Proposal to Establish
The Institute for Molecular Engineering at The University Of Chicago

December 18, 2009

Executive Summary

The environment for research at the molecular level is undergoing a paradigmatic shift that blurs traditional boundaries between the basic and applied sciences and engineering. This shift will have profound consequences for the nature and practice of molecular-level science in the coming century. It will also lead to the emergence of the new discipline of *molecular engineering*. Molecular engineering concerns the discovery of basic principles governing the behavior of natural or synthetic molecular systems and the application of such knowledge in the design of advanced devices and technologies. Molecular engineering involves the incorporation of synthetic molecular building blocks including electronic, optical, mechanical, chemical, and biological components into functional systems that will impact technologies from advanced medical therapies to quantum computing. The resulting innovations are likely to deliver solutions to the most pressing human problems, including energy supply and human health.

We have examined the question of whether the University should explore and create a new research and teaching component, The Institute for Molecular Engineering (IME). We find that there are compelling intellectual reasons for the University to move in this direction. This proposed endeavor, supported by extant strengths in the basic molecular, computational, and clinical sciences, offers tremendous possibilities to position the University as an intellectual leader in this emerging engineering discipline, bringing to bear its tradition of intellectual rigor and cross-disciplinary scholarship on questions of scientific importance and societal urgency. Such action will undoubtedly provide new partnerships and routes to discovery for our faculty in the basic molecular sciences, enabling them to continue to define the horizon in their respective fields of research. A molecular engineering program of the size we anticipate will inevitably spawn discussions about the complex social, economic, legal, political, ethical, and market dimensions of the technologies and discoveries produced, creating new opportunities for rich intellectual collaborations across the University. Molecular engineering will simultaneously yield the added benefit of increasing creativity and the strength of scientific inquiry.

It is the purpose of this document to present the rationale, grand intellectual challenges, viability, and practical aspects of how the initiative may be realized within the University. We summarize the deliberations that led us to where we are today, culminating with this proposal ready for consideration by the Council. Included in this discussion is elaboration of the intellectual problems that, in our view, provide compelling motivation for the proposed initiative.

We conclude with a cautionary note: There is a real and legitimate concern that *not* pursuing this activity risks negative consequences. Without the proposed Institute for Molecular Engineering, the University's research enterprise and education mission will continue to flourish at its traditionally high level. However, inaction in this area of endeavor may well abdicate activity in some of the most promising new directions of physical, biological, and medical research and applications.

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BACKGROUND

In 2006 the Ad Hoc Faculty Committee on Molecular Engineering was charged by the President and Provost to assess whether the University should establish a formal program in Molecular Engineering that would complement our already vital and internationally distinguished activities in the basic physical, biological, and medical sciences. The motivation for undertaking this assessment at that time was that a paradigm shift was underway, where the boundary that once separated the basic sciences (the study of natural phenomena) and engineering (the efficient solving of problems) has blurred, especially for research involving systems at the molecular level. This changing research landscape challenges the traditional models for engineering departments and raises profound questions for the optimal organization of the research enterprise at institutions that aspire to world leadership in this and related areas of endeavor for the next century. Chicago must carefully consider the consequences of remaining different from virtually all its peer institutions in this regard as the decision whether to establish, or not to establish, such an entity in the applied sciences and engineering will have tangible consequences for the scope and direction of research at the University in the coming century.

The Committee, chaired by Steven J. Sibener, consulted broadly with faculty and hosted widely publicized town hall meetings with the faculties of the Biological and Physical Sciences Divisions. The Committee also considered the relevant strengths that could follow from our evolving research relationship with Argonne National Laboratory. At the end of these deliberations the Committee found that compelling intellectual arguments exist for the creation of a molecular engineering program in the University's research portfolio and widespread enthusiasm among the faculties of the two Divisions. Moreover, the Committee argued that not taking this step at this time would place at risk the position of world leadership the University presently holds in the basic physical and biological molecular sciences due to the rapid evolution that is occurring in these forefront areas of research. Molecular level systems engineering is in its infancy. The creation, control, and hoped-for societal impact of such systems will require a synergistic partnership between the basic and applied sciences and related engineering disciplines.

The Committee also concluded that the field of molecular engineering, at this early stage of inception, is well matched to the culture and strengths of the University of Chicago. The last two decades have seen an explosion in the knowledge of molecular systems. There is ample opportunity for an innovative institution such as The University of Chicago to tap accumulated molecular knowledge and, in a cost-effective manner, design small-scale solutions that will be at the forefront of scientific and engineering advances. Doing so requires a nimble institution that can draw on and merge the expertise of the physical, biological, and computational sciences.

These assessments were echoed by an external committee, chaired by Robert Langer from MIT. As stated in the external committee's report, the University, unlike other universities with traditional engineering programs in place, is not constrained by the structure of any existing engineering programs. Instead, combining the deep analytical approach that has historically characterized science at the University of Chicago with problems in engineering that might now be considered intractably difficult (e.g., clean water, systems engineering of energy, global environmental stewardship and climate change, rational design of drugs, sentience as a branch of information engineering, materials by design, and so forth) could lead to new, high-level analytical engineering tools. The University also does not suffer—as many universities do—

from the confusion of having multiple long-standing and sometimes competing programs and departments or divisions in engineering fields (e.g., bioengineering). This group explicitly noted that "a great university has an obligation to work on the biggest problems of the times, and some of the great problems of *this* time—in energy, health, global stewardship, and others – will require engineering for their solution. The University is, we agree, entirely correct in considering how to engage in engineering. Since it has unique strengths it should develop a plan for how to begin to engage in engineering that is uniquely complementary to these strengths, and capable of giving it a unique position in the universe of engineering."

These assessments and deliberations were subsequently brought on two separate occasions to the Committee of the Council of the University Senate. The first meeting occurred on February 27, 2007, and centered on a discussion of the recommendations made by the University faculty committee. The second occurred on November 13, 2007, following the submission of the report from the external committee. In the first meeting a concern of some (but not all) Committee of the Council Members was that the faculty committee report did not make the intellectual case as clearly as it could have, while other members expressed enthusiasm. In response, the second meeting incorporated more detailed descriptions of the field and its importance, presented jointly by a University biologist and chemist, and was well received.

Late in calendar year 2009 our follow-on Molecular Engineering committee was assembled and charged by the Provost to consider the University's plans to launch a new program in Molecular Engineering. The Institute for Molecular Engineering is envisioned as an entirely new, free-standing academic unit at the University with the authority to appoint faculty in Molecular Engineering. The unit will report to the Provost but will maintain close relationships with the Biological and Physical Sciences Divisions as well as with Argonne National Laboratory. The Director of the new Institute will be tasked with developing and executing a research and educational vision for the Institute that integrates and amplifies complementary ongoing research and teaching at the University. The Director will in turn orchestrate the recruitment of additional faculty to the Institute, constituted primarily by new outside faculty hires to the University. The new Institute will represent a thematically important expansion of the University's overall research program at the interface of the biological, physical, computational, and medical sciences. Over time it is envisioned that the new Institute will offer an increasing number of joint appointments to appropriate new or extant faculty members from existing University units as well as from Argonne National Laboratory.

The results of the faculty committee's deliberations are organized below as responses to the central questions for starting a new academic program. The issue now brought before the Council is specifically whether the University should proceed to create this new academic unit with faculty appointive powers. The Council is not being asked to review and approve the Institute's educational program at this time. A full curriculum proposal will be developed and presented to the Council once a sufficient number of Molecular Engineering faculty have been appointed. In the interim, and in collaboration with the Biological and Physical Sciences Divisions and the College, the Institute for Molecular Engineering will offer research opportunities to both undergraduate and graduate students and develop introductory and specialized courses as appropriate given its initially constituted faculty.

ANSWERS TO CENTRAL QUESTIONS

Question 1: Intellectual Opportunities

What are the intellectual objectives of the program, and what are suggested research themes that serve to illustrate the broad vision that the University holds for Molecular Engineering? How will extant strengths in the basic biological, physical, and medical sciences enable these new activities in Molecular Engineering?

Engineering is the science of efficient problem solving through analysis, modeling, fabrication, and design. Molecular engineering involves the development of basic principles governing the behavior of natural or synthetic molecular systems, and the application of such knowledge in the design of advanced devices and technologies. The incorporation of synthetic molecular building blocks such as electronic, optical, mechanical, chemical, and biological components into intermediate scale, i.e., mesoscopic, and/or macroscopic functional systems lies at the heart of such activities. Intellectual opportunities are abundant and diverse. Moreover, traditional field categories break down when considering molecular-level systems. Profound lessons from the working of biological systems will undoubtedly inform advances in the physical sciences, with the converse being equivalently true. Many scientific and technological advances will likely involve hybrid systems involving organic, inorganic, and biological components.

With this in mind, we suggest a few broadly conceived themes that are ripe for exploration and development as illustrative examples of where a molecular engineering effort may focus its efforts. These topics have been chosen as worthy challenges in the Chicago tradition as they offer the promise of intellectual importance, broad and lasting impact, and, with lots of hard work and some good fortune, broad-ranging opportunities for societal impact in the physical, biological, and medical sciences. Of course this is only one list of the coming high-ground in the area of molecular engineering—the lead hires in this engineering initiative will, in addition to exploring some of these themes, undoubtedly move into unanticipated and worthy new directions, precisely the intent of bringing to the University a new cohort of investigators with fresh ideas, new tools, and a complementary perspective to our already world-class efforts in the basic sciences.

The molecular engineering themes that follow will be bolstered by extant strengths in the basic and biomedical sciences at the University and Argonne. Examples include expertise in catalysis, solar energy conversion, materials research, biosciences, and computation. Excellence in interdisciplinary research located within the James Franck Institute and the Institute for Biophysical Dynamics in the form of substantial intellectual efforts in the basic sciences will provide critical intellectual support to the proposed activities below. Illustrative themes include:

- **Energy Conversion, Transport, & Storage at the Molecular Level**
  Sustainable energy is a grand challenge of our time. Solar energy provides orders of magnitude more power than society needs, yet we are still far from capturing and utilizing this rich energy source. The development of new materials and their integration into systems will yield entirely new strategies to harvest this diffuse resource efficiently. Current battery technologies, for example, can provide neither the capacity needed for industry nor the energy density required for transportation fuels. Storing energy in chemical bonds represents an unexplored solution and would require the engineering of catalysts to form high-energy chemical bonds efficiently. Possible approaches would explore the engineering of precise quantum states that permit electrical excitation to enable reactivity without enabling the reverse reaction.

- **Photonic Materials and Systems**
  Today's high performance computational systems are electronic—that is, based on the movement of electrons through gradients of potential. Electronic systems have changed the world, but are approaching the limits of their performance. Future high performance systems may be based on photonics, or the use of light to carry, process, and store information. The use of photons brings several benefits, including faster transport, almost no resistive losses, and the opportunity to exploit quantum effects in processing information. Photonics claims several early successes, including light emitting diodes, tunable semiconductor lasers, and a host of materials for manipulating light. The field is moving towards designing and building—that is, engineering—systems that perform complex computations. These systems offer promise in energy capture, chemical and biological sensors and diagnostics, and computing.

- **Molecular Electronics & Devices**
  The electronics revolution that began with the invention of the transistor has yielded today's integrated circuits that have more than a billion transistors. The increasing computational power has followed from advances in lithography that have reduced transistor size and therefore increased their number on a circuit. As these components approach molecular sizes, there is a need for new methods that can fabricate these structures; these methods are likely to be based on bottom-up strategies including molecular self-assembly and those found in biology. Further, the smaller components will have properties that deviate from their larger analogs—because the physics of nanostructures materials is quantized—and new circuit design rules will be required to combine these components into functional devices. Moreover, molecular-scale physical analogs of neural networks do not yet exist. The ambitious goals for this field, first articulated in Richard Feynman's prescient 1960 manuscript "There's Plenty of Room at the Bottom," are now attainable given advances in the basic molecular sciences and related engineering disciplines.

- **Smart and Adaptive Materials**
  In building functional systems, the engineer selects materials according to their properties, for example, stiffness, conductivity, biodegradability, transparency, etc. There are few options, however, for materials that have dynamic properties—that is, properties that can change in response to the needs of the system. For example, materials that can shift between stiff and flexible states would enable new robotic systems, those that switch between conductive and resistive may enable computational systems that can be rewired for new functions and those that change their biological properties could provide a new generation of medical implants. The development of new materials that are adaptive and of systems that exploit these materials represents a broad goal that is uniquely suited for molecular engineering.

- **Bioinspired Materials and Machines**
  Biology has long provided humans with the inspiration, if not the design, for great technological innovation. Airplanes, for example, were inspired by birds but do not share the use of flapping wings. Advances in the molecular underpinning of biological function now provide inspiration for a new generation of technologies, including strong adhesives from the mussel and gecko foot, self-healing materials, structural materials based on spider silk, active camouflage coatings from marine organisms, and computational architectures based on brain function. These biological examples of molecular materials and systems can be reverse-engineered to unravel the design rules by which synthetic components can be assembled to give devices with new functions.

- **Engineering Complex Systems**
  There exists a range of systems, in both the biological and engineering realms, that are composed of simple building blocks that interact with one another by simple rules, and yet display remarkably complex properties. Examples of these systems include decision making in neural tissue, weather events, embryogenesis, regulation of metabolic networks, evolution of software,

riots in crowds, and many, many others. Further, these systems share the characteristics that they are robust and adaptive; they maintain their functions when challenged and can evolve to develop novel functionalities. These complex systems, which are both simple in their composition yet strikingly interesting in the emergent functions they display, are motivating a new branch of science and engineering that will elucidate the design rules that relate the components and interaction rules to the properties.

- **Molecular Imaging**
  Tools for imaging structures are critical in the development and operation of a broad range of technologies, from medical diagnostics to fluid dynamics in a fuel cell and observing the functions in brain tissue. New non-destructive approaches based on the combined interactions of matter with light, electric fields and acoustic waves together with the development of new classes of contrast reagents and engineered systems for collecting imagery data can radically advance this field. Such tools, and especially those that can image and dynamically monitor molecular systems, will help engineers to design improved catalysts for energy production, to create high-performance materials for information storage, and will allow biologists to elucidate the complex structure-function relationships that govern biological processes at the molecular level.

- **Bioengineering of Membranes and Their Applications**
  Biological membranes provide a selectively permeable structure that allows for specific transport and/or diffusion of chemical and biological materials from one compartment to another. Use of this basic biological principle has led to the development of a variety of synthetic derivatives with applications in medicine, energy storage and transport, and water purification including desalinization. Indeed, the use of membranes in chemical processes is highly energy-efficient, using only 5-10% of the energy typically used in distillation or chemical separations. However the field of membrane engineering remains in its infancy. Development of novel synthetic and organic membranes with different selective properties will have direct applications in many fields. Additional potential avenues for membrane engineering can include the ability to self-clean and self-repair as well as membranes that have the capacity to dynamically change the solutes they retain or pass.

- **Engineering of Evolvable Systems**
  The basis of life as we know it revolves around heritability of traits through a nucleic acid backbone. It is thought that this evolutionary process stemmed from random chemical events that resulted in the synthesis of ribonucleic acids (RNA), molecules endowed with the intrinsic ability to self-associate and form a code. Yet nucleic acids are presumably only one of many chemical products that have these properties of self-assembly and replication; their selection as the basis of life resulted from the chemical and environmental context in which they were formed. By exploring alternative chemical and physical environments with unique code precursors, can novel evolutionary blueprints be generated? Or can rational design be used to produce a system that has intrinsic evolvability? Development of a novel, adaptable system would have implications in a wide variety of fields, allowing synthesized systems to evolve with their environment or adapt to novel stimuli.

- **Medical Therapeutics**
  A rapidly developing application of molecular nanotechnology is the design and engineering of repair molecules that restore normal structure and function of the materials in which they are incorporated. Such molecules are often called chaperones because they adhere to and restore normal conformation to damaged molecules. The University has been a pioneer of this concept for biomedical applications. Already synthetic chaperones are being brought to clinical trial to treat victims of trauma and reduce the consequences of surgery, especially in the area of therapies to reverse brain and spinal cord injury in trauma. A systematic molecular engineering approach

focusing on molecule selection and delivery for achieving optimal efficacy represents the high frontier in this field of therapeutic medicine.

Question 2: The Rationale for Molecular Engineering

Why start a new effort in Molecular Engineering?

Research and teaching in the natural sciences and engineering disciplines have historically shared little overlap. The natural sciences have excelled in revealing the principles by which physical and biological systems operate and the engineering disciplines have brought this knowledge to the realization of methods and devices that solve real-world problems. This clean separation between basic principles and applications has blurred, and in many areas, an integration of basic science and engineering approaches is now common. Indeed, studies in the sciences routinely require sophisticated apparatus that are designed and built by engineers—for example, multielectrode arrays that are used to study neural tissues and electronic device technology to package displays and electrical circuits prepared from organic polymers. Moreover, advances in engineering often lead to observations that motivate studies in the sciences: examples include studies of surface forces in MEMS (micro-electro-mechanical) devices (the Casimir Effect); modulation doping and the quantum Hall effect in semiconductor devices, which garnered two Nobel Prizes in physics; formation of ultra-cold matter on microchips with applications in quantum computing; and massively parallel approaches to drug discovery and probing cellular function, and myriad applications of molecular level imaging and manipulation derived from engineering advances in electron, confocal, and specialized scanning probe microscopes (the direct observation of molecular conformational changes and the forces associated with such transformations). This increased collaboration between the sciences and engineering disciplines is correlated with a shift in project funding from the traditional single investigator model to co-investigator efforts. A significant and still growing fraction of the research portfolio at the NSF, NIH, and other agencies is targeted towards multi-investigator efforts that emphasize both problem-solving and basic science. We believe that this trend will continue and will make it increasingly difficult for universities with outstanding science departments, but an absence of engineering, to remain leaders in the traditional sciences.

Question 3: Why Chicago/Why Now

What makes this the proper moment to launch this initiative? Does the University actually have advantages in helping to define this new field given the absence of the traditional engineering disciplines at Chicago?

There is a critical time when key, empowering discoveries and technical developments lead to revolutionary rather than evolutionary advances. Molecular engineering holds the promise of being such a driver. Realizing this vision is going to require the kind of innovation that is central to the culture of the University of Chicago. Faculty members of the University are problem solvers— they recognize deficiencies and think "out of the box," often combining solutions from different disciplines. It has been said that most innovation arises from the application of the principles of one discipline to the problems of another. The close-knit nature of the campus and faculty at the University of Chicago catalyzes these kinds of breakthroughs—compared to many other institutions, where a long commute is required from biology to chemistry to physics to medicine—the University of Chicago's compact campus facilitates serendipitous collisions of ideas. There are numerous examples of cross-disciplinary collaboration as a result. Consequently, our campus is often the birthplace of ideas that change entire fields.

Chicago has a clean slate with respect to the traditional engineering disciplines and the infrastructure of the last century. We can leapfrog traditional engineering programs into the 21st century by focusing on the creation of new knowledge and thus move rapidly into the next forefront area of molecular systems based upon expertise in complex systems, bottom-up methods, self-organization, and biomimetics, along with their natural complements in theory and numerical simulation. We have the proper intellectual foundation in the physical and biological sciences to partner with a new engineering element in molecular engineering to bring Chicago into a position of intellectual leadership in this still-being-forged engineering paradigm of the coming century.

Question 4: Synergies with the Basic Sciences and other Divisions at Chicago

Does the University have extant strengths already in place that will intellectually enhance and logistically support the launch of the proposed new effort in Molecular Engineering?

Assisting this launch will be very powerful research elements that are already in the University's research portfolio. Our strengths in physical, materials, and synthetic chemistry; biochemistry; condensed matter physics; neurobiology; molecular genetics and cell biology; large-scale computation; and medicine are a subset of the disciplines that provide the enabling environment for nucleating a new engineering effort, and, in turn, stand to directly benefit from the establishment of a research arm in molecular engineering. We find pronounced synergies among departments in the PSD and BSD, especially those that have as their foundation the molecular sciences. Moreover, there already exists a powerful cohort of interdisciplinary Research Institutes, Committees, and innovative multi-investigator federal grants that will play a key role in welcoming Molecular Engineering to campus and in helping to weave it into our highly-interactive and cross-disciplinary research milieu. The University also has many beneficial adjacencies in the basic sciences that will further bolster this effort, including, for example, assembly of hybrid organic-inorganic functional materials; biomimetic design of functional materials; molecular electronics; polymer synthesis; nanostructures and self-organization; nanostructures and self-organization; protein engineering; synthetic chaperones; nanomedicine; molecular imaging and sensors; and synthetic biology.

Clearly, investigators in each of these areas will benefit from the presence of experts in engineering at the molecular scale. But more importantly, having such experts on campus will prompt the blossoming of interests among BSD and PSD investigators whose current work would benefit from extension toward molecular engineering but who have not attempted such forays previously because of insufficient opportunity.

We find that the field of molecular engineering, at this early stage of inception, is well matched to the culture, strengths, and intellectual aspirations of the University of Chicago. The direction of research, and the technologies produced by, the Institute for Molecular Engineering will inevitably have profound global and societal implications. Development in such areas as water remediation (through engineering of water purifying membranes) and alternative energy sources, to name only a few, will invite collaborations with researchers in the areas of political science, economics, and law, as well as sociology, philosophy, and the behavioral sciences. Interactions across these disciplines will capitalize on the strengths of the University in these areas, creating a synergistic cross-talk that will maximize the application of these technologies in addressing key societal and global problems. Thus, the creation of the Institute of Molecular Engineering will not only complement the research in the Biological and Physical Sciences, but will also have important ties to areas in the Social Sciences and the professional schools.

Question 5: Synergies with Argonne National Laboratory (ANL)

Are there synergies between the University and Argonne National Laboratory that will advance this new initiative?

The recently enhanced relationship between the University and Argonne National Laboratory will provide several key benefits to Molecular Engineering. Solving the big problems in molecular engineering will inevitably require the formation of diverse teams and access to unique large-scale capabilities available at Argonne such as the molecular-scale imaging capabilities at the Center for Nanoscale Materials (CNM), the Advanced Photon Source and the Electron Microscopy Center, the synthesis and nanofabrication capabilities at the CNM, and the extraordinary computing resources that are poised to exceed 10,000 teraflops suitable for the large-scale calculations that will be used for modeling systems and quantum mechanical behavior at the molecular level. Relevant programs in the Material Sciences, Chemistry, and Biological Sciences Divisions at ANL will offer other routes to productive research. Mutually advantageous joint appointments between the University and Argonne may also arise with this new initiative, further augmenting its engineering impact and scope. However, the desire for such joint appointments should not be allowed to mitigate the advantages we perceive that come with the University's "clean slate" in engineering, namely Molecular Engineering must be allowed to launch and evolve its program in optimal fashion, ultimately bringing great benefit to the combined research milieu of these institutions.

A potential programmatic partnership with Argonne will likewise deliver significant benefits to the University. University researchers will be able to more broadly engage Argonne's considerable strengths in engineering and in particular nanoscale, chemical, and mechanical engineering, as well as Argonne basic science strengths in materials science, chemistry, and physics. In addition, Institute faculty will gain more direct access to major scientific user facilities at Argonne including the Advanced Photon Source, the Center for Nanoscale Materials, the Midwest Structural Genomics Center, the Institute for Genomics and Systems Biology and unique high-performance computing. A programmatic partnership will overall be enriched through access to significant additional resources made possible by joint University and Department of Energy investments and support, including for jointly appointed University-Argonne faculty access to Lab-directed R&D (LDRD) funds and federal resources beyond the DOE.

Question 6: Examples of Related Successful Initiatives at Other Institutions

Are there examples of institutions that have launched new broad-reaching programs in the sciences and engineering that have achieved positions of leadership on the national and world stage, hence demonstrating that such launches can be successful when executed properly?
Are there common themes that emerge upon examination of these successful examples that provide guidance to us as we create the Institute for Molecular Engineering?

One question that can be asked is whether, in today's hyper-competitive environment for physical, biological, and engineering research, institutions can successfully grow new broad-reaching programs that achieve positions of leadership on the national and world stage. Examples do exist. These recently created entities share common characteristics: A clear and absolute commitment of the institution; a visionary leader who executes the institutions' aspirations for excellence in the chosen area of endeavor; a lead scientist of elite international reputation from inside or from elsewhere who may or may not have been the visionary cited previously; the financial resources to execute the programmatic launch; and in many instances lead senior hires, as individuals or groups of researchers, from other institutions around whom other recruits nucleate as they decide to join the building effort. Examples come from many directions.

The recent explosion of activity in nanoscience gives three powerful creations: The *Smalley Institute for Nanoscale Science and Technology* at Rice University; the California NanoSystems Institute; and the London Centre for Nanotechnology (a joint venture between University College London and Imperial College London). JILA (formerly known as the Joint Institute for Laboratory Astrophysics) is another unquestioned example of such a success. It is arguably the lead research institute in the world in the area of atomic, molecular, and optical (AMO) physics. The success of these institutes can be clearly linked to two key ingredients: A visionary, world-renowned leader and substantial institutional investment. Other successful launches can be cited from the biological sciences. Two excellent ones are The Scripps Research Institute in La Jolla and the new Janelia Farm campus for the Howard Hughes Medical Institute. Finally, we note the Max Planck Society runs an extensive network of research institutes that are created around forefront issues in science and technology.

Question 7: Consequences of Inaction on this Proposal

What are the consequences for the University if we fail to enact this proposal to establish the Institute for Molecular Engineering?

Given the strong and growing interconnections between the basic and applied sciences and engineering at the molecular level, there is also a strategically important downside that must be acknowledged should the University choose not to establish the proposed unit in molecular engineering. In the near future, the University may lose access to some of the most innovative young scholars in the basic and applied molecular sciences. This matter of faculty recruitment and retention can be summarized into four categories: (i) Currently, we miss opportunities to hire excellent researchers whom we do interview because their research programs look too different from the core missions of extant departments; (ii) we do not interview those with a clear engineering vision who would empower our basic sciences with needed technology and further enrich the milieu for discovery at Chicago; (iii) some recruits with programs in the molecular sciences whom we do want accept positions at peer institutions with engineering elements as we do not have the right environment to grow their programs; and (iv) science is changing—Chicago faculty who work at the boundaries of the basic molecular sciences may depart to peer institutions that do offer the engineering elements necessary to take their already successful programs to the next level.

With respect to medical research it seems clear that Chicago could fall behind its peers were it not to develop novel engineering science. For the most part, medical disease happens at the molecular level, and our interventions to reverse it (treatments) are aimed at the molecular level (e.g., small molecule drugs target protein domains). To fail to adopt or perform research to advance new technologies toward these goals is certain to disadvantage the BSD.

Question 8: Faculty Size and Recruitment

How many faculty members are expected to participate in the program in its early years and in its steady state? Is it expected that faculty for this program will be drawn from existing programs at the University, or will the program draw on a faculty pool from outside? Is the scale appropriate given the planned objectives for this new institute?

The original faculty committee gave considerable thought to the organization and scale of proposed activities in molecular engineering. For Chicago's new effort to have significant impact, the Committee believed that a target faculty size of 24 would be an appropriate goal. This size would be sufficient to host a broad range of activities spanning approximately four to six thematic areas, with the lead senior hires, perhaps two per theme, helping to identify those who would follow. This scale would be sufficient to cover the broad range of research activities that would encompass the physical and biological aspects of molecular engineering as well as related interdisciplinary fields of endeavor. Recruitment of the best faculty will steer the enterprise into the most promising new areas of molecular engineering, many likely unanticipated by the two faculty committees that have carried out this study for the University.

A crucial aspect will be autonomy for Molecular Engineering. It will need to set, after partnering with current faculty for the initial launch, its own research agenda. This autonomy will ensure that it can develop properly and free from faculty development constraints of existing science disciplines. For this purpose, we envision a department-sized effort administered as the Institute for Molecular Engineering. This institute will have the advantages of independence of budget, hiring, and space with respect to extant elements of the University.

What factors help to set the scale of such an endeavor beyond its programmatic themes? Realism dictates that the proper financial foundation must be in place for this to succeed. This will be discussed in the following section on resources and infrastructure. Another consideration is the time the University will allow for the launch. The goal of making the necessary hires to properly launch four or six theme areas could be realistically achieved in a decade or less including the construction of key infrastructure. If successful, further growth could then be added on in fractions or multiples of the initial ensemble.

In light of the current economic situation, the University has revised the original hiring proposal into a proposed two-phase approach. In phase one (approximately 2010 to 2015) the University would hire a total of 12 new faculty members and situate them in new space at the corner of Ellis Avenue and 57th Street (in the replacement structure for the Research Institutes Building). The University still envisions an ultimate target size total of 24 faculty members, to be reached by the end of phase two (2020). The Institute Director will orchestrate the recruitment of faculty to the Institute; these new faculty members will primarily be drawn from outside the institution. The new Institute therefore represents a thematically important expansion of the University's overall research program at the interface of the biological, physical, and medical sciences. Over time it is envisioned that the new Institute will offer joint appointments to appropriate faculty from existing units as well as from Argonne National Laboratory.

We also note that the University of Chicago Law School, the Divinity School, the School of Social Service Administration, and the Harris School of Public Policy Studies are all on order of the proposed faculty size for the Institute.

Question 9: Molecular Engineering Education

What is the proposed research and teaching focus for the Institute? To what extent will the Institute be open to other faculty in the University? To what extent will students have access? What impact will the establishment of the program have on the University's graduate and medical students, as well as on undergraduates in the College?

Establishing degree-granting programs in Molecular Engineering is important for the University's growth. Engineering is the science of solving complex problems, and in the case of Molecular Engineering, using tools and concepts that arise from the fundamentals of science at the nanoscale. The tools of engineering are important in making and translating basic discoveries in other fields into new intellectual opportunities and, sometimes, useful technologies. Therefore, strengthening engineering research and establishing engineering education would strengthen the University's ability to push the boundaries of knowledge.

The introduction of a new educational program in molecular engineering could have a fundamental impact on modern engineering education. As a National Academy of Engineering report noted, the hallmark of engineering education in the 20th century was the science revolution, which led to engineering curricula designed to emphasize science-based, all-embracing, fundamental principles. The fusion of science and technology that has occurred recently and that has disintegrated the former boundaries between basic science and engineering will undoubtedly have similarly profound implications for the pedagogical tools of engineering education in the twenty-first century. At the highest level, delivery of this modern form of engineering education will expand the capability of graduates to incorporate scientific advances and molecular building blocks into tomorrow's advanced products, materials, and processes.

This point of view leads from the molecular toward the macroscopic, and not the other way around, as was the case previously. This bottom-up perspective will lead not only to a deeper understanding of processes, but also to fresh insights and the application and production of a multitude of novel artifacts that serve useful purposes. From this perspective, the twenty-first century could very well herald the next revolution in engineering education, stimulated in large part by molecular engineering.

Because of the breadth and strength of The University of Chicago's existing research in molecular engineering, the graduate educational programs leading to S.M. and Ph.D. degrees would be developed first. The didactic graduate curriculum could be organized within the first year. Students entering this graduate program would need an engineering, math, or physical science background. Their background would be augmented by graduate courses in applied math and physics, synthetic and physical chemistry, materials science, imaging, computational methods, and statistics, among other topics to be planned and tailored to individual needs. The opportunities in molecular engineering that exist on campus and at Argonne National Laboratory are robust and would readily support excellent opportunities for doctoral thesis research. Within three years an undergraduate program could be developed drawing from existing courses and requiring newly developed courses. Models for this curriculum exist at several other prominent universities that have established applied science and engineering schools.

Students of the College will benefit as well. The Institute for Molecular Engineering will substantially augment the education through research opportunities for college students in fields with rich employment opportunities. Participation of Chicago caliber college students in the most advanced materials research will undoubtedly launch successful careers in technology.

This is one of the most important reasons to bring molecular engineering to campus. Of course, advanced students in the College will be able take advantage of the graduate curriculum as well. As it has in comparable institutions, establishing molecular engineering here on campus will likely spawn establishment of technology development companies in the vicinity of the campus that will offer important part-time employment and educational opportunities for the College students. In summary, the impact on quality and value of undergraduate education at the University of Chicago by the establishment of a formal molecular engineering program will be substantial.

With a focus on molecular engineering, baccalaureate and masters degrees in Engineering Science or Applied Physics would not fall under the auspices of ABET (Accreditation Board in Engineering and Technology) certification because it is unlikely that many students entering these programs would pursue careers in traditional engineering disciplines such as civil, electrical, mechanical or other traditional engineering fields that often require state board certification for independent engineering contractors and consultants. Rather, matriculates will become research scientists, scholars, business leaders, patent attorneys, etc.

Impact on other Programs: The introduction of engineering education at Chicago would have broad impact on the University's programs across all divisions and schools. As repeatedly stressed in this report, forefront research in the basic physical, biological, and medical sciences is presently undergoing revolutionary change with respect to critical linkages to the applied sciences and engineering. We must strive to imbue our students with the critical skills they will need to become tomorrow's leaders. They must be exposed to an appropriate and broad palette of basic science *and* technical engineering skills, especially for research at the molecular, nanoscale, and cellular levels. If done properly, we can be assured that future breakthroughs in the basic biological sciences and medicine in critical fields such as drug discovery, genomics, proteomics, and cellular dynamics will continue to flow from our researchers. Similar impact in the physical sciences will also occur, with training in molecular engineering enabling our studies on such diverse topics as nanomaterials, molecular electronics, complex systems, and energy.

Question 10: Oversight and Monitoring Program Quality

What plans have been made to provide adequate monitoring of program quality?

Overseeing and assisting the Director in the development and implementation of the scientific program will be an Internal Advisory Committee chaired by the Provost and including the Vice President for Research and for National Laboratories, the Deans of the University's Biological and Physical Sciences Divisions, and the Director of Argonne National Laboratory. An External Advisory Board to be assembled by the Provost will provide external advice and assistance, with membership potentially drawn from academic institutions, government laboratories, and the private sector.

Question 11: Administrative Structure and Governance of the Institute

What is the administrative structure of the Institute? How will it relate to departments? How will faculty be recruited and hired?

The Institute for Molecular Engineering will be a new program at the University, and the first critical step in its establishment will be the recruitment of a visionary, internationally respected Director to lead the Institute and to recruit the associated faculty. A search committee for the new Director will be chaired by the Provost and will include the Vice President for Research and for National Laboratories, appropriate University of Chicago faculty and appropriate representatives from Argonne National Laboratory. The Committee's efforts will be assisted by the External Advisory Board. We anticipate that the new Director will be identified before the end of 2010, with a term to begin upon appointment to the University. The Director will move into temporary space at the University pending completion of the new building. The Director will then guide the completion and fit-out of the facility and begin recruiting faculty timed to arrive when the facility opens.

Upon appointment the new Director will become a member of the University of Chicago faculty with a primary academic appointment in Molecular Engineering and secondary appointments in other University units as appropriate to the Director's scientific interests. The Director will report to the Provost. The Director may also have a joint appointment in an appropriate Argonne Division. As noted under Question 10, overseeing and assisting the Director in the development and implementation of the scientific program will be an Internal Advisory Committee and an External Advisory Board.

The Director will chair a search committee whose members will be appointed by the Provost, and with University faculty constituting a significant presence of this committee. This committee will be responsible for developing an initial hiring plan and for vetting and recruiting the first round of Molecular Engineering faculty hires. Faculty recruited to the University will have primary appointments in Molecular Engineering, with affiliations in other University units or Argonne divisions as appropriate. The Institute Director will have overall responsibility, reporting to the Provost and in coordination with the Internal Advisory Committee, with the appointment, reappointment and promotion of Institute faculty. Over time the University and Argonne appointees on the joint hiring committee will be replaced by new faculty recruited to the Institute. All faculty appointed to the Institute, with either full-time University appointments or joint appointments with Argonne, initially and thereafter, will either be tenure-track or tenured. The Institute faculty so appointed will be subject to the same appointment and promotion criteria that are the trademark of the University's faculty across the Divisions and Schools.

Question 12: Faculty Teaching and Responsibilities

What will be the teaching responsibilities of faculty in the Institute?

It is the expectation that the teaching responsibilities of the faculty in the Institute will be commensurate with those in the University's basic science departments. These details will be addressed when the educational program is submitted for consideration by the Council. At present the vision is for Institute faculty to conduct research and deliver a curriculum as would faculty in a basic science department. The initial Institute faculty will be expected to teach courses upon their arrival at the University, even if this comes in advance of their ability to offer a full program.

Question 13: Financial Resources and Infrastructure

What are the costs of establishing the proposed Institute? What new investments are required, including investing in personnel (both teaching and administrative), space, laboratory facilities, etc.? What is the budget of the proposed program for its first years of operation?

In terms of monetary resources, both the Sibener and Langer Committees were clear that unless sufficient funds were available, it would be unwise to launch an effort in Molecular Engineering.

These committees each estimated that costs will be in the range of $200M - $400M. Such resources were not readily identifiable at the time of those reports, but new leadership at DOE, stimulus funds, and continuing efforts at private philanthropy make it seem likely that the University can proceed with an appropriate resource base to provide for success. The Institute for Molecular Engineering will be expensive, and the Administration has and will continue to raise funds earmarked for molecular engineering.

A cost summary for the period spanning 2011-2015, *with all financial data provided by the Office of the President*, now follows:

Revenue will come from New Grants, projected to be $40M, and Secured Gifts, presently at the level of $45M. Expenses will include New Building Construction at $62M as well as Lab Fit-out including Clean Room Implementation and the purchase of tools for molecular engineering and nanotechnology research at $45M. Proposals for construction are pending to the National Institute for Science and Technology (ARRA funds) for $15M, the National Science Foundation (ARRA funds) for $10M, and a proposal for $62M has been submitted to the Department of Energy to fund program work and a portion of clean-room equipment in support of jointly appointed University-Argonne scientists in the Institute. The University estimates that the direct and indirect costs of the research program will total approximately $70M over the first 5 years. These costs consist principally of faculty salaries, laboratory start-up (including salaries for other research personnel), and overhead/administrative costs. This estimate yields a projected surplus of $5M.

The Institute will be situated in 60,400 gross square feet of research space in a new building standing in the location of the existing Research Institutes Building along Ellis Avenue, and will feature state-of-the-art laboratories and a 12,000 gross square foot clean room. The Institute will feature a molecular engineering clean room suite of Class 100 and Class 1000 designed to support its research program. Environmentally superior instrumentation suites having the necessary low noise characteristics and electrical isolation for state-of-the-art electron microscopes and lithography will be constructed. The new space will feature high-performance, utility-intensive laboratories located on the lower floors and basement of the new structure arranged in large blocks of space to allow a variety of internal laboratory configurations over time. Lighter duty electronic and computation laboratories will be located in the upper floors of the new structure. Institute laboratories will be positioned closer to the core of the building for improved vibrational and acoustical isolation.

SUMMARY

The Faculty Committee has examined critically the question of whether the University should create a new research and teaching component, The Institute for Molecular Engineering. We agree with the preceding Sibener and Langer committee reports that there are compelling intellectual reasons for the University to move in this direction. In this document we have presented the rationale, grand intellectual challenges, viability, and practical aspects of how the initiative may be realized within the University. The motivation for this is clear: The environment for research at the molecular level is undergoing a paradigmatic shift that blurs traditional boundaries between the basic and applied sciences and engineering. This shift will have profound consequences for the nature and practice of molecular-level science in the coming century. This proposed endeavor, supported by extant strengths in the basic molecular, computational, and clinical sciences, offers tremendous possibilities to position the University as an intellectual leader in this emerging engineering discipline, bringing to bear its tradition of intellectual rigor and cross-disciplinary scholarship on questions of scientific importance and societal urgency. Such action will undoubtedly provide new partnerships and routes to discovery for our faculty in the basic molecular sciences, enabling them to continue to define the horizon in their respective fields of research.

We also note that *not* pursuing this activity risks negative consequences. Without the proposed Institute for Molecular Engineering, the University's research enterprise and education mission will undoubtedly continue to flourish at its traditionally high level. However, inaction in this area of endeavor may well abdicate activity in some of the most promising new directions of physical, biological, and medical research.

A molecular engineering program of the size we anticipate will inevitably spawn discussions about the complex social, economic, legal, political, ethical, and market dimensions of the technologies and discoveries produced, creating new opportunities for rich intellectual collaborations across the University. Molecular engineering will simultaneously yield the added benefit of increasing creativity and the strength of scientific inquiry. The resulting innovations are likely to deliver solutions to the most pressing human problems, including energy supply and human health.

Respectfully submitted for the Ad Hoc Faculty Committee on Molecular Engineering,

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Carl William Eisendrath Professor
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Membership of the Ad Hoc Faculty Committee on Molecular Engineering:

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Ian Foster (Computer Science, Computation Institute; Argonne)
Raphael C. Lee (Surgery, Medicine, Organismal Biology & Anatomy)
Milan Mrksich (Chemistry, Institute for Biophysical Dynamics, HHMI, and the College)
Steven J. Sibener – Committee Chair (Chemistry, James Franck Institute, and the College)
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