AGENDA
For
UNIVERSITY GRADUATE COUNCIL

Monday, February 25, 2013 3:00 p.m. 114 Sherrick Hall

Approval of Minutes of January 28, 2013

Open Campus Forum – Comments from Campus

UGC Committee Reports:

- Policies & Procedures
- Governance
- Curriculum

PhD in Materials Science proposal – Robert Mokwa

Proprosal handout supplied for review

Montana Board of Regents

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PH.D. PROPOSAL IN MATERIALS SCIENCE

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Curriculum Proposal
Collaborative Ph.D. in Materials Science

1. Overview

The University of Montana-Missoula (UM), Montana Tech of The University of Montana (MTech), and Montana State University-Bozeman (MSU) propose a collaborative Ph.D. program in materials science (MatSci). As a field, materials science and engineering (MS&E) have roots in natural materials, and these fields have evolved to encompass minerals, metals, alloys, glasses, slags, ceramics, polymers, biomaterials, thin films, nanomaterials, and composites.

In general, materials science deals with the fundamental understanding of materials through their design, development, and characterization regarding structure, properties, processing, and/or performance along with the underlying theoretical framework; in contrast, materials engineering deals with how materials are prepared, fabricated, and/or manufactured into useful products that range in size from nanoscale communications components and biomedical devices all the way to large-scale aerospace and energy products. Encompassing a very broad range of spatial scales, academic disciplines, and applications, the proposed Ph.D. program will integrate these key aspects of materials science and engineering (Figure 1).

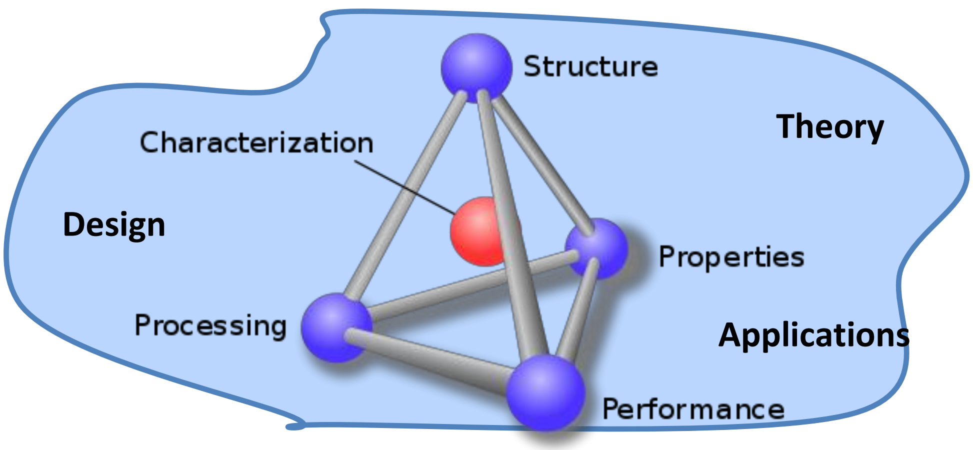

Figure 1. The Domain of Materials Science and Engineering and the Proposed MatSci Ph.D. Program.

Within the broad intellectual footprint of materials science and engineering, the proposed Montana University System (MUS) program will concentrate on four overlapping and interacting areas, which are important to Montana's economic interests: biomaterials; materials for energy storage, conversion and conservation; electronic, photonic, and magnetic (EPM) materials; and materials synthesis, processing and fabrication. In these areas, the three participating campuses already have significant faculty strength and ongoing research activities. These four research themes are described briefly below (see Figure 2).

Biomaterials. This thematic area includes bio-inspired materials and the interactions between materials and biological systems. Biomaterials and biomimetics research investigates and bridges the gap between bench-top investigations and clinical applications with the goal of improving health worldwide. Other important applications are in environmental sensors and bio-inspired or bio-compatible structural materials. Current activities at the three campuses include organic-inorganic hybrids for tissue engineering scaffolds; biomimetic chemistry methods to synthesize multifunctional nanostructured materials; biofilms; replacement bones; and using nanodiscs and liposomes to understand the dynamics of protein binding to cell membranes.

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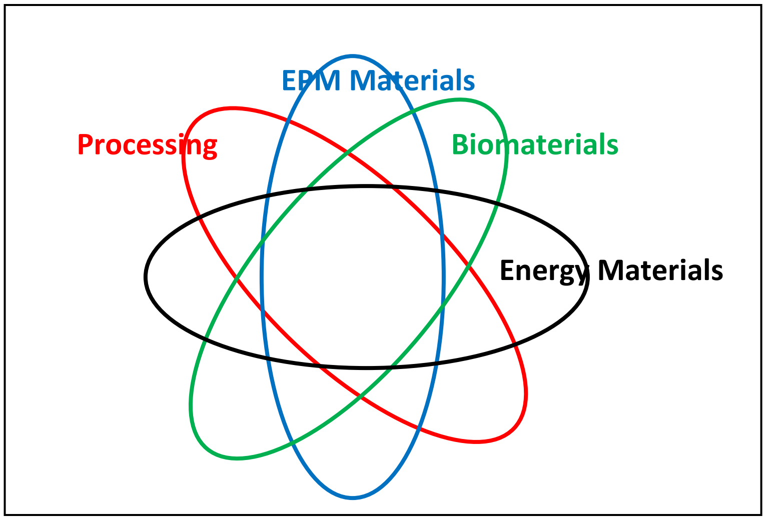

Figure 2. Montana's Proposed MatSci Ph.D. Program's Overlapping and Interacting Research Themes

Materials for Energy Storage, Conversion, & Conservation. A cornerstone of the MUS Materials Science Program is fundamental and applied research in the area of materials for energy storage, conversion, and conservation. Broadly, this research area focuses on transforming resources such as sunlight, wind, and biomass into fuels that can be used at later times to provide reliable, electrical power. Research underway addresses critical materials issues for developing sustainable means of producing and storing chemical fuels, improving energy efficiency, and for converting Montana's abundant natural and renewable resources into a clean, economical, and unlimited supply of electrical power.

Electronic, Photonic, and Magnetic Materials. Electronic, photonic, and magnetic (EPM) materials have applications in quantum information and cryptography, information storage, signal processing, communications, electronics, imaging and sensing techniques, and laser components. These materials are studied in nanoparticle, thin-film, bulk, and single-crystal form and also in optical waveguides and other device configurations. Theoretical directions are quite diverse, and they include determination of structure/function relationships, electronic structure calculations, optical energy levels plus coherence and spin dynamics for ions, properties of alloy phases, and unique phases of matter.

Materials Synthesis, Processing, and Fabrication. This focus area encompasses an exceptionally broad range of research that extends all the way from the extraction and refining of bulk materials to the synthesis of high-value-added advanced materials with application-specific properties. Success in the broad arena of materials processing requires a multi-disciplinary approach. The collaborative MUS MatSci Program pools expertise in solid state physics, metallurgy, polymer chemistry, ceramics, composites, and process engineering to conduct research that responds to and anticipates current and emerging industrial needs and interests.

Students entering the program will be drawn predominantly from backgrounds in engineering and the basic sciences. Major funding will be obtained from federal agencies and national laboratories. Industrial partners will be valuable collaborators in the program by providing opportunities for applied training along with topics and venues for research. Graduates of the program are expected to find employment with research, development, and manufacturing companies in Montana, the region, and the nation. Academia and government laboratories and agencies are also possible career pathways. State and local economies are

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expected to benefit significantly from the ensuing increase in material-based entrepreneurial ventures and to gain the ability to attract a diverse range of materials-based international corporations and start-ups.

2. One-Paragraph Description

Provide a one paragraph description of the proposed program. Be specific about what degree, major, minor or option is sought.

UM, MTech, and MSU propose a collaborative Ph.D. program in materials science (MatSci). The program will be a collaborative effort of the three campuses, and it will involve multiple departments, faculty, courses, and research infrastructure. Research specialties will focus in biomaterials; electronic, photonic, and magnetic materials; materials for energy storage, conversion, and conservation; and materials synthesis, processing, and fabrication—all areas where the three campuses collectively have considerable expertise. The curriculum will integrate a broad range of physical science and engineering disciplines with an even broader range of applications: from health and medicine to nanotechnology to energy, environment, and natural resources. Courses will be coordinated and shared by the three campuses, taking advantage of on-line instructional technologies where appropriate. Each student will complete original, independent research culminating in a dissertation. The program will offer optional, employer-based internships, in which the student tackles a current problem important to the employer.

3. Need

A. To what specific need is the institution responding in developing the proposed program?

Materials science and materials engineering are growing fields globally, recognized as critical to economic competitiveness. They serve and enable a broad range of high-tech industry from huge multinational corporations to entrepreneurial startups. In Montana, the latest MUS research strategic plan, *Montana Science Serving Montana Citizens: Socially Responsible Science and Technology in Higher Education and Related Enterprises* (http://mus.edu/che/arsa/Research/MUSSTACplan.pdf) identifies materials science and engineering as one of the five major research areas of focus for the state. However, NO doctoral program in materials science or materials engineering is currently available in Montana. This situation is surprising for a field identified as one of the state's top research priorities. In addition, the lack of a doctoral program puts Montana at a significant disadvantage in competing both for students and for high-tech materials industry with the accompanying high-wage employment opportunities.

Nationally, the doctoral degree production in "materials engineering," including Ph.D.s in "materials science" has been about 650 per year for the past few years. Data from NSF's on-line WebCaspar database indicates how the degrees awarded in 2010 were distributed among different materials specialties, as represented by the US Department of Education's 6-digit CIP code (see Table 1). The table includes the 6-digit CIP codes which together comprise the detailed field called "materials engineering" (unshaded), along with other materials fields, such as polymer chemistry, polymer/plastics engineering, materials physics, and materials chemistry (shaded in Table 1). Taken together, some 750 doctoral degrees are awarded in these fields, the overwhelming majority (about 87%) in the disciplines included in "materials engineering." Doctoral-level credentials in materials science/engineering are necessary for many positions and career paths: in advanced, high-technology materials-based industry, in government agencies and federal laboratories, and in universities.

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Table 1. Graduate Degree Production in Materials Disciplines, 2010[1]

Discipline by 6-Digit CIP Degrees Conferred in 2010	Research Doctoral Degrees Conferred	*Percentage of Materials Doctorates in this Subfield*	Master's Degrees Conferred	*Percentage of Materials Master's in this Subfield*	Graduate Degrees Conferred	*Percentage Doctorates of Graduate Degrees in Subfield*
14.0601 Ceramic Sciences and Engineering	11	*1.5%*	10	*1.1%*	21	*52.4%*
14.1801 Materials Engineering	513	*68.3%*	663	*72.3%*	1,176	*43.6%*
14.2001 Metallurgical Engineering	12	*1.6%*	38	*4.1%*	50	*24.0%*
14.3201 Polymer/Plastics Engineering	56	*7.5%*	90	*9.8%*	146	*38.4%*
40.0507 Polymer Chemistry	32	*4.3%*	7	*0.8%*	39	*82.1%*
40.0808 Condensed Matter & Materials Physics	9	*1.2%*	0	*0.0%*	9	*100.0%*
40.1001 Materials Science	118	*15.7%*	105	*11.5%*	223	*52.9%*
40.1002 Materials Chemistry		*0.0%*	4	*0.4%*	4	*0.0%*
Materials Degrees TOTAL	751	*100.0%*	917	*100.0%*	1,668	*45.0%*
Official "Materials Engineering" (unshaded CIP)	654		816			

Fortunately, Montana is positioned well to launch a doctoral program based on and advancing materials science and engineering. Already, UM, MTech, and MSU have considerable collective intellectual strength (faculty) and infrastructure assets (labs and instrumentation) in materials science and engineering. By incorporating and building on the existing strengths, assets, and grant-funded research at the three institutions collaboratively, the proposed program can be cost effective and nationally/internationally competitive. In August 2012, the review panel from the American Association for the Advancement of Science (AAAS), convened to assess this proposal concluded: "Overall, because of the national and international growth in the area of materials science and engineering, the review team can envision a joint Ph.D. materials science program, conducted by the three universities, which could significantly benefit the state of Montana and the innovation culture developing within it. To be effective, however, that program would have to be seen—and operated—as a system asset, rather than serving simply as an umbrella for the aggregation of separate programs at the respective universities—a state asset to which all three universities can contribute (based upon their respective strengths), in which they can and must collaborate, and from which each institution can benefit."[2] In Appendix V, this proposal describes how the three campuses will create and implement the proposed program as a system asset.

No Ph.D. level MatSci or MS&E programs are available anywhere in Montana. Only four small materials doctoral programs are available in the contiguous states: at the University of Idaho, at South Dakota School of Mines and Technology, at North Dakota State University, and a very new one at Boise State University. In the larger Pacific-Northwest/Rocky-Mountain region one can find materials Ph.D. programs only at Washington State University, the University of Washington, the Colorado School of Mines, Oregon State University, and The University of Utah. In this context, the proposed Ph.D. program would fill a considerable educational void in Montana, by providing outstanding educational opportunities at the highest level for Montana residents. The Ph.D. program would also attract students (and industry) from elsewhere in the USA and world,

[1] Extracted from the National Science Foundation's WebCaspar database,
[2] American Association for the Advancement of Science (AAAS), "AAAS Review of the Proposed Joint Ph.D. Program in Materials Science, Involving the University of Montana, Montana Tech of the University of Montana, and Montana State University, Conducted for the Montana Board of Regents," August 2012, page 2.

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program “could bring productive focus to this area among the universities’ researchers, bringing investigators from different disciplinary departments together for interchange and creating potential opportunities for collaboration on creative new topics of research and engineering.”[3] Moreover, the new Montana joint Ph.D. program is likely to attract highly qualified students and significant federal and industrial support, a conclusion validated by both the AAAS Review Panel in August 2012 and an earlier review conducted in February 2012, which focused on Montana Tech’s readiness for such a program.[4]

During the planning phase, various people were asked about their possible interest in the program. Several students, industrial representatives, and non-doctoral faculty were very positive, saying that they would enroll immediately if funding were available. Among undergraduate and master’s students in the MUS are several who are specifically interested in Ph.D. study in materials science. Nationally, the program would address a need to produce more Ph.D. graduates with this level and type of expertise.[5]

Additional evidence further reinforces the demand. For example, at UM, the sharp increase in undergraduate enrollment in Chemistry and Physics in the last few years can be attributed to the expansion of materials-related research, including undergraduate research. At MTech, the change in name of its Metallurgical Engineering department to Metallurgical “& Materials” Engineering has increased its undergraduate enrollments as well. Overall, materials-related research has grown on all three campuses. Of further interest is the fact that the MS&E programs (bachelor’s to doctoral) at Washington State University are reported to be among the fastest growing programs at that university. Job boards routinely post over 5,000 materials science vacancies, and Ph.D.-level job boards show large numbers of materials scientist positions as well. Substantial industrial and government interest in graduates is strong, because of the need to replace an aging professional workforce. Letters of support from stakeholders listed in Appendix II provide additional evidence of the demand.

4. Institutional and System Fit

A. What is the connection between the proposed program and existing programs at the institution?

The collaborative Ph.D. program will be anchored by faculty and facilities in the Chemistry and Biochemistry, Chemical & Biological Engineering, Mechanical & Industrial Engineering, and Physics departments at MSU, by the Chemistry and Physics departments at UM, and by the Chemistry, General Engineering, and Metallurgical and Materials Engineering departments at MTech. Numerous courses offered for graduate programs associated with these departments and some others will be available as electives to MatSci Ph.D. students. In addition, the new core courses and any electives developed for the MatSci Ph.D. program are likely to become electives for students in other graduate programs offered through these departments.

Appendix VI lists the initial faculty interested in being involved with the MatSci Ph.D. program. As the program evolves and grows, additional faculty from these and other departments are expected to become engaged, along with new faculty recruited to the participating institutions. To this end, faculty members from Computer Science, Geosciences, Mathematics, and Pharmacy at UM; Environmental Engineering and

[3] AAAS (2012), p. 3.

[4] Ad Hoc Montana Tech Review Panel (2012), “Panel Report on Montana Tech’s Contribution to the Proposed Ph.D. Program in Materials Science at Montana Tech, University of Montana and Montana State University.”

[5] National Research Council (2012), *Research Universities and the Future of America: Ten Breakthrough Actions Vital to Our Nation’s Prosperity and Security.*

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Biological Sciences at MTech; and Cell and Neurobiology, Civil Engineering, Geology, and Electrical & Computer Engineering at MSU are also interested, and in some cases, becoming involved already. Such broadened participation will further enhance the interdisciplinary character of the collaborative Ph.D. program. Moreover, multidisciplinary participation and shared or joint faculty assignments are typical of materials science and engineering doctoral programs at other institutions.

While the facilities and instrumentation assets of the existing departments, centers, and institutes are essential resources for the launch of the proposed MatSci Ph.D. program, additional state-of-the-art infrastructure acquired in the future for the new program will become shared resources benefiting other programs and departments. Thus, research efforts are likely to be enhanced more broadly on the campuses, in turn attracting additional research funding opportunities. In summary, the proposed MatSci Ph.D. program is anticipated to have a positive impact on the related bachelor's and graduate programs on the three campuses.

B. Will approval of the proposed program require changes to any existing programs at the institution? If so, please describe.

No. Approval of the proposed programs will not require changes to any existing programs at any of the three institutions. However, some courses developed for the proposed MatSci Ph.D. program are likely to be adopted as electives for existing programs—thereby enriching their curricula and increasing their course enrollments.

C. Describe what differentiates this program from other, closely related programs at the institution (if appropriate).

The proposed collaborative MatSci Ph.D. program builds on and enhances existing strengths at the three institutions and thereby enables Montana to compete with larger and better known universities and university systems in this high-demand area. First, the program will be intrinsically collaborative, multi- and interdisciplinary, and inter-institutional, drawing on and reinforcing the strengths of diverse materials-related departments on three campuses. Second, it integrates employers into the educational experience, both expanding and strengthening relationships—especially with industry and national laboratories—through a strong program involving external collaborations, research partnerships, and student projects. Third, it focuses and strengthens materials research activities, thereby actualizing one of the five research emphases identified in the MUS research strategic plan.[6] Fourth, the program will make available in Montana a terminal degree in an important multi-disciplinary area, where none of the three institutions has a dedicated degree program at any level, though MSU has a new undergraduate minor in materials, and MTech has both a bachelor's and a master's degree program in Metallurgical and Materials Engineering. Finally, the program will develop and demonstrate a new collaborative model for graduate education under the purview of the Montana University Graduate Schools (MUGS) partnership (see below). This model is likely to be of considerable national and international interest, as it is intrinsically less expensive and less duplicative than multiple single-institution programs, but it still provides to the students, faculty, institutions, and partners of each institution the full benefits of the program.

MUGS is a partnership of the five universities in the Montana University System that offer graduate degrees. These campuses are Montana State University — Billings, Bozeman, and Northern; and University of Montana — Montana Tech and Missoula. MUGS seeks to enhance graduate education by fostering full and comprehensive collaboration across the five MUGS Universities. MUGS is designed to utilize the strengths of

[6] http://mus.edu/che/arsa/Research/MUSSTACplan.pdf

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each University in an integrated manner and in this way increase the national/international competitiveness of graduate programs in Montana. The MUGS Universities are engaged in some key initiatives including the following: joint recruiting, a common application, course sharing, collaborative degree and certificate programs, doctoral student internships, and faculty mentoring across the campuses. Combined, the MUGS Universities offer a diverse and comprehensive array of master's, doctoral, professional, and graduate certificate programs, which are collectively comparable to the offerings of several of the largest and most elite universities in the United States.

D. How does the proposed program serve to advance the strategic goals of the institution?

The proposed program is aligned with and advances the goals in the separate strategic plans of the Board of Regents and Montana University System, along with those of each of the participating institutions. Here are listed the specific strategic goals, which the proposed program would serve.

BOR/MUS Strategic Goals

- **Goal 1: Access & Affordability,** Increase the overall educational attainment of Montanans through increased participation, retention and completion rates in the Montana University System.
- **Goal 2: Workforce & Economic Development.** Assist in the expansion and improvement of the state's economy through the development of high value jobs and the diversification of the economic base. With respect to Research & Development, one major goal is to "establish collaborative programs among institutions, the private sector, and the state to expand research, technology transfer, the commercialization of new technologies, and the development of our entrepreneurs." With respect to Graduate Education, the goal is to "expand graduate education capacity and opportunities in order to increase educational attainment of Montanans, fuel economic development, grow the research and development enterprise, and contribute to the cultural and social fabric of Montana and the region."
- **Goal 3: Efficiency & Effectiveness:** Improve institutional and system efficiency and effectiveness.

UM Strategic Goals

- Partner across the University to ensure student success.
- Provide leading-edge education for the global century.
- Enhance discovery and creativity for Montana and the world.
- Ensure the most dynamic learning environment possible.
- Implement the planning-assessment continuum to guide management decision making

MTech Strategic Goals (January 2013 draft)

- Be a national leader in providing education and in transforming undergraduate and graduate education.
- Support and grow research, scholarship, and technology transfer.
- Be responsive to the needs of industry, our community, and State.
- Improve the visibility, recognition, and reputation of Montana Tech in the State, nation, and world.
- Secure resources that support excellence.
- Create a culture and workplace environment that embraces excellence.

MSU Strategic Goals

- MSU prepares students to graduate equipped for careers and further education.
- MSU will raise its national and international prominence in research, creativity, innovation and

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scholarly achievement, and thereby fortify the university's standing as one of the nation's leading public research universities.

- Members of the MSU community will be leaders, scholars and engaged citizens of their local, national and global communities, working together with community partners to exchange and apply knowledge and resources to improve the human prospect.
- By integrating learning, discovery and engagement, and by working across disciplines, the MSU community will improve the world.
- MSU is committed to widening access to higher education and ensuring equality of opportunity for all.
- As steward of a land-grant institution, MSU will responsibly manage its human, physical, economic and environmental resources in an open and sustainable manner.

The proposed MatSci Ph.D. program incorporates and advances these strategic goals. The MatSci Ph.D. program takes advantage of faculty expertise and infrastructure in place on the three campuses, cost-effectively building a strong materials research and learning community, providing new educational opportunities for Montanans, and fostering industrial and economic development---including the potential to attract and/or nucleate and launch high-tech, high-wage materials-based industry and start-ups. Assessment is built into the plan and designed to improve the program and related decision making.

From the outset, cost-effective teleconferencing, video-conferencing, and distance-learning approaches will be an integral part of the program. As research infrastructure on the three campuses is enhanced (significantly through grant funding), undergraduate and master's programs and students will also benefit, especially in terms of enriched research opportunities and access to state-of-the art techniques and technologies in their courses. The collaborative effort will also be extended by engaging industry and other community partners. This approach will enhance funding opportunities for faculty and students and thereby help facilitate technology transfer as well as the dissemination of new knowledge to the public domain. MatSci Ph.D. graduates will be well prepared for careers, while undergraduates and master's students in related programs will be well prepared for careers and for further education they might wish to pursue. In summary, the collaborative MatSci Ph.D. program will foster a dynamic research and learning environments where participating students and faculty will learn, discover, and apply knowledge together in a manner that transcends campus, departmental, and disciplinary boundaries, thereby maximizing value to Montana.

E. Describe the relationship between the proposed program and any similar programs within the Montana University System. In cases of substantial duplication, explain the need for the proposed program at an additional institution. <u>Describe any efforts that were made to collaborate with these similar programs; and if no efforts were made, explain why. If articulation or transfer agreements have been developed for the substantially duplicated programs, please include the agreement(s) as part of the documentation</u>.

There are no comparable Ph.D. programs within the MUS or, for that matter, within any of the State's private colleges and universities. Currently, students wishing to pursue a doctoral degree in materials science either attend a university out of state or enroll in chemistry or the interdisciplinary doctoral program at UM or in chemistry, biology, physics, or interdisciplinary engineering at MSU. Their coursework follows the requirements for the program where they enroll, therefore not preparing them as well for materials science/engineering as the proposed program would. Few students interested in materials would COME to Montana under these circumstances, though some who are already here and have limited geographic flexibility for their graduate studies may take this path. The program has intrinsic built-in relationships with these related departments and programs, because the faculty involved in the proposed MatSci Ph.D. are

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already associated with and will keep their primary affiliation with these departments and programs. A major strength of the proposed Ph.D. program is that it provides access to the existing research infrastructure of the three collaborating campuses (Appendix I). Moreover, it explicitly complements and builds on related undergraduate, master's, and Ph.D. programs at the three campuses.

5. Program Details

A. Provide a detailed description of the proposed curriculum. Where possible, present the information in the form intended to appear in the catalog or other publications. NOTE: In the case of two-year degree programs and certificates of applied science, the curriculum should include enough detail to determine if the characteristics set out in Regents' Policy 301.12 have been met.

The MUS MatSci Ph.D. curriculum is designed to be flexible, but still provide students with an exceptionally strong and broad understanding of the theory, experimental techniques, current challenges, and societal/economic impacts of materials science and engineering. All students in the program—regardless of specialty—will understand how classes of materials derive their properties from the atomic to the macroscopic level and be familiar with the growing set of materials fabrication, assembly, processing, and characterization tools and techniques. Furthermore, students will be aware of and committed to the professional and ethical standards of the field. Students are also expected to become aware of the economic, societal, and other broader impacts of materials and materials research. Through their dissertation research, students will demonstrate that they can conceive, plan, design, conduct, analyze, defend, publish, and communicate original and creative research that advances understanding in an area important to MatSci.

Core Curriculum (20 credits)

1. *Survey of Materials Science and Engineering* (2 credits: 1 credit/semester) – A two-semester, seminar-format overview of Materials Science, with some units focusing on the specialty/niche areas of the MUS/MatSci Ph.D. program and introducing students to the faculty and research on the three campuses. Other professional-development content, such as research ethics, is included. Primarily distance/e-participation with different sessions organized and hosted at the three campuses. One face-to-face session at each campus each semester would bring students and faculty together for lab tours.

2. *Advanced Materials Science I and II* (7 credits: 4 credits 1st semester & 3 credits 2nd semester)

   Semester 1. Bonding, Structure and Defects. How do structure and bonding at a microscopic level lead to macroscopic material properties? Topics include treatment of ionic and covalent bonding; quantum mechanical foundation of the cohesion and properties of solids and the evolution of band structure; three dimensional crystallography including point groups, stereographic projections, Bravais lattices, space groups and representative crystal structures; and study of the electronic and mechanical properties of materials and the effects of point, line, and planar defects in crystalline solids.

   Semester 2. Function and Application. How are materials designed and synthesized to achieve specific applications? A team taught course broken up into three 12-lecture segments. Each segment will cover a specific topic where potential topics may include ceramics, polymers, magnetic materials, biomaterials, glasses, etc. This course will be taught in such a way that material discussed in Semester 1 is put into practice, introducing students to principles of "rational material design."

3. *Thermodynamics of Materials* (3 credits) Advanced thermodynamic principles in the context of materials science; solution thermodynamics, multi-phase mixing, entropy, and equilibria; state functions and free energies; statistical thermodynamics, including ensembles, lattices, and phase transitions.

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4. *Advanced Materials Characterization Techniques I & II* (5 credits: 2 credits 1st semester; 3 credits 2nd semester) A two-semester laboratory-based survey providing experience with the common qualitative and quantitative characterization and analytical tools used in materials science and engineering. Techniques include scattering, diffraction, microscopy (optical, electron, tunneling, etc.), optical, thermal, mass spectrometry, NMR, and other techniques. An important emphasis of this course sequence will be teaching students how to select the characterization/analysis tools appropriate to the research project, use the instruments effectively, and analyze and evaluate the data that result from the different types of measurements. Relevant data from actual materials systems (acquired from instrumentation at any one of the three campuses) will serve as the platform for discussing the basis (theory) of the instrument and assessing instrumental capabilities and limitations. Specific instrumentation and methods featured each semester are selected to complement the topics in Advanced Materials Science I/II.

5. *Kinetics and Phase Transformations* (3 credits) The mechanisms controlling the rates of structural/chemical changes and reactions in materials. The course examines quantitative diffusion theory and practical applications. The course considers nucleation and growth as a mechanism for phase transformations. The course then looks at examples of the application of phase transformations in materials processing.

Electives

Elective courses will be available, allowing students to deepen their understanding and research skills in the program's focus areas: (1) biomaterials; (2) materials for energy storage, conversion, and conservation; (3) electronic, magnetic, and photonic materials; and (4) materials synthesis, processing, and fabrication.

Some electives will be developed specifically for the MatSci Ph.D. program, others would be graduate courses from other related graduate programs at the three campuses. Courses in mathematics, statistics, and numerical modeling would be recommended for students with special interests in theory and simulation.

Summary of Degree Requirements

Courses. The MUS MatSci Ph.D. will require a minimum of 60 semester credits beyond the bachelor's degree. Of the 60 credits, at least 18 credits must be obtained for dissertation research, and at least 32 credits must be earned for coursework. Up to 24 semester-credits from a master's degree may be accepted toward the minimum degree requirements, but they must be applicable to the MatSci curriculum, and their acceptance is subject to the review and approval of the student's committee and the MatSci program's Leadership Council. No more than 9 credits may be from 400-level courses. To ensure that students benefit from the collaborative, three-campus nature of the program, at least 9 credits must be earned from courses offered away from the home campus. Full-time students are expected to complete the 20-credit core curriculum and pass the qualifying examination within the first year. Appendix III summarizes the new courses.

In addition to the core curriculum, each student must earn at least 12 credits of electives within or related to the chosen specialty. Typically, this coursework would be completed by the end of the student's second year. Additional elective courses intended to provide a student with specialized expertise and/or skills relevant to their dissertation research may be recommended by the individual student's advisor and committee.

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Other Requirements. Other requirements include the qualifying exam, the candidacy exam, the dissertation, participation in the program's annual summer symposium, annual meetings with a student's advisory committee, and an optional internship. These requirements and their timing are summarized in Table 2 and described in greater detail below.

Table 2. Typical Schedule for MatSci Ph.D. Program of Study

Year 1 Fall Term	**Year 1 Spring Term**
Survey of Materials Science & Eng. (1)	Survey of Materials Science & Eng. (1)
Advanced Materials Science I (4)	Advanced Materials Science II (3)
Thermodynamics of Materials (3)	Kinetics and Phase Transformations (3)
Materials Characterization I (2)	Materials Characterization II (3)
Total Credits: 10	*Total credits: 10*
Summer: Qualifying Exam & Summer Symposium	
Year 2 Fall Term	**Year 2 Spring Term**
Electives (6-9)	Electives (6-9)
Research (0-6)	Research (0-6)
Total Credits: 9-12	*Total Credits: 9-12*
Late Spring: Candidacy proposal and oral exam; June/July: Summer Symposium	
Summer: If needed, repeat Qualif. Exam	*Sept-Dec: Assemble dissertation committee*
Year 3 Fall Term	**Year 3 Spring Term**
Electives (0-6)	Electives (0-6)
Research (3-9)	Research (6-9)
Total Credits: 9-12	*Total Credits: 9-12*
June/July: Summer Symposium	
Year 4 *et seq.*	
Research (6-9 credits each semester)	
Every Year in June/July: Summer Symposium	
Final Term: Submission and Oral Defense of Ph.D. Dissertation	

Qualifying Exam—Every student must take and pass a comprehensive, written qualifying examination at the end of the first year. Qualifying exams will be offered at a specified time during the summer and prior to the start of fall classes. The outcome of the exam will be "pass," "conditional pass," or "fail." A conditional pass indicates that a student has significant deficiencies in one of the areas tested. This student would be required to take and pass (B or better) designated course(s) in the following year to "pass" the qualifying exam. Students who fail on the first attempt may retake the exam at the next scheduled date. Students who fail twice would be released from the Ph.D. program. By passing the qualifying exam, the students demonstrate that they understand materials and their properties from the atomic to the macroscopic levels and have familiarity with the growing set of materials fabrication, assembly, processing, characterization, and modeling tools and techniques.

Candidacy Exam—After passing the qualifying exam and typically before the start of a student's third year, the student will take a candidacy exam consisting of two parts: (1) the first part is a written proposal describing the student's intended dissertation research; and (2) the second part is an oral defense of the proposal to the student's doctoral committee. The defense will include an open seminar followed by a closed interview/examination by the Committee that can cover a broad range of topics related to the proposed dissertation research. The outcome of the candidacy exam will be either (1) full pass; (2) conditional pass; or (3) fail. Full pass enables the student to advance to candidacy with no further program requirements remaining other than the dissertation and annual meetings with the committee. A conditional pass will be awarded if the committee feels that the student is lacking knowledge in a specific area that is vital to the proposed research. The committee may recommend specific requirements for the student to fulfill in order to successfully advance to candidacy. These requirements may include taking (and passing) an additional course; preparing an appendix or response to questions that arose about the proposed research's viability; and/or reconvening with the committee for a 2nd oral examination. By passing the candidacy exam, the student demonstrates that he/she can both: conceive, plan, and design an original and creative research project on a topic important to advancing understanding in MatSci; and communicate effectively both orally and in writing.

<u>Dissertation</u>—A written dissertation describing original research must be prepared, submitted, presented orally, and defended.

<u>Collaborative MatSci Ph.D. Program Summer Symposium</u>—Every student is expected to attend and participate in the program's annual summer symposium. Every student who has advanced to candidacy will be required to present either a poster or a talk.

<u>Advisory Committee</u>—Not later than the first semester of Year 2, each student will form a faculty advisory committee with at least five members, of which at least one is from a non-home campus, and one is the Graduate School Representative. The committee will monitor the student's progress, help the student tailor elective course choices to his/her interests, and provide feedback and guidance to keep the student on track to completing all program requirements in a timely manner. Students will meet with their committees annually during every year they remain in the program following their candidacy exam. An additional "outside examiner" from outside the Montana University System may be added to the Advisory Committee prior to the time the dissertation is submitted. The outside examiner would review the dissertation, participate in the oral defense, and make a formal recommendation to the Committee about the quality and originality of the dissertation. Selection and appointment of the outside examiner will follow the standard practice on the campus where the student is enrolled.

<u>Optional Off Campus Activities in Support of the Student's Research</u>—Students have the option to participate in a collaborative research activity at affiliated University Research Center, national laboratory, or industrial site.

<u>Registration Requirements</u>—Full time students receiving financial support are expected to register for at least 6 credit hours per semester. In general, students will be eligible for no more than 12 semesters of financial support.

<u>Program Admission</u>

To enter the Ph.D. program, the student must have earned a B.S. degree (or equivalent) in materials science, materials engineering, physics, chemistry, metallurgy, or a related science or engineering field. The student's academic record must provide evidence of a strong background in the fundamentals of science and/or engineering principles. A student with such a background, who has not passed certain undergraduate courses, that are prerequisites for their required or elective graduate courses, must remedy this gap as expeditiously as possible, either by taking the prerequisite undergraduate course or through independent study and "credit by examination."

Faculty

Collectively, over 40 tenured/tenure-track, research-active faculty members at the three institutions have expressed interest in affiliation with the MatSci Ph.D. program, and they and their MatSci-related research interests are tabulated in Appendix VI. Both in number and in expertise these faculty provide a strong foundation for the proposed program, as verified by the AAAS review panel in August 2012. The faculty numbers are comparable to the average of the top quartile of materials-related research doctoral programs assessed by the National Research Council.[7] The faculty are primarily associated with the Chemistry/Biochemistry and Physics Departments at UM; the Chemistry, General Engineering, Environmental Engineering, Biological Sciences, and Metallurgical & Materials Engineering Departments at MTech; and the Chemistry, Chemical & Biological Engineering, Mechanical & Industrial Engineering, and Physics Departments at MSU. Appendix VI provides a listing of the faculty, including their institutional and departmental affiliations, a brief summary of their research specialties, and an indication of the MatSci Ph.D. program research theme(s) with which they would associate.

Description of Featured Research Themes

Biomaterials. This thematic area includes bio-inspired and biomimetic materials and the interactions between materials and biological systems. Biomaterials research within the MUS MatSci Program falls within five interrelated areas: (1) biological materials; (2) biomimetic, bioinspired, and bioenabled materials; (3) synthetic materials intended for applications in contact with biological systems; (4) biocompatibility of materials, especially nanomaterials; and (5) the processes through which nature produces biological materials. Projects are typically interdisciplinary and encompass scales from the nanoscale to large bulk samples. Research frequently involves some combination of characterization, design, preparation, and modification; studies of structure-property relationships and interfacial behavior; in vitro and in vivo studies; and combinations of experiment, theory, and simulation. Biomaterials research is highly interdisciplinary as it incorporates mechanical and electrical engineering, materials chemistry and engineering, and pharmacology, as well as medically relevant areas such as surgery, immunology, biochemistry, and molecular biology. Key applications are in health, sensors, and bio-inspired or bio-compatible structural materials.

Current activities at the three participating MUS campuses include designing and creating organic-inorganic hybrids for tissue engineering scaffolds; developing biomimetic chemistry methods to synthesize multifunctional nanostructured materials; characterizing and using biofilms in widely ranging applications from oil recovery to surface passivation; generating biocompatible replacement bones and cartilage; and engineering biomolecular structures, such as nanodiscs and liposomes to understand the dynamics of protein binding to cell membranes. Examples from the existing research portfolio include projects on Ti-alloys for medical use; a wide range of solubility and degradation-controlled polymers that could be used in devices inserted into human patients; and ceramic coatings for hip, knee, tooth implants. In addition, structure-activity relationship studies are being conducted using various in vitro and in vivo models. Recent studies have incorporated more than one material class into devices to achieve several levels of medical

[7] NRC (2010)

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function and to maximize the device's success rate. Other areas of research take inspiration from biologically derived materials such as silica diatom cages, nacre as a structural unit of sea shells, and the hierarchical structure of bone. These research efforts are focused on understanding the fundamental mechanisms that give rise to such functional structure and to apply these principles to fabricate structures that have superior bioperformance compared to conventionally processed materials.

Materials for Energy Storage, Conversion, and Conservation. America's energy independence and security have been a national priority for almost four decades. At various times during this period, the need for reliable, cost-effective, and clean power has catalyzed the development of innovative technologies, spurred exploration for new natural resources, and driven commercialization of renewable energy production systems. In spite of these efforts, however, the United States continues to rank as one of the leading nations in terms of oil consumption and CO_2 emissions. In its 2008 report "Directing Matter and Energy: Five Challenges for Science and the Imagination," the U. S. Department of Energy identified several interconnected "Grand Challenges" that must be met in order to realize "a clean, cheap, and virtually unlimited supply of electrical power."[8] These challenges ranged from learning how to control material processes at the level of electrons to designing and perfecting atom efficient synthesis of revolutionary new forms of matter with tailored properties. In short, the Grand Challenges Report made clear that meeting society's energy needs will require breakthrough discoveries in the materials needed for energy storage, conversion, and conservation.

Meeting these challenges requires harnessing the power-producing capacities from a suite of technologies ranging from solar to bio to wind. The fact that Montana enjoys a diverse and extensive array of energy-related resources makes this theme area especially important to the state and has resulted in "Energy Sciences and Engineering" being one of the five major research areas in the MUSSTAC plan.[9] Ranked 5th in the nation in terms of its "wind potential" and having 6% of the world's known coal reserves, Montana is well positioned to be a centerpiece of any comprehensive, multi-tiered plan that produces clean, renewable power at the local, state, and national scale. Faculty throughout the MUS are exploiting this geographic advantage by leading internationally recognized research programs that make tomorrow's energy solutions today's reality. From designing new material composites for wind turbine blades to exploring electron transfer mechanisms in high temperature fuel cells to producing biofuel from thermophilic algae, MUS researchers are already tackling the most important problems our nation faces when it comes to producing and using power in a clean and responsible way.

Thus, fundamental and applied research in materials for energy storage, conversion, and conservation is a cornerstone of the MUS MatSci Program. Faculty at MSU, MTech, and UM are directing research programs that address critical issues necessary to develop sustainable means for producing and storing chemical fuels. In doing so, these researchers are leveraging Montana's abundant natural and renewable resources to build the clean, economical, and sustainable supply of electrical power envisioned in the DOE's Grand Challenges Report.

Electronic, Photonic, and Magnetic Materials. Electronic, photonic, and magnetic (EPM) materials are the building blocks of modern technology. First impacting the telephone industry, later nucleating the

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[8] US Department of Energy, Basic Energy Sciences Advisory Committee (2007), "Directing Matter and Energy: Five Challenges for Science and the Imagination." http://science.energy.gov/~/media/bes/pdf/reports/files/gc_rpt.pdf

[9] Montana University System (2011), *Montana Science Serving Montana Citizens: Socially Responsible Science and Technology in Higher Education and Related Enterprises.* http://mus.edu/che/arsa/Research/MUSSTACplan.pdf

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electronics industry, and shortly thereafter providing the foundation for that would become the computer industry, discoveries related to EPM materials have continually sparked technology revolutions impacting nearly all aspects of society. Materials innovations have and continue to dramatically transform health care, communication, computers, data storage, electronics, refrigeration, imaging and sensing, display technology, transportation, and laser technologies. Progress in EPM materials are driving current advances in quantum information and cryptography, information storage, signal processing, communications, electronics, imaging and sensing techniques, and laser components, among others. Thus, research into applications of EPM materials and discovery of new ones is a target area of most major funding agencies because of the broad impact of these materials on modern life.

Faculty in the proposed MUS MatSci program are creating and studying advanced EPM materials in nanoparticle, thin-film, bulk, and single-crystal form and integrating these materials into optical waveguides and other device configurations. Theoretical efforts are similarly diverse, and they include developing models to predict structure/function relationships in newly discovered EPM materials; calculating electronic structures of condensed-matter systems; and modeling coherence and spin dynamics for ions and properties of alloy phases.

Going forward, the EPM theme will focus on creating EPM materials using conventional, advanced, and nano-scale synthesis approaches. To advance fundamental understanding, the relationship between physical properties and the synthesis method, structure, and morphology will be studied. Materials engineering at the nano- and micro-scale will develop electronic, photonic, magnetic, and microelectromechanical devices, as well as engineered nanoscale surface features for optics applications. Theoretical EPM work associated with the MatSci Ph.D. program will help to tailor and optimize EPM materials for particular applications, while simultaneously advancing fundamental science. This research will lead to new discoveries and new technological applications by building a better understanding of EPM materials while simultaneously training future scientists and engineers.

Materials Synthesis, Processing, and Fabrication. The State of Montana is renowned for its abundant natural resources, including great mineral wealth, energy resources, forests, and arable farmland. Historically, Montana's resources were sometimes exploited under socially and environmentally detrimental circumstances. This situation has led to an understandable suspicion of and resistance to potential development opportunities, even those with clear benefits to all parties. In response to such concerns, modern materials processing embraces the philosophy of industrial ecology. *C*urrent research efforts focus on developing efficient, cost-effective process technologies, designed for optimal energy efficiency and minimal environmental harm.

In essence, materials processing involves transformations. On the macro-scale, an estimated 15 billion tons of natural resources are harvested, mined, or otherwise extracted from the Earth's surface each year. Improved physical, thermal, aqueous, and electrolytic processes are needed to transform these raw materials into metal, ceramic, polymer, and composite materials; and several additional processing steps are needed to transform the engineering materials into finished products. In addition, when these consumer goods reach the end of their service lives, even further processing is required to enable efficient recycling or safe disposal.

The materials-processing theme has significant synergies with the other three MatSci themes (biomaterials, energy materials, and EPM), since materials of all types and for all applications share processing as a common denominator. Thus, the development of novel material synthesis and modification techniques—as well as improved casting, forming, machining, joining, coating, and blending technologies—will be critical to successful scale-up and commercialization of the products of innovative research. Because materials processing bridges the gap between science and industry, the material processing component of the program will provide key opportunities to conduct applied research in collaboration with industry, and—in some circumstances—to create new industries in Montana through start-ups and entrepreneurial ventures.

To advance the broad research frontier of materials processing requires a multi-disciplinary approach. The collaborative MUS Materials Science Program pools expertise in the fields of solid state physics, metallurgy, polymer chemistry, ceramics, composites, and process engineering. Faculty at MSU, MTech, and UM are engaged in research that responds to current and emerging industrial needs and interests in materials synthesis, processing, and fabrication for the entire life cycle from resource extraction through disposal.

B. Describe the planned implementation of the proposed program, including estimates of numbers of students at each stage.

The three institutions are prepared to initiate the Ph.D. program immediately following BOR approval. Recruiting activities would focus on enrolling the first full cohort and offering the core curriculum starting in Fall 2014. Three stages of program evolution are envisioned: Stage I – Inception and Early Program Development; Stage II – Sustained Growth; and Stage III – Program Maturity. The program would admit 6 to 8 students in Year 1, 8 to 12 students in year 2 (total enrollment of 15 to 20), and grow to a steady-state enrollment in the range of 50 to 70 students, with about 15 students entering each year and about a dozen Ph.D. degrees conferred each year. The proposed program's growth rate and enrollment would be driven by the success of program faculty in acquiring new external research funding, and the success of the program in attracting outstanding applicants. Stage I is anticipated to last about 3 years, and Stage II would last 3 to 5 additional years, including the award of the first MatSci Ph.D. degrees. Stage III is likely to commence between 6 and 8 years after the matriculation of the first students.

6. Resources

A. Will additional faculty resources be required to implement this program? If yes, please describe the need and indicate the plan for meeting this need.

Currently the number and expertise of faculty in place on the three campuses is sufficient to initiate a competitive and high-quality interdisciplinary MatSci Ph.D. program (see Appendix VI). In its August 2012 review, the AAAS panel reached this conclusion as well. However, the faculty members involved with the program are among the most research-active faculty on the campuses, and they are already fully engaged in existing programs by providing undergraduate and graduate instruction and mentoring, by conducting research, and by performing service.

To ensure that the MUS MatSci Ph.D. program can become rapidly competitive and highly regarded and produce successful graduates, the Provosts have each committed to establish one new tenure-track position in the materials field. The individuals selected for these new positions would bring additional expertise applicable to one or more of the program's research themes. The searches for these three new faculty would be initiated after the Regents approve the program, with the goal of having them on board between August 2013 and August 2014. The new faculty would have a home in the most appropriate department(s) on their home campuses, and would join the existing faculty in bootstrapping the start-up of the program into and through Stage I. Their presence would enable the core MatSci courses to be added to the course schedule without modifying existing offerings on the participating campuses. The arrival of the new faculty would also benefit the departments where they affiliate.

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On the research side, the new faculty will start research programs, submit grant proposals, and receive grant funding, thereby helping the program acquire revenue and grant resources for graduate-student support. Additional grant-funded research and course buyouts managed within each campus will help accelerate the program growth.

At MTech, where faculty teaching loads are higher than at MSU or UM, modest investments would be needed to modify the workload of these faculty by increasing the time for proposal-writing, research, publication, and doctoral-student mentoring and reducing the teaching workload from four to two courses per term for each full-time-equivalent (FTE) faculty actively involved in the Ph.D. program. This workload adjustment will be accomplished cost effectively by obtaining qualified adjunct faculty to teach the courses. In addition, at UM and MSU, it will be necessary to reduce the teaching commitments some of the MatSci faculty have in their home departments, to free them partially for teaching electives and core courses in the MatSci program and supervising MatSci students in addition to those in their existing programs. The resource estimate includes funding to provide replacement faculty to teach the courses in the home departments.

By the time the MatSci Ph.D. program reaches Stage III with enrollment in the range of 50-70 students, additional faculty lines are likely to be needed, but these new lines would be justified on the basis of program enrollments, revenues, and funded research as the program grows. Similar to most of the highly ranked materials science/engineering doctoral programs in the United States, faculty associated with the proposed MUS program are expected to continue to be involved with other programs and departments, such that the faculty FTEs allocated or dedicated to the materials program in Stage III would equal about half of the number of faculty involved.

B. Are other, additional resources required to ensure the success of the proposed program? If yes, please describe the need and indicate the plan for meeting this need.

In addition to faculty, the other resources needed to ensure the success of the program are (1) financial support for the graduate students, for their research, and for their professional development/travel; (2) funds to develop the core courses and electives for distance delivery; (3) resources for administrative support for the program, program development, recruiting, and marketing—especially during startup; and (4) investments in infrastructure enhancements at Montana Tech to bring the research instrumentation to the level needed for doctoral education.

The resource requirements per graduate student are estimated to average $58 K per year, including GTA/GRA plus doctoral stipend totaling $24 K per year, funding to cover resident tuition and fees ($6 K), and funding for the student's research supplies/costs/travel ($28 K). We assume these costs are covered by a combination of GTA and revenue from grants and contracts ($50 K/year). Because the ability to fund these per-student expenses is so critical to the quality of the program, the budget projection is based on a requirement that for every admitted student, the faculty must have in hand $50 K of grant/contract revenue per year allocable to these expenses. Thus, the number of students and the cost of the program linked to enrollment would be automatically regulated by the success of the faculty in winning grants, with revenues and expenditures balanced.

The cost of developing the core courses for distance delivery consists of the cost of specialized curriculum designers plus the cost of the typical stipend paid to faculty per course developed/configured for distance delivery. This staffing and budgets for the faculty stipend are already available on each campus. During Academic Year 2013/14, each campus would allocate resources to the development of two of the core courses within existing resources. A similar number of electives would be developed/adapted in 2014/15, with the new course development activity being reduced after that to a level comparable to the level experienced by an ongoing program. All three campuses have a budget for distance-learning course development, which would cover these needs for the MatSci Ph.D. as it starts up.

During Stage I the administrative support and program-development/recruiting are projected to consist of one FTE of administrative support shared by the three campuses plus a modest budget for administrative operational expenses, typical of similar departments and programs. The administrative support will coordinate advertising and recruiting, website maintenance, and communications. Operational costs include funding to support meetings of the External Advisory Board. Significant program-development resources are expected to be needed in 2013/14 and the first few years for recruitment, marketing, and related activities, essential to successfully launching the program.

As noted by the AAAS Panel, infrastructure enhancements are needed at Montana Tech to reach the level required for doctoral education. We plan to invest $160 K per year in these enhancements on a continuing basis, with an additional $150 K spread across the first three years (2013-2016).

Revenues for the program include advanced graduate tuition, funding from grants directed toward student stipends and research expenses (at $50 K per student per year), funding reallocated within the existing budgets of the participating campuses, and new revenue sources. The new revenues included in the analysis include private fundraising of an endowment for the program at Montana Tech, along with funds appropriated by Montana's legislature for doctoral programs at Montana Tech. The Montana Tech Foundation has embarked on a fundraising campaign to raise at least $2,500,000 for this program, which will provide $100,000 in annual funding for the program, at 4% return. The Montana Legislature appropriated $300 K/year for the current biennium, and continuation of this funding is included in Governor Bullock's budget request through 2019.

Table 3. Summary Resource Analysis and Projection for MatSci Ph.D. Program

Academic Year	**2014**	**2015**	**2016**	**2017**
Enrollment	0	7	16	25
Faculty (FTE)	42 (3)	45 (7.5)	45 (12)	45 (17)
PROJECTED REVENUE	**$516 K**	**$1,174 K**	**$1,676 K**	**$2,193 K**
New Grant funding for Student Support (Tuition included)	0	$350 K ($41 K)	$800 K ($93 K)	$1,250 K ($145 K)
Internal Reallocations	$206 K	$494 K	$516 K	$543 K
New Revenue: MTech-Private fundraising & State	$310 K	$330 K	$360 K	$400 K
PROJECTED EXPENDITURES	**$516 K**	**$1,174 K**	**$1,676 K**	**$2,193 K**
Faculty costs: new and buyouts	$48 K	$348 K	$396 K	$444 K
Per Student Costs	0	$406 K	$982 K	$1450 K
Course Development: Distance Delivery	$84 K	$84 K	$56 K	$28 K
Program Development & Administrative Support	$134 K	$136 K	$116 K	$111 K
MTech Research Infrastructure Investment	$250 K	$200 K	$180 K	$160 K

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7. Assessment

How will the success of the program be measured?

Informed by the recent National Research Council (NRC) national assessment of research doctoral programs, the success of the program is planned to be measured according to the measures and metrics in Table 3. The benchmark metrics from the NRC study[10] are for the top and bottom quartiles of the materials science/engineering doctoral programs. The proposed set of assessment measures also addresses factors that are particularly important to this collaborative program and to Montana: student outcomes and experience; research funding, productivity and impact; multi-campus collaboration; program reputation/recognition; and economic development.

These measures shown in Table 4 will be collected and reviewed annually, and in some cases averaged over a few years. They will be used to guide the program implementation to maximize quality; to enable growth in enrollment; and to assist the program in producing graduates who are in demand and enhance the intellectual, cultural, and economic development of Montana and beyond. The use of these measures will help encourage the program to promote economic development and launch or attract materials-based businesses.

Table 4. Benchmarks[10] and Assessment Measures for the Proposed MatSci Ph.D. Program

Assessment Measures	NRC Assessment*		MUS Proposed Program	
	Top 20 programs	Bottom 20 Programs	Year 1: 2014/15	Steady State Goal (10 yrs)
Program Ranking (R Ranking, 5th Percentile)	Top Quartile	Bottom Quartile	N/A	Top 50% in ~10 years
Publications/FTE Faculty/Year	5.13	1.65	2	>3
Percent of peer-reviewed pubs with PhD student as first author	N/A	N/A	10%	>50%
Average citation per publication	2.25	1.21	N/A	>2
Percent of faculty with grants	91%	85%	60%	>90%
Percent of multi-PI grants with co-PIs from > one campus	N/A	N/A	10%	>35%
Allocable grant $ per FTE student	N/A	N/A	>$50K	>$50K
Percent of first year students with full financial support	91%	74%	>85%	>85%
Percentage completing in <6 years	59%	55%	N/A	>60%
Median Time to Degree	4.92	4.39	N/A	<4.8 years
Average No. Ph.D. Graduates/year	12.9	2.9	N/A	10
Minimum number of course credits taken at non-home institution	N/A	N/A	at least 9	Larger of 9 or 20%
Collects and analyzes post-graduation employment information	60% of Programs	30% of Programs	N/A	Yes
Percentage of first-year students w/ external fellowships	10%	9%	0%	10%
Number of enrolled students	98	19	7	60
Average first year enrollment	19	5	7	15
International students as percent of total students	52%	67%	<75%	<60%
No. of professional development student activities (out of 18)	17	16	16	18
No. of materials-based start-up companies and relocations to MT	N/A	N/A	N/A	TBD

[10] National Research Council (2010), J. Ostriker, et al, editors, "Data-Based Assessment of Research Doctoral Programs in the United States." The NRC does not endorse specific numerical rankings. However, the "top quartile" and "bottom quartile" approach discriminates between programs of consistently different quality and productivity.

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8. Process Leading to Submission *(section to be finalized after approval by all campuses)*

Describe the process of developing and approving the proposed program. Indicate, where appropriate, involvement by faculty, students, community members, potential employers, accrediting agencies, etc.

The development of this proposal was initiated over four years ago by a team of faculty members from MTech and UM through meetings, e-mail discussions, and consultations with potential industrial partners. The resulting degree proposal was reviewed and approved during 2010 on each campus by the library staff, academic administrators of the colleges, the graduate school, and academic affairs office. The original proposal was also submitted through the curricular governing processes and bodies of the two campuses (e.g. Graduate Councils and Faculty Senates). Several potential industrial partners provided both informal and formal input in the form of conversations and letters, which reinforced the need for a MatSci Ph.D. program in Montana and helped to inform the curricular planning.

Following approval on the two campuses, and prior to formal submission to the Board of Regents, MSU was invited to participate, and a decision was made to include all three institutions with degree-granting authority. In winter 2012, a special review panel was convened by MTech, and this panel confirmed the readiness of MTech for such a program, including the conferral of doctoral degrees. In August 2012 the proposal was submitted to the Board of Regents (Item# 156-1003-C0812) for its first of two required public consideration sessions. Also in August 2012, a panel organized by the American Association for the Advancement of Science (AAAS) was engaged by the Regents, and the panel visited all three campuses to review the need, design, and plans for the program. The AAAS Panel validated the need for the program within the context of materials science and engineering graduate education in the United States and the capacity of the three institutions to deliver it successfully. In addition, the panel made several recommendations to strengthen the proposal and its potential benefits to Montana. Following the receipt of the AAAS review report, final consideration of the proposal by the Board of Regents was deferred, while the three campuses engaged in extensive and coordinated discussions and planning to address the recommendations made by the AAAS panel. Among the most important of these recommendations were to provide additional curricular details and to clarify specifically how the program would be operated as a MUS asset, rather than as an umbrella for separate programs on each campus. In parallel, at a public session associated with the September 2012 Board of Regents meeting in Butte, several community members and business leaders expressed their views of the importance and urgency of the program to Montana.

This revision of the proposal was led collaboratively by the Provosts on all three campuses, and it included from each campus a dean, the chairperson of the Faculty Senate, and one of the leading faculty members involved in the program. An expanded three-campus faculty team collaborated via several videoconference meetings between October 2012 and January 2013 to develop the details of the courses and curriculum for the degree program, the specific requirements for the degree completion, and the syllabi for the new core/required courses.

Updates resulting from this planning process have been incorporated into this revised Level II proposal. It is the same degree proposal as the original submission to the Board of Regents, with additional curricular and governance details, a resource estimate, assessment measures, and some updating of material originally assembled a few years ago, when planning started. This proposal was re-routed and approved through the curriculum approval process on each campus, with approval dates as indicated on the following page.

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No outside consultants were employed for the development of this proposal. This proposal was reviewed and approved by the following departments/programs/campuses:

University of Montana-Missoula

Dept of Physics and Astronomy Date: ________________

Dept of Chemistry and Biochemistry Date: ________________

This proposal was reviewed and approved by the following Deans and Faculty Governance:

Dean of **College of Arts and Sciences** Date: ________________

Dean of **Libraries** Date: ________________

Dean of the **Graduate School** Date: ________________

Graduate Council Date: ________________

Faculty Senate Date: ________________

Provost and Vice President for Academic Affairs Date: ________________

Montana Tech of the University of Montana

This proposal was reviewed and approved by the following Deans and Faculty Governance:

Dean of **College of Letters, Sciences, & Professional Studies** Date: ________________

Dean of **School of Mines & Engineering** Date: ________________

Dean of the **Graduate School** Date: ________________

Director of **Libraries** Date: ________________

Graduate Council Date: ________________

Curriculum Review Committee Date: ________________

Faculty Senate Date: ________________

Provost & Vice Chancellor for Academic Affairs Date: ________________

Montana State University

This proposal was reviewed and approved by the following Deans and Faculty Governance:

Dean of **College of Letters and Sciences** Date: ________________

Dean of **College of Engineering** Date: ________________

Dean of **Libraries** Date: ________________

Dean of the **Graduate School** Date: ________________

Graduate Council Date: ________________

Faculty Senate Date: ________________

Provost and Vice President for Academic Affairs Date: ________________

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Appendix I - Facilities and Equipment

University of Montana, Missoula

The participating faculty have approximately 1000 ft^2 of **laboratory** space fully equipped for the synthetic and analytical work proposed. In addition to standard laboratory equipment, the laboratory has a new Vacuum Atmospheres glove box, high-vacuum lines, and a computer controlled electrochemical apparatus. Through the Departments of Chemistry and Geology access is provided to Atomic Absorption (AA) spectrometry, along with Inductively Coupled Plasma (ICP) and ICP-Mass Spectrometry (ICP-MS) analytical instrumentation.

UM's Core Computational Facility located next door to the chemistry building has a two Octane 3000 computers for the molecular modeling studies with the associated software SYBYL 7.0 (Tripos, St Louis, MO), and AMBER 8.0 (Peter Kollman, UCSF) and Materials Studio, (Accelrys, San Diego, CA).

Center for Computational Biology is an interdisciplinary unit, which develops and applies complex computer methods to research on biological systems such as neurosystems. A major feature of the Center is its use of advanced, high-speed computer communication channels to the worldwide network.

The Department of Chemistry has two Varian NMR spectrometers operating at 500 and 600 MHz. The 500 MHz instrument is used for solution multinuclear experiments and is equipped with solid state CPMAS components and a triple resonance probe with field gradients and the 600 MHz instrument is equipped with a cold probe and with enhanced ^{13}C sensitivity and special sample equipment for high salt protein solutions. SEM/EDX and TEM is available at the electron microscopy lab in the Biology Department on a Hitachi S–4700 Type II. The Department also has a Thermo Nicolet 633 FT IR equipped with ATR and diffuse reflectance accessories. X-ray powder diffraction equipment is available through the Geology department on a Panalytical X'-Pert Pro.

5890 HP GC
Thermo S-series atomic absorption spectrophotometer (AA).
1260 Agilent Quaternary HPLC System with photodiode array detector
1090 Agilent HPLC
Shimadzu GC-17A
Nicolet Nexus 670 FT-IR
Shimadzu RF-1501 spectrofluorophotometer
Three Agilent 3D capillary electrophoresis instruments
Three Molecular Devices 96 well plate UV-Vis/Fluorescence spectrophotometers

Mass Spectrometry Facility

Two 6890/5973 Agilent GC/MS systems with electron Impact Ionization
Bruker microflex MALDI-TOF mass spectrometer with microScout ion source
Bruker's Biotools software
The spectrometer is well suited for biomolecules of MW up to 300,000 and proteomic analysis of tryptic digests of proteins.

EMtrix—A Globally Accessible Electron Microscope Facility

Hitachi 7100 TEM
Hitachi S-4700 cold field emission SEM
Fully equipped specimen preparation laboratory with ultramicrotomes, knifemakers, sputter coater,

critical point dryer, vacuum evaporators, embedding ovens, and light microscopes.

The University of Montana Spectroscopy Core Laboratory

Wet Laboratory for Core (840 square feet)

- pH meter, balance and microbalance
- -20 freezer, -80C freezer, refrigerator, fume hood
- Chromatography and gel electrophoresis equipment, FPLC
- Temperature-controlled shaker for protein expression, sonicator table-top centrifuge

Additional Departmental/Institutional Resources for Sample Preparation

- Cold rooms, refrigerated preparative and ultra centrifuges, lyophilizers, microscopes
- HPLCs, specialized electrophoresis systems, crushed and dry ice

Spectroscopy Laboratory Computers

- 5 PC workstations (2-GHz)

Spectroscopy Laboratory Steady-State Major Instrumentation

- Dual-beam UV/VIS absorption spectrophotometer
- Tthermostatted high-pressure cell for studying high-affinity systems (1 - 2,500 bar)
- Thermostatted cuvette holders: Quantum Northwest TLC50

Spectroscopy Laboratory Ultra-fast Laser Facility (450 square feet)

- Coherent ps laser system: 10 W diode laser (Verde) pumping a Ti:Sapphire laser (Mira)
    1. IR light pulses tunable between ~680 and ~1050 nm
    2. second and third harmonic generation: UV-visible light tunable from ~260 to ~520 nm
    3. frequency doubled optical parametric oscillator (OPO) generates ~520 to ~650 nm light
- Coherent fs IR laser (Chameleon) dedicated for two- and three-photon microscopy
- PicoQuant ps 470-nm, 480-nm and 635-nm Laser Diodes
- Time-correlated, single-photon counting (TCSPC) time-resolved anisotropy spectrometer designed and constructed in collaboration with Quantum Northwest, Inc. (Spokane, WA)
    1. modified format for simultaneous collection of three decay curves: V, H, magic angle
    2. each emission train can use monochromators or filter
    3. each emission train has dedicated PMT and TCSPC processing electronics
    4. sample chamber can accommodate different sample holders, including the high-pressure cell (up to 3 kbar), a goniometer, or a 5-position automated thermostatted cuvette holder
- Nikon TE2000-U inverted fluorescence microscope
    1. time-resolved fluorescence anisotropy and emission spectroscopy
    2. direct laser excitation and total internal reflectance fluorescence (TIRF) excitation
- Olympus IX71 inverted microscope with FluoView 300 confocal scan-head
    1. multi-and single-photon imaging
    2. fluorescence lifetime imaging(FLIM), FRET and FCS
- Two-channel correlator (TimeHarp 200, Picoquant, Inc.) that generates time-tagged time-resolved (TTTR) data for TCSPC, FCS, FLIM or FRET

Machine Shop (housed in Chemistry Department)

- band saw, drill press, lathe, mill, and tools to machine light metals, plastics, wood

Electronics Shop (housed in Physics Department)

- Available as needed – Core has minor electronics (i.e., oscilloscope, signal generator)
- [1] The ultra-fast laser facility is equipped with electrical protection. Constant temperature and clean air protect the optics and electronics, assuring stable operation.

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Montana State University, Bozeman

Montana State University's facilities and equipment that support materials science and engineering research are distributed through the College of Engineering and the College of Letters and Science. MSU researchers have access to several user facilities http://www.montana.edu/wwwvr/userfacilities.html across campus to utilize Materials Science and Engineering related tools such as those included in the

- Center for Biofilm Engineering Microscopy Facility
- Chemistry and Proteomics & Mass Spectrometry Facility
- Image and Chemical Analysis Laboratory (ICAL)
- Ion Beam Group
- Montana Microfabrication Facility (MMF)
- Nuclear Magnetic Resonance Laboratory.

Furthermore, the multi-disciplinary materials research at MSU benefits from access to following centers:

- Energy Research Institute (ERI) and
- Center for Bio-film Engineering

Through these centers other researchers can obtain access to many specialized research instruments and tools located in individual researchers' laboratories. Such core user facilities combined with research resources in individual laboratories place MSU materials science and engineering research capabilities at levels that meet or exceed those at many Universities that currently offer Ph.D. programs in materials.

Key materials science and engineering related equipment available at MSU is categorized below:

Processing (Bulk/Thin Film): Multiple high temperature box and tube furnaces with full atmosphere control up to 2200C, mixing/homogenizing systems (ball mills, planetary mills, ultrasonic), tape casting, screen printing, spin coating, dip coating, electro/chemical plating, particle size analysis (nano to micro scale), rheological (viscosity) measurement systems, Pulsed Laser Deposition (PLD), Electron Beam Evaporation, DC/RF Sputtering, and Metal-Organic Chemical Vapor Deposition (MO-CVD). Optical image furnace (NEC SC1-MDH-20020) with dual elliptical mirrors, maximum temperature 2150˚C, high-pressure option (up to 10 atmospheres), cold-trap option, and outfitted for a range of gaseous environments. One 1700˚C box furnace, one 1500˚C box furnace, two 1500˚C tube furnaces, and one three-zone 1100˚C tube furnaces. A 260˚C box furnace for drying chemicals. MBraun Unilab glovebox with purification system (<1 ppm moisture and oxygen levels) outfitted with a 10-microgram balance. A second 10-microgram balance for weighing starting materials used in sample preparation. Two laboratory presses for pressing powder into rods for crustal growth or pellets. Two laboratory microscopes for preparing specimens for measurements and work on the thermal expansion cell. A low-speed diamond saw for cutting samples. Iodometric titration equipment for establishing oxygen content of samples. Nicolet x-ray generator with Laué camera for orientation of single crystals. Glass blowing bench and gas handling system for sealing samples in quartz tubes under a variety of gas atmospheres. Retsch planetary ball mill model PM400/2 for making large quantities (30+ grams) of powder for crystal growth. Denton Vacuum DV-502A evaporation system equipped with a turbo pump.

Thermal Analysis: High temperature, up to 1600C, atmosphere controlled dilatometer and DTA/TGA with evolved gas analysis (mass spectrometry).

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Image/Chemical/Structure/Performance Characterization: MSU's Imaging and Chemical Analysis Laboratory (ICAL) is a user-oriented facility that supports basic and applied research in all science and engineering disciplines at MSU. The laboratory provides access to state-of-the-art equipment, professional expertise, and individual training. ICAL instrumentation is dedicated to the characterization of materials through high-resolution imaging and spectroscopy. The suite of instruments available include the following: a VEECO MultiMode V and Dimension 3100 Atomic Force Microscope (AFM), a Zeiss SUPRA 55VP Field Emission Scanning Electron Microscope (FE-SEM) with energy dispersive spectroscopy (EDS) capability, a JEOL JSM-6100 Scanning Electron Microscope, a SCINTAG X1 X-ray Powder Diffraction Spectrometer (XRD), a Physical Electronics 5600 Small-Spot X-ray Photoelectron Spectrometer (XPS), a PHI TRIFT 1 Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS), a Physical Electronics 6600 Scanning Auger Electron Microprobe (AUGER), an Olympus BX-61 Epifluorescence Optical Microscope, Microarray Chip Writer and Reader System, Critical Point Drying System, and Video Contact Angle System. Elsewhere on campus faculty and students can perform Transmission Electron Microscopy (TEM), Raman Spectroscopy (UV & optical, with Ar^+, Kr^+, and Ti-sapphire lasers), X-ray Absorption Spectroscopy (XAS), X-ray Crystallography, Rutherford Backscattering Spectrometry (RBS), Nuclear Reaction Analysis (NRA), Confocal Scanning Laser Microscopy (CSLM), Magnetic Resonance Microscopy (MRM), Nuclear Magnetic Resonance Spectrometry (NMR), Laser Doppler Vibrometer, High Resolution Digital Image Correlation System, Magnetic Properties Measurement System (MPMS), Induction Coupled Plasma (ICP), a variety of mass spectroscopy systems, and multiple electrochemical testing systems.

Automated electrical resistivity system for four-probe measurements in the temperature range $4.2\ K < T < 300\ K$; this same system is used with three high pressure cells for making measurements at pressures up to 1.6 GPa. Physical Properties Measurement System from Quantum Design with ^{3}Helium option (temperature range down to 0.3 K) and 9 tesla magnet, can measure heat capacity, dc magnetic susceptibility (vibrating sample magnetometry option, measures from 2 K to 1000 K), ac magnetic susceptibility, ac transport (electrical resistivity, critical current density, magnetoresistivity, Hall effect), and dc electrical transport. Thermal expansion systems (*all with sub-angstrom resolution using fused quartz dilatometer cells*): (1) Unit with home-built cryostat ($5\ K < T < 350\ K$), Varian turbo pumping system (dry pump), one Andeen-Hagerling AH2500A capacitance bridge, Lakeshore 340 temperature controller, and Labview controlled data acquisition,

Microfabrication and Specimen/Sample Preparation: Deposition, Etching, Lithography, Metrology, and Packaging capabilities within Class 1000 and Class 10,000 cleanrooms , along with a wide range of additional equipment for preparing a wide range of materials specimens, samples, and prototype devices from the nano/microscale to the macroscale.

The ambitious research agendas of MSU faculty involved in materials science research are facilitated by the strong complement of instrumentation. In addition to high-field NMR instruments (e.g. 300 MHz and 500 MHz instruments, along with a 600-MHz NMR with autosampler for metabolomics research) and mass spectrometers for proteomics, metabolomics, and chemical composition measurements (ultra-high pressure LCMS, ion traps with CID and ECD, chip and standard nanoflow ESI, Maldi ToF-MS/MS, and ultra-high resolution Q-ToF-MS), routine optical spectra can be acquired using FTIR, UV-Vis, and steady-state fluorescence spectrometers.

Instrumentation for dynamic light scattering, zeta potential, isothermal titration microcalorimetry, cryogenic electron microscopy, and stopped-flow spectrophotometry ais also state of the art. Protein crystallographers have the necessary equipment for macromolecular crystal-structure determination. Protein-protein interactions can be studied using surface Plasmon resonance (Biacore 1000), with quartz crystal microbalance with dissipation (Q-Sense), and using a fluorescence lifetime microplate reader. A large number of instruments provide access to several different forms of chromatography, time-resolved spectroscopy from femtosecond to second time scales, and other methods, including synthesis and sequencing of peptides and oligonucleotides, along with recombinant DNA techniques.

Montana Tech

Montana Tech's labs and research equipment applicable to materials science and engineering reside in several departments. These infrastructure assets provide a significant research foundation and resource for the proposed collaborative MatSci Ph.D. Program, especially for certain types of materials studies. In metallurgy, minerals, materials processing, trace-element analysis, and high-pressure testing, they are unique assets of the MUS.

The Metallurgical and Materials Engineering (M&ME) Department is located in the Engineering Laboratory and Classroom (ELC) Building, where extensive laboratory facilities and equipment related to mineral, materials, and metallurgical processing, characterization, and testing are available in about twenty different laboratory rooms. The co-located **Center for Advanced Mineral and Metallurgical Processing (CAMP)** shares the research facilities and conducts research supporting the global mineral industry, including processing of minerals & metals and developing processes that minimize waste generation. The ELC Building has a loading dock for receiving large samples, along with a high bay, where MTech's faculty/student machine shop is being installed.

Within the high bay on the first floor of the ELC Building is the Thermal Processing Area, housing a pilot plant roaster donated by Newmont Mining Company, and the Roasting/Calcining Lab with induction, box, and kiln furnaces as well as investment and traditional casters. The Materials Manufacturing Lab houses a freeform fabricator, two types of porosimeters, and an autoclave, as well as sample-preparation and wet-chemistry equipment. A nearby lab houses a ThermoFisher ICAP6000 inductive coupled plasma (ICP) spectrometer, an ion chromatograph and an Agilent 300A Micro Gas Chromatograph. The Separations/Recycling Lab is used for particulate processing and includes various chemical, density, electrostatic, hydrophobic, magnetic, and particle-size separators. The Comminution Lab contains equipment, such as crushers, grinding mills, pulverizers, splitters, and sieves.

The Physical Metallurgy Lab houses a cold pressure roll and vacuum furnace. Metallographic Lab 1 houses samples, microscopes, and sample-preparation equipment, as well as a macro-hardness tester. Metallographic Lab 2 includes manual polishing wheels, submerged cut-off and diamond-blade saws. Metallographic Lab 3 contains automatic polishing equipment, as well as sample preparation benches. The Microhardness Lab houses three microhardness testers and a Neophot21. The Imaging Lab houses a computer-aided optical microscope and a table-top imaging SEM. The X-ray Lab has an x-ray diffraction (XRD) instrument and a Bruker A20A4 x-ray fluorescence (XRF) spectrometer. The Scanning Electron Microscopy (SEM) Lab houses two instruments: a 1430VP SEM with two energy-dispersive x-ray analyzers (SEM/EDX) for mineral liberation analysis (MLA), and a Leo 1430 Upgrade SEM.

The three labs on the second floor of the ELC Building are the Materials Thermochemistry Lab, the Environmental Hydrometallurgy Lab, and the Corrosion and Special Projects Lab. The Thermochcemistry lab

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contains a Carbon/Sulfur analyzer, a TA Instruments Q5000 ThermoGravimetric Analyzer (TGA), a Netsch DIL 402C dilatometer, a TA Instruments Q800 dynamic mechanical analyzer (DMA), a scanning calorimeter, and several furnaces—for characterizing various types of materials, particularly polymers, ceramics, slags, composites, sulfide minerals and coals. The Hydrometallurgy Lab is basically a wet-chemistry lab, equipped additionally with water purification systems, drying ovens, and weighing scales. The Corrosion Lab houses potentiostats, galvanostats, plating equipment, and electrochemical cells and has space for short-duration research projects.

The Environmental Engineering Department has a Metal-Contamination Research Lab with instruments for analyzing and detecting trace amounts of mercury and other toxic heavy metals. The suite of equipment includes a Thermo inductively coupled argon plasma emission spectrometer (iCAPES), four different types of mercury analyzers, and a Leica microscope with imaging software to take pictures of mercury-contaminated specimens. The fully equipped sample preparation lab includes a microwave digester to prepare samples for the iCAPES. The lab benefits from co-ownership of the patent on a metal nanoparticle filter capable of removing trace metals from air and water, which provides a revenue stream and an industrial partnership with a new local firm, Energy and Environmental Research and Technology, LLC.

The Mining-Engineering and Geological-Engineering Departments share a Geomechanics Lab equipped with a $1-million 330,000-lb load frame with the capacity to test specimens under confinement pressure up to 20,000 psi and at temperatures up to 100 degrees C. The Lab also has a recently upgraded servo-controlled direct-shear apparatus and superfine surface grinding and polishing equipment for rapidly preparing specimens polished thin sections and slabs of geological and other materials for examination by transmitted and reflected light microscopy and/or scanning electron microscopy.

MTech's Biology Department is equipped with microbiology and molecular biology equipment for teaching and research. This equipment includes two gradient-temperature thermocycler (PCR) machines, two systems for visualizing and recording digital images of gels and Petri dishes, a nanodrop system, temperature-controlled tabletop centrifuges, and a Beckman Coulter ultracentrifuge. In addition, the department shares use of a Hitachi 4500 scanning electron microscope.

The Chemistry and Geochemistry Department houses a well equipped analytical and chemical analysis laboratory. It is equipped with: (1) a Thermo Scientific iCE Series Atomic Absorption Spectrometer (AAS) with flame and graphite furnace capabilities; (2) a Bruker Avance 300 MHz Fourier Transform Nuclear Magnetic Resonance Spectrometer (FT-NMR); (3) a Nicolet Nexus 670 Fourier Transform Infrared Spectrometer (FT-IR) with sample cells for transmission, diffuse reflectance, and attenuated total reflectance measurements; (4) a Thermo Scientific Trace GC Ultra/ITQ 900 Gas Chromatograph-Mass Spectrometer (GC-MS); (5) an Agilent 1100-Series/Bruker Daltronics Esquire 4000 Liquid Chromatograph-Mass Spectrometer (LC-MS); (6) a Dionex Ion Chromatograph (IC); (7) a Hewlett Packard 8453 UV/VIS Absorption Spectrometer; (8) a Thermo Scientific Nicolet iS5 FT-IR; and (9) a Rudolph Research Analytical Autopol 1 Automatic Polarimeter. In other locations, the Department has (1) an EG&G Princeton Applied Research 263A Potentiostat/Galvanostat; (2) a Horiba Jobin Yvon Fluorolog 3 Fluorescence Spectrometer; (3) a Thermo Scientific 1300 Series BL2 Safety Cabinet; (4) a Thermo Scientific Heracell 150i CO_2 Incubator; and (5) a LABCONCO 2.5 L Freeze Dryer.

The General Engineering Department has several labs with devices to test and characterize asphalt, concrete, soil, timber, metals, composites, and ceramics. Nanomaterials, fluids and energy conversion can also be measured and tested. Equipment for materials testing includes standard machines for

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tensile/compression, impact/toughness, three-point bending, hardness and fatigue testing. The testing devices include a full range of systems for analysis of materials of many different descriptions. Characterization equipment for nondestructive evaluation includes dye-penetrant, magnetic-particle, eddy-current, ultrasonic, and radiographic testing, as well as optical microscopes, a probe station, and soil analysis equipment. There is also a range of manufacturing equipment in both subtractive (milling, lathe, and cutting equipment) and additive (welding, arc, laser, friction, stir, and 3D printing) forms. The standard range of specialized software is available, including Auto-CAD, Solidworks, Civil3D, MATLAB, MathCAD, Octave, and COMSOL.

MTech's Data Center houses a high-performance computing (HPC) cluster accessible from any Internet-connected computer on or off campus. The cluster consists of 20 compute nodes with dual Intel Xeon processors (8 cores/processor) and 64 GB of internal RAM for a total of 320 available cores and over 1 TB of memory. A three-dimensional data visualization room is also available, along with an additional 25 TB of permanent storage. In addition, plans are in place to expand the cluster with over 1,000 additional cores by integrating hybrid nodes that contain many core GPUs.

The Montana Bureau of Mines and Geology (MBMG) is a state agency and a unit of Montana Tech, located in the Natural Resources Building. The MBMG is the principal source of earth-science information in Montana. Since 1919, it has been mandated to serve Montana in research and the orderly development of the state's mineral and water resources. MBMG's Analytical Laboratory is licensed by the state of Montana to analyze public water supplies and it has a QA/QC program meeting the criteria established by the U.S. Environmental Protection Agency (EPA) and the U.S. Geological Survey (USGS). Available instrumentation includes the following major instruments.

- Thermo ICAP inductively coupled argon plasma emission spectrophotometer (ICAPES)
- Thermo X-series® Inductively Coupled Plasma/Mass Spectrometer (ICP/MS)
- Dionex ion chromatographs
- Agilent gas chromatograph with mass spectrometer detector (GS/MS)
- Agilent gas chromatograph with electron capture detector (ECD)
- ELISA testing in magnetic particle and 96 well plate formats
- Beckman scintillation counter
- Picarro water isotope analyzer

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Appendix II, Representative List of Interested and Participating Stakeholders

In-State Industry

John Krstulich, GT Solar, Missoula
Tom McIntyre, REC Silicon, Butte
Jim Liebetrau, AFFCO, Anaconda
Craig Wilkins, Zinc Air, Inc., Kalispell
Dan Brimhall, American ChemMet, Helena
Bert Robins, SeaCast, Butte
Arif Karabeyoglu, AeroTec, Butte
Gary Rivenes, Cloud Peak Energy
Jaye T. Picketts, Rare Element
Peter J. Simonich, PPL Montana, LLC
Jeff Ruffner, MSE-TA, Butte
Larry Twidwell, Montana Enviromet, Butte
Hugh Craig, Polymeric Interconnect, Butte
Lawrence Farrar, Resodyn Corporation, Butte
David Briggs, Purity Systems, Inc., Missoula
Don Kiely, Rivertop Renewables, Missoula
Don Profota, Lattice Materials, Bozeman
Hank Rawlins, Montana Process Engineering, Butte
Tom Russell, Emission Resource Group, LLC
Yuval Avniel, MicroPowder Solutions LLC, Missoula
Todd Johnson, Federal Technology Group, Bozeman
Dave Micheletti, Universal Technical Resource Services (UTRS), Butte
Randy Equall, Scientific Materials Corporation, Bozeman
Howard Bateman, Advanced Materials (Semi-Tool), Kalispell
Tom Hoffman, Summit Aeronautics Group (Boeing Fabrication), Helena

Out-of-State Industry (Based on Known Research Interests or Letters)

Exotic Metals, Kent, WA & Germany
Hercules
REC Silicon, Moses Lake, WA
Bloom Energy, Sunnyvale, CA
Taggart Global, Pittsburgh, PA
Imerys, Sandersville, GA
Boeing Materials, Seattle, WA
Newmont Mining Corporation, Denver, CO
General Electric, Fairfield, CT
Freeport McMoRan, El Paso, TX
Hecla Greens Creek Mining Company, AK
DuPont, Wilmington, DE

State Centers of Excellence

Optical Technology Center (OPTEC), MSU
Spectrum Labs, MSU
Energy Research Institute, MSU
Center for Computational Biology, UM
Center for Biofilm Engineering, MSU
Western Transportation Institute, MSU
Center for Advanced Mineral and Metallurgical Processing (CAMP), MTech

Federal Departments, Agencies and Laboratories Supporting or Performing Materials Science and Engineering Research (Partial Listing):

Department of Defense (DoD)
U.S. Department of Energy (DoE)
National Science Foundation (NSF)
National Institutes of Health (NIH)
National Aeronautics and Space Administration (NASA)
Idaho National Laboratory (INL), ID
Oak Ridge National Labotory (ORNL), TN
Argonne National Laboratory (ANL), IL
Brookhaven National Laboratory (BNL), NY
Los Alamos National Laboratory LANL), NM
Sandia National Laboratory (SNL), NM, CA
Lawrence Livermore National Lab (LLNL), CA
Lawrence Berkeley National Laboratory (LBNL), CA
Pacific Northwest National Laboratory (PNNL), WA

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Appendix III – Courses for the MatSci Ph.D. Program

CORE COURSES

MTSC 501 ADVANCED MATERIALS SCIENCE I (4 cr). Required. *Bonding, Structure and Defects.* How do structure and bonding at a microscopic level lead to macroscopic material properties? Topics include treatment of ionic and covalent bonding; quantum mechanical foundation of the cohesion and properties of solids and the evolution of band structure; three dimensional crystallography including point groups, stereographic projections, Bravais lattices, space groups and representative crystal structures; and study of the electronic and mechanical properties of materials and the effects of point, line, and planar defects in crystalline solids. Fall.

MTSC 502 ADVANCED MATERIALS SCIENCE II (3 cr). Required. *Function and Application. Semester 2. Function and Application.* How are materials designed and synthesized to achieve specific applications? A team taught course broken up into three 12-lecture segments. Each segment will cover a specific topic where potential topics may include ceramics, polymers, magnetic materials, biomaterials, glasses, etc. This course will be taught in such a way that material discussed in Semester 1 is put into practice, introducing students to principles of "rational material design."

MTSC 511 THERMODYNAMICS OF MATERIALS (3 cr). Required. Advanced thermodynamic principles in the context of materials science; solution thermodynamics, multi-phase mixing, entropy, and equilibria; state functions and free energies; statistical thermodynamics, including ensembles, lattices, and phase transitions. Fall.

MTSC 512 KINETICS AND PHASE TRANSFORMATIONS (3 cr). Required. This course covers the mechanisms controlling the rates of structural/chemical changes and reactions in materials. The course examines quantitative diffusion theory and practical applications. The course considers nucleation and growth as a mechanism for phase transformations. The course then looks at examples of the application of phase transformations in materials processing. Spring.

MTSC 551/552 ADVANCED MATERIALS CHARACTERIZATION I/II (2 cr/3cr). Required. Two-semester materials characterization sequence. A laboratory-based survey providing experience with the common qualitative and quantitative characterization and analytical tools used in materials science and engineering. Techniques include scattering, diffraction, microscopy (optical, electron, tunneling, etc.), optical, thermal, mass spectrometry, NMR, and other techniques. An important emphasis of this course sequence will be teaching students how to select the characterization/analysis tools appropriate to the research project, use the instruments effectively, and analyze and evaluate the data that result from the different types of measurements. Relevant data from actual materials systems (acquired from instrumentation at any one of the three campuses) will serve as the platform for discussing the basis (theory) of the instrument and assessing instrumental capabilities and limitations. Specific instrumentation and methods featured each semester are selected to complement the topics in MTSC 501/502 ADVANCED MATERIALS SCIENCE I/II. MTSC 651: Fall; MTSC 652: Spring.

MTSC 500 SURVEY OF MATERIALS SCIENCE & ENGINEERING (SEMINAR) (1 cr each semester). Two semesters required. A two-semester, seminar-format overview of Materials Science, with some units

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focusing on the specialty/niche areas of the MUS/MatSci Ph.D. program and introducing students to the faculty and research on the three campuses. Other professional-development content, such as research ethics, is included. Primarily distance/e-participation with different sessions organized and hosted at the three campuses. One face-to-face session at each campus each semester would bring students and faculty together for lab tours. (No more than 2 credits may be applied to the program's course credit requirements). Every Semester.

MTSC 690 DISSERTATION RESEARCH (1 cr-9 cr). Dissertation research. A minimum of 18 credits is required.

<u>ELECTIVES</u>

MTSC 580 SPECIAL TOPICS (1 cr-3 cr) Selected topic of special interest or currency in the broad interdisciplinary area applicable to materials science or engineering. Topic will be designated at the time the course is offered. Sections may be offered concurrently to address different topics. There is no limit to the number of different special topics course credits a student may earn and apply to the degree. TBD.

MTSC 589 COLLABORATIVE PROJECT (1 cr-9 cr) Independent collaborative research project conducted on location at or in collaboration with a center of excellence, national laboratory, or industrial organization. Student must identify a willing faculty supervisor and a co-supervisor from the partner organization hosting the project, and obtain the approval of his/her committee. No credits may be applied to satisfy the minimum course requirements for the degree. Up to 6 credits may be applied to the minimum dissertation-credit requirements, if the project is applicable to the dissertation. Prior to passing the candidacy exam, students would register for MTSC 589, which is also open to graduate students (master's or Ph.D.) in other programs, on permission of the MatSci faculty instructor. After passing the candidacy exam, students would register for MTSC 689.

Many graduate-level electives applicable to the MatSci Ph.D. program exist at all three campuses. These applicable electives are offered in the following departments, for example:

Montana State University:
Chemistry, Biological Sciences, Physics, Chemical and Biological Engineering, Earth Sciences, Electrical and Computer Engineering, Mechanical and Industrial Engineering, Mathematics, and Computer Science.

Montana Tech:
Biological Sciences, Chemistry, Environmental Engineering, General Engineering, Geological Engineering, and Materials and Metallurgical Engineering.

University of Montana:
Chemistry, Biology, Mathematics, School of Pharmacy.

Other electives are expected to be developed by participating faculty, subject to review and approval by the normal curricular review process on the campus where the course is developed.

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Appendix IV – Benchmarking Study of Materials Science and Materials Science & Engineering Doctoral Programs

There are approximately 100 materials science and/or engineering doctoral programs in the United States and Canada (Table IV-2). Included among the universities offering these doctoral programs are 11 of the 15 campuses with Schools of Mines (designated by + symbol) and 32 land-grant institutions (designated by * symbol). Only nine programs are offered in the Pacific Northwest and states bordering Montana: Colorado (1), Idaho (2), Oregon (1), North Dakota (1), South Dakota (1), Utah (1), and Washington (2). The American Society of Engineering Education (ASEE) collects enrollment and degree-production data from most of these institutions and programs. Nationally doctoral enrollment is about double the enrollment in master's programs in materials science/engineering at the campuses responding to the ASEE surveys.

In 2010 the National Research Council published its "decadal" comparative assessment of research doctoral programs.[11] Overall, this study included some 2,000 degree programs in over 60 fields (including materials science/engineering) at over 200 doctoral intensive institutions. This study included about 80 programs classified as being in materials science/engineering. Only three of the programs in the Northwest (Utah, Washington, and Washington State) were included in the NRC's recent materials program comparison. All of the doctoral programs in materials are interdisciplinary. While some are in a dedicated and so-named "materials" department, others transcend departmental and in some cases school/college lines.

A review of the metrics from materials doctoral programs in the NRC study results in some key benchmarks presented in Table IV-1. Because MatSci is intrinsically interdisciplinary, many faculty members involved in materials doctoral programs tend to have commitments to other programs as well. Thus the faculty effort available to the materials programs tends to be in the range of 50% of the faculty numbers. Other metrics from this study have been used to inform the assessment plan included in this proposal.

With approximately 40 faculty members across the three campuses having relevant research activities and showing interest in the program (see Appendix VI), it is clear that the proposed MUS program has sufficient faculty numbers to be viable. The administration and governance approach described in Appendix V has been designed to help the program be competitive, sustainable, and operated as a Montana University System asset.

Table IV-1. Benchmarks from Doctoral Programs in Materials Science/Engineering

Criterion	Top Quartile Average	Bottom Quartile Average
Number of Faculty (Heads)*	46	20
Allocated Faculty (~FTE)*	23	11
Number of enrolled students	98	19
Degrees granted per year	12.9	2.9
Median time to degree (yrs)	4.9	4.4

* Not used in assessment.

[11] NRC (2010) *op cit.*

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Table IV-1. Institutions Offering Ph.D. Programs in Materials Science and/or Engineering

*Auburn University, AL
*Tuskegee University, AL
University of Alabama, AL
University of Alabama at Birmingham, AL
Arizona State University, AZ
*+University of Arizona, AZ
California Institute of Technology, CA
Stanford University, CA
*University of California-Berkeley
*University of California-Davis
University of California-Irvine
University of California-Los Angeles
University of California-San Diego
University of California-Santa Barbara
University of Southern California
+Colorado School of Mines, CO
University of Colorado, CO
University of Denver, CO
*University of Connecticut, CT
Yale University, CT
*University of Delaware, DE
Florida International University, FL
Florida State University, FL
University of Central Florida, FL
*University of Florida, FL
Georgia Institute of Technology, GA
Boise State University, ID
*University of Idaho
Illinois Institute of Technology, IL
Northwestern University, IL
University of Illinois-Chicago, IL
*University of Illinois at Urbana-Champaign, IL
*Purdue University, IN
*Iowa State University, IA
*+University of Kentucky, KY
John Hopkins University, MD
*University of Maryland-College Park, MD
*Massachusetts Institute of Technology, MA
*University of Massachusetts, Amherst, MA
University of Massachusetts, Lowell, MA
Worcester Polytechnic Institute. MA
*Michigan State University, MI
+Michigan Technological University, MI
University of Michigan, MI
Wayne State University, MI
*University of Minnesota, MN
+Missouri University of S&T, MO
University of Nebraska-Lincoln, NE
*University of New Hampshire, NH
+University of Nevada, Reno, NV
New Jersey Institute of Technology, NJ
Princeton University, NJ
* Rutgers University, NJ
Stevens Institute of Technology, NJ
+New Mexico Tech, NM
Alfred University, NY
Columbia University, NY
*Cornell University, NY
Rensselaer Polytechnic Institute, NY
Stony Brook University, NY
SUNY Albany, NY
SUNU Binghamton, NY
University of Buffalo, NY
University of Rochester, NY
Duke University, NC
*North Carolina A&T, NC
*North Carolina State University, NC
University of North Carolina, Chapel Hill, NC
*North Dakota State University, ND
Case Western Reserve University, OH
*Ohio State University, OH
University of Dayton, OH
University of Cincinnati, OH
Wright State University, OH
*Oregon State University, OR
Carnegie Mellon University, PA
Drexel University, PA
Lehigh University, PA
*+Pennsylvania State University, PA
University of Pennsylvania, PA
University of Pittsburgh, PA
Brown University, RI
*Clemson University, SC
+South Dakota School of Mines and Tech., SD
*University of Tennessee-Knoxville, TN
Vanderbilt University, TN
Rice University, TX
*Texas A&M University, TX
Texas State University, TX
University of North Texas, TX
University of Texas-Arlington, TX
University of Texas-Austin, TX
University of Texas-Dallas, TX
University of Texas-El Paso, TX
+University of Utah, UT
*University of Vermont, VT
Norfolk State University, VA
University of Virginia, VA
*+Virginia Polytech. Inst. & State University, VA
University of Washington, WA
*Washington State University, WA
*University of Wisconsin-Madison, WI
University of Wisconsin-Milwaukee, WI

**Land-Grant University*
+School of Mines

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Appendix V - Governance and Administration

1. Governance Principles
   a. The collaborative MUS Materials Ph.D. program must be designed, governed, and administered so that it attracts top-quality students nationally/internationally, creates a close-knit, Montana-wide community of scholars/researchers, and graduates Ph.D.s who are competitive and in demand for positions in industry, in government, and in academia.
   b. The administrative and academic procedures and processes must be clear, seamless, and transparent to the students.
   c. Student benefits (total stipend amounts, etc.) should be uniform and independent of home campus, and students should enroll at the campus where faculty expertise and research activity/opportunity best match the student's interest. Notwithstanding this parity principle, campuses may recruit students to the program and their campus with such "signing bonuses" and special fellowships and honors as are used to entice the highest caliber applicants in other graduate programs to enroll.
   d. The program shall be responsive and responsible to the collaborating campuses and *vice versa.*
   e. Academic and administrative standards for the program must be consistent with the graduate program requirements of the MUS, of each of the campuses, and of the top-ranked materials Ph.D. programs.
   f. Faculty in the MatSci Ph.D. program must be active in research, publication, and teaching/mentoring in the Ph.D. program. Ph.D. program faculty will be automatically appointed to "affiliated faculty" status at partner institutions at the same faculty rank as at their home institution. No compensation, office space, research space, etc. will be associated with the affiliate appointment.
   g. The selection/appointment of tenure-track faculty, terms and conditions of faculty appointments, and promotion and tenure (P&T) decisions are the sole responsibility of the home campus. The institutions commit to coordinating searches and expertise to maximize the quality and strength of the Ph.D. program. Teaching duties of Ph.D. program faculty will not necessarily be limited to the MatSci Ph.D. program, and faculty member will be a full member of a specific department on the home campus. A faculty member's contributions to the MatSci Ph.D. program will included in the annual evaluation and P&T process of the home department and campus.
   h. Courses in the Ph.D. program will be available to all students in the Ph.D. program, regardless of their home institution, and also to other qualified graduate students in accordance with campus, MUS, and MUGS policies and practices.

2. Governance (See Figure V-1)
   a. Each campus will elect a program director, who is a faculty member involved with the program. Each campus director will be designated as a co-director of the MatSci Ph.D. program. Together the three co-directors comprise the Program Leadership Council, with primary responsibility for academic content, quality, and coordination.
      i. The selection and appointment of the campus director results from an election by the program faculty on that campus followed by official appointment by the campus' graduate dean. Faculty nomination of two candidates with different expertise would allow the graduate deans to coordinate appointments in a way that ensures that the three co-directors are disciplinarily diverse, representing the breadth of the program.
      ii. Campus directors will have staggered 4-year terms with their performance subject to annual review by the graduate dean at the home campus.

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iii. Campus directors direct the program on their campuses, serve as the primary academic coordinator with the other campuses, and provide leadership for the collaborative program.

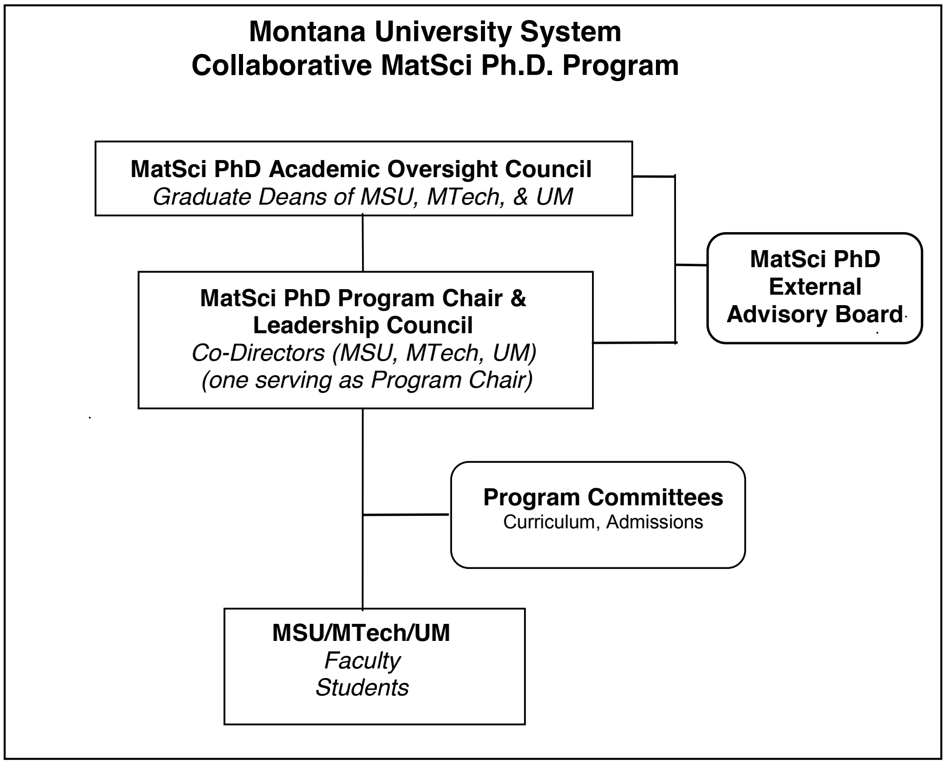

Figure V-1. Governance and Organization Chart for Proposed MatSci Ph.D. Program

b. One of the Campus Co-Directors will serve as the Materials Ph.D. Program Chair and Chair of the Leadership Council. Another one will serve as the Materials Ph.D. Program Vice Chair and chair of the Curriculum Committee. The third co-director chairs the Admissions Committee. The Program Chair should have a strong national reputation and be able to represent the program, when necessary, at the state and/or national levels.
   i. The Program Chair and Vice Chair will be nominated and elected by the Ph.D. program faculty, with the appointment confirmed by the Academic Oversight Council.
   ii. The Program Chair has responsibilities typical of program chairs, including course scheduling across the campuses, advised by the other co-directors.
c. The Leadership Council reports to the Academic Oversight Council, consisting of the graduate deans of the participating campuses. It is Leadership Council is responsible for the operation and development of the program, providing input for and prioritization of faculty searches, fostering research collaborations.
d. The Academic Oversight Council and its members resolve issues related to the MatSci Ph.D. program and ensure that the Program complies with MUS and institutional requirements.
e. Program Committees will be established, e.g. for curriculum and admissions, as is typically found in a department or program. Some committees will have student members, as appropriate. Each committee will include member(s) from all three institutions.

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f. Every course offered each term will be listed in the course schedule at each campus, indicating the faculty member(s) and lead campus/location for that course. Courses will be taken "in residence" by all Ph.D. students, with the detailed mechanism and process being agreed by the registrars on the three campuses.
g. A program-wide faculty meeting, chaired by the Program Chair, will be held at least once each academic year with participation in person, and at least once per academic year by using distance technology.
h. The MatSci Ph.D. program curriculum committee will review/approve new course proposals along with modifications to the curriculum and degree requirements.
i. The MatSci Ph.D. External Advisory Board will consist of outstanding, nationally recognized, diverse individuals, collectively bringing expertise in the scientific theme areas, from materials industry/employers in Montana, and in graduate education at the Ph.D. level. Members may be nominated by anyone, and they will be appointed by the Academic Oversight Council to staggered renewable 3-year terms.

3. Admissions
   a. The Ph.D. program will have an Admissions Committee, with membership from all three campuses. The Admissions Committee member from each campus is designated as the MatSci Ph.D. program admissions representative on that campus.
   b. Students would apply to the MatSci Ph.D. program through the graduate admissions office of any one of the three campuses, ideally the campus where they wish to enroll. Each application would be processed in the normal way by the graduate admissions office and forwarded to the campus' MatSci Ph.D. program admissions representative, who shares it with the Admissions Committee. The Admissions Committee reviews the applicants, including the match between the applicant's interest and preferred campus. Admissions recommendations for the Program will be made as they are for all graduate programs, considering the applicant's quality, the availability of financial support, and the availability of willing mentor(s)/advisor(s). The admitted students will be extraordinary applicants with interests spanning the research themes of program and an appropriate distribution of enrollment across the three institutions. The Program's recommendation on each applicant is forwarded for action to the graduate admissions office on the campus where the student is recommended or waitlisted for admission. In the case of students not recommended for admission, the recommendation is returned to the graduate admissions office of the campus where the student applied.
   c. Once the program's admission recommendation is made, the remainder of the admissions process follows the normal graduate admissions process on the campus where the student is admitted, waitlisted, or applied. Admissions offers are made by the campus where the student will matriculate, in the same manner and by the same official as for other graduate students at that campus.

4. Committee Structure
   a. Each student will have a committee, chaired by a faculty member (the student's advisor) on the campus where the student enrolls.
   b. With input from the student, the MatSci Leadership Council will recommend the committee composition for each student. The committee will have at least five members, including at least one faculty member from a collaborating campus and one member appointed by the graduate dean of the campus where the student is enrolled. The process for approving and establishing the committee

membership follows the process of the student's campus, with the final approval provided by the graduate dean for that campus.

   c. The role and responsibility of the committee and the timing for its actions will follow the policies of the student's campus.

5. Academic Good Standing Policies
   a. Students are subject to the academic progress and good standing policies of the institution where they are enrolled.
   b. Students in good standing at the home institution are accepted as being in good standing at all institutions, and they will be allowed to enroll in any courses identified as part of the Ph.D. program at any of the institutions, providing they have the specific prerequisites for that course.
   c. Course grading is subject to the grading standards and policies of the institution offering each course.

6. Access to and Use of Research Equipment
   a. Ph.D. students and their supervising faculty have access to research equipment on all three campuses.
   b. Regardless of the home campus of the student/faculty, he/she will be accorded reservation priorities/privileges, training opportunities, and usage charges as if he/she were a student/faculty at the campus where the equipment is located.

7. Financial Support for Students
   a. The Ph.D. program will agree on and offer a standard total financial support package to students in the program. There may be variability based on whether the student is in candidate status, but not based on the home institution or type of support.
   b. In accordance with BOR 940.31, Ph.D. students will be identified as GTA/GRA and be charged the in-state tuition rate. The tuition may be covered by each campus with some combination of waivers, grant funds, and other funds (institutional fellowships, endowment income, industrial funding, etc).
   c. Fees are the responsibility of the student and follow the policies and rates of the home institution.
   d. Financial support is reserved for students enrolled for 6 or more credits in an academic term. Students in the program are eligible for financial support during the summer, without being enrolled, provided they were enrolled and eligible for financial support the previous spring term, have not yet completed the degree, and are working on their research.
   e. Financial support and the tuition reduction provided through BOR 940.31 would normally be limited to a maximum of 12 semesters of enrollment.

8. Employer Involvement and Collaborative Research Projects Conducted at a Partner Site
   a. Students may complete one or more collaborative projects hosted by industrial partners, national laboratories, or Centers of Excellence, typically involving a project with a duration of at least 4 months (one semester). However, the dates of the residency at the host location need not align with the start and end dates of an academic semester.
   b. Such projects will be reviewed by the student's committee, which will determine—in consultation with the student and the sponsor/host—whether the project is suitable as the dissertation project or as a component of the dissertation.
   c. Intellectual property and proprietary issues associated with such projects will be addressed by the host organization, the student, and the student's campus, and will follow the process and policies on that campus related to intellectual property and proprietary work.

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d. Compensation from the project sponsor/host paid directly to the student will be counted as part of the student's financial support "package."
e. The project must be summarized in a written report. This report may be the entire dissertation, a chapter in the dissertation, or a separate report.

9. Curriculum Revisions
   a. Major curriculum revisions would be developed by the program faculty and approved by the MatSci Ph.D. Program Curriculum Committee, then forwarded in parallel through the normal review/approval process on all three campuses, starting with the Graduate Deans. If the campus approval processes result in different amendments to the proposal, these differences would be reconciled and the revised proposal would be cycled for final review/approval on all three campuses.
   b. Individual course proposals would be developed by member(s) of the MatSci Ph.D. Program faculty, reviewed by the MatSci Ph.D. Program Curriculum Committee, endorsed by the MatSci Program faculty, then forwarded only to the Graduate Dean(s) of the campus(es) where the course would be taught. The Graduate Dean would then submit the proposal for the normal review/approval process required for course proposals on that campus.

10. Dissertation Process and Format
    a. The dissertation process and format follows the standard for the campus where the student is enrolled.
    b. Program policies and requirements are those of the MatSci Ph.D. program.

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Appendix VI. Initial MatSci Ph.D. Program Faculty

Name (Last,First)	Campus	Department	Materials Research Focus	Bio	En	EPM	Proc
Amendola, Roberta	MSU	M&IE	Degradation of materials, tribological behavior, thermo-mechanical performance, oxidation, surface engineering and rapid development of novel compositions and customized microstructures		x		x
Avci, Recep	MSU	Physics	Biocorrosion, bacterial immobilization, bacteria manipulation at nanoscale, bacteria trapping and concentration, bio sensors	x			
Cairns, Doug	MSU	M&IE	Materials, polymer/ceramic matrix composites, manufacturing, & structural performance link for new engineering systems		x		
Cameron, Doug	MTech	Chemistry	Biofuel characterization and environmental factors affecting algal biofuel production	x	x		
Carlson, Ross	MSU	Chemistry & Biochemistry	Metabolomic systems analysis & biofuel production.	x	x		
Chu, Xi	UM	Chemistry	Electronic structure, geometry, and dynamics of molecules of technological or fundamental interest			x	
Cone, Rufus	MSU	Physics	Resonant optical materials for quantum information, signal processing, and solid state lasers			x	
Douglas, Trevor	MSU	Chemistry & Biochemistry.	Bio-inspired nanostructures	x	x	x	
Downey, Jerry	MTech	M&ME	Vapor phase transport. Determination of fundamental properties of ionic melts		x		x
Fields, Matthew	MSU	Microbiology	Bacterial systems for biofuel production	x	x		
Ganesan, Kumar	MTech	Environ. Engineering	Development of nano-metallic filters to remove contaminants from water & air		x		x
Gannon, Paul	MSU	C&BE	High-temperature corrosion and corrosion protection in metals and ceramics, thin-film coatings		x		x
Gleason, William	MTech	M&ME	Metallic membrane hydrogen purification		x		
Holian, Andrij	UM	BMED	Biocompatibility and mechanisms of interactions studies using multiple in vitro and in vivo approaches	x			
Huang, Hsin-Hsuin	MTech	M&ME	Aqueous systems, thermodynamics, chemical speciation calculations/programming for StabCal, & computer applications to metallurgy & MatSci.				x
Idzerda, Yves	MSU	Physics	Interfacial & nanostructured behavior in oxide materials		x		
Jenkins, Chris	MSU	M&IE	Bio-inspired materials, self-healing materials, smart materials, polymer membranes	x			
June, Ron	MSU	M&IE	Cartilage drug delivery and mechanotransduction	x			x
Klem, Michael	MTech	Chemistry	Ternary element doping in various ferrite systems & impact in microwave power loss, magnetic response, and potential MRI contrast	x	x	x	
Kasinath, Rajendra	MTech	Environ. Engineering	Organic-inorganic hybrids for tissue engineering scaffolds; biomimetic synthesis of functional nanostructured materials	x			

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Kohler, Bern	MSU	Chemistry & Biochemistry	Pump/probe spectroscopy for ultrafast electron transfer through inorganic membranes for artificial photosynthesis	x	x		
Kukay, Brian	MTech	General Engineering	Destructive, semi-destructive, and non-destructive evaluation of structural materials				x
Macaluso, David	UM	Physics	Experimental atomic physics	X	X	X	x
MacLaughlin, Mary	MTech	Geological Engineering	Mechanical behavior and engineering properties of geomaterials; Numerical modeling (FE/FD, discrete element) of shear failure & fracture				X
Madigan, Bruce	MTech	General Engineering	Application and automation of welding processes for additive manufacturing				x
Malovichko, Galina	MSU	Physics	Magnetic resonance study of intrinsic, extrinsic and radiation defects in photonic materials and materials for telecommunications and computing			x	
Meier, Alan	MTech	M&ME	Fuel cell interconnect materials & joining; brazing in gas separation systems, metals, ceramics, & dissimilar material interfaces		x		X
Miller, David	MSU	M&IE	Mechanical behavior and active materials: composites piezoelectrics, and shape memory alloys		x	x	
Neumeier, John	MSU	Physics	Magnetism and superconductivity, single-crystal growth, structural and thermodynamic and electrical properties measurements			x	x
Palmer, Chris	UM	Chemistry	Colloids, polymers, polymeric nanoparticles for use in separation science				x
Pedulla, Marissa	MTech	Biological Sciences	Interaction of bio-compatible nanoparticles with biological systems, including bacterial and eukaryotic viruses and their host cells	x			
Rosenberg, Edward	UM	Chemistry	Synthesis and application of silica-polyamine composites in the mining and metallurgical processing industries				x
Ross, Sandy	UM	Chemistry	Time-resolved spectroscopy; model bio-membranes (nanodiscs and liposomes); single-molecule spectroscopy	x		x	
Shaw, Steven	MSU	Elec. & Comp. Engrg. & ERI	System identification & controls, energy and fuel-cell systems, instrumentation		x		
Singel, David	MSU	Chemistry & Biochemistry	Magnetic resonance spectroscopy for structural and chemical composition determination	x		x	
Skinner, Jack	MTech	General Engineering	Plasmonics; metamaterials; micro/nano-scale structures		x	x	
Smith, Dick	MSU	Physics	Epitaxial growth and formation of alloys at metal-metal surfaces		x		x
Sofie, Stephen	MSU	M&IE	Materials synthesis (nano/micro-scale), electro-ceramics, materials for thermo-electrics and high-temperature electrochemistry, innovative processing	x	x	x	x
Sudhakar, K.V.	MTech	M&ME	Mechanical behavior & surface characteristics of non-toxic, low modulus beta titanium alloys for medicine & healthcare	x			

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Thomas, Aaron	UM	Chemistry	Transport Phenomena and Separations, Mechanical Gas Separations and Biological Separations in MEMS Devices		x		
Walker, Robert	MSU	Chemistry & Biochemistry	High-temperature surface spectroscopy for probing oxidation and degradation in solid oxide electrochemical cells		x		
Young, Courtney	MTech	M&ME	Metal recovery, hydrometallurgy, mineral processing, separations, recycling, waste treatment, photo-conversion, & coal gasification		x		x