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BIOMOLECULAR ENGINEERING
AY 2006—10 PLAN

Introduction and overview

Maintaining and building excellence

Biomolecular engineering has been a program of great promise within the long-term planning in the School of Engineering for a considerable period of time. The departmental goal is to develop an innovative and interdisciplinary department at UCSC, clearly bridging perceived boundaries between engineering and the sciences. A second goal is to integrate powerful new physical and information engineering tools and practices with modern biology and biochemistry. With an international head start in the area of bioinformatics, we have sought to create a truly unique program. We believe we have succeeded, but are at such a delicate stage and so far from critical mass that this success is in imminent danger of failure.

As to be expected in such a thriving area at the forefront of modern biotechnology, it is both difficult and expensive to recruit faculty. Additionally, the rapid growth of our discipline has left the School, as well as the Division of Physical and Biological Sciences and the Campus unprepared for the laboratory needs of our faculty. Our international stature has assisted greatly with the difficulty of faculty recruitment, but can only partially mitigate the issues of insufficient resources. As an individual program, we have no way to address the short-term and long-term space issues related to wet laboratories and contiguity, and recognize that such will require some combination of renovation, remodeling, construction of new space, and review of the distribution of wet-lab resources in relationship to other academic plans and campus priorities.

Thus, we find our nascent (though nearly 5-year-old) Department at a crossroads, which is an appropriate place to be as we commence a five-year planning process. The Faculty of the Department of Biomolecular Engineering expects that a clear and committed choice of priority for the School of Engineering, Division of Physical and Biological Sciences, and the campus as a whole must take place. All parties must decide whether creation of a program in biomolecular engineering and bioengineering is a major priority of the campus. As a major priority, it then follows that research space, faculty positions, and start up funding appropriate to such a venture must be allocated.

Sustainability within Available Resources

We look forward to the discussion and development of a coherent academic plan for the Santa Cruz campus, and hope that a world-class and interdisciplinary Department of Biomolecular Engineering will be a major part of that plan. If so, we will need to be assured of sufficient resources in order to develop a long-term plan for new faculty positions, adequate start up packages, and research space that will enable these aspirations. There are three alternative outcomes that depend on decisions by the school and campus with respect to Biomolecular Engineering:

1) We can proceed with the current plan to create and maintain a Biomolecular Engineering program. This plan is feasible, but requires significant investment by the campus, which has not occurred in the past few years. The department has made a substantial effort to bring in a chair and a senior faculty member, but our ability to do so has been hindered by lack of competitive start up funding, wet lab space, and contiguous office space that would allow the daily contact so important to a thriving department.
2) We can abandon the idea of Biomolecular Engineering and instead build a Bioinformatics Department that will have reduced need for start up funding and wet lab space. We have the nucleus of a world-class program, but the failed attempt to hire wet-lab Biomolecular Engineering faculty without adequate resources has prevented us from growing our bioinformatics program. This solution would remove or severely delay the possibility of developing comprehensive undergraduate and graduate programs in bioengineering.
3) The least desirable alternative is to reabsorb existing faculty into other departments or have them migrate to other institutions If resources continue to be limited as they have been over the past several years, this will be the implicit choice.

The difficulty in creating interdisciplinary organizations within academic institutions is well known, and was recently studied in the report *Facilitating Interdisciplinary Research* from the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine (2005). The report includes five recommendations regarding institutional structure, and we find the following to the most relevant: "U-2: Allocations of resources from high-level administration to interdisciplinary units, to further their formation and continued operation, should be considered in addition to resource allocations of discipline-driven departments and colleges. Such allocation should be driven by the inherent intellectual values of the research and by the promise of IDR [interdisciplinary research] in addressing urgent societal problems."

Future Opportunities for Investment in New Endeavors

The Department of Biomolecular Engineering has had, since before its inception, plans for development of biomolecular engineering undergraduate and graduate programs, providing the appropriate community for mixing science and technology in an interdisciplinary program at the forefront of modern engineering research and training. The program faculty, also at the request of the Dean of Engineering, have expanded this vision into a full-fledged interdepartmental bioengineering program plan. Biomolecular engineering is leading the effort to create an undergraduate bioengineering program among the faculty of biomolecular, computer, and electrical engineering, along with other colleagues in the sciences and engineering. Although, on considering the 4 active bioengineering searches (2 in BME, 1 each in EE and CE), we have (just) sufficient resources for launching an undergraduate program in bioengineering in 1 to 2 years, the graduate program will take additional time and resources. Within current SOE hiring plans, and successful recruiting efforts (primarily dependent on startup and laboratory space issues) over the next several years, we will be able to launch M.S. and Ph.D. programs in Bioengineering in five years UCSC presently has 20-30 faculty members working in bioengineering and affiliated areas. Members of this group are already working to create a unified vision of research, graduate training, and undergraduate education in the broad area of bioengineering. We will present the ideas generated by some of these members, and an evolving draft plan in the main portion of our revised academic plan.

Synergistic Graduate Programs

If the space and startup resource issues with respect to biomolecular engineering can be solved, we will be able to quickly expand the planned new undergraduate program in bioengineering into a graduate program. The graduate program will clearly incorporate synergistic features, in that it will include not just BME faculty, but also faculty from other departments such as Electrical Engineering, MCD Biology and Chemistry. The synergism will arise from the interdisciplinary nature of bioengineering in which material science, nanotechnology, applied mathematics and statistics, computer engineering, computer science, and electrical engineering will all play a role. A current example of such synergy in BME is the nanopore project, which now includes faculty and students from bioinformatics, chemistry and electrical engineering. If the project is successful, the synergy will result in an instrument that will sequence DNA at rates exceeding 1000 bases per second, three orders of magnitude faster than existing sequencing technology.

Biomolecular Engineering as an interdisciplinary department at UCSC.

Biomolecular engineering has emerged nationally as a central theme of interdisciplinary investigation in both academic and industrial settings. This discipline developed from the fusion of molecular and cellular science with engineering. Typical problems in biomolecular engineering concern the design, creation, characterization and manipulation of macromolecules such as proteins and nucleic acids for specific applications in basic research, health sciences and biotechnology. Biomolecular engineering also includes the development of new tools for these applications, such as microchips, single molecule biophysics, and nanoscopic machines.

For the purposes of this planning document, bioinformatics can be considered to be a sub-discipline within biomolecular engineering which focuses on the information content of nucleic acids and proteins. Research in bioinformatics typically uses sophisticated computational approaches to analyze large amounts of complex data. Genome sequences and data sets from high-throughput experimentation (such as microarrays) are examples of such data. The aim of bioinformatics is to establish relationships between sequence information and biological function. Understanding such relationships has become an important focus of modern medical diagnostics and new therapeutic approaches, and promises a more broadly based knowledge of molecular biology and evolutionary mechanisms.

The Department of Biomolecular Engineering was founded at UC Santa Cruz in January, 2003. The Baskin School of Engineering considers the BME Department its highest priority to develop, with commitments in new faculty and staff FTE and in space. We are the newest academic department in the School of Engineering, and administer the undergraduate and graduate program in bioinformatics. As will be outlined later in this plan, we also propose to establish an interdepartmental bioengineering program as we grow our faculty UCSC enjoys international acclaim for its pioneering research and graduate instruction in Bioinformatics and its ongoing contributions to the Human Genome Project. Also, a substantial number of UCSC faculty are already focused on collaborative efforts in BME, and are actively developing courses and programs of study in these areas. Bringing these faculty together in a departmental setting has provided the infrastructure and organization to allow these faculty and programs to thrive. The department will offer an interactive environment in which colleagues and their students can undertake cutting-edge interdisciplinary research and develop exciting new academic programs for the next generation of biomolecular engineers. The students will find career opportunities in both academic and industrial settings.

Planning for additional faculty FTE.

Our near term goal is to recruit a sufficient number of faculty in order to achieve critical mass. We will recruit only the most talented faculty members who regard themselves as cross disciplinary, and can work at the molecular and nanoscale level with the tools of both computational and experimental science. The department plans to grow to a total of 14 ladder-rank faculty by 2010-11, including at least one Howard Hughes Medical Institute (HHMI) investigator, plus one faculty member who will has a split appointment with the BME and Computer Engineering Departments. It will also attract several affiliated faculty from UCSC's Molecular, Cell and Developmental (MCD) Biology and Chemistry and Biochemistry (CBC) Departments, as well as other School of Engineering Departments.

Our definition of biomolecular engineering encompasses three overlapping fields:

Engineering of biomolecules, including protein engineering and synthetic biology;

Engineering with biomolecules, including biosensors, synthetic biology, biomolecule-assisted nanotechnology; and

Engineering for biomolecules, including bioinformatics, laboratory automation, especially for high-throughput experimental techniques.

The biomolecular engineering hiring plan for the next three years is focused on solidifying our core strengths to enable delivery of a comprehensive program in biomolecular engineering. Our program will also be a component of future bioengineering initiatives. The positions include a mixture of wet lab and computational lab needs, though in all cases, our ideal researchers will span computational and wet lab approaches, using the knowledge an understanding of each to accelerate discovery and design.

<u>2005-06, two full range recruitments in</u>

Bioinformatics

Protein Engineering.

Our expectation is that one of the two hires may be able to come in as chair of the department. However, our primary interest is to increase our numbers from 3 to 5 active faculty members who can help develop the department.

<u>2006-07, two assistant professors</u>

Protein Bioinformatics or Computational Proteomics

Synthetic biology/Biosensors/Systems Biology

<u>2007-08, one assistant professor, one full range</u>

Nanotechnology applications in biomolecular engineering

Stem cell research/ Genomics

<u>2008-09, one assistant professor</u>

Nanotechnology/Macromolecules

<u>2009-10, two assistant professors</u>

Genomics, Stem cells/biomaterials

Biomaterials/Microbial Engineering

Justification of recruiting priorities

We currently have one of the leading groups in the world in protein structure prediction, but much of the future of computational study of proteins will be in designing proteins. The leading group in protein structure prediction (David Baker's group at University of Washington in Seattle) has already ventured into protein design with some success, and this is a natural direction for the Biomolecular Engineering Department here to pursue. With the departure of Carol Rohl, our strength is all in the computational end of things, but we need someone who can lead the wet-lab work, as purely computational protein design is a rather empty exercise. Even if Dr. Rohl returns from leave, her work has been more than half computational, so we would still need an experimentalist to balance the research.

Protein bioinformatics

This position could either be a replacement for Carol Rohl or could be an expert in the computational aspects of proteomics (which is mainly concerned with identifying complex mixtures of unknown proteins), to complement prospective experimentalist hires within the sciences.

Synthetic biology position

A new field in bioengineering is the engineering of existing biological systems by adding several genes to existing organisms to create new signaling pathways and new functions. The approach can be quite modular, reusing standard components, thus fitting in well with engineering design styles in other disciplines. We have had one candidate for chair who is particularly interested in this field, and it promises to be a fruitful new field for 21st century bioengineering.

Bioinformatics position

We are facing up to the fact that we may not have adequate wet lab space to recruit effectively in 2005-06. For this reason we have decided to use one of the positions for the area of bioinformatics. David Haussler and Jim Kent have made the genome browser at genome.ucsc.edu the best resource for comparative genomics in the world. Dr. Haussler sees the grand challenge of the human genome as explaining the evolutionary history of every base of the genome. This requires comparison with many other genomes across a wide variety of organisms. The rate of new discoveries is exceeding what the current team can handle. Furthermore, since Dr. Haussler and Dr. Kent are not teaching (except by advising grad students), we are seriously short of faculty who train undergrads and first-year graduate students in the techniques of comparative genomics. We need to add a faculty member to research, teach, and mentor in this new field to maintain our lead position. Since we already have the premier research group, recruiting in this field should be relatively easy.

Nanotechnology development/high throughput engineering

Our primary current expertise in Engineering for Biomolecules is in bioinformatics, a form of information engineering. We also have expertise in DNA microarray technology, but need to expand into additional high throughput techniques, such as micro fluids, proteomic and microarray technologies, robotics, and many other areas. Without such an expansion, it will be difficult to launch our academic programs in biomolecular engineering.

Our current expertise in these fields is restricted to non-permanent faculty. Adjunct Associate Professor Mark Akeson and Interim Chair David Deamer use a transmembrane protein to create nanopores that are used for studying DNA. In this research, biomolecules, biophysics, and signal processing are being combined to potentially create an ultra-high-speed DNA sequencer. Adjunct Professor Jonathan Trent

(NASA) has been studying the heat-shock protein HSP60 and applying it to self-assembling nanostructures.

We would expect these new faculty members to have strong collaboration potential with our existing research programs. Thus, proteomics or microarrays would be the most likely areas for the high-throughput technology position, and nanotechnology related to existing nanopore science or other areas in BME and collaborating programs. Of course, we will maintain broad searches to ensure recruitment of top candidates in these rapidly evolving areas.

Stem Cell Biology

We seek to recruit faculty members taking a biomolecular engineering approach to solving problems in stem cell biology. New research in stem cell biology is opening doors to understanding fundamental problems in molecular biology. The differentiation of stem cells into specialized cells is a complex process involving networks of genes linked together by transcriptional regulatory circuits, intracellular signaling cascades, and cell-cell interactions. Our understanding about the detailed events and the genes involved in these processes is incomplete.

New developments in stem cell biology take a genome-wide approach at analyzing the entire network of genes and how their function is modulated during development. New biomolecular engineering techniques in stem cell biology will contribute to our understanding of the causal genetic events underlying how cells specialize from stem cell progenitors. These approaches will greatly complement our strengths in genomics and bioinformatics, creating opportunities for new avenues of scientific investigation.

The passage of Proposition 71 in 2004 gave California universities and research institutes three billion dollars for research in stem cell biology over the next ten years. In collaboration with the Molecular Biology Department, BME Professor Haussler will lead a stem training program with more than a million dollars from the California Institute of Regenerative Medicine to support graduate students and postdoctoral scholars in stem cell biology. BME has already committed itself to this exciting and promising area of research. To guarantee our future success in this area, we seek colleagues who can both help train these students and who will be able to compete for Proposition 71 research grants that will be made available in the near future.

Systems Biology

We seek to recruit faculty members doing research in the area of Systems Biology. New high-throughput advances in molecular biology research are quickly changing how biological problems are being solved. Exciting research in this area lies at the interface between biology and engineering. To complement our expertise in computational analysis of genome-wide datasets, we seek colleagues that will develop new technologies for measuring molecular phenomena of entire cells or tissues on a global scale. These include but are not limited to techniques for measuring transcriptional changes, alternative splicing, protein abundance, protein modification state, genome-wide knockout studies, and synthetic genetic interaction mapping. We seek faculty that are applying existing technologies to new biological questions, especially those relating to stem cell research, as this is another one of our target areas. We believe our scientific impact as a department will be maximized by integrating our efforts with scientists that are taking a global engineering approach to understanding molecular systems.

Biosensors

We aim to recruit faculty involved in biosensor research for two reasons. First, biosensors can be highly specific, inexpensive and portable, therefore they will play an increasing role in disease diagnosis, forensics, detection of pathogens in food and water supplies, and detection of airborne pathogens released from bioweapons. Second, biosensors require research expertise at the interface between electrical engineering, nanoscale fabrication, data processing, control theory and biochemistry. Biomolecular Engineering (and the Baskin School of Engineering more generally) has already established effective interdisciplinary research between faculty in these areas. Therefore, we are optimistic that new faculty recruits working on biosensors will thrive in this environment.

Genomics/Stem cell biology

The priority here is determined by the same issues described above for seeking a stem cell biologist. Here the emphasis will be to complement that hire with a second hire using computational analysis of stem cell data. The differentiation of stem cells into specialized cells involves networks of genes, and signaling cascades. Understanding the genes involved in these processes can only be done using the methods of genomics and bioinformatics. We therefore seek colleagues who can train undergraduate and graduate students in this burgeoning field, as well as competing for Proposition 71 research grants.

Modeling

Computational modeling of biological processes is now an essential aspect of contemporary research in biomolecular engineering. Such modeling ranges from molecular dynamics simulations of individual molecules as they interact with other cell structures, to establishing interactomes that describe all protein-protein interactions occurring in a given cell type, to models of physiological and electrophysiological processes that underlie tissue level function. Expertise in modeling is therefore required for Biomolecular Engineering, and we will seek new faculty members who can bring their expertise to the UCSC campus.

Biomaterials

Virtually all of the advances in understanding biomolecules and their applications in research and biotechnology now involve novel materials. Examples in Biomolecular Engineering and Electrical Engineering include the silicon nitride nanopores being developed for DNA sequencing, the ARROW waveguides that will be applied to single molecule detection devices, and implantable electrodes that will enable vision in the blind. All of these materials are being investigated on an ad hoc basis, and we do not have colleagues who focus on biomaterials in their research. For this reason we seek to hire a faculty member who will establish this area in BME, who can train undergraduate and graduate students in biomaterials and thereby provide a valuable resource for our department.

Microbial engineering

Synthetic biology relies in large part on devising "toolkits" of genetic information that can be used to program microorganisms and eukaryotic cells such as stem cells. A faculty member specializing in microbial engineering will therefore complement our new hire in synthetic biology that was described above, as well as providing expertise in growing an engineering live cells. We see this individual as an essential component of a complete department with the research theme of biomolecular engineering.

Hiring schedule

An accelerated hiring plan is required to place BME back on track with respect to our long-range plan. The 10-year plan for 2005-06 shows BME with 11 positions, and one vacant (HHMI). Thus, for 2005-6, we will be at 38-47% (after first hire in 2001-2). Meanwhile, the School is at approximately 72%, and the other programs are at 100% of plan (ISM, 5 faculty, first hire 2003-4), 83% (AMS, 10 faculty, first hire 1998-99), 70% (EE, 12 faculty, first hire 1997-98), 72% (CE, 16 faculty, first hire 1985-85), and 71% (CS, 22 faculty, first hire 1965-66).

Research program

A recent comparison by the School of 2003-04 quantitative information with the the10-year plans shows a high level of achievement in our program. Although our undergraduate enrollment numbers are below target (as can be expected with a tiny faculty that must, as first priority, cover its internationally respected graduate program), we are presently addressing this issue with by offering cross-listed electives for biology majors. All other measures show great strength. Our graduate and undergraduate major headcount numbers are, per capita, virtually identical to plan. Indeed, the small number of BME faculty is the strongest restriction to growth in our highly competitive graduate program. Our direct research expenditure ($5.6M) is over 3 times higher than per-capita plan, and we generated $1.3M of indirect costs on those expenditures. Our graduate program is a huge success, as evidenced by the rare receipt of an NIH Training Grant by a program in its first year of existence.

Qualitatively, our research program has been a shining beacon of the School of Engineering and campus. Our international reputation is extraordinary, and as a result it has among the lowest acceptance rates for graduate students on campus, and is unique in the School in its ability to attract a large body of high quality domestic applicants. Despite these obvious successes, we are justifiably concerned that the faculty foundation of our beacon may be crumbling, and thus an accelerated faculty schedule is required.

Evaluation indices for Biomolecular Engineering

We have chosen the following indices to be appropriate for our department. The numbers cited under the Planned column are for AY 2010-11, assuming 14 ladder faculty in BME.

Academic indices for evaluation

Enrollment in UG courses
Graduate student enrollment
Graduate students per faculty member

Research indices for evaluation:

Extramural research grants
Publications in peer-reviewed journals
Citations per paper
National and international recognition

Plan for enrollment FTE

The Department of Biomolecular Engineering, even with its small size, has high international recognition in bioinformatics and the core areas of computational genomics and protein structure prediction. Our bachelor's program in Bioinformatics was the first in California, and the graduate program has instantly become one of the most selective on campus.

Program	AY01	AY02	AY03	AY04	AY05	AY06	AY07	AY08	AY09	AY10
Bioinf 2001 Plan	25	30	60	74	85	85	85	85	85	85
Biomol 2001 Plan				10	30	60	75	75	75	75
Bioinf Act & Revised Plan	6	30	44	47	57	65	75	85	85	85
Bioengineering Planned						30	50	70	90	100
Bioinf MS/PhD Planned			35	50	75					
Bioinf MS/PhD Act & Rev			17	26	26	35	40	45	50	55

The above table includes the 2001 planned headcounts for the bioinformatics BS and graduate programs, as well as the biomolecular engineering undergraduate program. The remaining rows show the actual and updated projections for these majors. As can be seen from the above table, the Bioinformatics programs have not met the 2010 goals. In both cases, this is primarily due to the exceptionally slower than planned growth of the faculty -- Biomolecular Engineering presently has 1 full-time faculty, one with full teaching relief. This slow growth has forced us to concentrate resources on the demanding graduate program, primarily composed of PhD students, and has also forced us to admit fewer of the exceptional applicants to the Bioinformatics graduate program than desirable.

During the coming years, the joint developing of a B.S. in Bioengineering by BME, Computer Engineering, Electrical Engineering, and MCD Biology greatly increase the number of majors working at the interfaces of biology, medicine, and engineering, and planned growth in faculty will begin to remove this bottleneck to the growth of our nationally-recognized graduate program.

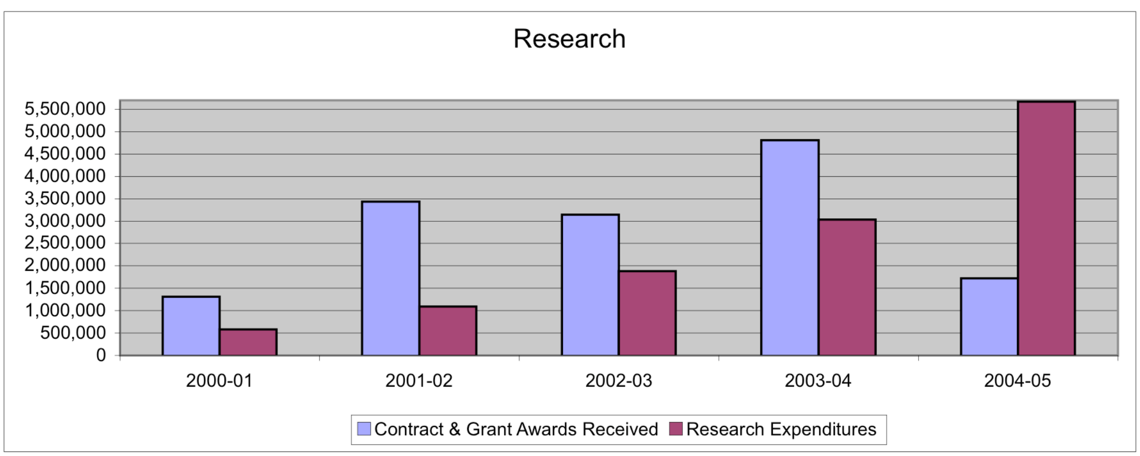
The table below shows undergraduate and graduate majors headcount and enrollments in BME (Bioinformatics program) since its inception.

7Year	2003	2004	2005
Undergrad	-	32, 119	25, 223
Grad	-	17, 84	26, 147

It is clear that the graduate program is robust and growing, but that the undergraduate major has not yet attracted sufficient numbers of students. We believe that the Bioengineering will drive increased enrollments in courses offered by Biomolecular Engineering. The undergraduate program in bioinformatics is not intended to become huge, as with Computer Science or MCD Biology, but to remain a relatively small, highly demanding program. A detailed plan for this major is included later in this academic plan.

Plan for extramural research support.

The graph below shows income and expenditures from grants to BME faculty. The major fractions of the current funding goes through HHMI, with Prof. Haussler as PI, but all BME faculty have existing grants or pending applications. The graph does not show recent awards to the Deamer laboratory ($1.5 M, 3 years) which started in October 2005, not does it show a new NIH grant to Dr. Mark Akeson, adjunct Associate Professor in BME.



With only four active ladder faculty, it is not possible to engage in a detailed planning effort related to extramural funding except to note that we will continue to seek substantial extramural funding for our research efforts. If we are able to hire six new faculty by 2010, according to our plan, the expected annual external funding for the department is projected to be $8M, comprised of an average of $350K/yr for each of the

10 state-funded faculty members, plus an additional $4-$5M per year from HHMI and large, multi-PI project grants.

Additional measures of success appropriate for Biomolecular Engineering

The Department of Biomolecular Engineering has taken a leadership role in the creation of an undergraduate degree program in bioengineering. The success of this program, and of the related development of a graduate program in bioengineering, and possibly biomolecular engineering, will provide a discrete measure of success of the program. Although maintaining this leadership will be a strain on present faculty resources (BME presently has only 3 full-time, full-duty faculty, two part-time leadership faculty, 2 adjunct faculty, and one HHMI Investigator), the critical importance of this area to the School of Engineering and campus means that we will work hard to ensure the success of this collaborative venture. . UCSC presently has 20-30 faculty members working in bioengineering and affiliated areas. Members of this group are already working to create a unified vision of research, graduate training, and undergraduate education in the broad area of bioengineering. Here we will present the ideas generated by some of these members, and an evolving draft plan.

In the first half of the 20th century, the advent of high-speed communication and electrification enabled high-technology engineering. In the second half of the 20th century, the transistor and integrated circuits were the drivers of high technology. Now, in the first half of the 21st century, it is expected by many that advances in understanding biosystems, and manipulation of biomolecules will be the foundation of 21st-century engineering. At UCSC, the late advent of engineering has allowed us to be on the forefront of developing trends. In 1984, we were able to focus our growth into a new, interdisciplinary area of engineering strongly coupled with the neighboring Santa Clara region: Computer Engineering. Now, with our focus on Biotechnology, Information Technology, and Nanotechnology, we are maintaining a commitment to looking forward to the advent of new hybrid, cross-disciplinary technologies. This is a significant advantage in comparison to other schools with strongly established programs in the older branches and subdisciplines of engineering. We were able to leap ahead of such programs with the creation of cross disciplinary engineering programs emphasizing the cutting edge of technology and its impact on society, as in our electrical engineering program focused on nanotechnology and biomolecular engineering program with worldwide recognition for its contributions to bioinformatics.

The next natural step for UCSC is bioengineering. Within the 21st-century, the rapid advances in the biological sciences, here and elsewhere, provide the underlying framework for a broad bioengineering program at UCSC that focuses on macro, micro, molecular, and societal bioengineering. Engineering is not just the discipline of technology, but one of technology in the service of society. According to the recent report of the National Academy of Engineering (NAE), *The Engineer of 2020: Visions of Engineering in the New Century*,

> It is our aspiration that engineering educators and practicing engineers together undertake a proactive effort to prepare engineering education to address the technology and societal challenges and opportunities of the future.

At UCSC, with a strong emphasis on liberal, scientific, and engineering education, as well as existing research and education in bioethics and the human sciences, we are ready to combine technology, science, and society not just at the research level, but also in the development of undergraduate and graduate academic programs. In this draft discussion of bioengineering, we are focused on the applications of engineering to medicine and the biological sciences in collaboration with the exceptional strong existing programs in the biological sciences, physical sciences, and biomedical research at UCSC.

Our campus presently engages in bioengineering research within the biomolecular engineering, computer engineering, and electrical engineering programs in collaboration with the biological sciences, computer sciences, mathematics, philosophy, physical sciences, and psychology. With existing faculty, it may be possible to create modest graduate minors in areas of bioengineering, such as biomedical imaging, bioinformatics, and assistive technologies. A moderate investment may enable the creation of more general graduate and undergraduate minors in bioengineering. A larger investment will be required to create graduate and undergraduate programs in bioengineering to serve the needs of our students, California, and society.

At all levels, students have realized the importance of the joining of biology and engineering into a discipline focused on using technology to better society, both collectively and individually. Indeed, according to the NAE report, creating and designing “technology for an aging population" is one of the four broad technological challenges that the engineer of 2020 will face. It is only by providing a unified program that we can effectively train our engineering graduates to solve these problems.

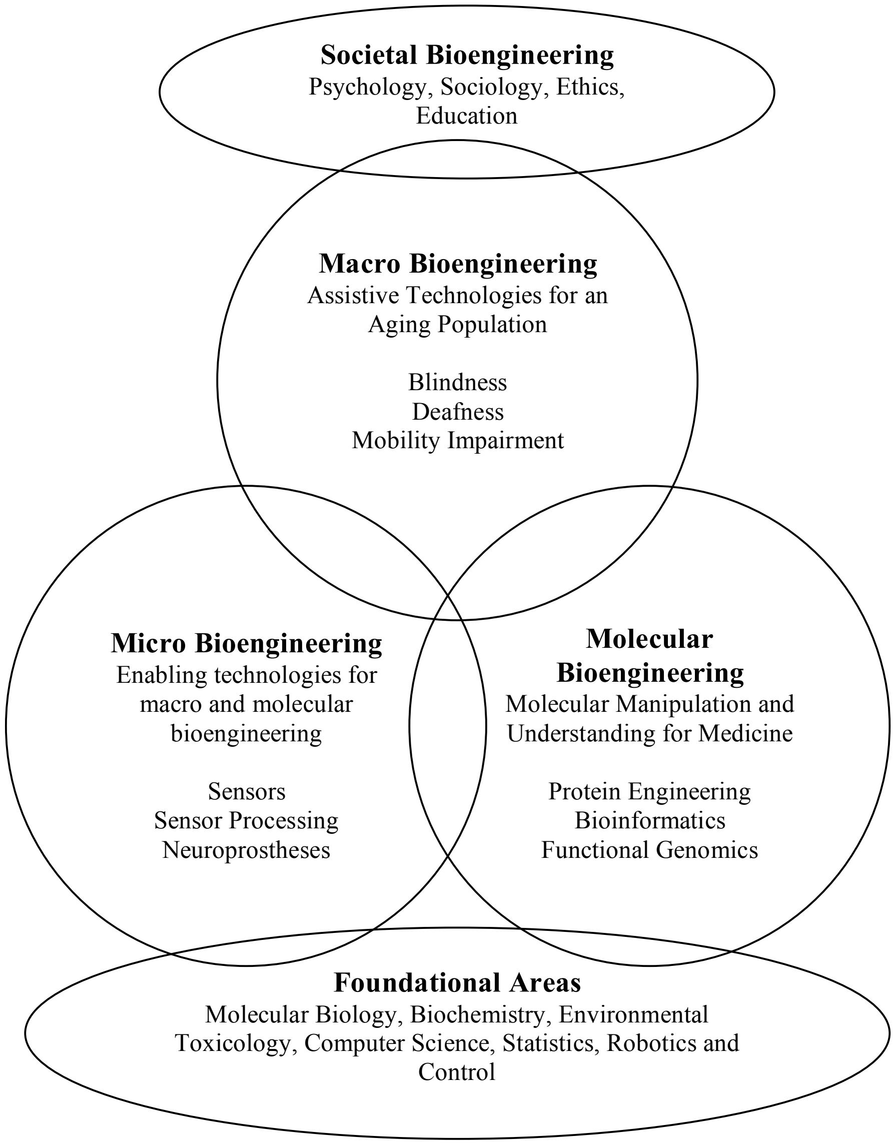
Growth in bioengineering has been spectacular, as technology advances enable discovery and design of the highest impact to our aging population. Over 1999-2002, the number of Bioengineering BS degrees granted increased by 50%, MS by 78%, and PhD by 30%. The formation of a new NIH Institute, the National Institute for Biomedical Imaging and Bioengineering is another indicator of the growth and permanence of this discipline. In the University, bioengineering programs and departments exist at 9 of the 10 campuses; ours is the only campus without a bioengineering program.

For undergraduates, "bioengineering is one of the fastest-growing majors at many universities" (ASEE PRISM, November 2004). At UCSC, the strong interdisciplinary focus of much of our research can immediately enable undergraduate minors in areas related to bioengineering, and with a few targeted faculty hires, enable a complete degree program.

At the graduate level, there is similar growth, spurred in part by the influx of Whitaker Foundation funding. The University of California has recently formed a Multi-Campus Research Unit (MRU), the Bioengineering Institute of California. Founded as a collaboration of all of our campuses, the MRU focuses on using distance and Web technologies to enable a broad coverage of bioengineering academics at all campuses, and an annual UC Bioengineering Symposium. In summer 2005, the UCSC School of Engineering and Center for Biomolecular Science and Engineering hosted this system wide event.

Undergraduate and graduate bioengineering is also an exceptional opportunity for diversity within engineering. At the undergraduate level in 2003, 40% of biomedical engineering degree recipients were women. Presently, the School of Engineering has fewer than 20% female students. Bioengineering also provides an opportunity for gender diversity within our faculty; although in 2003 our School of Engineering was eighth nationwide in percentage of woman faculty, 13.6% woman faculty is not an accomplishment that indicates that the work is complete. UCSC also has a low population of disabled students, who are, because of the potential direct impact, often interested in bioengineering and assistive technologies. This confluence of research directions, societal needs, and opportunities for diversity makes the development of a bioengineering program particularly timely.

The figure on the next page shows diagrammatically how we envisage bioengineering to fit into our research programs, the UCSC campus, and society at large. The goal of all bioengineering is in a sense societal in nature - assisting people and society to better the quality of living. In the "primarily macro" area, we propose continuing to develop our current excellence in assistive technologies for the aging population. In the “primarily micro" area, we propose a strong emphasis on bio sensors, sensor processing including biomedical imaging, and the creation of micro prostheses, leapfrogging existing programs with macroscopic prostheses programs. In the "primarily molecular" area, we will continue to develop our excellence in biomolecular engineering and informatics. And societal bioengineering, we will use our understanding of individuals and societies to develop new technologies and seek to understand the impacts of these technologies on individuals and societies.



Macro Bioengineering

We envision a new generation of researchers, educators, and entrepreneurs committed to shaping the future of human–centered assistive technology. Mainstream approaches to engineering education may not adequately take into account human factors that directly affect the usability of new technology. The gap between engineering creativity and final user considerations is particularly serious in the case of technology designed to aid the disabled or the elderly. All too often, engineers are tempted to build tools and devices "just because computers can do it", without enough awareness of the reality and actual needs of disabled individuals. The net result is a very limited adoption of advanced technology by such communities.

We propose a multidisciplinary, “participatory” approach to the development of tools and practices for assistive technology, which relies on close collaboration between technology designers, cognitive scientists, and end–users. This approach offers great potential for cooperation between the UCSC School of Engineering and the Psychology Department. In addition, the establishment of UARC opens new opportunities for research and graduate student training at the NASA Ames Research Center (ARC). In the past, interaction between mathematical science and engineering on one end, and psychophysics and cognitive science on the other hand, has proven very successful, for example in the development of theories of human vision and in the implementation of biologically inspired algorithms and systems. The proposed cooperation also draws from a large body of knowledge in human–centered design, pioneered by NASA ARC in the context of engineering systems for aeronautical and space systems.

Developing technology to assist an aging population encompasses a number of research fields, straddling across Engineering (sensor processing, human–machine interface, robotics, hardware integration) and Psychology (psychophysical models of sensory loss, predictive cognitive models). Specific areas of research that will be emphasized by the Macro Bioengineering program include:

Mobility, wayfinding and accessibility for the visually impaired and mobility impaired.

Integrated and wearable mobility tools to aid safe and comfortable deambulation; indoor/outdoor wayfinding technology; control of autonomous or semi–autonomous wheelchairs; increased independence in assisted living environment for blind and mobility impaired individuals. (Professors Manduchi, Tao, Elkaim, Dunbar, Nourbakhsh)

Human–machine and human–environment interfaces.

Tactile/acoustic virtual map exploration for the blind; speech recognition for deaf or hard–of–hearing individuals; eye tracking, along with the translation of eye motion patterns into desired actions, for human/machine interface for the mobility impaired. (Professors Manduchi, Pang, Tao)

Cognitive models for predicting and assessing user performance.

Analysis of the influence of cognitive aging and task–coordination strategies for dual–task performances; computational models to simulate aging effects; emotional bias in elderly and disabled individuals and its influence on memory and attention. (Professors Massarro, Travis, Mather)

Assistive technology for the blind at the Macro Bioengineering level ties in with research in Neural Prosthetics, which is part of the Micro Bioengineering area. The prosthetic retina project conducted by Prof. Liu offers opportunity for innovative sensor processing technology and raises fascinating new questions about the psychological and psychophysical aspects of sensorial augmentations.

Additional potential benefits of the proposed Macro Bioengineering program include the establishment of long–term relationships with external research institutions in different areas of assistive technology, fostering continuing exchange of experience, user studies, and technological solutions, and providing insight into psychological, social, and day-to-day practical aspects of living with a disability. Even more important is the potential for creating an open and attractive environment at UCSC for disabled students, who may provide a unique perspective on the future of assistive technology.

Beyond the specific focus on assistive technology, we believe that students formed under this program will represent valuable assets in many other fields of today's professional world. Participatory and human–centered design are important paradigms for the creation of really usable hi–tech products. We have received very encouraging feedback from several companies, not necessarily directly related to Bioengineering, about job placement prospects for students equipped with the skills developed under the proposed program.

Micro Bioengineering

Micro bioengineering includes the development of sensors for biomedical applications, the computational and algorithms for understanding sensors, and the creation of micro-scale prostheses and other devices for medical use. Presently, all three of these areas are represented by faculty research programs, and there is some likelihood that new research programs will involve in micro bioengineering and nanobiotechnology.

Sensor development, at the boundaries of micro and molecular bioengineering, include "lab-on-a-chip" technology, such as that integrated optical waveguides with liquid cores, enabling light propagation and measurement through small volumes of liquids on a chip (Schmidt), microscopy (Isaacson), and nanopore technology (Deamer, Akeson).

Once sensed, data must be understood using statistical and algorithmic techniques. Examples include cell tracking (Tao, Hughey, Di Blas, in collaboration with Ottemann), signal and image understanding, and related areas.

The use of micro and nano devices to directly solve medical problems is best illustrated in the artificial retina project (Liu) and biomimetic technology development (Liu and Isaacson).

The continued development of robotic and high-throughput technologies for the biomedical science and engineering, a focus of the draft document on biomedical research at UCSC is also an area of micro-scale bioengineering.

Molecular Bioengineering

Molecular-level bioengineering includes the analysis, manipulation, and detection of biomolecules. While the central core for molecular bioengineering at UCSC will be the Department of Biomolecular Engineering, the area also involves many researchers within the biological sciences, computer science, physical sciences, and electrical engineering.

Molecular bioengineering concerns three overlapping fields:

- *Engineering of biomolecules,* including protein engineering and synthetic biology;
- *Engineering with biomolecules,* including biosensors, synthetic biology, biomolecule-assisted nanotechnology; and
- *Engineering for biomolecules,* including bioinformatics, laboratory automation, especially for high-throughput experimental techniques.

The Department of Biomolecular Engineering, founded upon the international prominence of our research in bioinformatics, is one of the Schools most strongly targeted growth areas. In addition to expanding the graduate program in bioinformatics to better meet demand (faculty advising capacity limits admission to 20% of Ph.D. candidates), the program will continue to expand into protein engineering, synthetic biology, nanotechnology applications in biomolecular engineering, and high throughput experimentation and analysis.

The natural allies of these technological disciplines include molecular biology, biochemistry, micro fluidics and all areas of micro bioengineering, computer science, and statistics. This fundamental work at the molecular level of bioengineering will provide the basis upon which new medicines, technologies, and procedures will be developed within the domains of macro bioengineering and micro bioengineering.

From its start, the academic programs in bioinformatics have also cultivated relationships with philosophy, co-creating a general education course (required for the undergraduate mathematics degree) in bioethics, and also providing a ready stream of students to upper-division in graduate courses in bioethics as required by the MS and Ph.D. programs. We would like to further strengthen this relationship, in particular with collaborative research associated with the modern ethical quandaries created by the biotechnology revolution.

Societal Bioengineering

We have begun discussions with psychologist and collaborator Dom Massarro about the societal level of bioengineering. Although we have not fully defined this area (this would be a topic of the bioengineering planning retreat discussed below), this area is expected to examine the human factors, human impacts, ethics, and quandaries that our next generation of technologies will bring to bear upon individuals and societies.

We will seek to collaborate with researchers in psychology, sociology, education, and philosophy to develop research in this area and, most importantly, continue our commitment to this most important aspect of bioengineering, as bioinformatics has emphasized and required academic courses in bioethics for all undergraduate and graduate degrees.

BIOENGINEERING MAJOR for the Bachelor of Science Degree

> *The UCSC Bioengineering Engineering program prepares graduates for a rewarding career in engineering. The BS in Bioengineering provides students with fundamental knowledge of mathematics, science, and technology, and advanced training in engineering principles and practice at the molecular, cellular and*

organismal levels. Graduates will be prepared to work as engineers solving problems in the biomedical and biomolecular domains, and to pursue advanced degrees in engineering, medicine, or science.

One of BME's most important efforts is the development of the BS in Bioengineering. It is our intention to complete the approval process of the BS in Bioengineering during AY05, accept first-year students in AY06, transfer students in AY07, and see the first graduates in AY08. After we have had students graduate from the program, we will immediately seek ABET accreditation to bring the total number of UCSC accredited engineering programs up to three. The addition of this third program (and the potential development of controls, robotics, and mechanical engineering led by Computer Engineering) will help move the SOE to becoming a full-service School of Engineering. No longer will students choose to attend our other campus' simply because there is an insufficient diversity of engineering majors and careers paths on our campus.

The draft table below indicates projected major and premajor headcounts: the planned of the 2001 10-year plan, the actual bioinformatics numbers through AY05, and planned bioinformatics and biomolecular engineering numbers in AY06 and beyond. Although the bioinformatics numbers are somewhat lower than planned in 2001, it must be noted that also our faculty count is 60% below plan, and has had to focus on our renowed graduate program, reducing the opportunity to further expand the majors. The current revision of SOE hiring priorities indicates that this will not be a problem during the coming half decade.

Program	AY01	AY02	AY03	AY04	AY05	AY06	AY07	AY08	AY09	AY10
Bioinf 2001 Plan	25	30	60	74	85	85	85	85	85	85
Biomol 2001 Plan				10	30	60	75	75	75	75
Bioinf Act & Revised Plan	6	30	44	47	57	65	75	85	85	85
Bioengineering Planned						30	50	70	90	100

The Bioengineering BS curriculum is actively under development in a group convened by BME Professor and Vice-Chair Hughey, and including faculty from BME (Akeson, Deamer, Karplus), Computer Engineering (Manduchi and Dunbar), and Electrical Engineering (Liu and Isaacson). As discussed above, the foci of the three programs is clear: BME focuses on the molecular-level bioengineering, electrical engineering focuses on micro-level bioengineering, and computer engineering focuses on macro-level bioengineering. Of course, as with all areas, these are not strict boundaries but overlapping clouds of interest.

The curriculum, designed for ABET accreditation, will require broad training in mathematics (6 courses in calculus, multi-variable calculus, engineering mathematics, biostatistics, and signals and system, the latter course being revised by EE to include more examples of biological systems), science (10 courses in chemistry, biology, biochemistry, and physics), programming (2 courses), and technical writing.

Unlike some bioengineering programs, we have paid special attention to ensuring there are first and second year courses that advance student understanding of bioengineering without requiring all the above prerequisites. To that end, Computer Engineering Professor Manduchi is creating a new topical course on Assistive

Technology and Universal Access to introduce students to the problems of the aging society, Electrical Engineering Profess Liu is creating a new topical course Introduction to Bioengineering that will focus on the interfaces between medicine and technology, and Biomolecular Engineering Lecturer Rothwell has created a low-prerequisite course, Introduction to Medical Biotechnology, focused on the biomolecular aspects of bioengineering. We expect these three courses to both maintain interest in the technology and application of bioengineering, as well as to give a broad overview of the problems that bioengineers can solve.

Toward the Junior year, students will take 3 more advanced core courses: EE's circuits course, BME's planned molecular biomechanics, and a course on physiological systems – physiology as explained using the tools of engineering. This last course is will to be taught by one of the new hires in EE, BME, or CE, depending on qualifications.

Students will then complete 3-4 electives in engineering or the sciences, a combination of existing courses and new courses planned by BME, CE, and EE. Bioengineering students will join other SOE engineering majors in the 123A/B 2-quarter senior design program. Bioengineers must of course apply their bioengineering training to the project, and indeed will bring a breadth of experience that could have improved many prior projects tackled by our design program groups, such as in animal and human monitoring.

It is expected that many bioengineering students will make use of summer session to complete their degrees. While the interdisciplinary bioengineering curriculum can theoretically fit into 4 years, we expect most students will proceed at a slightly slower pace, making use of summer instruction or one or two extra quarters. This is typical of most bioengineering programs in the system, where, as with ours, the total unit requirements for the major and campus are slightly above 200 quarter units. Nonetheless, we are convinced that this is the minimum acceptable program for our undergraduates.

Cluster hiring related to bioengineering

The bioengineering program is focused on cross-disciplinary faculty and projects, research that interfaces with other fields of engineering, the biological sciences, the physical sciences, and in the humanities (bioethics).

Our hiring plan is based on these three core areas of bioengineering, with recruitments in broad range of interdisciplinary research areas. The continued creation of this boundary-crossing program will enable continued success in training grants, centers, and other collaborative research.

BME faculty believe that we could usefully engage in interdepartmental cluster hires in the following areas:

Nanotechnology of biomolecules (Chemistry, Electrical Engineering)
Proteomics (MCD, Chemistry)

Biomaterials (Chemistry)
Bioengineering (Computer Engineering, Electrical Engineering)

The Department also sees need for the campus to develop clear and functional policies with respect to split appointments. In interdisciplinary fields, often faculty most appropriately wish to affiliate with multiple departments. Such practice is common in the more long-standing bioengineering programs at our University (for example, the Berkeley and Santa Barbara programs have a large number of zero or partial appointments), and is currently a great administrative barrier for this type of collaborative research. We advocate most strongly that the campus develop simplified procedures for formal zero and non-zero appointments of limited term (e.g., 5 years), as well as incentives for split appointment hiring at the tenured level. We lost one recent star faculty candidate from Santa Barbara who had a split appointment between bioengineering and chemistry on that campus, in part due campus inertia against such appointments. Although BME and Chemistry were both excited about the potential hire, the lack of existing policy made it impossible to complete such a venture within the hiring timeframe. The candidate decided to remain at Santa Barbara with, unfortunately, the clear impression that Santa Cruz is an exceedingly conservative campus. If we wish to move the campus to the top research tier, we must begin to experiment with our program and departmental structures in ways that administratively encourage cross-program collaboration and center-scale grants.

Near-term and longer-term investments

As part of the three-year hiring plans of the several departments, the near-term growth in the broad area of bioengineering is already underway. Biomolecular Engineering has proposed hiring six faculty members in Molecular Bioengineering. Computer Engineering has proposed hiring one faculty member specifically working in the area of assistive technologies, and has hopes and expectations that other hires will have interests in assistive technologies as well. The planned growth in general biomedical research at UCSC will provide continuing opportunities for leveraging and expanding research at all scales.

Planning for affirmative action and diversity

Our plan is simple. We will take every opportunity to assure that women and under-represented minorities have access to our academic programs and recruiting. We note that we have made serious offers to Prof. Pam Silver, Harvard University, and to Prof. Tony Guiseppi-Elie, an African American, to chair the department. For a variety of reasons, mainly having to do with limited resources available to the department, we were unable to attract these candidates to UC Santa Cruz. We also have Carol Rohl as an assistant professor in the department. Carol is currently on leave, taking advantage of an opportunity in Seattle, but we hope she will decide to return to Santa Cruz in 2006.

Space requirements for Biomolecular Engineering

Laboratory space is essential for recruiting talented faculty. While the delayed construction of PSB is a problem for the department, we must always remember that PSB does not include any wet lab space for Biomolecular Engineering. The only wet lab space and expected to be specifically allocated to BME is as a result of the ALTS2 and ALTS3 projects in E2. The quality of the planned laboratory space in these alterations has been markedly reduced due to budget restrictions, so that only two of the six laboratories will be ready for occupancy at the end of construction. This means that BME will be crippled in recruiting activities for the foreseeable future. This of course raises the additional issues that even in the best of scenarios, our faculty will be spread across four different buildings. Our Department was never planned to be large, so it will be difficult to maintain a sense of community in such a configuration.

After completion of the construction efforts over the next 2 - 3 years, BME will have approximately 12,000 asf available as wet lab, dry lab and office space. This includes 4,300 asf in PSB, and 7,600 asf in the Alts 2 and 3 remodeling of Baskin Engineering. We plan to recruit two new ladder faculty each year AY 05-06, 06-07 and 07-08. If all department faculty were to be accommodated in the space assigned to BME, we would fill the available space in AY 07-08, when we hope to have 10 faculty members including a full time chair of the department. To accommodate our planned growth to 14 faculty members by AY 09 -10, BME will require an additional 12,000 asf for offices, labs, support, and specialty spaces such as a tissue culture facility. Details have been previously provided.

It will also be essential to have two dedicated instructional wet lab spaces for certain undergraduate courses planned for the Bioengineering major. These include Molecular Biomechanics, Electrophysiology and the associated lab courses.