, melting and annealing facilities.