Report from the Faculty of Life Sciences Retreat

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Executive Committee of the Faculty of Life Sciences

Challenges and Opportunities for the Life Sciences at UNL in the 21st Century

How to feed a growing world population, provide sustainable and affordable energy, protect the environment and improve human health are some of the greatest challenges facing 21st-century society (NRC 2009). The world population will increase to approximately 9 billion people by 2050 and even the most optimistic scenarios require increases in food production of at least 50%. Climate change is also set to have a profound impact on food production. Rising temperatures, altered rainfall patterns and more frequent extreme events will increasingly affect crop and animal production. The harvesting, processing, and conversion of energy using current technologies also cause a large share of the world's most difficult and damaging environmental problems, such as increasing levels of greenhouse gasses. Moreover, our current energy supply is not sustainable since it is hugely dependent on nonrenewable sources. Carbon-neutral biofuels are being explored as a sustainable alternative to petroleum-derived fuels, but the emerging ethanol and biodiesel industries are presently a co-product from crops, such as corn and soybeans, grown as a food source. This poses problems of competition for land usage, expansion of crops into agriculturally marginal areas, deforestation, and potential threats to food security. The phrase 'perfect storm' has been used to describe the future coincidence of food, water and energy insecurity (The Royal Society 2009).

Research in the Life Sciences has the potential to contribute practical solutions to these crucial societal problems. UNL has strategic strengths in several key areas but a concerted investment will be required to advance towards an integrated understanding of complex biological systems in order to solve societal problems related to food, energy, the environment and health. It is essential and urgent, now and for future generations, to take on these challenges, given projections about population growth and resource availability (NRC 2009). A bio-economy, based on renewable resources rather than fossil fuels, is ambitious but necessary if we expect to achieve sustainability in a semi-closed Earth system ("We need to learn to live within our means," M. Jahn). Attaining these goals will eventually require coordinated public and private sector commitment and a reversal of the decline of investment in agriculture that has characterized the last few decades (N. Fedoroff). UNL is well positioned to take a leadership role in this area and promote the re-imagining of the land grant university. Moreover, building the foundation for a sustainable bio-based economy can provide a unifying theme for the development of Innovation Campus.

Land Grant Universities in the 21st Century

The Morrill Act of 1862 represented a profound innovation in higher education. The land grant universities were charged by law with promoting "without excluding other scientific and classical studies … the liberal and practical education of the industrial classes in the several pursuits and professions in life." While the institutions of the time focused almost exclusively on philosophy and theology the land grant universities would focus on broader practical instruction, based on the view that higher education could be a major engine for socio-economic development. Within this context, land grant universities must strive to break new ground and seek innovative approaches to serve society.

The land grant mission and the land grant tradition are as relevant today as they were in 1862 (M. Jahn). However, the mission, intended to be dynamic and responsive, must be adapted to the challenges and realities of the decades ahead. The fundamental principles of accessibility, practical as well as classical education, research and innovation in the public interest, and community engagement remain powerful and profound. Yet, the public, once unconditionally confident in science, now is more skeptical and even distrustful. There is a perception that scientists often give ambiguous or contradictory answers to important questions and that science is not fulfilling its promise. Despite evidence showing unparalleled rates of return on past research (The Royal Society 2009), there is a growing reluctance on the part of taxpayers (and funding agencies) to support research on an open ended, unrestricted basis (limiting our ability to pursue innovative approaches to fundamental problems). In part, the perception issue is caused by our inability, as natural scientists, to provide definite answers to some concrete problems, due to our limited understanding of complex systems such as the changing world's climate and its consequences for the biosphere.

Land grant universities will need to lead the way in redefining the social contract on science and in reeducating the citizenry with respect to the benefits of public support for research and discovery. New approaches to research and education in the Life Sciences will be necessary to understand complex systems in an integrative, predictive manner in order to provide answers to imperative societal needs. New outreach approaches will also be required to convey, more than ever, the significance of these studies to local communities and society at large.

The 'New Biology'

Research in the Life Sciences can contribute practical solutions to crucial societal problems (NRC 2009). However, almost since their inception, the natural sciences (those fields that use the scientific method to study nature) have been divided into two branches, the biological sciences and the physical sciences, and each has flourished into a number of sub-disciplines. Over time this has served functional purposes allowing scientists to concentrate on understanding simplified modules with astounding intellectual and practical successes. For instance, during the latter half of the 20th century, cellular biology was strongly influenced by reductionist approaches ('components' biology) that focused on the generation of information about individual cellular parts, their chemical composition and their biological functions. This strategy had a large impact on drug discovery and healthcare and has been greatly accelerated with the emergence of genomics and other 'omics' approaches. We can expect eventually to have what amounts to a 'catalog' of cellular components in a large number of organisms, although functional gene assignment is presently incomplete.

Yet, addressing some of the most fundamental societal challenges will require advancing from identifying parts to understanding complex systems and modeling their function in a predictive manner ('systems' biology). The barriers to advancement, comprehending systems structures, dynamics, quantitative design, modeling, simulation, are likely to be similar at all levels of organization, from cells to ecosystems (NRC 2009). Biologists will increasingly need to integrate ideas and methodologies from physics, mathematics, computer science, engineering and other fields to solve highly complex problems such as the biology of human health and disease or understanding how biological systems adapt and influence global processes such as climate change. In addition, understanding how society at large will respond to new technology and unexpected challenges is critical to improving the transfer of knowledge across the science-policy interface. A major challenge to realizing this vision of a 'New Biology' (NRC 2009) is finding effective ways to integrate disciplines by promoting collaborative approaches to research and education in the Life Sciences and related fields.

The Scientific Challenges

The central goal of the 'New Biology' is to understand and manipulate intricate biological systems in order to solve societal problems (NRC 2009). We have reached a point in research where we can truly appreciate the remarkable complexity of biological processes. However, if we can overcome the complexity barrier, the knowledge gained will provide means to effectively address vital societal needs. A deeper understanding will advance biology from an era of observation and mechanism to one of deciphering design principles for biological processes, making them accessible to manipulation and eventually predictable. This will require integration across disciplines, advances in basic science and the creation of innovative funding opportunities across university departments, federal agencies and interest groups. It seems reasonable to focus on a small number of inspiring problems that are important and urgent, intractable with current knowledge and technology, but perhaps solvable in one or two decades through transformative approaches. Six proposed scientific deliverables (supported by the presentations of M. Jahn and N. Fedoroff and the discussions at the retreat) include:

1. Stress Biology. Understanding how plants and animals can best adapt to a changing climate and thrive under unfavorable temperature, water, nutrient, pest and disease conditions in order to optimize food, biofuel and biomaterial production (higher yielding crops and animals with limited resources). Understanding stress biology will also have a significant impact on human health.

2. Bioenergy. Developing new feedstocks for the production of next-generation carbon neutral biofuels and other biomaterials in novel environments (without competition for agricultural land or quality water). Emergent new feedstocks may include algae, lignocellulosic, oil or sugar crops for saline or semi-arid environments.

3. Health and Food Design. Improving human health through a better understanding of nutrition and diet. Taking advantage of complex animal systems and their microbiota for advancing our knowledge of human nutrition as well as for improving the efficiency of feed use by livestock while minimizing environmental footprints.

4. Ecosystems. Understanding complex natural ecosystems to ensure sustainable agricultural systems. Current agroecosystems are based on optimizing gross production through monoculture and intensive fossil fuel and water inputs (NRC 2010), while ignoring ecosystem services provided by the rest of the system. Understanding the complexity characterizing natural ecosystems, the services they provide, and their responses to global change may help increase agricultural productivity and sustainability.

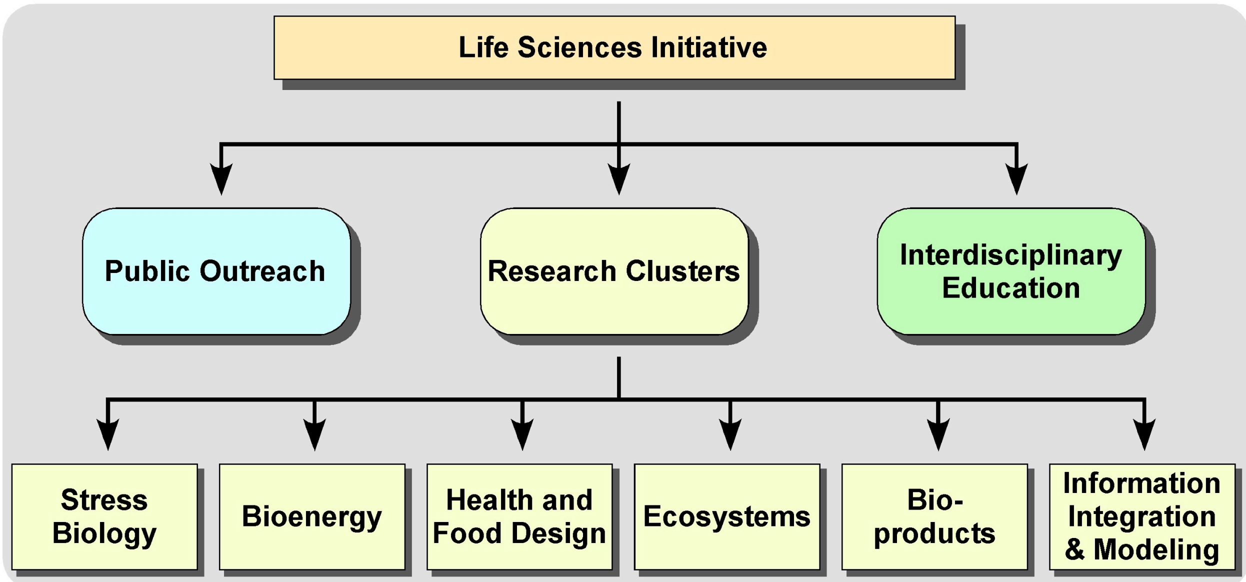
5. Bio-products. Developing new and innovative bio-based materials through closer coordination between researchers and industry to create novel plant, microbe and animal forms with desirable traits. New technologies based in our understanding of cellular metabolism will need to be employed to generate more efficiently drugs and nutraceuticals. The replacement of fossil fuel derived materials and the development of 'green' bio-processing technologies will become critical steps to achieve sustainability.

6. Information Integration and Modeling. Developing the quantitative tools to understand and model complex systems, from metabolites in cells to ecosystems (data storage and mining, pathway and network analyses, quantitative system design, modeling and simulation), and generating databases with publicly important information. Accurate data and policy relevant forecasts will be significant for scientists, extension services, and decision makers as well for engaging the public.

A new Life Sciences Initiative

UNL already has strategic strengths in each of the outlined scientific challenges but a concerted investment will be required to advance towards an integrated understanding of complex biological systems in order to solve societal problems related to food, energy, the environment and health. UNL is well positioned to take a leadership role in this area and promote the re-imagining of the land grant university. Inspirational but realistic objectives can potentially motivate the public. We propose the creation of a new Life Sciences Initiative with the overarching goal of achieving an integrated understanding of complex biological systems (from cellular metabolites to ecosystems) towards solving important problems. The initiative will have an executive director and consist, initially, of six research clusters, each addressing one of the outlined scientific challenges. Each cluster will comprise 5 to 8 new hires (at least two at the senior level) who will have a shared appointment in the initiative and in a home department of their choice. The Life Sciences Initiative will have a virtual structure allowing the participation of current faculty and the promotion of interdisciplinary research and education. However, a new building will be required to house core faculty members and provide much needed space for integrative, innovative science. The initiative will also require the establishment or re-structuring of service facilities in bioinformatics/quantitative analysis, metabolomics/proteomics and bio-processing. In our vision, the new Life Sciences Initiative will promote excellence and focus on areas of distinct comparative advantage while encouraging partnerships with industry to advance commercialization of useful products. The organization will be modeled after the Huck

Institutes of the Life Sciences, established by N. Fedoroff, at the Pennsylvania State University (www.huck.psu.edu).



Facilities: Bioinformatics/Quantitative Analysis; Metabolomics/Proteomics; Bio-processing

Research Clusters

1. Stress Biology: Research in stress biology is fundamental to developing sustainable production of food, fuel, and fiber in the face of diminishing water resources, extreme temperature variations, new biotic challenges, and an increasing need to produce in marginal agricultural areas. In addition, stress biology addresses host-pathogen interactions related to plant, animal and human health and impacts widely on the pathogenesis of numerous human diseases. The research cluster will encompass a diverse group of faculty representing many units across college campuses whose research focuses on understanding various aspects of stress biology, particularly unraveling metabolic stress networks. Despite faculty emphasis on particular organisms and scientific approaches, there are strong commonalities in the molecular basis of stress responses in bacteria, fungi, plants, animals and humans. Discovery of metabolic stress networks that are critical for survival, adaptation, and disease progression will be the common focus of this interdisciplinary research group. In addition, the cluster will strengthen ties across the NU system by incorporating/complementing existing scientific research programs affiliated with various Centers and Programs, including UNL's Redox Biology Center and Center for Plant Science Innovation, UNMC's Center for Environmental Health & Toxicology, and the system-wide Water for Food Institute. Establishment of a Stress Biology research cluster will also facilitate strategic planning to apply for external graduate training grants and multi-investigator awards focused on stress biology. Advocating for efficient and effective curriculum offerings across departments will be another goal of the cluster.

2. Bioenergy: Due to the established infrastructure, the current transportation fleet is likely to remain liquid fuel based to some extent well into the future and a focus on liquid biofuels, in particular next generation biofuels with high energy density, seems warranted. In addition, to achieve sustainability, next generation biofuels may need to derive from a variety of nonedible sources, including novel feedstocks that prosper in diverse environments and may integrate with other activities such as CO_2 mitigation, water conservation, or landscape recovery. Towards developing new feedstock sources, the bioenergy research cluster will focus on: system level understanding of the physiology, metabolism and gene regulation of unicellular eukaryotic algae to direct the engineering of biofuel and bio-materials synthesis; development of emergent lignocellulosic, oil or sugar crops for semi-arid or saline environments (rapid breeding, 'omics' tools, transformation technologies); identification of potential pests and diseases of novel feedstocks and development of management options or disease resistance; evaluation of alternative, regionally adapted feedstock solutions that integrate with existing agricultural or industrial systems (biorefinery concept); assessment of bio-processing technologies (bio-material harvesting, biofuel extraction, industrial microbiology processes, thermochemical conversion); evaluation of the potential for value added co-products and environmental credits; and integrated production system analyses, including life cycle assessment and economic output. Achieving the specific goals will require integration across disciplines (including, besides biology, math, engineering, computer science, economics…), core support in bioinformatics, metabolomics/proteomics and bio-processing and eventual partnership with industry. New hires in key areas are expected to serve as catalysts for the research and education efforts currently underway and contribute to the integration with other research clusters.

3. Health and Food Design: The world food supply is threatened in two opposing ways. On the one hand, a large portion of the world's population suffers from food insecurity defined by the World Health Organization as access to sufficient, safe, and nutritious food to maintain a healthy and active life. On the other hand, health problems related to excess nutrition and obesity are an overarching issue for developed and developing nations. In the US, obesity-related illness is affecting the GNP in quantifiable parameters such as lost productivity and health care costs that

are disproportionally high in low income and ethically diverse populations. Nebraska and its land grant university UNL are centers of agricultural research and productivity. As such, we are poised to make a large impact on food production, distribution, and in defining what constitutes "healthy" food. The concept of the Health and Food Design cluster is to expand and integrate existing programs in agricultural, food science and biomedical research at UNL into a dynamic nationally recognized center of excellence. In past years, there has been limited interaction between researchers and educators involved in these various fields not only at UNL but also more broadly in academia. Therefore, the concept of a research cluster to provide a collaborative environment to researchers in these fields is both innovative and high impact. The strategic areas to be integrated and expanded in this cluster include:
(a) Animal Science – in recent years internationally recognized research programs in this area at UNL and elsewhere have been weakened. However, recent breakthroughs in genomics and other aspects of molecular genetic techniques have allowed a resurgence in bovine and swine genetic research. Together with faculty of the School of Veterinary Medicine and Biomedical Science, UNL animal scientists are poised to make significant impacts in our understanding of disease prevention and resolution in domestic animal production for food. This will require retooling of technical skills for established investigators as well as hiring of individuals with unique advanced skills.

(b) Plant Science Innovation – this center of excellence in plant research, established about 10 years ago, has significantly increased UNL's national and international visibility in agronomy and plant pathology. With the new Life Sciences Center, we have the opportunity to expand this already strong program and to further coalesce individual research programs into a collaborative unit contributing to improve the nutritional quality of food and feed.

(c) The Gut Initiative and the Microbiology Initiative – these new initiatives bring together investigators from across the university with focuses in microbiology, immunology, and nutrition using sophisticated analytical, molecular and genetics tools. Their research has broad applicability to ruminant and human nutrition and health.

(d) Nutrition and Health Science – It is broadly accepted that diseases including metabolic syndrome, diabetes, cardiovascular diseases, cancer and immune dysfunction have a basis in diet. Therefore, research in nutrition must focus on determining what constitutes a healthy diet and must devise ways to implement healthy dietary practices in diverse populations. The research methods and approaches toward nutrition have changed drastically in recent years, in part, due to major technological advancements that have occurred due to the “omics” revolution but also due to the failure of the behavioral and social science research to find effective solutions to the complex problems that have led to the obesity epidemic. UNL has one department devoted to nutrition science, dietetics, and exercise with a limited number of faculty members. The Life Sciences Initiative offers the opportunity to expand this human resource base to include additional molecular geneticists and basic scientists focused in functional genomics, epigenetics, and physiological dynamics. Additionally, researchers should be added that evaluate population dynamics with regard to food choice to devise ways to alter unhealthy eating practices. Competition for faculty with these modern skill sets is quite fierce. However, the Life Sciences Initiative will provide the dynamic environment and technological tools to ensure UNL is a major competitor for these experts. Importantly, not all faculty positions need to be housed in one department but should be more broadly positioned to expand and coordinate health sciences research within the university and in partnership with UNMC.

4. Ecosystems: “We need to learn to live within our means” (M. Jahn). The notion of “more crop per drop” expressed in the Water For Food Institute is clearly consistent with this idea. However, even if we can obtain more crop per drop, unless we also understand how many drops are available we will be unable to navigate the fearsome tradeoffs facing humanity. Part of learning to live within our means involves a clear understanding of what our means are, and more significantly, what our means will be as the global biosphere changes. Faculty in the Ecosystems cluster will seek to understand the “denominator” in any calculation of efficiency – how much water, energy, and biodiversity are available, how will these quantities change both locally and globally, and how will they respond to increased anthropogenic pressure as human populations, food production, and manufacturing increase? Understanding how complex ecosystems provide critical support services for agriculture will be necessary to ensure sustainability of the agricultural enterprise in the long term.

5. Bio-products: A research cluster for Bio-products would provide a critical framework to develop innovative bio-based materials that would grow industrial relations and help populate Innovation Campus by establishing and expanding industrial relationships with commercial entities. The Bio-products research cluster would consolidate existing faculty strengths in diverse fields through the establishment of a Bio-products Coordinator and a website, market-relevant seminars, and core facilities for Bio-products. The Coordinator would promote integration among faculty with bio-product interests in the sciences and engineering with those in business, law and economics. Market-relevant seminars would provide access to the expertise of industrial consultants to better focus efforts on new and innovative bio-products derived from renewable resources using green processes. Bio-products presently under development at UNL include unique cell and plant lines, nutraceuticals, value-added derivatives of renewable feedstocks, biocomposites, textiles and tissue engineered scaffolds, bio-nanomaterials as well as pharmaceutical intermediates and enzymes. To bring these highly disparate bio-products closer to market relevance, support for core facilities will be required. A bio-processing facility for genetically modified organisms (GMOs) would allow for pilot scale production as a necessary stage in product development. A metabolomics core facility would facilitate analyses of molecular bio-products during research and early development phases and expand current efforts on both UNL campuses.

6. Information Integration and Modeling: The ‘New Biology’ requires that we understand and exploit complex biological systems, ranging from individual organisms, assemblages of microbes and higher organisms, and assemblages of higher organisms in large-scale ecosystems. The need for more quantitative expertise in the life sciences was reflected in the 2009 review of the molecular life sciences report as a call for increased bioinformatics resources, but the need extends far beyond bioinformatics. The broader field of dreams can be divided up along the lines shown in Table 1. In order to focus the collection of biological information and technology on socially and economically relevant issues, the genomic data from these assemblages of small and large organisms must be linked with phenotypic data and other higher-order quantitative measurements of ecosystem behavior, telling us how genetic infromation translates into character traits that define entire ecosystems. It is these character traits that define valuable characteristics in production crops and livestock, risk factors predisposing humans to disease, and carbon-neutral approaches for managing food production. Our success in identifying and linking the complex arrays of genes conferring valuable or undesirable characters or ecosystem behaviors will therefore depend on well-integrated systems for managing and analyzing the data, as well as linking the data to robust statistical, mathematical, and computational methods. The Information Integration and Modeling cluster will serve as the primary resource warehousing data for the ‘New Biology’ and linking this data to the analytical platforms necessary for examining it. This cluster will: (a) provide leadership in computational, mathematical, and statistical aspects of life science research and provide a means for uniting campus researchers around quantitative approaches to analysis and forecasting; (b) provide core functions to handle immediate faculty needs in computational, mathematical, and statistical aspects of life sciences research, and (c) advocate for strategic planning as a critical part of the development of Innovation Campus.

Table 1. Broad divisions of quantitative approaches in the life sciences. Bold entries in the body indicate areas with multiple faculty currently working at UNL; some faculty at UNL have work situated in the other cells, but these are fewer or not well connected to the life sciences. Question marks indicate that the box name is not clear or settled.

Mathematical approach	**Biological organization**	
	Cells and smaller-scale processes	**Populations-> Ecosystems**
Theory (equations)	Math biology?	**Math Ecology**
Information and analysis (large datasets)	**Bioinformatics**	Enviro-informatics?

Interdisciplinary Education

The "New Biology' presents unprecedented opportunities to draw attention to the excitement of and need for the Life Sciences in the 21st century, but will require new ways of thinking about how to attract, educate and retain students. The biologist of the future will need to be conversant in math and computational science, with highly developed quantitative skills, and able to interact effectively with a broad range of collaborators (chemists, physicists, engineers and many others). Allowing students to make connections between the science they study and the problems that their communities face will encourage greater interest in science as well as provide motivation to learn scientific concepts more deeply. Novel, integrative educational approaches will inspire top students to pursue scientific careers and dedicate their efforts to make technological and intellectual advances towards solving key societal problems. The initiative will promote the interdisciplinary training of graduate students through competitive fellowship support as well as establish an integrated graduate recruitment system. The aim is to organize flexible programs with a diverse collection of experts and students who work toward ambitious goals in multidisciplinary teams (towards the concept of a global knowledge society, N. Fedoroff). Organization of mini-symposia on specific topics and periodic research meetings/retreats will also be used to stimulate interdisciplinary integration among faculty. Changes in the biological education of undergraduate and younger students will also need to be addressed. Increased connections with local K-12 school districts, an especially students in grades 4-6 (where students' interest in science is often either fixed or lost), will have to be cogently explored. The key will be a sustained commitment with a measurable impact on what students and teachers learn. UNL will also benefit from its participation in the Committee on

Institutional Cooperation (CIC), a consortium of the Big Ten universities plus the University of Chicago, which has generated unique opportunities for students and faculty and has leveraged collective strengths for innovation and impact in research and education.

Public Outreach

Achieving an understanding of complex biological systems in order to provide meaningful solutions to societal problems will require the committed involvement of many stakeholders, not only in science and education, but also those who make funding decisions, develop policy or participate in advocacy groups, as well as, the public at large. The Life Sciences Initiative will partner with the Public Policy Center and UNL extension services and employ diverse outreach approaches to engage stakeholders with different perspectives, areas of expertise and expectations on these issues. The public and policymakers may react best to clearly enunciated ‘diagnoses’ of the problems related to food, energy, the environment and health, and how ‘New Biology’ approaches can lead to potential ‘solutions.’ However, proposed solutions will involve challenging technological and conceptual advances, integration across fields and partnerships with industry. Alternative views will have to be articulated in concise, exciting and easily comprehensible, but realistic, ways. There is a need for reliable, accurate information on complex issues, as well as for an open discussion on alternative developments and their expected outcomes, to allow policymakers and the public make informed decisions. There is also a need to convey the urgency to start building the foundation for a sustainable bio-based economy. UNL and the State of Nebraska can become leaders in this endeavor, which may provide a unifying theme for the development of Innovation Campus.

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