FINAL REPORT OF THE PRESIDENT'S ADVISORY PANEL ON THE BIOSCIENCES AT THE UNIVERSITY OF MICHIGAN

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Table of Contents

1. Introduction

We are in an era of unprecedented discovery potential in the biological and biomedical sciences. This is a consequence of decades of basic research and is being driven by powerful new technologies and sophisticated tools and devices that allow for molecular level analysis and pinpointing mechanisms of perturbation of organisms from microbes to humans. Advanced tools developed from fields outside biology, such as microfluidics and NMR spectroscopy, have become integral to basic biological research. High-throughput experiments that rely on robotics and the light-speed manipulation of massive data sets are routine today. Perhaps most importantly, bioscience research has now become a fundamental driver of discoveries in many fields once far removed from biology. Indeed, the opportunities to impact the world in positive ways through new discoveries in the biosciences have never been more profound.

Consistent with our standing as a world-class institution of higher education, the University of Michigan (UM) aims to be a "powerhouse" in the biosciences, where academic leaders in these fields are drawn to pursue groundbreaking research and to educate students who become the future stars in the field. UM is greatly advantaged in this highly collaborative and multidisciplinary landscape because of our impressive breadth of academic excellence. At the same time, there is also a widespread sense that we are not fully capitalizing on these advantages, and do not yet provide the resources or incentives, nor have the optimal structure to attain our aspirations.

In the fall of 2014, President Mark Schlissel appointed an advisory panel consisting of faculty from across campus and charged it with developing recommendations about how best to advance the university's efforts in the biosciences. The panel intentionally did *not* attempt to pick areas of biology that would be "winners", but instead focused on issues of institutional structure and culture, asking what it would take to develop a pervasive culture of high caliber scientific discovery at all levels, from undergraduates through senior faculty, and thus to become home to one of the most prominent programs in the biosciences in the world. The panel embraced the need for change, perhaps even fundamental change, in the way we approach science at the University.

This report summarizes the panel's analysis and highlights possible strategies for advancing the University's efforts in the biosciences. The body of the report is intentionally concise, but we include a number of appendices that provide additional background and detail. The analyses and suggestions are based both on the panel's own deliberations, and a broad set of outreach activities both on and off campus, which are summarized in the appendices.

2. Current State

The University has significant strengths on which to build when developing best-in-class bioscience programs. The most prominent of these include:

- The size and disciplinary scope of the overall biosciences enterprise at UM.

- The breadth of excellence in disciplines outside of the biosciences that can provide insights, methods, and data relevant to bioscience research.
- Many outstanding scientists pursuing bioscience research individually or in groups in units across campus.
- A strong culture of faculty collaboration.
- A number of first-rate scientific facilities, including a significant set of core facilities.
- A wholly owned and geographically contiguous hospital and health system that provides a platform and focus for translational science and clinical research.

At the same time, the current state of the biosciences at UM is not at the level of excellence to which we aspire. A sense of the scale of and trends in the biosciences research at UM can be obtained from the data in Appendix 4. While research expenditures are only one measure of activity, they do provide important information. About half of the research expenditures on campus are in the biosciences: approximately $700M out of a total of about $1.3B in research expenditures in 2014. The lion's share of those expenditures—about $555M—are in the medical school, with the School of Public Health a distant second, followed by the College of Literature, Sciences and the Arts (LSA) and the Life Sciences Institute (LSI). While overall research expenditures in the biosciences have been essentially flat for the past 4 years, after growing between 2010 and 2011, there has been a significant decline in the number and amount of NIH R awards over that same period, and the University's overall market share of NIH funding has also declined in recent years. Outside of the NIH, funding for the biosciences from foundations has been relatively flat, and there has been modest growth in industry support. Looking to other measures, there has been steady growth in invention disclosures, new patent applications, and new patents, but without concomitant growth in IP revenue, which is up somewhat in 2014, but flat for several years prior to that, and in any case, is relatively small. Finally, the University lags its peers in the number of faculty members, including bioscientists, in the National Academies: only 9 UM bioscientists, and 24 faculty members in total from UM are in the National Academy of Sciences compared with 50 bioscientists and 126 total NAS members at Berkeley. We are better represented in the National Academy of Medicine (formerly called the Institute of Medicine), with 52 members; for comparison, Stanford has 73 members, UC San Francisco has 72, and Johns Hopkins has 57.

What are the barriers that impede us from achieving our goals? The panel identified some issues that are elaborated on below. More than anything, however, the panel believes that the future of the biosciences at UM rests on the people that we recruit, cultivate, and retain. We need to identify areas where we already have strength and where we are compelled by the importance of the research problems to expand that strength. That said, we should not discount the idea of moving into new areas of research, particularly if we identify world-class leaders to recruit to UM. We need to support and nurture those faculty already here who are innovative, risk-seeking, and highly productive, while at the same time recruiting new faculty who are game-changers, who will come with creativity, vision and energy, and will bring national and international visibility to the biosciences here. We especially need to recruit and retain talented leadership in the biosciences, particularly individuals who can identify scientific excellence and promote it above all else.

To make advances on these many fronts, we will need to invest significant resources, including major new funds to entice game-changers to come to and stay at UM. We will also need to create an intellectually rich and diverse scientific environment in which bioscientists and other scientists and scholars can easily and effectively interact and collaborate. That means addressing many of the following challenges.

Cultural Barriers

- Too high an emphasis on extramural funding—as opposed to high-impact discoveries—as the metric of success.
- A high tolerance for mediocrity and a leadership culture that does not sufficiently incentivize risk-taking.
- Not enough done by the institution to retain its rising stars.
- Faculty who are increasingly less hopeful about biosciences research.

Barriers to Interdisciplinary Integration

- A lack of common mission, most notably between the Medical School and other units on campus.
- Different budget models in various schools and colleges.
- Inadequate space on campus for faculty from different units to congregate.
- Difficulties in finding out about what's happening in the biosciences outside one's home unit, especially across different schools and colleges.
- A lack of coordinating organizational structures at the campus level for strategic scientific planning, including faculty hires.
- Limited opportunities for medical school faculty to engage in teaching of biosciences to undergraduate students.

Resource Limitations

- Insufficient investment in the basic sciences in the Medical School and in the biosciences in LSA.
- Insufficient support for graduate programs.
- Duplication of services and facilities that creates inefficiencies that reduce the availability of other needed services and facilities.
- Significant decline in NIH and other funding sources that is stressing the entire system, particularly at the Medical School.

3. Desirable Future State Attributes

What would the biosciences enterprise at the University look like in an ideal future state? As noted in the introduction, we would be a magnet for the very best faculty, post-docs, and students in the world, who would come to UM to work across boundaries, conducting world-class science—science that leads to new diagnoses and treatments for a host of diseases, that alters our understanding of our origins and the evolutionary history and basis of our behavior, thoughts, and emotions, and that advances our knowledge of the myriad species of living organisms. We would attract, nurture, and retain the stars of the bioscience world, and they would not only work seamlessly with one another, but would also draw on the rich scholarship that exists in disciplines across campus. We would train the leaders of the next generation of bioscientists, many of whom would initiate their own independent research programs around the world and magnify the work being done here. The world would further recognize and value the research and educational initiatives at Michigan, perhaps as reflected in major awards to our faculty and students, and funding that supports their work.

The panel believes that achieving this ideal future state will require changes in both culture and structure. We need to develop *a culture where everyone, from undergraduates through senior faculty and administrators, value scientific discovery, inquisitiveness, innovation, and risk-taking, and believe in recognizing and rewarding exceptional performance.* More specifically, the panel identified some attributes needed for the biosciences to thrive at the University of Michigan:

- Strong, visionary leadership drawn from the ranks of the best scientists in the world.
- A culture that rewards exceptional scientific rigor and risk-taking, and gives high value to pioneering scientific discoveries.
- An appreciation of and support for high-quality education at all levels.
- A culture of collaboration both within and across disciplines.
- Low barriers to high faculty excellence.

Institutional administrative efficiency and effectiveness, well-designed incentive structures, and some level of organizational change are all necessary to realize these attributes. Change is needed for multiple reasons: i) to enhance the research and educational opportunities for faculty and staff; ii) to facilitate more effective coordination of, interaction between, and advocacy for biosciences activities at UM; iii) to provide new opportunities for leadership, both for internal and external scientists; and iv) to signal both to our community and to the world that UM is ready to re-establish itself as a leader in the biosciences.

4. Recommendations

Because change will be needed to achieve our aspirations, the panel has identified a set of discrete actions that it recommends be taken by the University; these are described below in Section 4a. The panel recommends that these actions be taken independent of particular structural changes. Alternatives for such structural changes—i.e., for new organizational models—are listed in Section 4b.

4a. Recommended Actions

Leadership

- Appoint or hire nationally visible department chairs and deans who lead by example in continuing their research and teaching.

- Provide chairs and deans with resources that are commensurate with those provided to the highest quality leadership nationally.
- Have ongoing assessments of progress and achievements and provide further resources to meet the needs of chairs and deans over time.
- Foster leadership potential in faculty at all levels through targeted programs.
- Ensure that the University and the schools/colleges have strategic plans for their research and teaching efforts in the biosciences, and that these plans are well aligned.
- Create advisory boards in the biosciences to support the President, Provost, VP for Research, and deans, drawing on the best scientists on campus as well as external leaders from across the world.

Academic Excellence

- Develop and use metrics of success that recognize scientific discovery and impact, in addition to external funding.
- Implement new peer-reviewed funding programs that support innovative ideas.
- Develop procedures for setting salaries and for allocating space and other resources that reward excellence, even if that comes at the cost of not treating everyone the same.
- Continue to reward high quality teaching, both inside and outside the classroom.
- Implement more rigorous standards for awarding tenure. Ensure that the processes are uniform, fair, and transparent.
- Create additional named professorships for all ranks, including junior and mid-career professorships that continue with faculty even after they are tenured and promoted.
- Promote mentoring throughout the faculty lifecycle, by creating programs that help faculty successfully mentor others and that reward them for mentoring work.
- Promote and assist faculty with nominations for important awards and positions of national and international prominence.
- Develop strategies to reengage faculty who are no longer productive in research, by finding new scientific direction and/or by serving the university in other ways.
- Provide more financial support for graduate programs.
- Implement regular reviews of departments and other units conducted by external committees consisting of the most accomplished members of their disciplines.
- Foster a broader research funding portfolio, to include industry and philanthropic support.
- Coordinate faculty recruiting across bioscience departments and schools/colleges.

Collaboration

- Provide larger-scale seed funds to teams of researchers.
- Co-locate researchers from different disciplines.
- Address challenges that arise today when different units have different space and budget models.
- Adjust funds flow so that it is easier to create and support interdisciplinary graduate programs.

- Establish a process whereby the planning of new bioscience facilities includes input from multiple units, and the facilities themselves have space for faculty from different units.
- Develop mechanisms that provide a consolidated view of activities and opportunities in the biosciences at UM and that are easy to access and use.

Faculty Productivity and Institutional Effectiveness

- Create more flexible approaches to space allocations.
- Create more flexible faculty workload assignments.
- Improve the uneven quality and duplication of cores.
- Provide adequate staff support for faculty members especially in grant preparation, submission, and reporting, as well as in dealing with regulatory requirements.
- Take steps to reduce regulatory burden, including active engagement in Washington.
- Develop models to maximize teaching capabilities and effectiveness across campus.

4b. Possible Structural Changes

The panel was asked to consider whether the University has the right array of departments, centers, and institutes and the appropriate governance structures to support the bioscience research and teaching priorities of the University in the years ahead. We were invited to suggest "innovative or even potentially radical ideas for organizing the biosciences" and to take into account any instructive models that already exist within or outside UM. This "thought experiment" yielded important insights and was instrumental in informing the observations and recommendations in this report. By asking ourselves how we could be structured differently so as to optimize the future state, we necessarily had to wrestle with what is not working well, what the priorities should be among desired outcomes, and what tradeoffs (relative to our current structures) would be necessary and tolerable. In this spirit, we offer brief descriptions of different models that should be considered for further development.

It should be noted that none of these reorganizations on their own are sufficient for most appropriately positioning UM for future successes in the biosciences. Specifically, while structural changes are necessary, they will not, by themselves, yield a change in culture in which innovation and risk-taking are valued over dollars generated. Structural changes will also not lead to more rigorous and transparent standards for tenure and promotion, or the recruitment and retention of visionary, high-profile faculty. However, structural changes can help in establishing an environment in which cultural changes may be initiated and ultimately flourish. Structural changes can also help in addressing certain other, more specific challenges, as identified in each description below.

The models below, while presented separately, are not mutually exclusive. For example, departmental reorganization may be done on its own, or in concert with the development of either a virtual or actual school of the biosciences. Similarly, new research centers could be created and the connections between them and existing centers could be strengthened, perhaps at the same time as the creation of new units. In this fashion, the biosciences network model would be compatible and complementary to other models. As another example, a virtual school of biosciences might be an initial step towards a larger reorganization into a distinctive School of Integrated Biosciences.

Departmental Reorganizations

At present, our bioscientists work in a variety of departments across multiple schools and colleges. The orientations of those departments are, in many cases, quite traditional. It might be reasonable to consider reconstituting existing departments into new ones. Reorganizations might be internal to a school: as an extreme example, all the basic science departments in the medical school could be consolidated into a single mega-department. Alternatively, department reorganization might involve multiple schools, akin to the model of our biomedical engineering department, which is currently jointly administered by the Medical School and the College of Engineering. Departmental reorganization could potentially even involve moving a department or the faculty in a department, from one school to another.

By consolidating faculty who are presently spread across multiple departments with overlapping missions, departmental reorganization could lead to greater visibility for selected areas in the University's larger scientific enterprise. Additionally, department reorganization could potentially enhance scientific and educational interactions, in part as a result of physical and administrative clustering of like-minded faculty and students. This may in turn lead to better individual and team science, as well as improved coordination in teaching and course development. Such clustering might also create new opportunities for leadership on campus. At the same time, departmental reorganization may have potential negative consequences in that it disruptive to faculty, students and staff as well as to alumni relations. Departmental reorganization may also have a major impact on external rankings and ratings, although in some cases this impact may be positive rather than negative.

Virtual School of Biosciences

A second approach, a virtual school model, is motivated in part by the sentiment conveyed by numerous bioscience faculty that there needs to be more coherent strategies and stronger coordination mechanisms to fully realize the potential of the tremendous intellectual and physical bioscience assets already in place at Michigan. For example, the study of biological diversity permeates Michigan, but there is no current structure to draw scholars from the wide range of academic units studying the generation, maintenance, and loss of biological diversity. A virtual school of biosciences, leaves intact the model of having departments within various schools and colleges, although it is responsive to the possibility that those departments might be reorganized. Indeed, it seems likely that departmental reorganization may be a key complement for the approach to have maximal success, as the virtual school will not, on its own, address some perceived current challenges for existing departments and units, such as the fragmentation of faculty expertise.

A critical feature for the virtual school of biosciences is the creation of a new leadership position, the Dean of Biosciences, who would be charged with fostering collaboration, and coordinating interdisciplinary research and undergraduate and graduate teaching. The dean would have a broad understanding, appreciation, and acceptance of the diversity of bioscience researchers at Michigan, and would work with department chairs, directors, and deans. Department chairs and directors of biosciences units would report both to the dean of their current school or college (medicine, LSA, natural resources and the environment, etc.) and to the Dean of Biosciences. Faculty recruitment would be coordinated so that areas of growth are identified collectively and departments partner in recruitments. The Dean would also work to coordinate undergraduate teaching in the biosciences, and teaching revenue would be allocated appropriately. For this model to be successful, the Dean would need to be provided with sufficient funds to facilitate and coordinate activities across biosciences units.

All faculty who are in the biosciences would be members of the virtual school. The structure would enable the coordination of faculty hiring, teaching, and the creation of new and oversight of existing cores and other physical resources. The Dean of Biosciences would also be in a position to provide broad advocacy for the biosciences amongst campus leadership and externally. In turn, this should lead to greater visibility and recognition for the biosciences at UM. In addition, because of the overarching structure of the virtual school, it would potentially be easier to construct promotion and tenure standards and processes that are more uniformly rigorous and transparent.

In one example of how the virtual school of biosciences might be combined with a departmental reorganization, there could be a restructuring of the departments in the medical school into a Molecular Medicine Institute (MMI), which would include both basic and clinical scientists, further organized into divisions that are primarily disease-based, for example, Cancer Biology, Cardiovascular Biology, etc. A division of General Medical Sciences could be created to house scientists whose research has broad biomedical relevance but does not fit into one of the specific disease-oriented divisions. Outside of the medical school, other life scientists could be organized into an expanded LSI, which would reflect the breadth of the life sciences research at Michigan, and would report to the dean of LSA. Like the MMI, it would be organized into divisions, e.g., biodiversity, chemical biology, neuroscience, and systems biology. Of course, many other configurations of a virtual school are also possible.

One key challenge of the virtual school of biosciences is that all department chairs would have dual reporting lines; i.e., to the dean overseeing their home departments as well as to the dean of biosciences.

Bioscience Network: Matrix Organization

The biosciences network is yet a different approach that also largely maintains the existing structure of having bioscience departments within schools and colleges (although again allowing the possibility that these departments may be reorganized). However, it adds a network of interdisciplinary research hubs, which might include some existing research centers as well as some new ones. The major role of the research hubs and their leadership will be to nucleate larger activities within the UM research community and to engage in cross-cutting, interdisciplinary research. In this model the departments continue to define traditional biological sub-disciplines and to be home to teaching and degree-granting activities, while the overlaid hubs are major facilitators and drivers of research.

The Bioscience Network should interlink existing *and* new research hubs. There might, for example, be new hubs in neurosciences, biodiversity, regenerative medicine and so on. The LSI (or perhaps a reorganized version of LSI) and some other existing centers, such as the Biointerfaces group would presumably also be hubs. The thematic foci and lifetime of hubs and their connectors should be mutable so that the network is responsive to the environment and hubs do not outlive their relevance.

Membership in a hub would be privilege, awarded to high-performing faculty in a particular field as well as those that would benefit most from the interdisciplinary environment. Because hubs will be focused on particular research areas, not all faculty will necessarily fit within a hub. However, the goal would be to select and build on areas of strength, thereby bringing in a number of top researchers. The research hubs should be housed in spaces that ensure proximity and collaboration among members.

The hubs and their directors should be financially endowed by the University and funded independently of departmental resources (i.e., without redirection of indirect or operating costs from participating departments). They would not be expected to transition to financial independence quickly, as that expectation creates instability and thwarts success.

The leadership of each hub should be independent of departments and colleges, should promote team science and strategic activities through seed grants, programs that support scholars, and association with university-wide core facilities.

All bioscience-relevant research hubs should be integrated under a single administrative leader, which might be an existing position (such as the Vice President for Research) or might be a new position. Together with that administrative leader, the hub directors should foster intellectual exchange across the network and build core capabilities that are shared across the hubs, as well as the university more broadly.

A bioscience network has the potential to address some of key issues identified by the panel. Perhaps most notably, it would require the university to select key strategic priorities in the biosciences and focus its investments in them, re-assessing and updating those priorities periodically. It would also intentionally promote and facilitate interactions among faculty from diverse units who are working in one of the selected priority areas, and foster connections between different priority areas. It would not, however, lead to better coordination of teaching. In addition, without a creative approach, it would not on its own lead to better coordination of hiring, particularly since the faculty members' tenure lines would reside in their departments within schools and colleges.

School of Integrated Biosciences, and School of Sciences

Most dramatically different from the current structure at the University would be a newly created School of Integrated Biosciences (SIB), under the leadership of a Dean—or even more radically, a School of Sciences (SIS). Such a school would house all faculty in the biosciences (or all the sciences): the new school would provide their tenure home, their home for teaching, and their home for research.

Different internal structures could be considered. Indeed, a key advantage of this approach is that it allows for a "fresh start" in organizing all of our biosciences activities. As just one example, similar to the one provided in the discussion of the Virtual School of biosciences, faculty in the SIB could be organized into two major institutes: a Molecular Medicine Institute (MMI) and a Life Sciences Institute (LSI), with internal structures as described above. Here however, in contrast to the virtual school, these institutes would report to the degree-granting School of Integrated Biosciences, not jointly the Medical School and another home unit.

Existing departments from across campus where all or the majority of scientists are engaged in basic bioscience research would be the primary feeders into the school. This would primarily include the medical school, LSA, public health, and SNRE, but could also include departments from other health-sciences schools. All faculty from these departments would have their line within the new school. Faculty from other departments would also have the opportunity to change their appointment to the new college, or be able to participate via joint appointments.

This model has all of the advantages of the virtual school of biosciences, without the complications of having dual reporting lines for departments and division heads, and the need to sort out resource sharing between the traditional schools and colleges, on the one hand, and the virtual school on the other. The economy of scale would result in more efficient distributions of resources including core facilities, a more rational distribution of teaching effort and course offerings, and increased external recognition of scientific disciplines such as biochemistry, microbiology, and cell biology that are currently fragmented within the university. A significant downside of this approach is that it dramatically changes not just the existing structure, but also the nature of some of our schools and colleges. For instance, the Medical School would no longer have a basic science faculty, and LSA would no longer be equivalent to a "complete" liberal arts college. Similarly, the School of Public Health, which is accredited and very highly ranked, might lose its ranking and accreditation, as that requires having certain departments within it.

Summary of Potential Structural Changes

The alternatives described above are obviously not detailed descriptions of organizational models. Rather, they represent a spectrum of structures, ranging from the least disruptive (departmental reorganization) to the most disruptive (a school of the sciences). Each has its advantages and disadvantages, and as noted earlier, they are not mutually exclusive. Moreover, any structural change must be combined with the types of discrete actions and shifts in culture described in previous sections of this report. Nonetheless, the panel believes structural change is needed, and that the alternatives highlighted here present candidate paths towards a more ideal future for bioscience research and education at UM. It further believes that leadership should seriously consider these alternatives, and then quickly do the detailed analysis and hard work needed to implement one or more of them.

5. Conclusion

Our aspiration is to become one of a handful of top institutions pursuing bioscience research and education in the United States and the world, as judged by the quality and number of transformative discoveries in the field and the success and impact of our students and trainees. Our goal is indeed a challenging one. Perhaps equally challenging will be how best to measure our near-term progress in achieving this goal. Conventional fiscal metrics, such as total NIH funding or similar measures, might seem straightforward, but they perhaps most accurately measure ongoing research activity and not necessary impact and innovation, and measures of total funding might reflect faculty numbers and/or particularly active and well-supported research fields at any given time.

To achieve our goal, it will require a qualitative change in our approach, at multiple levels. Given the magnitude of the bioscience enterprise at the University of Michigan, and the intrinsic richness and diversity of the field, it is unlikely that a single mechanism will be sufficient to transform the bioscience ecosystem at our institution. Moreover, it is also possible to undertake massive structural changes that do not produce the desired results because they do not address fundamental issues, such as the nature of the culture, the misalignment of incentives or the significant barriers that stand in the way of moving to a higher level of innovation and risk- taking.

Taking our inspiration from biology itself, we propose a series of adaptive strategies that optimize the use of our many assets while allowing us greater flexibility in responding to challenges in both our immediate and our broader environment. We have identified several pressure points where interventions are likely to yield significant impact on bioscience research. These include:

- ***Aligning incentives for greater innovation,*** by encouraging faculty to frame and pursue major questions in the biosciences, and to take calculated and thoughtful risks to address them. A critical complement is that the leadership at Michigan should avoid incentivizing a conservative approach to science that only aims at pleasing study sections and securing funding. While securing substantial outside funding for research is absolutely vital, and the art of grant writing is essential, this process should not limit the imagination or the range and type of research that the scientist is willing to undertake. The more conservative path may seem superficially adaptive, but its long-term viability is limited, both in terms of the science it generates and the motivation and excitement it produces for individual scientists, their trainees and the larger scientific community at Michigan and beyond.
- ***Rewarding leadership in the creation of scientific teams***, and ***redefining the meaning of***

scientific success in terms of both individual accomplishments as well as accomplishments at a team level. This is a necessary change in culture that will require a reframing of the meaning of collegiality and healthy competitiveness.

- ***Creating explicit and visible mechanisms that prioritize these values.*** These include using them as criteria in reviews and promotions, discussing them during mentoring sessions with junior faculty, and especially providing some safety nets (financial and otherwise) to ensure the survival of innovators in the face of shrinking funds.
- Being willing to make some difficult choices by ***prioritizing and investing in certain areas around current talent and leadership.*** This does not mean excluding other areas where individual laboratories may be fruitfully engaged. However, prioritization and investments are needed to ensure that a critical mass of talent in certain arenas is in place for the research to have transformative potential.
- ***Thinking strategically about large-scale problems and challenges that require unique disciplinary combinations in which UM excels.*** We need to capitalize on these unique capabilities to take the lead, coordinating not only internal efforts but also larger efforts at the national and international level.
- ***Striving to integrate knowledge across the biosciences.*** We are increasingly aware that life is made of the same, continuous fabric and that what we do can alter other organisms and the entire context of life on earth. This means that universities should integrate their approaches to the study of biology across its sub-disciplines—from molecule to environment and evolution. It is only then that we can begin the process of defining the best ways to approach big, cross-cutting questions, developing theoretical aspects of biology that can help unify it, and enabling its interface with other fields of knowledge.
- ***Preparing and mentoring our students and other trainees at all levels to confront the range, power and complexity of the biological sciences*** and the multiple layers of understanding and engagement needed to be a biologist.

Of course, the hard work is in implementing specific actions and structural changes that make real these interventions. Rather than recommending a single mechanism, the panel contemplated a range of possible discrete actions as well as alternative structural changes. While leadership will need to decide among those alternatives, the goal is clear: ***for Michigan to become a powerhouse in the biosciences.***

Appendix 1. President's Charge to the Panel

The President's Advisory Panel on the Biosciences is charged with developing a recommended strategy that will propel Michigan to the forefront in critical areas of life science research by optimally leveraging our comprehensive excellence. The overarching challenge is how to develop and then implement a life sciences research and education strategy that reaches across the entire enterprise, permeabilizes the barriers that exist between departments and schools, and allows us to make synergistic investments in faculty, students, and infrastructure that enhance the excellence and impact of research at the university. Put simply: how do we make the whole greater than the sum of its parts?

Questions:

The panel is asked to address the following questions in fulfilling the charge:

Do we have the right array of biological and biomedical science departments, centers, and institutes and the appropriate governance structures to support the research and teaching priorities of the university in the years ahead?

Are there innovative or even potentially radical ideas we might consider for organizing the biological and biomedical sciences at the University? What are the most successful organizational and financial models for supporting multi-disciplinary approaches to life science and how might they be adapted to Michigan's circumstances and scale? What types of incentives would be necessary to promote convergence amongst complementary disciplines?

How might we reorganize biological and biomedical education at the undergraduate and graduate levels given the presumption of convergence in life science research?

What can we do to enhance interactions between life scientists and faculty from the other natural & physical sciences, engineering, and clinical departments—and potentially draw in other areas of strength as well?

Mindful of the fact that even an institution of Michigan's scale cannot be the best in all areas, what are our areas of greatest opportunity and where are the critical gaps that need to be filled for us to achieve excellence and impact in these areas?

How might we best take advantage of opportunities that come with the new Biological Sciences Building, the NCRC, and other existing and potentially new facilities? Which types of adjacencies are most important? How can space planning be used to promote interdisciplinary thinking by our faculty, graduate students and post-doctoral fellows?

How can we better position ourselves to enhance the impact of our discoveries? What are the optimal incentives and pathways for developing our discoveries toward commercialization? How can we interact more effectively with private sector partners to bring the results of our research into practice and to collaborate with us or provide funding for us to pursue goals of common interest?

Appendix 2. Panel's Outreach Process

To ensure that this report was informed by the perspectives of many, we engaged in a number of outreach activities. The results of these activities are explicitly in the appendices below, and, even more importantly, are reflected in the observations and recommendations made in the main body of the document. In particular, the panel:

- Hosted a series of 4 town halls, held across campus: on the main campus, the medical campus, and North campus. Faculty and graduate students working in the biosciences were invited to participate in any of the town halls, and dozens attended. The main points of discussion are summarized below in Appendix 3a.
- Invited input through an anonymous online site. 584 responses were obtained and analyzed for content, as described in Appendix 3b.
- Conducted hour-long, targeted interviews with current UM leaders in the biosciences, as well as with bioscience leaders from other institutions, particularly including those who used to be on the faculty at UM. The results of these are summarized in Appendix 3c and 3d, respectively.
- Visited faculty and administrators at three other universities—University of Washington-Seattle, University of California-San Francisco, and Stanford University—to gain insights to alternative approaches to organizing and fostering work in the bioscience. Appendix 3e presents the lessons learned from these visits.

Appendix 3. Summary of Input to the Panel

3a. On Campus: Town Hall Meetings

Summary of Main Points from the Town Hall Meetings

1. Connectivity and Communication

Challenges: Michigan has a strong tradition of collaboration and interdisciplinary interaction among faculty, but the current structure of biosciences poses impediments to capitalizing on their potential for new discovery. There are physical and administrative barriers to creative connectivity among bioscience faculty, especially decentralized budgets and the constraints they impose regarding teaching and the creation of a coherent, non-duplicative curriculum.

Solutions:

- Break down perceived barriers to collaboration and foster scientific innovation and formulate structure that coordinates bioscience research and teaching. It would foster both non-medical as well as medical biology and bring together faculty around research and teaching in centers of excellence.

- Provide financial support for joint departmental retreats and seminars
- Establish a campus faculty café, or other venues where faculty can meet.
- Develop a cross-departmental postdoctoral scholar program, which would forge new collaborations among faculty from different biosciences departments.

2. Recruitment and Retention

Challenges: It was suggested that one of the major problems limiting the visibility and stature of the biological sciences at U of M is the difficulty in retaining outstanding faculty members. While the university is viewed as being particularly effective in attracting outstanding young faculty members, the same does not seem to be true when it comes to retaining exceptional faculty members. A second challenge is recruiting exceptional mid-career to senior scientists, including those who would assume leadership positions within the university.

Solutions:

- Retain good faculty – we invest a lot into the start up of new faculty, but do not follow with further support throughout their career. This is critical to retain outstanding faculty and build strong programs.
- Award collegiate professorships to successful Associate Professors in addition to full Professors
- Be proactive in recognizing and rewarding success.
- Invest in joint 'wet' appointments.
- Build on strength created by cluster hires by fostering connectivity.
- Reduce administrative and regulatory burden on faculty.

3. Core Facilities

Challenges: There is an impression that the university does not want to invest in major equipment and support for basic cores, and yet there are redundancies in core facilities in different units on campus that are driven in part by different financial structures. The expectation that cores should be self-supporting may not be realistic and yet state-of-the-art facilities are needed to enhance research and training at the university.

Solutions:

- Establish infrastructure for sharing expertise and protocols.
- Remove barriers to cores (costs from units other than the one hosting the core).
- Create state of the art facilities, e.g. in mass spectroscopy.
- Personalized medicine will require lots of sequencing. A decision needs to be made now as to whether or not an investment is made to be competitive in this arena.

4. Teaching

Challenges: While teaching is a common mission of the university, the balkanization of programs has led to overlap and competition among units on campus. For instance, both biochemistry and cell and molecular biology are housed within multiple units on campus. Are there opportunities for strengthening the biological science by creating a more unified vision of and structure for teaching across the university?

Solutions:

- Combine graduate training in departments with strong overlap and propagate that model if it proves successful.
- Create financial model to accommodate faculty members teaching across campus.

3b. On Campus: Online Feedback

Feedback Form

The Biosciences Committee created an anonymous online feedback form. Faculty, researchers and students were invited by a mass mailing from the Provost's office to provide feedback to the committee. Faculty were not required to identify themselves, but were given the option to supply their name and email (58 respondents provided such information). There were 584 respondents to the feedback form.

Analyses

In order to process the responses to the eleven open-ended questions we implemented several basic text mining techniques. For example, we examined the most frequent words in each of the responses and conducted cluster analysis of pairs of words mentioned in the same response. For the cluster analysis we used Ward's method, hierarchical clustering and plotted dendograms. This provided phrases that we used to construct a response template. For example, for the "list features that the University does well in supporting and promoting biological research" question, phrases such as "core facility" and "grant support" emerged as most common. One of the committee members read through all responses and added content information to the response template to construct a summary paragraph of the key themes. Similar results emerged with another text mining tool, Topic Modeling, using latent variables.

While there were 584 respondents, not every respondent answered all eleven questions. Analyses were conducted for each question; we made use of all available responses to build the response template for each question.

Q1: List features that the University does well in supporting and promoting biological research.

Key themes that emerged were strong biological research at all organizational levels (university, school, program, department); excellent graduate students and graduate student funding; excellent core facilities (e.g., transgenic mouse and sequencing, flow cytometry, chemical genomics, microscopy, libraries, MICHR, CSCAR); solid internal grant support (e.g., bridging funds, academic drug discovery, Mcube, grant writing support); excellent animal housing and ULAM staff; good system for mentoring junior faculty; and solid interdisciplinary collaborations.

Q2: List features that the University does well in supporting and promoting teaching in the biological sciences.

The key themes that emerged were recruiting and supporting excellent students, peer teaching, the UROP & PIBS programs, offering strong biology courses and field work opportunities, and supporting teaching excellence through awards and CRLT efforts.

Q3: Are there other factors (e.g., colleagues, students, facilities, interdisciplinarity, Ann Arbor) that lead to your general satisfaction about working or studying at UM?

The key themes that emerged were Ann Arbor; great colleagues, collaborators and students; opportunity to provide excellent patient care; and excellent work/research environment (e.g., facilities).

Q4: List ways the University (central, school/college and department levels) can improve the support and promotion of biological research.

The key themes that emerged were to provide funds to support research facilities; provide leadership to align researcher, department and university goals; avoid intellectual silos; improve cross-unit strategic planning and avoid duplication/redundancy; improve proposal writing resources (e.g., editing, graphics, tutorials); reduce administrative and regulatory burden; retain and reward top researchers who do high quality science; and provide funding for graduate students (e.g., enable tuition waivers) and for post docs. A minor theme expressed by a few respondents: the balance between bottom-up faculty-defined interdisciplinary research initiatives and the need for better leadership in strategic planning.

Q5: List ways the University (central, school/college and department levels) can improve the support and promotion of teaching in the biological sciences.

The key themes that emerged were to improve funding support for graduate students; involve post docs in teaching; improve faculty and graduate student training in teaching; reward excellent teaching; include mentoring of students in merit and promotion review; incentivize team teaching that leads to a coherent experience for students; add more classrooms that support problem-focused learning formats; improve access to field sites; and do more to include undergraduates in research.

Q6: List any factors at UM that detract from your productivity.

The key themes that emerged were the cost of funding graduate students; high administrative and regulatory burdens; understaffed IRB; tensions between colleges, schools and institutes; too many surveys/response forms such as this one; parking; and collaborators spread across campus making it difficult to interact frequently.

Q7: List any barriers that inhibit the ability to collaborate across UM units, both units in the biological sciences and units outside the biological sciences.

The key themes that emerged were territorial battles over indirect cost sharing, physical distance between collaborators spread across units, limited opportunities to meet potential collaborators in different units and reward mechanisms for collaboration with other faculty.

Q8: If given a "clean sheet" of paper with the ability to re-construct any part of the educational/research programs on a campus-wide scale, what might you recommend?

The key themes included provide more program support, consolidate departments and programs (example: diabetes, obesity and metabolism) by physically grouping people to facilitate interaction and collaboration, broaden the scope of the LSI concept, recruit top researchers in important areas, reconsider current departmental structures and consider new training programs that cut across multiple areas, and appoint strong leaders.

Q9: What are the best mechanisms to facilitate interactions between bioscientists in disparate fields (i.e. basic scientists and clinical investigators as well as biologists in different colleges)?

The key themes included fund collaborative research that brings researchers from different perspectives together (programs such as Mcubed, "speed dating" style interactions so researchers can meet, interest groups, informal social events), sponsor interactive seminars, locate researchers in physical proximity to facilitate collaboration, create opportunities for bioscience researchers to meet researchers in other nonbioscience disciplines, leverage existing large interdisciplinary centers such as IHPI, LSI, Cancer Center and ISR to facilitate interaction.

Q10: Can you identify any "grand questions" in the biosciences that might bring diverse groups together?

The key themes were data science and bioinformatics, let smart people do their research and grand questions will emerge, support basic biology (stem cell, virology, immunology, aging, biodiversity, microbiome, regenerative science, epigenetics, systems science, neuroscience, the "omics") and health (obesity, diabetes metabolic disorders, third world disease, drug resistance in infectious diseases, disparities, sepsis, cancer), and promote drug discovery.

Q11: What structures have you seen that enhance research excellence and productivity?

The key themes included large interdisciplinary research centers like LSI and Cancer Center, well-run core facilities, opportunities for pilot research, opportunities for diverse researchers to work together, high expectations for quality science, and clear and transparent reward systems.

3c. On Campus: Leadership Interviews

A subgroup of committee members interviewed deans, chairs, and other thought leaders in the biosciences in multiple units across campus. Anonymized notes from a subset of these interviews are included below.

Basic science and non-medical school chairs:

Chair 1: There has been a lack of investment by the med school in high profile basic scientists and also a lack of investment in platform technologies. For example, some platforms have been co-opted by some clinical departments. There are often underfunded and lack dedicated faculty who themselves are conducting research in these platform areas. The chair recommended creating a dedicated program in some cross-cutting areas.

Chair 2: The chair's department is well integrated into other science groups within the university at large. The department also maintains active research collaborations with clinical departments. The chair had few suggestions for improvements or grand questions to be pursued. This chair would like to see more attention paid to laboratory design. The chair also indicated that refunding the endowment for basic sciences, the biological scholars program and cluster hire initiative should be high priorities.

Chair 3: The medical school is characterized in some measure by a culture of exclusion. Individuals, rather than programs, tend to be funded. There is a lack of equity in opportunities for faculty to be supported. While M-cubed represents a good program in concept, the administrative demands and cost-sharing structure place this program out of reach for most faculty. There is a need for the institution to support more risk taking on the part of faculty. Additionally, with an aging faculty, institutional incentives for retirement need to be considered. There should also be institutional support and mentoring for basic science faculty to pursue translational targets. Financial models for basic science departments, even including teaching, do not seem to work.

Chair 4: This chair didn't offer specific structural changes in the biosciences and more specifically, felt that imposing major changes would be counterproductive. The department's position in the Medical School has allowed it to cultivate clinical collaborations in ways that would harder if they were not in the same school. Incentives (rather than co-location) are the important part to stimulate collaborations. The department has robust collaborations with departments in other schools and one could envision cross-disciplinary initiatives in, for example, tissue engineering. One research question that could be used a unifying focus is principles of self-organization, from protein folding to human behavior.

Chair 5: In addition to individual excellence at the university, the development of successful cross cutting programs needs connectors – people and resources that bring high-performing research teams together. The team science that results from connecting people, e.g. in regenerative medicine, is not happening at the university to the degree possible. This was attributed in part to the size of the institution. We discussed the value of a scientific advisory board that would help find and connect people, for instance to bring ethics into a research team in regenerative medicine. Similarly, a resource board could would help coordinate facilities and identify needs, for instance in mass spectroscopy. The boards would be assembled by and report to a Science Czar who would be an advisor to the president. The conversation also included identifying the pillars in the scientific community on campus and how they might be better rewarded, acknowledged and retained.

Clinical chairs:

Chair 6: Research opportunities were seen in the areas of using large clinical data sets using home grown platforms, though opportunities for leadership in digital medicine have largely passed by UM. This department is amassing large data sets with real time monitoring of patients. They are building interactions with public health and genetics to better understand the relationships between genotypes, epigenetics and physiological responses and with the computer science and mathematics departments. When queried about grand challenges, understanding the biological basis for consciousness was deemed an important area. With regard to research culture, this chair noted that the department was unwilling to support PhD scientists "doing their own thing" in the lab.

Chair 7: This department's research efforts focused on the creation of a multidisciplinary center with involving close association with the College of Engineering. The department has completed a joint recruitment with a basic science department, but in general, it has been hard to co-recruit with the basic science departments. Barriers to co-recrutiment include unaligned research goals and fundamental differences in culture between the clinical department and the basic sciences. Additionally, there are major hurdles to agreements on indirect cost recovery, shared space, and equipment between clinical departments and the basic science departments. No suggestions for grand scientific challenges were offered.

Chair 8: This chair would like to see any new redesign of the biosciences result in an increase in the opportunities for collaboration between the chair's department and the School of Public Health and the School of Natural Resources and the Environment. The chair saw opportunities in research on personalized medicine, the remote monitoring of patients, and the impact of the environment on health. A major focus of this work should be understating the role of poverty in health and the pursuit of improvements in the delivery of care to underserved populations. This chair noted that a major barrier for the department's research-active faculty is the inability to physically co-localize with investigators who have shared interests. This chair has a difficult time obtaining monetary support for faculty for effort not directly devoted to the generation of clinical revenue. A suggested structural improvement that would enhance research excellence is a fund for joint recruitments akin to the cluster hires that were initiated through the Interdisciplinary Junior Faculty Initiative.

Chair 9: This chair did not offer a specific plan for redesigning the research programs. However, the committee was strongly urged to consider addressing the following issues with any plan. First, the medical school has a highly problematic funding model for the basic science departments and their faculty. This is based, in part on the imbalance between tuition and teaching effort. Second, there is no comprehensive program in the neurosciences. Currently, several programs that address the cognitive sciences are directly competing with one another for finite resources. The chair indicated that a major hurdle that prevents the department's faculty from collaborating outside their department is the lack of platforms for regular interactions. The co-advising of student could be a vehicle for collaboration.

Chair 10: The chair would like to see more institutional support for faculty driven efforts that support collaborative research. The chair also felt that it would be useful to have more effort to bring undergraduates into research labs. Both goals require the commitment of significant resources at an institutional level. The chair emphatically believed that "top down" research initiatives do not work, and that programs like M-cubed are a better approach. The chair sees great potential opportunities in research on rare diseases.

Chair 11: This chair offered no specific suggestions for the redesign of the basic sciences but indicated that any new design should foster collaboration and provide ample opportunities for senior faculty to mentor junior faculty. The chair also felt that the institution needs to invest in talent and cores and facilitate the pursuit of institute and center funding mechanisms. Precision medicine was proposed as a paradigm for research initiatives and might include a specific emphasis on the study of biomarkers of disease. Other initiatives that have received attention have been late in coming and include the microbiome and epigenetics where the "train has already left the station".

***Chair 12*:** This chair suggested that we modernize the promotion and tenure system with a matrix portfolio approach. This approach would help normalize evaluations in different units and raise the bar for promotion. A matrix approach is sufficiently flexible to accommodate contributions to teaching, research and clinical service and recognizes contributions of team science.

Chair 13: This chair emphasized four factors critical for success: collective action, active management, entrepreneurship, and revenue. NCRC was cited as an example of collective action leading to a favorable outcome. By aligning stakeholders (clinical departments), programmatic development and cost avoidance have been possible. Active management requires the university leadership to sunset underperforming units and create incentives for underperforming faculty.

Deans:

Dean 1: This dean was concerned that proliferation of institutes will further splinter campus, in parts, because institutes can poach strong faculty and dump them back on departments if they are unproductive. Better practices are needed regarding splitting of responsibilities for faculty. The dean was in favor of developing strategic plans for the biosciences with a limited number of themes. These should cut across all academic units; the dean acknowledged the units would need to be taxed to support these initiatives. Rather than focusing on centers and the like, the chair thought we all benefit from having some stars, and envisioned mechanisms, for example, "presidential biosciences scholars" (super-endowed positions) as a possible mechanism.

Dean 2: This dean felt that were substantial inequities in resources across campus and differences in cost models access to wet lab spaces difficult for smaller units. The dean thought that training programs and students are ways to draw collaborative units together.

Dean 3: This dean expressed disappointment in the limited partnering that occurred between units. The dean saw great potential for interactions with other units, in particular the medical school. The dean indicated that productivity could be greatly enhanced by co-localization of the school's faculty with those outside of the school but with aligned scientific interests, and suggested that the committee consider St. Jude's Childrens Hospital as a model. They are ranked first in the success rate of their RO1 applicants.

Comments about specific programs and structural changes:

The Balkanization of biochemistry with multiple small groups across campus often place faculty and programs at odds with one another. Examples of programs with groups of biochemists include chemistry, MCDB, chemical biology, medicinal chemistry, and biophysics. This is a case where the sum is definitely less than the whole.

One suggested specific institutional structure would be the creation of a division of clinical pharmacology within internal medicine, the formation of an "institute of precision medicine", and support for partnering with the College of Pharmacy to enhance programs in drug discovery.

A suggested structure would be for the medical school to create a "Learning Health System" for continuous study and improvement of the health system. This kind of learning system would be relevant to educational programs and may be valuable to the broader effort in the Biosciences.

3d. Off Campus: Interviews with External Peers

Interviewees:

Peter Agre, MD
Professor, Molecular Microbiology and Immunology
Johns Hopkins School of Public Health
Director, Johns Hopkins Malaria Research Institute

Jack Dixon, PhD
Professor, Departments of Pharmacology, Cellular & Molecular Medicine and Chemistry& Biology
Associate Vice Chancellor of Scientific Affairs
University of California San Diego

Kun-Liang Guan, PhD
Professor of Pharmacology
University of California San Diego School of Medicine

Michael Marletta, PhD
Cecil H. and Ida M. Green Chair in Chemistry
Professor, Department of Chemistry
California Campus
The Scripps Research Institute

David J. Mooney, PhD
Robert P. Pinkas Family Professor of Bioengineering

Harvard School of Engineering and Applied Sciences
Core Faculty Member, Wyss Institute for Biologically Inspired
Engineering at Harvard University

Sean Morrison, PhD
Mary McDermott Cook Chair in Pediatric Genetics
Director, Children's Medical Center Research Institute
Howard Hughes Medical Institute
University of Texas Southwestern Medical Center

Paul Meister
Co-Chair, Advisory Boar of the University of Michigan Life Sciences Institute
Co-Founder & CEO, Liberty Lane Partners
Hampton, NH 03842

Questions:

- Please tell us about your current appointment and roles and your individual research program at your current institution.
- Please tell us a bit about your current department or unit, and how your unit or department is connected to other units working in the biological sciences at your institution.
- How is inter-disciplinary research in the biological sciences pursued at your institution? What structures, if any, have helped in building research initiatives across the spectrum of biological science in multiple units and even across distinct schools at your University?
- What is the relationship between graduate education (PhD) training programs at your institution and the department or unit structure? What changes might you envision to the current structure at your institution to create a more ideal graduate training experience?
- What units and institutions do you believe have the most ideal structures and research cultures for major successes in biological research?
- What should the medical school of the future look like? What is the role of basic science in medical schools?
- What are the best mechanisms to facilitate interactions between bioscientists in disparate fields (i.e. basic scientists and clinical scientists, biologists in different colleges)? Is physical proximity essential?
- What structures have you seen that enhance research excellence and productivity?
- What is the policy or policies at your institution that has had the largest positive effect on research excellence and creativity?

Selected Consensus Points:

1) There are a variety of structures for organizing faculty research and education activities in the biosciences at peer institutions. Most of the external faculty peers were of the opinion that the University of Michigan's current organizational structure in the biosciences was not inconsistent

with that at many other peer institutions. In addition, it was felt the structure at the University of Michigan was not a major impediment to current and future success for major impact in biosciences research and education.

2) Successful interdisciplinary research initiatives at peer institutions are often catalyzed by individual faculty members and small faculty teams working together in an organic fashion. The merits and significance of most "top-down" approaches to build interdisciplinary research were questioned. Interdisciplinary graduate programs and new research initiatives with groups of scientists working at the interfaces of established disciplines in the biosciences were felt to be major catalysts for major new inter-disciplinary research initiatives in the biosciences at peer institutions. The breadth and depth of research and graduate training across the biosciences at the University of Michigan was felt to be among the major strengths of the University at the present and for the foreseeable future. It was recommended that the University should establish several new and innovative interdisciplinary research and educational initiatives that would further strengthen biosciences research and its links to other areas of scholarly work and inquiry across the University of Michigan.

3) The organization of graduate education programs in the biosciences was varied at the institutions represented by the external peers. However, most institutions now embrace the view of an "umbrella" structure for recruitment and admissions, with biosciences graduate students choosing distinct tracks and units once they arrive at an institution. The theme of considerably more extensive and enhanced opportunities for interdisciplinary training and mentorship across the bioscience field and in other areas of science (e.g., chemistry, engineering, public health) was highlighted as an important future direction for the University of Michigan to emphasize in graduate education in the biosciences.

4) Research units and institutions with potentially ideal structures and research cultures for the biosciences were felt to have the following attributes: i) strong and visionary leadership who value the full range of biosciences research and that of complementary research fields; ii) an overarching mission and core principles that are clearly articulated by the leadership and broadly embraced by the faculty, staff, and trainees at the institution; iii) a strong mix of federal and non-federal funds for support of existing research and educational initiatives as well as bold new plans; and iv) robust strategic planning and critical on-going assessment of the progress in achieving defined objectives and metrics.

5) There was no consensus opinion about what the top medical schools of the future would look like. However, the majority of external peers indicated that a strong exposure to foundational bioscience discoveries and laboratory-based biosciences research would likely continue to be a critical component of medical student education at many top-rated institutions for the foreseeable future.

6) There was no consensus opinion on the most effective current mechanisms to facilitate substantial interactions between bioscientists in disparate fields or that might bring bioscientists together with scientists in complementary disciplines. Nevertheless, there was near uniform agreement that inter-disciplinary research and graduate education would continue to grow in importance and that institutions might foster interdisciplinary research and training through a variety of mechanisms: i) individual research laboratory physical co-localization strategies; ii) incubator and flexible research space assignments; iii) new core facilities and "matrix" research programs; and iv) new inter-disciplinary undergraduate, graduate, and post-graduate education and training programs.

7) The consensus opinion of the external peers was that scientific culture and cultural changes likely had a much greater impact on research excellence relative to organizational structure or changes to organizational structure. Co-location of groups of investigators with complementary research expertise and distinctive research interests was felt to a common strategy that was employed for enhancing research excellence and productivity. However, the success of such approaches was most often dependent on a few selected investigators acting as catalysts for innovation and excellence, rather than the particular research topics or themes chosen.

8) The policies that were thought to have the largest positive effects on excellence and creativity in bioscience research were to incentivize faculty to take some significant risks and pursue highly innovative research on major unsolved questions and problems as well as highly innovative technologies and approaches, rather than to emphasize research efforts that might simply have strong prospects for near-term success with regard to publications and extramural funding.

3e. Off Campus: External Site Visits

In March 2015 the external outreach subcommittee met with more than 18 faculty and administrators at the University of Washington-Seattle, University of California-San Francisco, and Stanford University. University of Washington-Seattle was chosen for a site visit due to its organizational similarities with UM, a similarly strong funding profile in key life sciences/biomedical sciences departments, and its reputation for being particularly successful at obtaining research grants to support centers. University of California-San Francisco was chosen because of its overall reputation and standing in the life sciences/biomedical sciences community, because the research enterprise there has undergone considerable structural and organizational changes in the last decade with great success, and because the medical school is undergoing a curricular revision that includes major changes in incorporation of the basic sciences. A visit to Stanford was arranged because of the longstanding life sciences research excellence and also due to several examples of cross-campus institutes that appear highly successful in encouraging and sustaining innovation. In addition to informal conversations with individual faculty members, formal meetings with leaders at all three institutions took place over four days.

The stage for these discussions was set by the following questions provided in advance to each person with whom the subcommittee met; the questions are very similar to those asked in the phone interviews to external leaders described just above:

- How is inter-disciplinary research in the biological sciences pursued at your institution? What structures, if any, have helped in building research initiatives across the spectrum of biological science in multiple units and even across distinct schools at your University?
- What have been the best mechanisms to facilitate interactions between bioscientists in disparate fields (i.e. basic scientists and clinical scientists, biologists in different colleges, computational biologists and experimentalists)? For example, have you found that physical proximity is essential?
- What structures have you seen that enhance research excellence and productivity? What is the policy or policies at your institution that has had the largest positive effect on research excellence and creativity?
- What structures give your institution and its faculty the agility to adapt quickly, to be in step with the dynamic frontiers of the bioscience research landscape? Are there elements of your institution's structure, values, and/or culture that promote scientific risk taking?
- What should the medical school of the future look like? What is the role of basic science in medical schools?

Institutes as a model to foster innovation, collaboration and excellence

All three institutions use institute structures superimposed upon the usual departmental structure to support efforts in emerging and/or cross-disciplinary areas. At the University of Washington-Seattle, it is remarkably straightforward to start an institute or center: UW has developed resources (both a website and a consulting service, see http://www.washington.edu/research/topics/complex-proposals) to help faculty set up and apply for funding for new centers and large collaborative projects. However it is institutional policy to provide no more than small amounts of initial seed money and, in general, to provide no dedicated space. A positive aspect of the ease of center/institute creation is that faculty members find it generally easy to organize and to apply for large scale funding. However, once created, centers/institutes rarely have longer-term committed funding.

At UCSF, the construction of dedicated space and the recruitment of faculty for Institutes organized around a particular disease focus has been a priority and highly successful in the previous 10 years, with a Cardiovascular Institute, an Institute for Neurodegenerative Diseases, and the Broad Center of Regeneration Medicine and Stem Cell Institute being recent examples. While impressive in scope and scale, our view was that this model would be unlikely to be replicated at most other institutions since it requires highly focused, long term fundraising on a scale that would be difficult to accomplish at comprehensive universities with a larger range of priorities.

The institute model at Stanford appeared both highly successful and potentially adaptable to the University of Michigan. We found Stanford's newest institutes that follow the Bio X model to be the most innovative and far-reaching institute concept. Stanford's Bio X has supported, organized, and facilitated interdisciplinary research connected to biology and medicine since its inception in 1998. It has a well-defined yet broad identity characterized by its focus on human health and disease. Of particular note are a variety of programs to stimulate collaboration and innovation, including seed grants for high risk, high reward collaborative research projects at a level sufficient to make significant progress ($200,000 over 2 years), Ph.D. fellowships and postdoctoral fellowships that are awarded for students to do crosscutting research projects guided by several mentors, A BioSTAR partnership program for identifying corporate sponsors for research projects or areas, and Bio X Ventures, a program for stimulating research in newly identified cutting edge questions. The return on the Bio X programs is significant; one metric is the grants secured by Bio X members after the receipt of seed funding and currently this is over 10 times the institute's annual investment in seed grants.

A recurring theme among all of the Universities we visited is that genuine collaboration that broadly crosscuts disciplinary boundaries is essential for research innovation. This kind of collaboration is at the heart of the mission of Bio X and most other institutes, and many of them have found ways to lower institutional barriers that make collaboration difficult. At the University of Michigan, we value collaboration, and there are several University-wide initiatives and institutes that have fostering interdisciplinary collaboration as one of their primary goals. However, barriers still exist and they tend to be at the college level, making it challenging to collaborate at scale (not at a faculty-faculty level) across schools and colleges. The most successful and far-reaching bioscience institutes are at institutions that have successfully lowered these barriers.

One reason the institutes at Stanford have prospered is that the university decided to embrace this model as a means to support and promote interdisciplinary scholarship in the early 1980's. At that time they added to their Research Policy Handbook specific and detailed policies for establishing, managing, funding and sun setting institutes and centers (see: http://doresearch.stanford.edu/policies/research-policy-handbook/establishing-and-managing-independent-laboratories-institutes-and-centers/establishing-and-managing-independent-laboratories-institutes-and-centers). These policies have allowed them to think carefully about unique challenges that could impede the success of new institutes and to create a programmatic focus to multidisciplinary research that allows new institutes to successfully branch out and connect faculty across schools and colleges, as opposed to evolving into silos that only impact a small number of core faculty. We believe the Bio-X model could be effectively reproduced, with necessary modifications to scale and identity, at the University of Michigan.

Policies to facilitate a collaborative, innovative research environment

A theme at the institutions visited was a belief that, as stated by Vice Provost Mary Lidstrom of University of Washington "Policy should drive the budget; budget should not drive the policy." That is perhaps easiest to accomplish at Stanford where the budget model is substantially different than the Michigan model but this was an administrative core value also stated at the other institutions. Clearly basic research was highly prized and valued on its own merit, and each institution had clear mechanisms for facilitating success at a variety of levels.

A common theme among all three institutions was the clear and important role that faculty played in decisions regarding resources and research. At the University of Washington-Seattle, the Vice Provost altered the composition of high-level committees such that there are faculty members on all. Additionally, while UW administrators noted particular challenges associated with cross-unit collaborations on educational projects, Associate Deans for research play a high-profile role there to facilitate cross-unit research collaborations and initiatives (in addition to other things such as hiring). In other words, a key role of an Associate Dean for Research is to be an outward-looking advocate. UW has developed a strategic plan, including a website, to facilitate collaboration across campus (http://depts.washington.edu/research/fostering-collaboration/). At UCSF there is a faculty Leadership Committee made up of 15 faculty across the basic science departments that meet weekly with the Provost. Additionally every Friday there is an all-faculty lunch at which there is a science presentation. Attendance is a high priority for everyone (if you come 5 minutes late, you will be eating your sandwich on the floor), you never know what flavor of science you will hear about, and the discussions are active and engaged; many collaborations have come out of this. Perhaps most importantly, it keeps excellent research front and center in the mindset. Similarly, at Stanford it is faculty who make decisions about where and how innovation/seed grants are awarded to faculty and who make funding decisions regarding postdoctoral and doctoral innovation fellowships.

Already touched upon in the previous section was the role of seed funding in facilitating innovation and collaboration cross-campus and the policies governing seed funding appeared key to success. Seed funding was fairly limited at UW-Seattle but a high priority for external fundraising at USCF and at Stanford. Critical components were faculty decision-making regarding funding; in other words, peer review by active scientists is considered vital. UCSF offers seed funds on the order of $150,000 (total), approximately 20 per year, that are targeted for highly innovative, bold research ideas. There are also technology awards for more applied but bold ideas that can go up to $1 million. At Stanford there are innovation seed funds in the Medical School on the order of $200,000 per awardee over two years that the departments control. Other innovation seed funds of the same magnitude are awarded via institutes with faculty peer review leading to decisions. At the level of Institutes and Schools/Colleges a major fundraising priority is innovation funds and, as discussed in the previous section, the return on investment in terms of new grants and inventions is impressive.

Faculty hiring practices as a mechanism for innovation and maintaining excellence were also a topic of discussion at all three institutions. At both UCSF and Stanford hiring committees always contain at least one member external to the unit. The positives noted by UCSF faculty/leaders include the rigorous evaluation of the candidates by the broader panel ('quality control') and the increased likelihood that faculty with research interests that span departments and/or institutes would be hired. Particularly for hiring via the institutes, a similar model is in operation at Stanford and is resulting in a broader group of candidates and hires, at least in terms of research interests. One issue to consider is that this strategy will only work if there is real commitment by the search members such that there is real consideration of the science and not a simple reliance on the numbers. Other institutions (such as Johns Hopkins University) have developed programs to hire faculty jointly appointed in two schools to enhance cross-campus collaboration.

Graduate student support

Not surprisingly, at all three institutions, financial support for graduate students was a priority topic. At the University of Washington, there were not consistent mechanisms for support, particularly in the School of Medicine. At UCSF and Stanford graduate student support has been for some time and continues to be a high fundraising priority. At UCSF, this is the legacy of several leaders with considerable foresight who began fundraising to endow key graduate programs and this set a precedent that newer programs have sought to mimic. At Stanford this has also been a high priority and it was clear that this was viewed as another mechanism by which innovation and research nimbleness can be stimulated. At the medical school, after considerable fundraising, all students are funded for the first four years. The conflict of interest inherent in having graduate students funded by PI research grants was noted as part of this discussion. The many graduate student fellowships offered by the Institutes represent a mechanism of innovation at Stanford. These typically fund students in their 3-5th year and are awarded to the students based upon their ideas, often leading to co-mentorship for the final years of their degree. The institutes do not confer degrees (are not academic units) so these fellowships are a direct benefit to the departmental structure.

An example of major reorganization

Perhaps the only example of serious reorganization of departments/units was found at University of Washington-Seattle and it appears to be highly successful. Several years ago the College of the Environment was formed from a merging of Earth & Space Sciences, the Atmospheric Science department and the Forestry and Ocean Colleges. This was a large challenge from a political standpoint but there have been significant payoffs. This school is now the largest College of the Environment in the country, with 250 faculty organized into 7 internal units. The intellectual theme is that all think of the earth as a system and each of the individual programs are strong applied science sections focusing on distinct aspects of this. The success of this reorganization is measured through high impact publications, collaborations with industry, and work with large conservation organizations. Additionally, grant support has been significantly increased overall, with $120 million in external funds (approximately 50% through the NSF for discovery work and then 50% through a combination of USGS, US Forest Service and foundation money). The College is now second only to the College of Medicine in terms of funding and has a more diversified grants portfolio. Additionally, the College has had a major impact on education, with 1500 undergraduate majors in earth science, atmospheric science, fisheries, forestry, oceanic, science & policy and 600 graduate students. Some of the courses offered/developed by the new college are taken by students in the Arts and Science College and Engineering so some tuition revenue flows back to the College of the Environment through such courses. Overall the impression was that this reorganization has made a difference intellectually and faculty have found it more straightforward to assemble teams to take on grand challenges and high-risk research problems.

Additional notes

1) Role of co-localization At each institution one topic of discussion was the role or importance of co-localization in stimulating innovative, collaborative environments. The broad consensus is that having some degree of dedicated common space with good coffee is critical for new

initiatives/centers/institutes – to facilitate formal and informal interactions and to solidify feelings of solidarity and ownership.

2) Role of basic science in the medical school. The administrators at all three institutions indicated that strong basic science research was fundamental to the current and future reputation, function and educational mission of a biomedical research enterprise. The new medical schools being formed without a strong research component were viewed mainly as doctor-training institutions.

Appendix 4. Data on Biosciences at UM

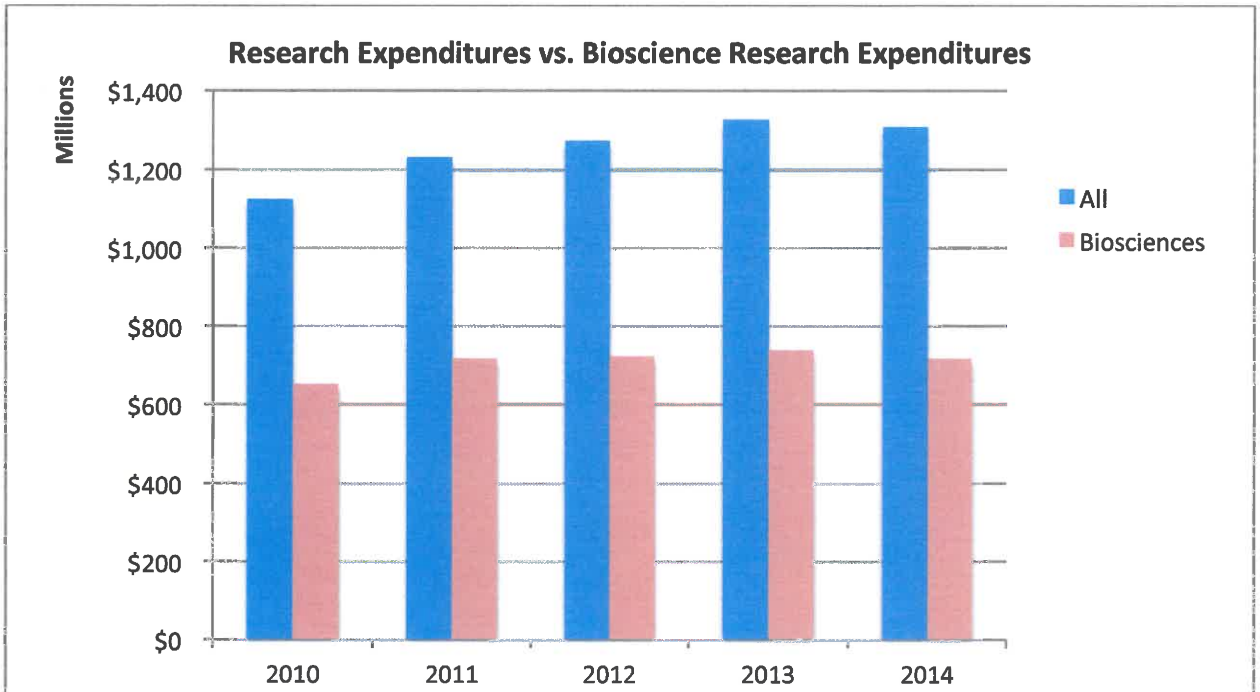

Figure 1. UM total research expenditures vs. expenditures in biosciences.

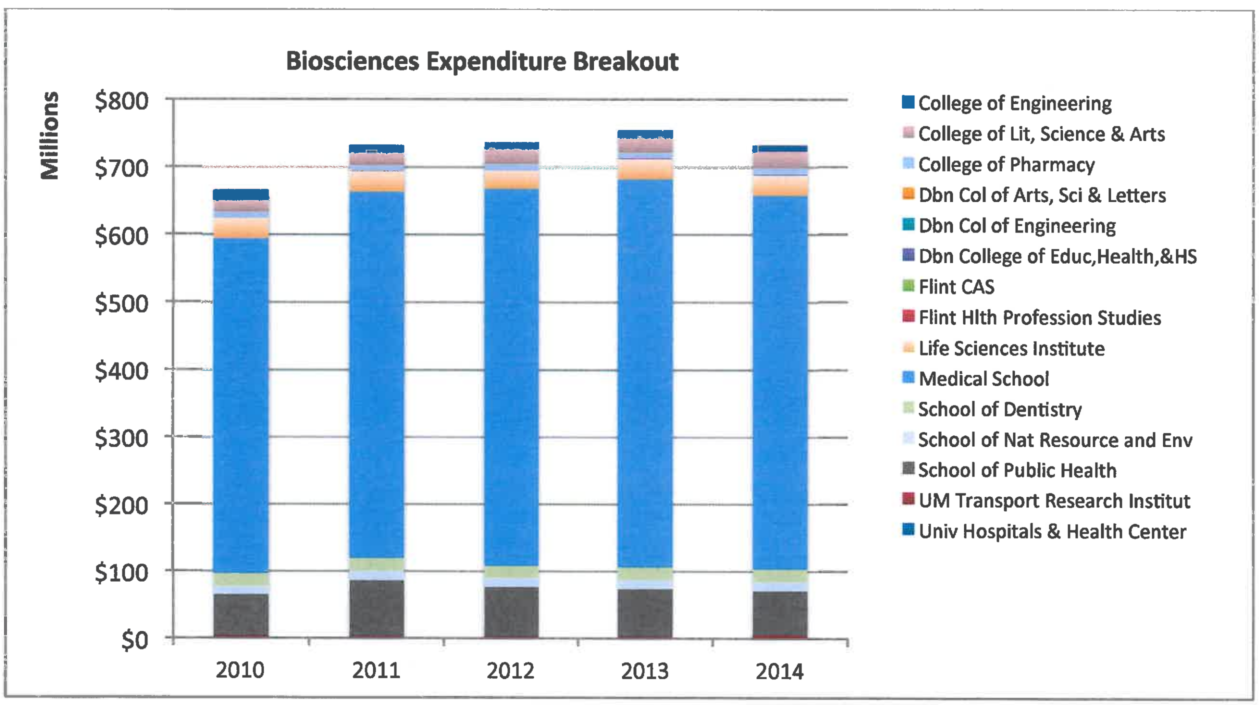

Figure 2. Research expenditures in biosciences and breakdown by school.

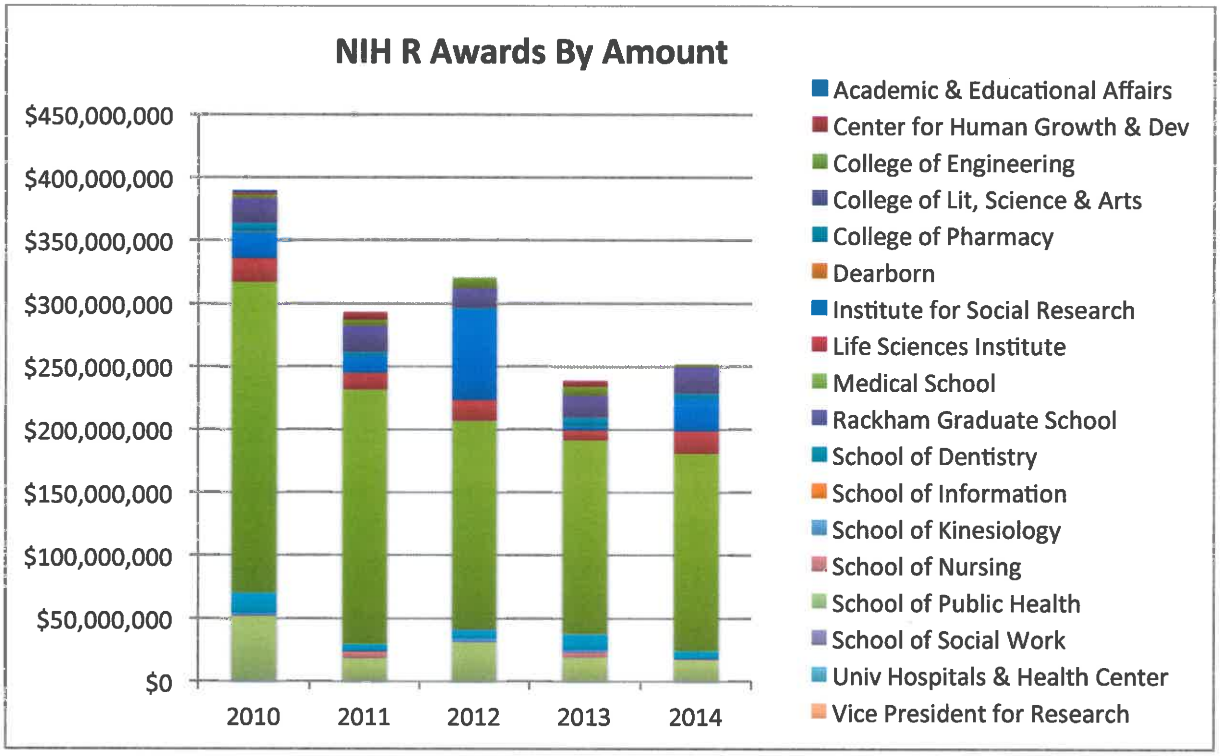

Figure 3. NIH R awards by amount.

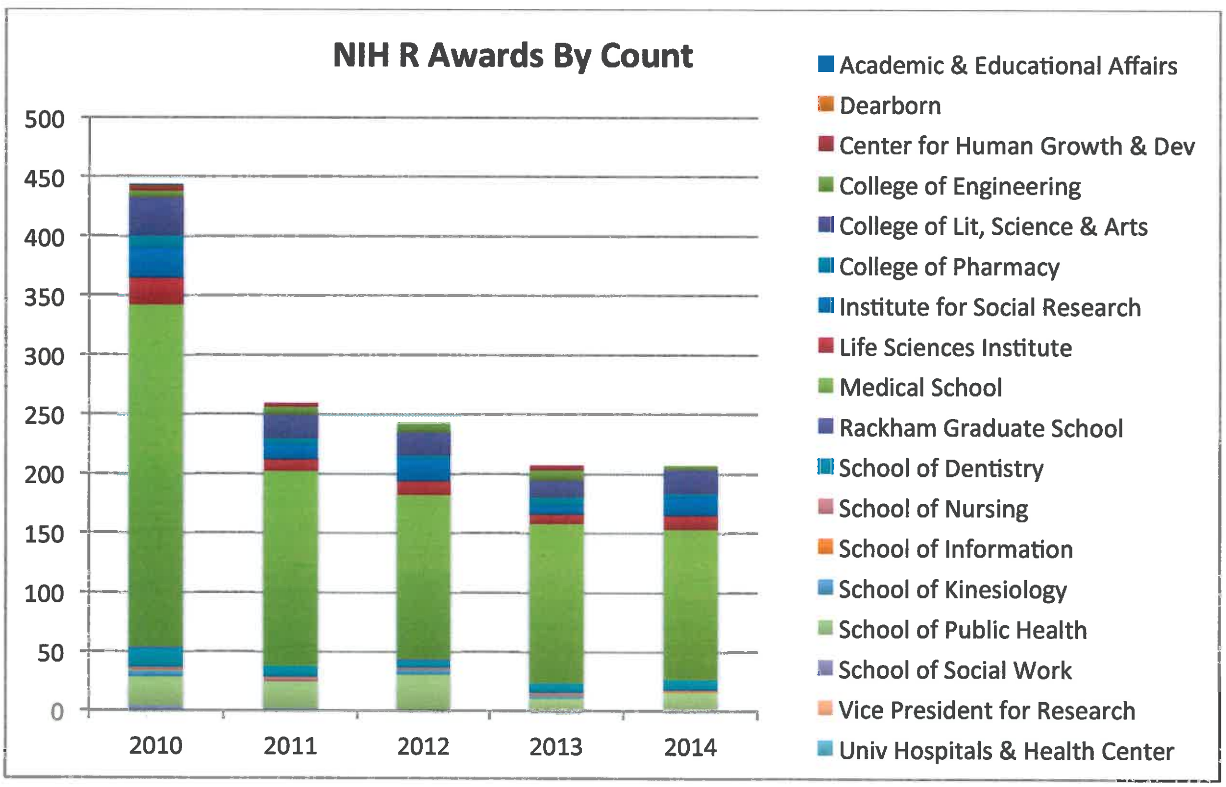

Figure 4. NIH R awards by number of awards.

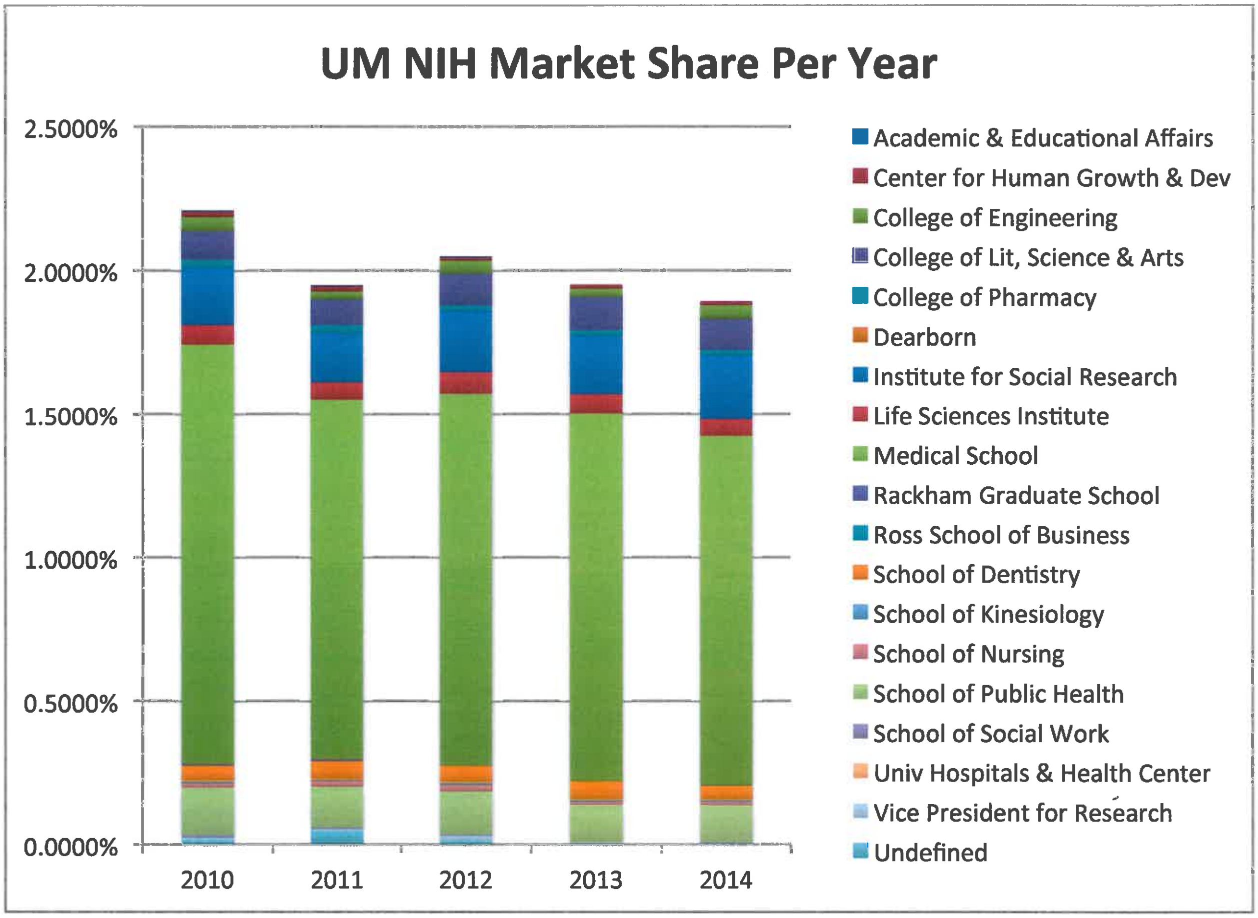

Figure 5. NIH Market share.

Table 2. Foundation support in biosciences: award amount.

	Award Publish FY				
Admin Home School	2010	2011	2012	2013	2014
College of Engineering	$70,744		$180,000	$884,165	$300,600
College of Lit, Science & Arts			$170,000	$225,800	
College of Pharmacy					$40,000
Dearborn			$35,000		
Flint	$9,375		$50,000	$115,000	$65,000
Life Sciences Institute	$670,500	$260,000	$290,000	$823,500	
Medical School	$10,542,222	$11,277,792	$11,416,440	$15,593,917	$11,735,022
School of Dentistry	$294,372	$350,000	$177,734	$166,298	
School of Public Health	$3,403,566	$9,842,005	$5,163,161	$5,954,194	$9,166,103
Univ Hospitals & Health Center	$64,415	$110,842	$70,083	$77,000	$57,628
Total	**$15,055,194**	**$21,840,639**	**$17,552,418**	**$23,839,874**	**$21,364,353**

Table 2. Foundation support in biosciences: number of awards.

	Award Publish FY				
Admin Home School	2010	2011	2012	2013	2014
College of Engineering	1		1	1	2
College of Lit, Science & Arts			2	3	
College of Pharmacy					1
Dearborn			1		
Flint	2		1	2	2
Life Sciences Institute	5	2	2	3	
Medical School	52	37	41	58	56
School of Dentistry	2	2	2	2	
School of Public Health	8	13	15	13	9
Univ Hospitals & Health Center	4	4	3	3	5
Total	74	58	68	85	75

Table 3. Industry support in biosciences: award amount.

	Award Publish FY				
Admin Home School	2010	2011	2012	2013	2014
College of Engineering	$143,743	$187,500	$425,436	$717,339	$24,888
College of Lit, Science & Arts	$163,671	$1,008,754		$40,000	
College of Pharmacy	$876,038	$532,772	$976,563	$480,867	$582,758
Flint		$89,862	$58,556		
Life Sciences Institute	$908,771	$251,518	$105,244	$4,801	$780,000
Medical School	$47,098,369	$67,127,865	$54,003,195	$74,920,222	$83,291,270
School of Dentistry	$1,027,316	$825,712	$4,829,696	$1,217,326	$998,266
School of Public Health	$1,667,803	$1,499,967	$1,349,124	$628,962	$805,552
UM Transport Research Institut	$307,840	$413,562	$1,077,729	$561,745	$928,565
Univ Hospitals & Health Center	$31,500	$54,500	$2,500	$70,000	$7,500
Total	$52,225,051	$71,992,012	$62,828,043	$78,641,262	$87,418,799

Table 4. Industry support in biosciences: number of awards.

	Award Publish FY				
Admin Home School	2010	2011	2012	2013	2014
College of Engineering	3	3	5	7	4
College of Lit, Science & Arts	2	3		1	
College of Pharmacy	14	7	11	6	11
Flint		1	9		
Life Sciences Institute	5	3	7	1	1
Medical School	302	297	297	372	358
School of Dentistry	20	11	23	14	18
School of Public Health	14	18	18	12	13
UM Transport Research Institut	13	22	25	27	23
Univ Hospitals & Health Center	5	5	1	1	2
Total	378	370	396	441	430

Table 5. Invention disclosures, patents, and IP revenues.

FY '10

	Royalty Revenue	Equity Revenue	Total	Invention Disclosures	New Patent Applications	Issued Patents
Dentistry	70,000	-	70,000	3	3	1
Med Schl	13,005,238	159,174	13,164,412	118	57	31
Pharmacy	419,501	-	419,501	8	9	3
Public Health	1,636,163	20,684,561	22,320,725	0	0	1
Life Science Inst	750	-	12,824	3	2	0
Biomedical Engineering	183,500	-	183,500	18	6	4
TOTAL UNIVERSITY	**17.5M**	**22.3M**	**39.8M**	**290**	**153**	**82**

FY '11

	Royalty Revenue	Equity Revenue	Total	Invention Disclosures	New Patent Applications	Issued Patents
Dentistry	86,789	-	86,789	8	1	2
Med Schl	11,998,751	14,023.29	12,012,774	119	42	37
Pharmacy	264,078	-	264,078	6	3	2
Public Health	-	-	-	10	1	1
Life Science Inst	2,000	-	2,000	6	3	0
Biomedical Engineering	4,000	-	4,000	14	8	0
TOTAL UNIVERSITY	**14.7M**	**0.9M**	**15.6M**	**322**	**122**	**87**

FY '12

	Royalty Revenue	Equity Revenue	Total	Invention Disclosures	New Patent Applications	Issued Patents
Dentistry	41,972	-	41,972	5	2	2
Med Schl	11,135,317	14,328	11,149,645	117	47	28
Pharmacy	50,040	-	50,040	11	5	3
Public Health	250,000	-	250,000	4	1	0
Life Science Inst	-	-	-	7	2	1
Biomedical Engineering	45,000	326,814	371,814	23	13	6
TOTAL UNIVERSITY	**13.4M**	**0.4M**	**13.8M**	**368**	**145**	**101**

FY '13

	Royalty Revenue	Equity Revenue	Total	Invention Disclosures	New Patent Applications	Issued Patents
Dentistry	70,500	-	70,500	9	2	3
Med Schl	10,135,345	934,256	11,069,601	133	44	41
Pharmacy	165,522	-	165,522	6	1	1
Public Health	-	-	-	10	3	1
Life Science Inst	11,186	-	11,186	5	6	1
Biomedical Engineering	59,293	38,588	97,880	18	4	8
TOTAL UNIVERSITY	**13.4M**	**1.0M**	**14.4M**	**421**	**148**	**128**

FY '14

	Royalty Revenue	Equity Revenue	Total	Invention Disclosures	New Patent Applications	Issued Patents
Dentistry	287,943	-	287,943	14	2	4
Med Schl	10,036,750	1,308,024	11,344,774	133	45	39
Pharmacy	102,343	325,390	427,733	16	6	0
Public Health	-	-	-	5	2	2
Life Science Inst	5,513	-	5,513	7	3	2
Biomedical Engineering	229,185	-	229,185	12	5	4
TOTAL UNIVERSITY	**16.8M**	**1.7M**	**18.5M**	**439**	**189**	**132**

Table 6. UM faculty in the national academies.

NAS – 24 (9 members in biosciences)
NAE - 30
IOM - 52

Numbers in comparison to peer institutions:

- IOM: UC San Francisco-72; Stanford-73; John Hopkins-57; University of Pennsylvania-70; U-M-52

- NAS: Harvard-162; MIT-114; Standford-143; UC Berkeley-126; UM 23

- NAE: MIT-108; Stanford-86; UTexas: 51; UC Berkeley-76; U-M-30

Table 7. Top 50 institutes with the most faculty members in the NAS.

National Academy of Sciences -- Members as of 5/13/2015			
Organization	Number of Total Members	Number of Bioscience Members	% of bioscience members
Harvard University	160	90	56.3%
Stanford University	140	79	56.4%
University of California, Berkeley	128	50	39.1%
Massachusetts Institute of Technology	114	45	39.5%
Princeton University	81	25	30.9%
California Institute of Technology	70	20	28.6%
University of California, San Diego	61	36	59.0%
Yale University	60	37	61.7%
Columbia University	54	28	51.9%
University of Washington	51	33	64.7%
National Institutes of Health	50	50	100.0%
The University of Chicago	44	9	20.5%
University of Wisconsin-Madison	41	25	61.0%
University of California, Los Angeles	40	21	52.5%
University of California, San Francisco	40	40	100.0%
New York University	36	14	38.9%
Cornell University	35	15	42.9%
The Rockefeller University	31	30	96.8%
University of California, Santa Barbara	31	9	29.0%
University of Pennsylvania	27	19	70.4%
Johns Hopkins University	26	19	73.1%
University of Illinois at Urbana-Champaign	24	7	29.2%
University of Michigan	24	9	37.5%
Rutgers, The State University of New Jersey, New Brunswick	23	9	39.1%
University of Cambridge	23	10	43.5%
Duke University	22	16	72.7%
University of California, Davis	22	18	81.8%
Northwestern University	20	7	35.0%
The University of Texas Southwestern Medical Center at Dallas	19	19	100.0%
University of California, Irvine	19	12	63.2%
Washington University	18	15	83.3%
University of Colorado Boulder	17	6	35.3%
Institute for Advanced Study	16	1	6.3%
The Scripps Research Institute	16	12	75.0%
The University of Texas at Austin	16	7	43.8%
The Pennsylvania State University	14	8	57.1%
University of Florida	14	8	57.1%
University of Maryland, College Park	14	6	42.9%
Arizona State University	13	10	76.9%
ETH Zurich	13	3	23.1%
Salk Institute for Biological Studies	13	13	100.0%
University of Southern California	13	4	30.8%
Memorial Sloan-Kettering Cancer Center	12	11	91.7%
The University of North Carolina at Chapel Hill	12	4	33.3%
University of Minnesota, Minneapolis	12	7	58.3%
Carnegie Institution for Science	11	7	63.6%
The Ohio State University	11	7	63.6%
University of Arizona	11	3	27.3%
University of California, Santa Cruz	11	4	36.4%
University of Oxford	11	8	72.7%

Appendix 5. Vision Statement for the Biosciences

One subgroup of the Presidential panel worked on developing a textual statement of a vision for the future of the biosciences, not just at Michigan, but more broadly. We include it here, because we believe it provides important context for the observations and recommendations in the main body of the report.

"It is not the strongest of the species that survive, nor the most intelligent, but the one most responsive to change". Charles Darwin.

Biology is the study of life, and the 21st Century has been dubbed the Age of Biology, both because of the explosion of knowledge in this branch of science and because of the great impact of biological discoveries on modern civilization. Biological knowledge has transformed medicine with better diagnoses and new treatments for a host of diseases, thereby changing the quality and duration of human life. But more fundamentally, the biosciences have altered our understanding of our origins, our evolutionary history and the basis of our behavior, thoughts and emotions. In effect, the science of biology has changed our view of ourselves as humans.

Moreover, bioscience research has led to a greater realization of how the environment can impact us, including our DNA, epigenome, immune system, microbiome and even the structure and function of our brains. Thus, environmental factors can alter cell signaling and patterns of gene and protein expression, produce stable modifications of chromosome structure and even cause mutations affecting DNA sequence. These effects can impact all adult tissues as well as modifying the developing embryo and fetus. Furthermore, diverse microbial communities populate our bodies, and increasing evidence indicates that environmental factors can have dramatic effects on these communities. In turn, the microbial communities appear to play complex and sometimes unexpected roles in health and disease states.

Our increased biological knowledge also underscores the impact of human behavior on life on earth --- from inducing climate change to altering the habitat and the survival of other species. These bidirectional influences between the individual and the totality of the environment underscore the continuity of life. Thus, the biosciences have changed how we think about our place in the world.

Perhaps most importantly, the biosciences have uncovered the richness and complexity of the myriad species of living organisms, while pointing to commonality and continuity amongst them, with shared mechanisms across evolution at the molecular and systems levels.

This unprecedented growth in knowledge in the biosciences is the result of very broad and deep scholarly efforts and tremendous conceptual and technical developments from many fields of science.

The transformative advances in the biosciences have, in turn, impacted many other fields. There is no evidence that the explosion in biological knowledge is reaching an asymptote. We are still developing new tools and techniques, taking advantage of progress in other fields of science, and gathering fundamental information about the entire range of living organisms, from viruses to humans. Increasingly so, we appear to be producing more data than we can process and synthesize or harness in ways that are both conceptually interesting and translatable into real-life applications. The gathering pace of biosciences advances and the potential for even greater achievements in the years to come motivate considerations about the opportunities and challenges in the biosciences, including how the University of Michigan might best position itself to continue to be a leader and perhaps even among the most pre-eminent institutions in the world in the biosciences field over the next decades.

General Considerations:

The overall strategy for achieving excellence is inspired by biology itself: to excel in the biosciences in the coming decade and beyond, an organization cannot rely on a single tactic or mechanism. Rather, we need to deploy an array of adaptive strategies that will sustain us and allow us to flourish in a changing and often stressful environment. A critical component of the overall strategy for success will be to define the feedback mechanisms that ensure ongoing and successful adaptation.

While diverse, these strategies need to rely on an analytical approach that examines the major challenges faced by the field, the major assets and liabilities specific to our university, and ascertains the cost-benefit ratio of various approaches. The following two issues are of general importance: el:

1- The current ***conceptual challenges*** faced by the larger biosciences field. How can we prioritize the most important and promising areas and issues and take a leadership role in addressing them?

2- ***The changing culture and execution of the biosciences nationally and globally***. How do we adapt to the recent changes and take full advantage of them.

1- <u>Conceptual Challenges in the Biosciences:</u>

While the prodigious growth of the biosciences has catalyzed great progress, it has also become a centrifugal force, making it impossible for scientists to be familiar with, much less master, branches of biology beyond their specific areas of expertise. There is, of course, a common overarching theory- the theory of evolution-- as well as a set of fundamental mechanisms common to most living organisms that form the foundation of biological thinking. There are also shared and increasingly more powerful techniques to investigate, visualize and analyze biological processes. However, biologists are primarily empiricists and, unlike fields such as physics or astronomy, they do not typically define the next challenges in terms of theoretical or conceptual questions. This being the case, there seems to be an endless number of permutations on the molecules to be studied, the signaling pathways to be described, the cellular processes to be defined, the organs and systems to be analyzed and the organisms to be understood. There is even a more dizzying range of interactions between organisms within and across species, with their environment and with the overall ecosystem.

Clearly, the biosciences need to continue their quest to understand the biology of life. Curiosity-driven research has shown time and again that it is not only intrinsically productive in informing us about the nature of the world, but it often yields knowledge that can be useful in unexpected ways, including the development of new drug treatments and very powerful scientific tools for the bioscience field itself. It is also clear that all domains of the biosciences field have a great deal to contribute to the quest of understanding life on earth. But, given the changing demands in terms of costs and technologies and the desire for greater synergies amongst bioscientists, can we define some overarching questions and concepts or even levels of analyses that might represent a general framework for inquiry in the biosciences?

Below, we provide some examples of broad-scale questions that can subsume a range of research efforts in the biosciences. It should be noted that none of these examples are specific to any given discipline or domain in the biosciences area. Rather, they are intended to represent broad scientific perspectives and levels of analysis, within which an array of questions might then be developed and pursued.

- ***Complexity and diversity of life:*** Complexity is a characteristic of biological systems that is worthy of understanding at both a conceptual and quantitative level. Whether considering the self-assembly of viruses, the interactions and emergent properties of complex microbial communities, the resilience of diverse plant communities, or the functioning of a mammalian brain, the processes are never uniform or unidimensional, and adaptive mechanisms are at the core of this very complexity. What conditions promote the evolution of complexity of life? Are there fundamental mechanisms that maintain complexity? Are there principles that we can elaborate to understand the mechanisms that preserve complexity across multiple biological systems?
- ***Quantitative and conceptual approaches to uncover organizing principles of interactions in biological systems:*** *The emergent properties* of cells, organs, organisms or ecosystems are the result of the ***dynamic interactions*** among the elements. While *"Systems Biology"* has thus far tended to focus chiefly on signaling and metabolic networks in cells, the interplay between complex networks is far from being modeled or understood. The functioning of the mammalian brain is a prime example of this challenge, as it is clear that functions such as cognition, thoughts, moods, actions are not the result of the activity of single cells but of the orchestration of neural circuits with literally hundreds of millions of active molecular elements. Can we achieve a more scientific and quantitative understanding of the emergence of function from simpler elements? How can we take advantage of mathematical tools, computer science, informatics, big data analysis strategies, physics and engineering approaches to enhance our understanding of fundamental principles in the biosciences?
- ***Mechanisms of speciation:*** What are the genetic and epigenetic differences that underlie the emergence of a new species? How do environmental changes (including human-induced) lead to selective pressures and loss of certain species?

- ***Fundamental mechanisms of development and homeostasis in diverse species***—how does a changing environment impact them and the ecosystem? This can be explored through a range of biological, chemical and applied (engineering) approaches.
- ***The path from basic bioscience research to translation:*** Translation in the biosciences can mean uncovering causes and treatments for various disorders in humans, animals or plants. But it can also mean other types of applications, including better tools, techniques, machines or algorithms. To date, this process has been encouraged but rarely formally studied. Are there principles that can be elaborated to better capitalize on fundamental knowledge and apply it broadly to better understand practical implications and to develop better biologically based tools and treatments?
- ***The biosciences in a psychological and humane context:*** Biological understanding, no matter how broad and deep will not translate into changes that improve individual lives or the greater environment without understanding the behavior of humans, their motivations, decision-making processes, beliefs and values. Moreover, the bioethical issues that arise from new technologies will likely become increasingly more complex and thorny. For example, recent technological advances now enable us to not only identify genes that underlie disease states, but also to correct or modify them in cells of various types both in adult and in embryonic tissues. In what conditions and settings should we pursue gene correction or modification approaches? We also have the power to directly target specific areas of the brain and alter thought and behavior. Are there conditions under which it would be ethical to do so, or not do so? More broadly, how can we integrate biological understanding both with our values and our understanding of human behavior in multiple contexts?
- ***The biosciences in a societal and global context:*** Broad factors, including social structure, socio-economic status, education, public health, policy and politics all influence health and health-related behaviors. It is said that aging and disease risk start in the womb, or even before conception. Poverty can make people sick. Early life adversity can ruin the rest of people's lives, biologically and otherwise. Understanding the causes of health vulnerability and devising thoughtful strategies for prevention require the integration of biology, epidemiology and the range of social sciences. In a global setting, such an effort requires recognizing and understanding major cross-cultural differences that impact health behavior and modify the resulting prevalence, course and outcome of various disorders.

These general themes, individually or in various combinations, could provide a broad framework for some of the collaborative entities that have been envisioned in this report, be they new institutes, centers, consortia or other mechanisms of cross-campus integration. They would need to be refined and adapted to local capabilities and exciting opportunities. But they exemplify ways of framing large questions in the biosciences that require multidisciplinary and transdisciplinary approaches, while leaving ample space for individual and highly focused projects within their umbrella.

2- <u>The Changing Culture and Execution of the Biosciences:</u>

The increasing complexity of biological research, and the broader scope of the questions being addressed impacts the scientific discovery process. Historically, biological discovery resulted from the work of single individuals or small teams of scientists. Increasingly, major accomplishments and discoveries in the biosciences are requiring the formation of larger teams. These teams may be "horizontal" in nature, whereby a large group of scientists within one or two disciplines take on a major problem in a coordinated fashion. Completing the sequence of the Human Genome is an example of a large-scale team effort. There are also numerous consortia, based on given diseases, that combine their clinical, genomic, informatics and data integration resources to uncover genetic risk factors of complex medical disorders. Other teams may be "vertical" in their organization, bringing together several disciplines to address a problem at multiple levels of analyses. For example, a team may study the structure of a given family of proteins at the genetic and molecular level, the expression and regulation of members of that protein family in a particular organ, the altered expression or function of the proteins in a particular disease condition, the potential of the protein family as a drug target for treatment, and even the possible translation of the entire body of knowledge to clinical trials. Such a team might include geneticists, molecular biologists, biochemists, cell biologists, anatomists, physiologists, pharmacologists, medicinal chemists, and clinician scientists. It would also likely need to include informaticians, statisticians and sometimes epidemiologists and other types of specialists in the biosciences.

Most exciting is the fact that the biosciences are increasingly taking advantage of methods and advances from other fields of science and, in fact, working to develop new fields at the intersections. Partnerships with mathematicians, physicists, chemists, engineers, environmental and climate scientists, social scientists and humanists are not only much more common but represent some of the most exciting frontiers of the biosciences.

Team science poses unique challenges of leadership, integration and coordination at the scientific and social levels. But, it also poses some potential academic challenges, because the biosciences have typically recognized and rewarded individual accomplishments. A balance of individual discovery and team-based efforts will need to be better appreciated, and new approaches for appropriately recognizing and assessing both types of endeavors may be a near-term challenge in the biosciences. There is room for systematic investigation of the conditions and models that promote creativity and success in team science, specifically in the context of the biosciences. As it experiments with various strategies for integration, and in view of the presence of deep social science expertise on campus, the University of Michigan is in a unique position to assess various models, provide thoughtful analyses on the key variables for team effectiveness, thereby transforming the conduct of major research in the life sciences.

Conclusions

The French author, Antoine de St. Exupery said: *"As for the future, our task is not to foresee it but to enable it".* Because of the richness, complexity and diversity of the field of biosciences it would be unwise to attempt to predict the specific areas that will explode or the particular ideas that will emerge as the next breakthroughs in the field. But the forces that shape the growth and dynamism of the biosciences are clear—they include creativity, innovation, talent, and the passion to uncover the unknown. These characteristics of individual scientists are necessary but not sufficient, as success today also require a powerful infrastructure, both scientific and cultural, that enables the quest for knowledge at the very limits of our imagination. Modern research universities of the caliber of the University of Michigan have the rare power to bring together these critical ingredients. By attracting the best and most passionate scientists, providing them with an environment rich in intellectual and technical resources, minimizing the barriers, and ensuring that these great talents are able to remain focused on the scientific enterprise, the University of Michigan can emerge as a major force for enabling the future of the biosciences for the greater good.

Appendix 6. Membership of The President's Advisory Panel on the Biosciences

Martha E. Pollack, Chair, Provost and Executive Vice President for Academic Affairs, Office of the Provost, Professor of Computer Science and Engineering, College of Engineering, and Professor of Information, School of Information

Huda Akil, Gardner C. Quarton Distinguished University Professor of Neuroscience & Psychiatry, Co-Director & Research Professor, The Molecular and Behavioral Neuroscience Institute

Ruma Banerjee, Associate Chair and Vincent Massey Collegiate Professor of Biological Chemistry, Medical School

Liz Barry, Special Counsel to the President, Office of the President

Dana Dolinoy, Associate Professor of Environmental Health Sciences, School of Public Health

Kojo Elenitoba-Johnson, Henry Clay Bryant Professor of Pathology and Professor of Pathology, Medical School

Eric Fearon, Emanuel N. Maisel Professor of Oncology, Professor, Departments of Internal Medicine, Human Genetics and Pathology, Associate Director for Basic Science and Deputy Director, University of Michigan Comprehensive Cancer Center, Chief, Division of Molecular Medicine & Genetics, Department of Internal Medicine

Carol Fierke, Jerome and Isabella Karle Distinguished University Professor of Chemistry, Professor of Chemistry, Chair, Department of Chemistry, College of Literature, Science, and the Arts and Professor of Biomedical Chemistry, Medical School

Rich Gonzalez, Professor of Psychology, Professor of Statistics, LSA, Professor of Marketing, Stephen M. Ross School of Business & Research Professor, RCGD, ISR & Research Professor, Center for Human Growth & Development

S. Jack Hu, Interim Vice President for Research, J. Reid and Polly Anderson Professor of Manufacturing Technology, College of Engineering

Trachette Jackson, Professor of Mathematics, College of Literature, Science, and the Arts

Joerg Lahann, Professor of Chemical Engineering, Professor of Materials Science and Engineering, Professor of Biomedical Engineering, Professor of Macromolecular Science and Engineering and Director of the Biointerfaces Institute, College of Engineering

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