Part I: Polymer Science and Engineering Department
Strategic Planning Report
(December, 2014)

The Department

The Polymer Science and Engineering Department (PSE) enrolls approximately 120 doctoral students who study in PSE alongside approximately 20 additional doctoral students from other UMass departments. PSE does not support degree programs for undergraduate or terminal masters students, but over a calendar year, PSE hosts approximately 30-40 post-doctoral fellows and an equal number of UMass undergraduates, who are mentored and trained while working on projects within individual PI research groups. The first-year PSE graduate students take a well-developed set of core polymer courses, and these courses, along with preparation for the Ph.D. qualifying exams, occupy all their time. PSE has no university-assigned TA positions, and the department supplements the RAs of upper level graduate students to get TA support for its core curriculum; 100% of PSE graduate students are supported by RAs and fellowships, and except for periods spent at collaborating institutions, all PSE students participate in research and education over the full calendar year in PSE labs and classes. In addition to undergraduate research projects, the PSE faculty teaches a university-wide introductory polymer course taken mostly by UMass and Five College undergraduates, and several PSE faculty members organize freshman seminars.

Polymer research is multidisciplinary, and most research projects require routine access to instrumentation that is too expensive or complicated for acquisition and support within a single PI research group. PSE thus organizes nine shared instrument facilities, which together house over $25 million in equipment; all operate as cost centers and are open to researchers from across the University as well as students and scientists from other universities and industrial sponsors. Approximately $10 million of additional instrumentation is supervised within PI laboratories, most of it accessible to the University community and all of it located in the Conte National Center for Polymer Research. PSE has 18 tenure-track faculty members (17 of whom are tenured and one almost through the tenure process) and eight technical staff members, four at the Ph.D. level, who support the shared instrument facilities. PSE faculty members engage in a large amount of collaborative research, involving multiple PIs from within the department, across campus, and outside the University. Many research and outreach collaborations are organized by federally supported multi-investigator research centers. Annual external research funding has recently ranged from $12 to $16 million, with a significant portion (approximately $2.5 million) coming from a slate of about 40 industrial firms. The same firms hire a majority of PSE graduates. Approximately 15% of PSE graduates choose to pursue academic positions, mostly at major research universities. Campus-wide industrial interactions related to polymers are promoted and managed by CUMIRP, an administrative center within PSE.

The Department's Stature in the Field

PSE strives for a top position in the academic polymer world, with its research and educational efforts setting international standards. While most institutions with programs similar in scope to PSE are located overseas, U.S. academic competition comes mainly from universities that don't organize polymer efforts into a formal academic department, as done here at UMass. Among the few (5-10) U.S. polymer-directed programs/department/schools, PSE ranks at the top in nearly all assessments of research and education. For example, the PSE doctoral program was ranked well ahead of its polymer peers in the last NRC rankings, where such programs were mostly evaluated in the field of "Materials Science and Engineering". In this field, PSE was assigned S and R ratings of 3 to 15 and 4 to 11, placing it squarely among the nation's top ten Materials Science and Engineering departments out of the 80 departments ranked in this category. All others in the top cohort were large, broadly focused Material Science and Engineering departments with two to three times the number of faculty members in PSE. Although the category was discontinued, U.S. News and World Report always placed PSE as number 1 in "Polymer Chemistry", a subfield of its "Chemistry" rankings. A key feature that PSE shares with traditional Materials Science and Engineering departments is the need for expensive and extensive shared instrument facilities. Of the top Materials Science and Engineering departments in the NRC rankings, only one (Caltech) had an annual external funding per faculty member greater than that of PSE, where the average is about $890,000. Similar statements can be made in regard to industrial funding and citations in the scientific literature – PSE is in the top tier of its discipline.

Departmental Vision

Polymer Science and Engineering is a broad discipline, merging components of Chemistry, Chemical Engineering, Physics, and Materials Science and Engineering. No reasonably sized faculty could cover all topical areas across the discipline. At the intersection of science and engineering, PSE pursues both fundamental and applied pursuits, and in the trade-off between the two, the former usually outweighs the latter, explaining the department's placement in a college of natural sciences rather than in a college of engineering. PSE's strength in polymer fundamentals has always been a distinction. Building from a comprehensive science base, and encouraging collaborations between faculty members with different expertise, PSE can move flexibly to exploit intellectual developments within its field.

Throughout its 50-year history, PSE has carefully crafted its hires and investments to maximize overall outside impact, and unlike many peer institutions, most of its strategic decisions have led to ample rewards. Intellectual foci have been particularly influenced by two philosophies:

(i) Scholarly productivity is enhanced by collaboration, and in science and engineering disciplines, collaborations work best when the participants are jointly funded. This vision had led PSE to emphasize the pursuit of large, campus-based federally funded research centers, with a good fraction of the PSE faculty, as well as faculty members from aligning departments, engaged at each funding opportunity. Approximately half of PSE's funding involves multiple PIs, with some projects gathering as many as 30 faculty participants.

(ii) Outstanding scientific research inevitably has technological potential, and so, successful engagement with industry should go hand-in-hand with federal support. A goal for each large, federally supported collaboration is the establishment of an analogous multi-investigator industrial initiative as a mirror. Basic research and applied research are thus pursued in tandem, partnering with the same industries that typically hire PSE graduates.

PSE has no desire to change these philosophies. Their consequences are numerous, in ways both obvious [a high fraction (approximately 50%) of publications with multiple UMass authors, many (approximately 25%) jointly advised doctoral students, single PI laboratory spaces that are open to investigators from across the department and university] and subtle [all core classes taught by two or more faculty members, most major instruments shared, frequent (weekly) faculty gatherings to discuss research topics and opportunities]. The philosophies have withstood the test of time, having emerged from PSE's earliest days and sustained since. A large number of the current faculty members started and sustained their academic careers within the unique PSE culture.

The Student Experience

At UMass, PSE is unique among departments in the absence of an undergraduate major. U.S. programs offering undergraduate polymer degrees have fared poorly, producing few majors and then few employment prospects for their graduates. The PSE faculty firmly believes that a specialized graduate education is best approached after the comprehensive undergraduate training obtained in a traditional science or engineering discipline. Current PSE students have undergraduate backgrounds in 10 or more of these disciplines, including Chemistry, Physics, Biology, Biochemistry, Materials Science and Engineering, Plastics Engineering, Polymer Science and Engineering, Chemical Engineering, Mechanical Engineering, and Civil Engineering. Polymer undergraduate programs are common overseas, where success has been better than in the U.S. The goal of the PSE graduate curriculum is to create professionals who can solve a broad sweep of polymer-related problems. In this aspect, PSE differs from nearly all the polymer efforts found in traditional academic programs, where the intellectual endeavor centers on polymer issues specific to a single discipline. For example, polymer scientists trained in a chemistry department nearly always have deep understanding of polymer synthesis but shallow understanding of polymer physics. Our graduates are polymer generalists, able to address chemistry, physics, materials, and engineering aspects equally. Given the range of student backgrounds and the training goal, the interdisciplinary teaching challenge in PSE is substantial. The job market for graduates has always been strong, especially now, as employers see PSE graduates able to approach and solve an entire polymer problem, not just a piece of such a problem. In a recent survey of the 181 PSE doctoral graduates from the period 2001 to 2011, 178 were determined to be working in the polymer field.

The average time to doctoral degree completion is 5.1 years, with approximately 85% of matriculated students receiving a doctoral degree (about 70% doing so within 6 years). The latter percentages are exceptionally high relatively to peers departments and doctoral programs in general, and perhaps are explained by two factors, the comprehensive first-year curriculum and student financial support through mechanisms other than TA

positions, which often impede students from their demanding course and thesis work. The major attrition of PSE students occurs by failure of the qualifying exams. All PSE students receive stipend support as RAs or fellowships, and the department's average stipend is $25,500/year, a figure comparable to that at many peer departments, but some offer stipends up to 20% higher.

PSE enrollment is highly selective, on par with competitive departments at major research universities. About 20 doctoral students enroll each year from a pool of about 220-260 applicants, with domestic applicants numbering about 65. Foreign students make up about 50% of the enrolled group. Currently, the chief recruiting goal is to attract more applications from top-notch U.S. candidates; success in attaining enrollment from U.S. candidates is high, with the yield for accepted applicants reaching 40 to 50%. While GRE scores do not weigh heavily in the admission process, the average GRE quantitative score gives an indication of program standards; for last year's class, this average was 165. The recruiting of U.S. applicants is a major departmental activity each year and includes a faculty-hosted weekend for the top applicants and separate pre-admission interview visits for those ranked slightly below. Various initiatives attempt to increase the size and diversity of the U.S. candidate pool, including special relationships with a minority-serving professional societies, recruiting bonuses for highly qualified U.S. candidates, recruiting visits by enrolled students to local universities, offers of research experiences for undergraduates from targeted schools, and working closely with the UMass-based NEAGEP. The annual student-recruiting budget exceeds $30,000, making the cost per enrollee over $1,000 (these amounts do not include recruiting bonuses). More resources must be devoted to PSE recruiting to achieve the target of 25 doctoral students each year. In years when sufficient students are not available, the research needs of PIs are typically met by the hiring of post-doctoral fellows. At last count, over 20% of all UMass post-doctoral fellows worked in PSE.

Current and Projected Areas of Intellectual Strength

No major near-term changes in PSE intellectual foci, educational mission, or research operations are planned. The markets for both PSE research and graduates are booming. A static posture, however, leads to a loss of academic stature, so trends must be recognized and developed BEFORE becoming obvious to the external community. For example, about 15 years ago PSE focused on polymer nanotechnology ahead of the trend and saw rich ensuing dividends (funding, hires, and stature). More recent targets included fire-safe polymers, polymers that self-assemble in aqueous media, and polymers in ionic liquids. Emerging targets are seen in functional polymer biomaterials, polymers from renewable feedstocks, polymers in energy, polymer informatics, and polymers in electronic devices. More generally, to increase research funding and keep pace with trends of the field, PSE must improve connections with the biological and life sciences, developing focused strengths in biopolymers, polymers in the neurosciences, and in the interaction of synthetic polymers with living tissues. There is a growing focus on polymer materials for the human interface, an area that threads through current research groups and projected to be a central theme of many future projects.

The current PSE faculty can be divided about equally into groups focused on synthesis, engineering, and physics/materials. Anticipated (5-year time frame) faculty departures will mostly impact the third group, which traditionally has been the largest in

terms of outside impact and number of students trained. This group is also the one most important to successful development and operation of major instrument facilities. The anticipated departures must be countered shortly through hires of younger faculty members with talents in areas such as solid-state materials properties, scattering, and microscopy.

Facilities

All PSE activities are currently conducted in the Silvio Conte National Center for Polymer Research, a building of sufficient size and excellent infrastructure for these and most planned future activities. A few of the latter will eventually move to LSL2, but PSE intends to keep Conte as its home, adjusting uses of the building to accommodate additions and changes to its programs.

Acquiring and operating state-of-the-art instrument facilities is becoming increasingly difficult at universities everywhere, and although the current major instrument facilities in PSE are strong and running well, the complement of essential instruments is not complete. Even more concerning is the problem of facility operations, and particularly, support of the requisite technical staff. UMass has never had a strategic plan for its shared instrumental facilities, developing them as a hodgepodge, with individuals and groups making plans in isolation. PSE is far more involved in instrument facility operation than other campus departments although a majority of the users of its facilities are not from PSE. Other universities are organizing their instrument facilities to maximize campus-wide use and impact, but at UMass, no entity is in charge. The consequences of this poor planning are likely to be significant facility staffing problems over the next few years, with expensive (>$1 million) instruments potentially shut down for a lack of supervision. Graduate research and education in polymers, and in the materials field more generally, requires access to expensive, staff-supervised instruments. Departments do not have sufficient resources and authority to manage campus-wide instrument facilities entirely on their own.

Recent Initiatives

Several recent PSE initiatives are pertinent to the issues probed in this strategic planning exercise. PSE, for example, has started a major fund-raising campaign to coincide with the department's 50th anniversary in 2015-16, when the first ever PSE-wide reunion will be held. While bolstering development activities, the campaign should also connect PSE better to its 700+ alumni, who often are in positions to influence research funding, advise potential student enrollees, and help graduates find jobs.

PSE is also redoubling efforts to ensure its faculty receive more professional awards; while major polymer awards are received regularly, the number of more broad-based awards is not commensurate with the faculty's stature, especially for awards at the most senior level. This deficiency was clearly identified in the recent NRC report, where PSE lagged peers significantly. At least one or two additional faculty members should be in the National Academy of Sciences. Award nominations have frequently been pushed aside because of limited administrative resources to help candidates prepare packages (PSE has just 4.5 administrative staff members for the central department).

Outreach initiatives, often funded through grant funds, are many, including substantial polymer programs presented at elementary and middle schools as well as in-house, intensive laboratory experiences for those in high school. Graduate student involvement significantly leverages PSE outreach efforts, which are much larger than the faculty could offer on its own.

Contributions to the Campus

PSE makes of a multitude of contributions that enhance the scholarly activities of the college and campus, but by far the largest such contribution is research leadership. Over the past two decades, PSE faculty members have led numerous successful multi-investigator teams that landed large centers/projects, including the current EFRC, MRSEC, and CHM, which alone have distributed tens of millions of research dollars. Even with leadership from PSE, project funds have mostly been directed to PIs outside of PSE, usually for PI-supervised research but also to augment faculty start-up and retention packages, to help purchase and maintain equipment, and to support polymer students after their advisors left the University. The presence of such centers, and PSE itself, have enabled outside departments to recruit numerous faculty candidates successfully. This impact is manifest in the large number (20+) of polymer-oriented faculty members at UMass in departments other than PSE. Funded research collaborations between PSE and outside departments extend to Chemistry, Molecular and Cellular Biology, Vet and Animal Science, Mechanical and Industrial Engineering, Chemical Engineering, Physics, Biology, Biochemistry, Kinesiology, Civil Engineering, Electrical Engineering, and Food Science. Many doctoral students supervised by PSE PIs come from these departments.

A PSE campus contribution almost as large as leadership has been research infrastructure. Each year, members of more than 100 campus research groups use the PSE-administered shared laboratory facilities administered as cost centers, and just as many take advantage of the unique instrumentation in other PSE laboratories. Indeed, most shared instrument facilities on the UMass campus were organized by PSE faculty members, often with funds these faculty members obtained independently. Examples include state-of-the-art fabrication tools, mass spectrometry, electron microscopy, X-ray photoelectron spectroscopy, X-ray scattering and diffraction, a clean room, NMR, photovoltaics, thermal analysis, rheology and mechanical properties, light scattering, surface analysis, and chromatography. Such infrastructure requires not just funding and know-how but also initiative and energy, almost all contributed from within PSE. Going forward, the College of Engineering initiative to create a Materials Science and Engineering program hinges on the instrument infrastructure provided by PSE, illustrating that educational and research benefits go hand-in-hand.

A third contribution from PSE is research stature and visibility. Four faculty members have achieved National Academy membership for work in PSE (three are now retired), many PSE innovations have garnered national media attention, PSE has repeatedly been placed at the top of its field in highly publicized national rankings, and PSE has brought to campus numerous national honors, as for example, three of the campus' four Presidential Early Career Awards for Scientists and Engineers (PECASE). Since the federal government created CAREER awards for young scientists and engineers in 1993, every eligible faculty member from PSE has won this award, a

testament to the quality of faculty members hired. All major honors of the polymer field have been won by UMass faculty members, more times than at any other university.

Dozens of outside undergraduate and graduate students are supervised in research each year by PSE faculty members and many others take PSE courses. PSE-hosted seminars by outside experts, typically several per week, are well attended by the broader campus campus.

List of Key Departmental Strengths

The following PSE strengths are clear:

(i) *Faculty* – The PSE faculty has the highest stature in the world for polymers. This stature is manifest in the numbers of major professional awards, the numbers of citations and publications, the numbers of keynote and invited talks, and the external research dollars obtained. Big-name institutions constantly recruit PSE faculty members; on the flip side, PSE has rarely recruited high stature faculty members but instead developed them from early career stage in-house.

(ii) *Students* – PSE successfully competes for the best polymer students in the U.S. and from around the world. More students of high caliber could be absorbed, particularly with an increase in top quality U.S. applications.

(iii) *Grantsmanship, Leadership, and Collaboration* – The PSE culture is well honed for collaborative projects, with several faculty members adept at initiating and leading such projects. PSE pursues as many federal "mega" grants as possible, and for the polymer field, the number of such grants is substantial, so the faculty devotes much time to these efforts.

(iv) *Facilities and Infrastructure* – As documented above, with some exceptions, the tools to do world-class research are present. PSE continually strives, with considerable success, to identify and attack its infrastructure needs.

(v) *Curriculum* – PSE offers the most comprehensive polymer educational program in the world, being viewed as the trendsetter in polymer education. Many peer institutions copy its curriculum.

(vi) *History and Reputation* – PSE has been on top of the academic polymer world for almost 50 years. Its alumni can be found everywhere in this world, and the department's past discoveries are widely recognized.

(vii) *Stability* – Because of the quality of the polymer environment at UMass, PSE is regarded as perhaps the top institution in the world for polymer research. Since 2003, no faculty member has left the department for another institution even when a lucrative outside offer couldn't be matched.

(viii) *Growing, Developing Discipline* – The demand for PSE research and students has never been greater. Industrial funding and job placement for graduates are at their highest levels ever.

(ix) *Technological Relevance* – As clear from the large number of industrially funded projects and the breadth of engaged industries, PSE's activities are technological relevant and impact society. In recent years, the national and international media have repeatedly cited the importance of PSE discoveries.

List of Key Departmental Weaknesses and Vulnerabilities

The following PSE weaknesses and vulnerabilities are of concern:

(i) *Diversity* -Although underrepresented group members are present in significant numbers on the PSE faculty (3 of 18), the fraction of women is disappointingly low (1 of 18). The current fraction of female students is about 30%, on par with female representation in the field as a whole. The hiring of more female faculty members is an urgent need.

(ii) *Faculty Hiring* - PSE has not conducted a faculty search since 2007. New blood is needed to spur innovative ideas, attract the best students, and ensure continuity of educational and research programs.

(iii) *Facilities* - First-rate instrument facilities are threatened by poor campus organization and looming losses of funding for staff. These issues could hinder PSE's ability to compete for large federally funded centers, which weight infrastructure heavily in proposal review; they also harm industrial partnerships and competitiveness of single PI research proposals.

(iv) *Advancing Competition* - Many first-rate research universities are investing to improve their polymer and materials efforts; there is a perception that, although our environment is very strong, it is not progressing at the rate of important peers (Georgia Tech, Florida, Minnesota, UC Santa Barbara, etc.).

(v) *Cost and Administration* - The costs of research (i.e., high overhead rate, excessive student fees, obstacles to proposal submission, burdensome accounting) are higher than at all peer polymer programs/departments.

(vi) *Research Centers* – Although traditionally successful in competitions for large federally funded centers, a juxtaposition of unfortunate developments has reduced center awards this year. New initiatives must quickly obviate impacts, and on-going faculty efforts must be met with generous university support.

(vii) *Faculty Retention* – While many outside offers have been fended off, more continue to surface and each case presents difficulties; in a small department, one loss could lead to a cascade of losses. Retention of the individuals with the expertise and stature to lead current and future collaborations is crucial.

Summary

PSE provides the campus with a stable, well-funded, high stature department that competes successfully with the best programs of its discipline from across the country and around the world. The physical resources available for PSE to do its research and educational missions are mostly adequate, and except in a few targeted areas, substantial new investments are not needed to advance PSE's position relative to peers. The organization of major instrument facilities needs urgent attention as do efforts at faculty renewal and to increase female faculty representation.