THE STATE OF IOWA:

BIOSCIENCES PATH FOR DEVELOPMENT: ECONOMIC AND CORE COMPETENCY ANALYSES

PREPARED FOR:
The Iowa Department of Economic Development

PREPARED BY:
Technology Partnership Practice
Battelle Memorial Institute

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The Business *of* Innovation

The State of Iowa Biosciences Path for Development: Economic and Core Competency Analyses

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Acronyms

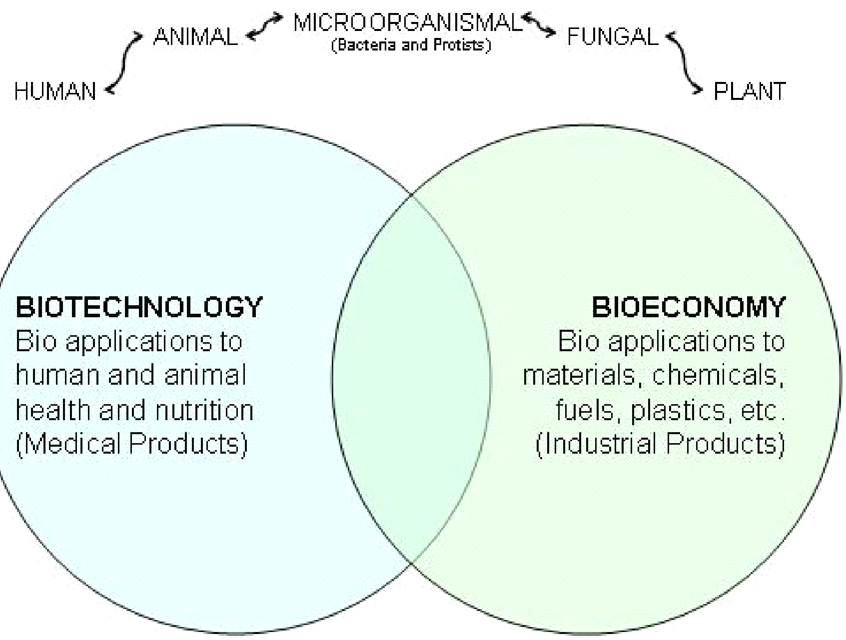
ABIC	Agricultural Biotechnology International Conference
ABIL	Agriculture-Based Industrial Lubricants, University of Northern Iowa
ARS/NADC	USDA's Agriculture Research Services National Animal Disease Center
BECON	Biomass Energy Conversion Facility
BLS	Bureau of Labor Statistics, U.S. Department of Labor
CADD	Center for Advanced Drug Development at University of Iowa
CBB	Center for Biocatalysis and Bioprocessing, U. of Iowa
CBCB	Center for Bioinformatics and Computational Biology
CEW	Covered employment and wage
CF	Cystic Fibrosis
cGMP	current Good Manufacturing Practice
CMV	Cytomegalovirus
CPRES	Center for Plant Responses to Environmental Stresses
DOE	U.S. Department of Energy
ENT	Ears, nose, and throat
EPA	U.S. Environmental Protection Agency
FIRE	Finance, insurance, and real estate
GLP	Good Laboratory Practice
GSP	Gross State Product
HM	Human medicine
IENICA	Interactive European Network for Industrial Crops and Their Applications
IP	Intellectual Property
IRS	Internal Revenue Service
ISI	Institute for Scientific Information
ISU	Iowa State University
LQ	Location Quotient
MEMS	Microelectromechanical systems
MOL	Molecular Opthalmology Laboratory
MSA	Metropolitan Statistical Area
MUM	Maharishi University of Management
NAICS	North America Industrial Classification System
NIDCD	NIH National Institute for Deafness and Other Communication Disorders
NIH	National Institutes of Health
NINDS	NIH National Institute for Neurological Disorders and Stroke
NSF	National Science Foundation

QCEW	Quarterly Census of Employment and Wages
SCOR	Specialized Center of Research (an NIH designation)
SEER	Surveillance, Epidemiology and End Results (a program of the National Cancer Institute)
SESA	State Employment Security Agencies
SIC	Standard Industrial Classification
SPORE	Specialized Programs of Research Excellence (an NIH designation)
SSA	Social Security Administration
TPP	Battelle Technology Partnership Practice
UCFE	Unemployment Compensation for Federal Employees
UI	Unemployment Insurance
UNI	University of Northern Iowa
USDA	U.S. Department of Agriculture

Executive Summary

Much attention has been paid in state economic development circles to the importance of biosciences as an engine for innovation and technology growth in the 21st century. The genomic revolution, and the resulting advances in bioscience knowledge, are generating multiple potential bio-pathways to innovation-based economic development.

Figure ES-1: Genomic and Biomass Resources for the Biosciences.



To facilitate understanding of Iowa's core bioscience competencies and opportunities and its current economic base, the Iowa Department of Economic Development engaged Battelle's Technology Partnership Practice (TPP) to perform economic and core competency analysis of the biosciences in Iowa.

Battelle examined the state's existing biosciences industry, broadly defined for this study to include most aspects of agriculture, e.g., agricultural machinery and equipment, agricultural processing, etc., because it is an important component of the "biosciences cluster" that also includes supplier chains and end customers. It includes key industry segments such as medical devices, drugs and pharmaceuticals, and research and testing. The economic analysis section of this report analyzes trends, current strengths, and emerging subsectors of the biosciences cluster in Iowa.

For the core competency analysis, Battelle used quantitative data sources (bioscience grant funding data, research output data, patent data, etc.) in combination with more than 220 qualitative fieldwork interviews in Iowa among faculty, administrators, trade and business associations, industry, and others to develop an in-depth profile of the State's core bioscience competencies. The results show that Iowa has broad and substantial bioscience expertise in each of the core bioscience areas. Because of the need for a strong research base as a prerequisite for any state to succeed in the biosciences, these documented competencies position Iowa with the potential to advance in bioscience-based economic development.

IOWA BIOSCIENCES ECONOMIC CLUSTER

Introduction

Bioscience is a set of knowledge-based industry sectors that, together, form a cluster of established and emerging opportunities. It is a set of industries with roots in academic and clinical discovery as well as engineering and ecological advancements. The innovative nature of the industry has positioned bioscience as a growing sector of the economy. The industry has given rise to new establishments and increasing employment. Over the past four years, bioscience industry has grown by 4.6 percent across the United States, adding close to 270,000 jobs nationally, using the definition of biosciences used in this report.[1] Case studies have documented the links between research and development activity and economic growth.[2]

The inherent diversity of the bioscience sector is a strong factor contributing to the growing industry focus. The cross cutting technologies embedded in the bioscience has led to many companies to pursue market opportunities in associated technologies, from bio-engineered foods and fuels to advanced new botanical medicines, from breeding healthier animals to mapping the human genome—each contributing to the advancement of life science activities, whether related to plant, animal, or human health discoveries and opportunities.

The bioscience industry is a strong driver for the U.S. and Iowa economies, diversifying the base, offering good, well-paying jobs, and contributing to overall economic productivity. There are a number of reasons to target Iowa's bioscience industry for economic development:

1. The bioscience industry is a significant part of the Iowa economy. In 2002, bioscience employment accounted for 7.0 percent of total employment in Iowa, exceeding the national average. The health services, food and kindred products, and chemical product subsectors comprising the bioscience sector account for large shares of Iowa's gross state product (GSP).

2. The bioscience industry has a wide-ranging impact on industries not typically perceived to be linked with bioscience technology. The innovative nature of the bioscience industry has positioned it as a value adding sector of the economy. The diverse industrial applications of the biosciences can be attributed to the innovative capacity of the industry in both the agriculturally related and clinical related fields.

3. The bioscience industry is a tremendous source of well-paying jobs. The average salary of a bio-science worker was more than $10,000 more than the statewide average annual wage in 2002, significantly above the statewide average wage.

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[1] The bioscience industry in this analysis includes the following subsectors: agricultural services, agricultural processing, organic and agricultural chemicals, drugs and pharmaceuticals, agricultural machinery equipment, medical equipment and supplies, research and testing, and hospitals.

[2] The National Commission on Entrepreneurship examined the link between university R&D spending and new business starts. The authors found that the lag time between the investment of research and development dollars and economic growth is shorter than previously expected. A significant number of new firms spring up within the first year after the funding and the growth trend continues for at least five years, albeit at a lower rate after the first year. The full report can be found at: http://www.nasvf.org/web/allpress.nsf/pages/5415.

Table ES-1: Average Iowa Annual Wages per Employee 2002.

Average Iowa Annual Wages per Employee 2002*	
Organic and Ag Chemicals	**$52,760**
Ag Machinery and Equipment	**$51,672**
Ag Processing	**$46,318**
FIRE	$40,471
Biosciences	**$39,253**
Wholesale Trade	$38,300
Manufacturing	$38,230
US Total Private Sector	$36,517
Transportation and Utilities	$35,708
Information	$34,830
Construction	$34,777
Iowa Total Private Sector	**$29,158**
Professional Business Services	$28,630
Ag/Natural Resources and Mining	$25,364

*** Wages are based on 2002 ES-202 data from the Bureau of Labor Statistics (BLS) and the Iowa Workforce Development, Employment Statistics Bureau. 2002 Information for the U.S. was retrieved from BLS and is considered preliminary according to the Department of Labor.**

Definition

To address the diversity of the bioscience industry in this analysis, it was divided into three sectors: agricultural, medical, and plant-life sciences. The agricultural sector consists of those industrial subsectors involved in developing, supporting, and manufacturing new farming and food production technologies for advancing health and nutrition. The medical sector consists of those industrial subsectors involved in manufacturing and developing clinical techniques aimed at and directed toward advancing human health care. The plant-life sciences sector consists of those industrial subsectors involved in research, testing, developing, and manufacturing clinical and agronomic techniques and products for improving the functions of living organisms.

The eight major subsectors of the bioscience industry identified for this economic analysis report appear in Figure ES-2. The eight subsectors of bioscience activity each encompass a wide variety of industrial activity upon which Iowa is well situated to further build and strengthen its overall bioscience base (Figure ES-3).

Figure ES-2: Broadly Defined Iowa "Bioscience" Industry.

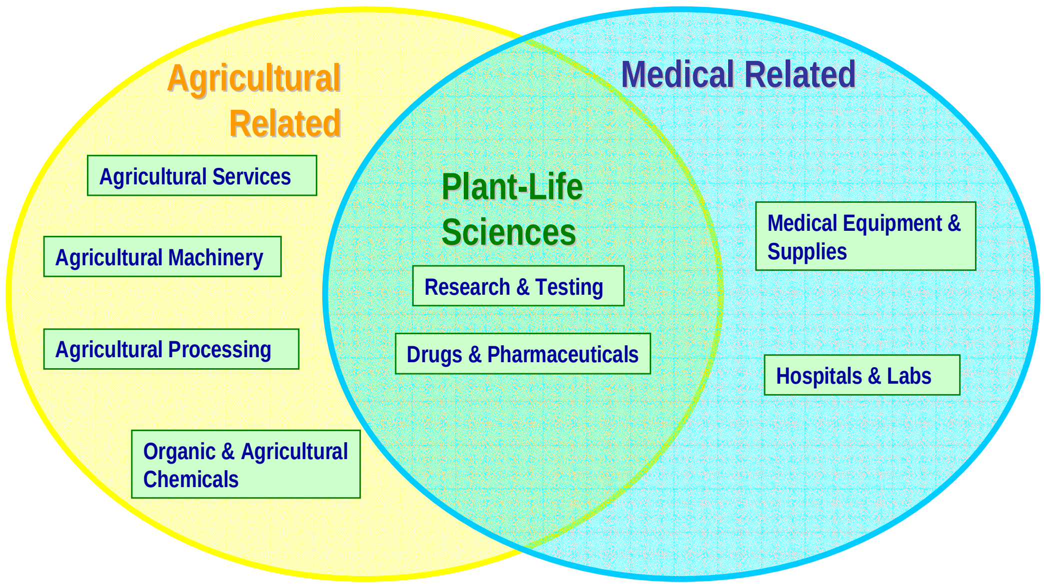
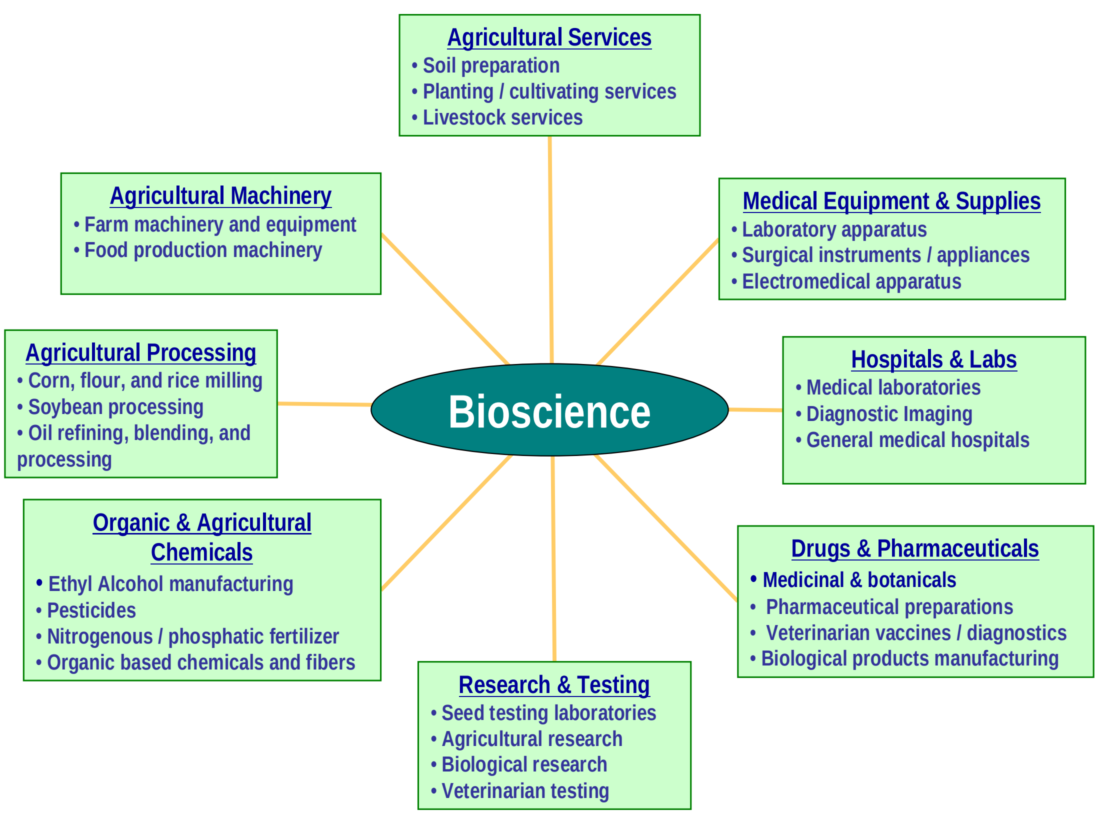


Figure ES-3: Detailed Description of Bioscience Industry Breakout.



Iowa Bioscience Industry Cluster

Overall, in the four-year period analyzed, the industry experienced a period of decline and then growth. In 2002, the Iowa bioscience industry employed 82,849 individuals across 1,856 establishments. Although this level of employment represents a drop from the 1998 level, the industry has demonstrated above average growth since 2000. Key conclusions from this analysis include the following:

> *Despite Iowa's bioscience industry decline overall since 1998, recent trends since 2000 indicate a growth rate that is above the national average.*
>
> *Although the bioscience employment base fluctuated over time, the industry remained a sizable portion of Iowa's economy throughout the four years analyzed.*
>
> *The current level of Iowa's bioscience employment concentration is considered to be regionally specialized.*

Iowa Bioscience Cluster Subsectors

Iowa's bioscience subsectors can be categorized into four classes based upon their performance from 1998 to 2002 (Figure ES-4). The four categories are based on the subsector's growth relative to U.S. growth and the subsector's location quotient. The four classifications of subsectors are stars, emerging potential, transitional, and divergent. Subsectors classified as stars or emerging are vital for the overall industry and its future development potential. These subsectors are often seen as the driving force behind the industry's success. Subsectors classified as transitional or divergent are in a stage of either becoming less important or are evolving to once again become stars. Though the four-year trend is not irreversible, these subsectors demonstrate current characteristics that may threaten the long-term viability of the industry base.[3]

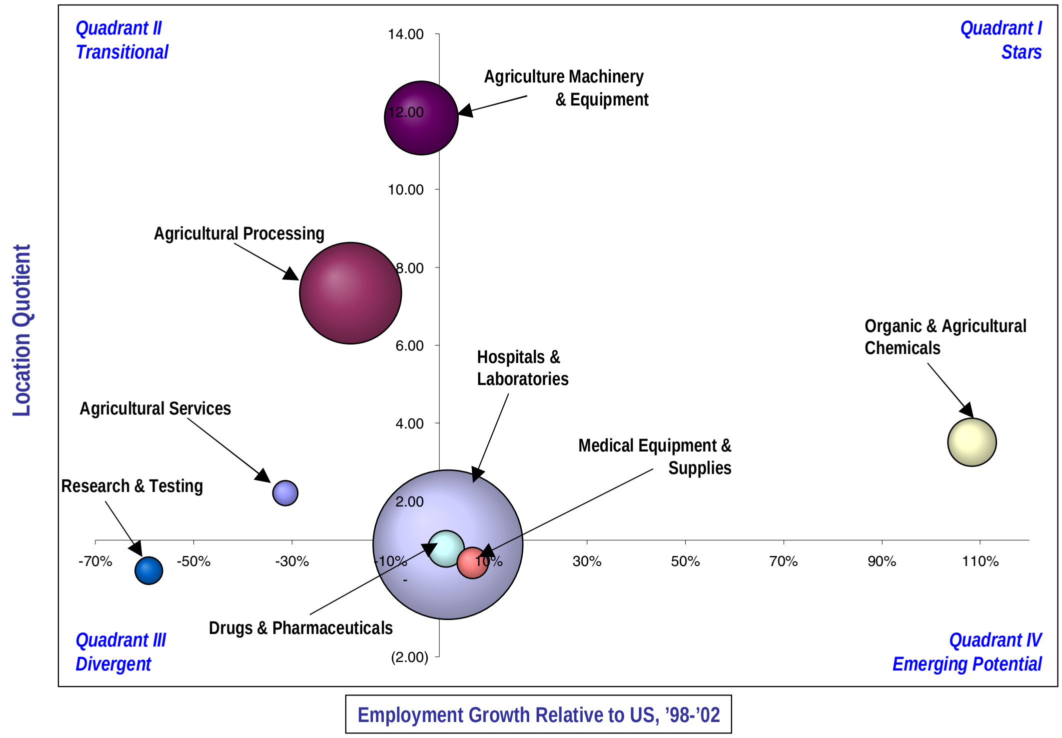
Detailed Cluster Subsector Strengths

It is useful to further isolate particular strengths of the subsectors within these industry segments as shown in Figure ES-5.

Industries that fall within the confluence of all three circles are considered major bioscience subsector strengths. These industries exhibited very large employment bases, significant specializations, and growth over the last year that surpassed U.S. growth rates. These industries demonstrate the potential for the state to create new opportunities and niches in the bioscience industry that can be leveraged to jump-start other promising industry segments. The diversity of the bioscience industry clearly indicates that advancements within particular subsectors can be leveraged to strengthen others. By focusing on its existing strengths, Iowa can build a promising future in the biosciences.

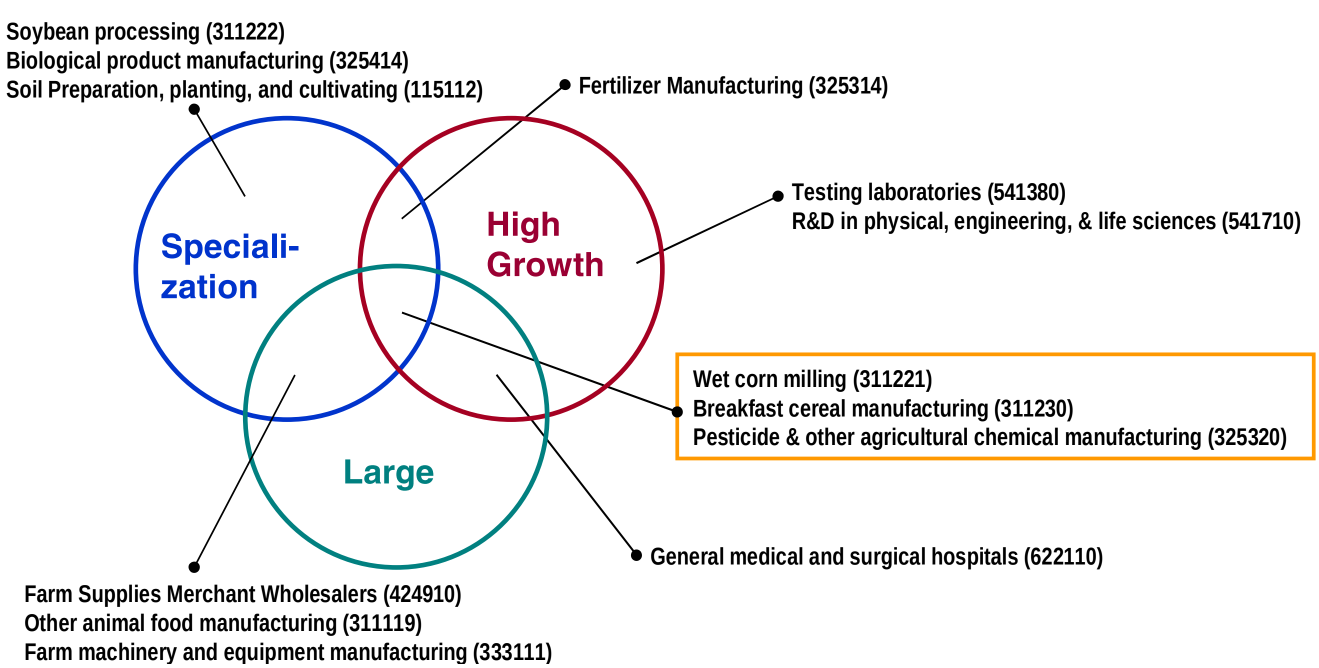
[3] A detailed table of Iowa's bioscience subsector performance can be found in Appendix A.

Figure ES-4: Iowa Bioscience Subsector Performance, 1998-2002.



Note: Bubble size indicates the subsector employment size
Source: Battelle calculations based on ES-202 data from the US Department of Labor, Bureau of Labor Statistics and Iowa Workforce Development, Employment Statistics Bureau

Figure ES-5: Assessment of Iowa's Detailed Industry Strengths within the Bioscience Subsectors.



Iowa Research Core Competency Analysis in the Biosciences

Iowa National Position in the Biosciences

From the standpoint of academic funding for R&D, the State of Iowa is performing well for its size. With $439.8 million in research funds, Iowa ranks 24th in total university R&D funding (according to the National Science Foundation)—notably exceeding its population rank of 30th.

Within the academic R&D arena, the state is performing particularly well in the biosciences, with 66 percent of all academic research funds falling under this definition. This level of performance places Iowa 21st in the nation. Also, Iowa ranks well across the three major macro-categories of bioscience R&D, ranking 19th in Medical Sciences, 20th in Agricultural Sciences, and 22nd in Biological Sciences. In all three cases Iowa's performance exceeds its ranking among the states in population.

Iowa's comparatively strong performance in bioscience R&D cannot, however, be taken for granted. Bioscience is a key target for growth in many states and in recent years, Iowa's total growth in bioscience funding has not kept pace with that of the nation—resulting in a slightly declining bioscience R&D market share of total academic R&D.

Iowa's Quantitative Bioscience Strengths

The biosciences are broad and no state has core strengths in every aspect of them. In Iowa, quantitative data on funding by discipline, publications citations and numbers of grants serves to highlight some of the fields in which Iowa has a specialization.

National Institutes of Health (NIH) data show that the University of Iowa College of Medicine performs particularly well in funding for

- Orthopaedics (where it ranks 3rd in the nation)
- Public Health and Preventative Medicine (ranked 5th)
- Otolaryngology—Ear, Nose and Throat (5th)
- Pediatrics (8th)
- Anesthesiology (10th)
- Biostatistics and related Math Sciences (11th).

Iowa State University also received NIH awards, but performs particularly strongly in accessing National Science Foundation (NSF) and U.S. Department of Agriculture (USDA) awards. Iowa State performs well in multiple disciplines, including biological infrastructure, environmental biology, integrative biology and neuroscience, and molecular and cellular biosciences. Iowa State's USDA funding highlights its work in veterinary medicine and animal sciences.

The Institute for Scientific Information (ISI) publishes statistics on the publications frequency and impact of academic institutions. Within Iowa, several university disciplines are strong performers on ISI metrics. The data show that Iowa is particularly powerful in

- Clinical Immunology and Infectious Diseases
- Agriculture and Agronomy
- Anesthesia and Intensive Care

- Otolaryngology
- Entomology and Pest Control
- Ophthalmology.

Other disciplines that are strong in terms of citations include Agricultural Chemistry, Dentistry, Oral Surgery and Medicine, Microbiology, Veterinary Medicine, and Animal Health.

Both the grants funding and ISI data serve to highlight several factors:

- There is significant institutional depth in a broad range of bioscience, biomedical, and related disciplines. Both Iowa State University and The University of Iowa contribute to this depth.
- Iowa has strengths in the three primary components of bioscience—human medicine, veterinary medicine/animal health, and plant sciences/agricultural science.
- The University of Iowa is particularly strong and productive in Clinical Immunology and Infectious Diseases, Immunology, Otolaryngology, Ophthalmology, Anesthesia and Intensive Care, and Clinical Psychology and Psychiatry.
- Iowa State University has demonstrable impact in Agriculture/Agronomy and Entomology and Pest Control. The University also has a strong concentration in Agricultural Chemistry, Animal and Plant Sciences, Veterinary Medicine and Animal Health, and Food Sciences and Nutrition.
- Both the University of Iowa and Iowa State University have strengths in environment/ecology research.

A quantitative analysis was completed, using Battelle' own proprietary Starlight™ cluster analysis software system. Starlight™ uses pattern recognition algorithms on text data (grant abstracts) to find areas in which a critical mass of research is occurring. This analysis identified six "meta clusters" of research in Iowa comprising:

- **Cell and Molecular Studies**
- **Crop and Soil Analysis**
- **Disease and Infection Studies (both human and animal/agricultural)**
- **Genetics**
- **Neural Studies**
- **Vascular Analytics.**

Iowa's performance in the Cell/Molecular Studies and Genetics fields (with 510 grants and 259 grants respectively) is particularly noteworthy given the importance of these disciplines to modern bioscience progress. Strengths in these disciplines are provided by both The University of Iowa and Iowa State University.

Taking all of the quantitative data into account, Iowa has the broadly based core focus areas shown in Table ES-2 and human medicine/health core focus areas shown in Table ES-3.

Table ES-2: Broadly Based Core Focus Areas Suggested by Quantitative Data.

Core Focus Areas	***Federal Research Grants***			***Publication & Citation Strength (ISI Data)***	***Starlight Cluster Analysis***		***Academic Reputation (U.S. News & World Report Rankings)***
	NIH	**NSF**	**USDA**		**Grants**	**Patents**	
Plant Breeding and Genetics		✓	✓		✓	✓	
Biotechnology and Applied Microbiology	✓	✓	✓	✓	✓	✓	
Immunology and Infectious Disease	✓		✓	✓	✓		
Agricultural Equipment Engineering			✓			✓	✓
Food Safety and Nutrition	✓		✓	✓			
Materials Science						✓	
Agricultural Chemicals			✓	✓			
Entomology and Pest Control		✓	✓	✓			
Veterinary Medicine and Animal Health		✓	✓	✓			✓

Table ES-3: Human Medicine/Health Core Focus Areas Suggested by Quantitative Data.

Core Focus Areas	*Federal Research Grants*			*Publication & Citation Strength (ISI Data)*	*Starlight Cluster Analysis*	*Academic Reputation (U.S. News & World Report Rankings)*	*Best Hospitals (U.S. News & World Report 2003 Rankings)*
	NIH	**NSF**	**USDA**		**Grants**		
Anesthesiology	✓			✓		✓	
Audiology	✓					✓	
Biostatistics	✓						
Cardiovascular	✓				✓		
Neurosciences, Neurology & Neurosurgery	✓	✓			✓		✓
Nursing						✓	
Oncology				✓	✓		
Ophthalmology				✓			✓
Orthopaedics	✓						✓
Otolaryngology	✓			✓			✓
Pediatrics	✓						
Public Health & Preventative Medicine	✓					✓	
Radiology & Radiation Diagnostics	✓						

Qualitative Assessment of Iowa Bioscience Strengths

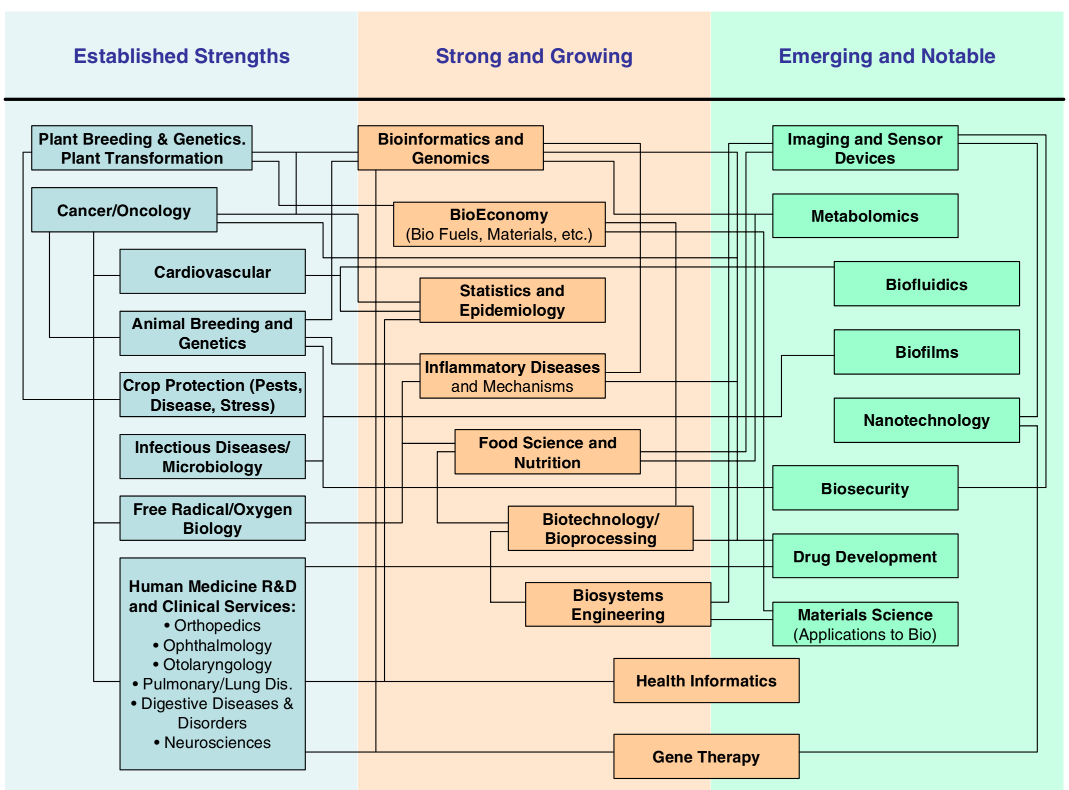
The analysis of quantitative data sets a context for understanding where Iowa's core competencies in bioscience research are focused. To further investigate these fields and deepen our understanding of the core bioscience focus areas in Iowa, extensive qualitative interviews were conducted with university administrators, faculty, scientists, clinicians, industry executives, and development agencies in the state. These interviews are essential in developing an understanding of how the data on publications and grant awards translate into on-the-ground focus areas in Iowa. They also contribute to a far stronger understanding of institutional directions and plans for the future.

After performing the qualitative interviews, conclusions were formed that placed each of the identified strength areas into one of three categories:

- **Established Strengths**—comprising the "powerhouse" disciplines in which Iowa has a clear leadership position to build upon.
- **Strong and Growing Areas**—comprising fields that are fast growing in general (such as genetics and bioinformatics in which the state is particularly strong, but must be developed further) but less fully established than the preceding category.
- **Emerging and Notable**—comprising smaller or embryonic programs that still show significant potential for bioscience development in Iowa.

Based on this categorization, the qualitative assessment resulted in the following summary chart, Figure ES-6:

Figure ES-6: Qualitative Summary Chart.

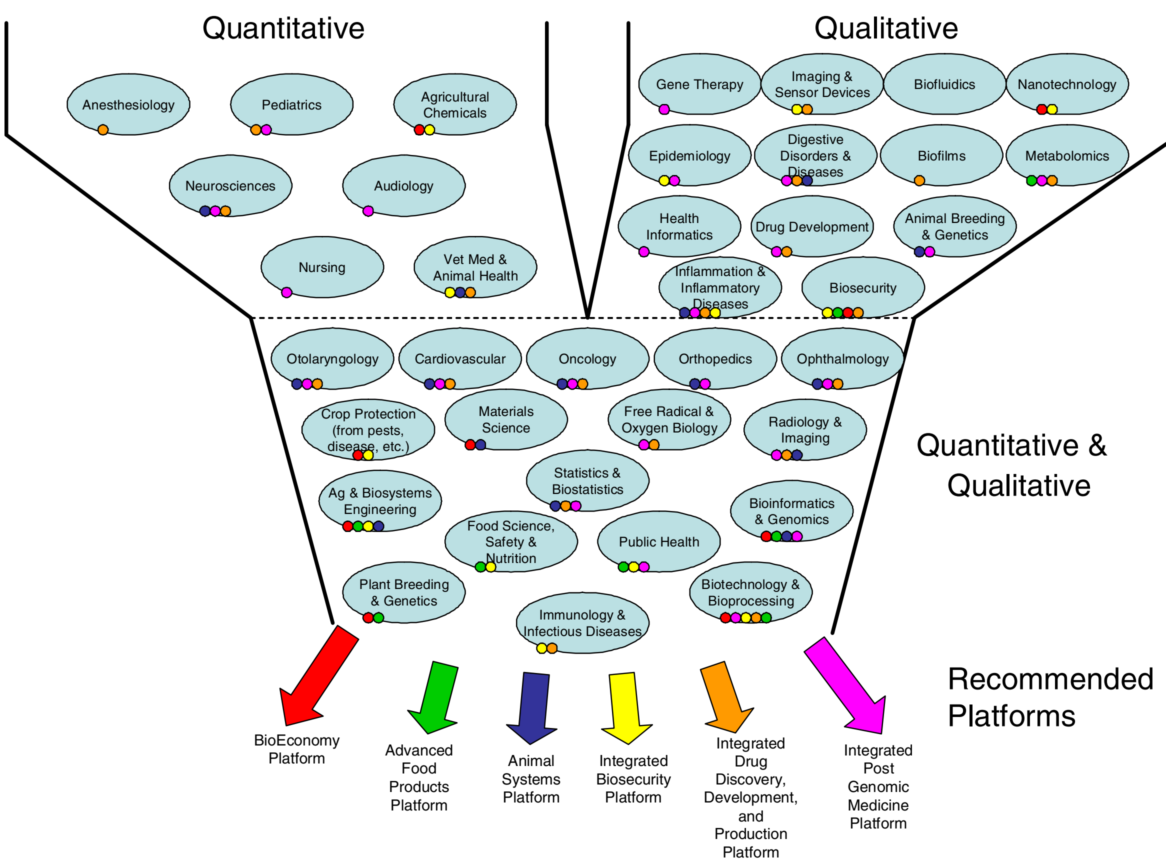


Core Platforms for Iowa Bioscience Development

The quantitative and qualitative data served to identify core areas of strength and expertise in Iowa biosciences. Not all of these, however, can form the basis of platforms upon which economic development can be built. Rather, the project team's experience and expertise, in combination with market data, helped determine which core competencies, or combinations of core competencies, may form solid technology platforms for economic progress.

Battelle's quantitative and qualitative analysis reveals multiple core competency areas within academic R&D in Iowa—most notably centered on Iowa State University and The University of Iowa, with some supporting strengths at the University of Northern Iowa (notably in the BioEconomy and Integrated Biosecurity platforms). These core competency areas are summarized in Figure ES-7, which shows the strengths identified by Battelle's quantitative and qualitative analyses, together with recommended technology platforms for resulting bioscience development.

Figure ES-7: Iowa's Validated Research Strengths Leading to Recommended Platforms.



As Figure ES-7 shows, Battelle sees opportunity for Iowa to develop its bioscience economy upon multiple **short or near-term** "platforms". These include:

- **BioEconomy Platform**—Using plant and animal biomass and waste streams to generate chemicals, energy, fuels, and materials for industrial and commercial applications.

- **Integrated Drug Discovery, Development, Piloting and Production Platform**—Leveraging Iowa's strengths in basic biomedical research, drug development, and GMP production into an integrated pipeline of new drugs and therapeutics.
- **Advanced Food Products Platform**—Using Iowa's established strengths in plant and animal sciences, production agriculture, food science, nutrition, and processing technology to develop and produce functional foods and nutraceuticals.
- **Integrated Post-Genomic Medicine Platform**—Using Iowa's genomics expertise and specific disease/disorder skills, in conjunction with epidemiologic data and Iowa's stable population, to produce rapid advances in post-genomic medicine and associated discoveries.
- **Animal Systems Platform**—Using Iowa's bioscience expertise to establish a leadership position in the modeling of animal systems and in the development of technologies and applications for transgenic animals, chimeric animals, and cloning.
- **Integrated Biosecurity Platform**—Deploying the strengths of Iowa's institutions in human, animal and plant disease prevention, protection, and treatment to establish an integrated approach to securing the environment, food production systems, human health and safety.

These six areas represent broad platforms upon which a significant R&D, business base, and bioscience economy may be built in Iowa in the near to short-term. They each specifically draw upon Iowa's institutional expertise in multiple fields, since it is multidisciplinary research that increasingly is gaining importance in driving funding, new study areas, technologies, commercializable innovations, and discoveries. In each case, the analysis shows that these platforms match well to large and rapidly growing projected domestic and international markets. In most cases the markets are characterized in terms of having expanding multibillion dollar existing and emerging potential.

In addition to the broad technology platforms, several additional areas of emerging, longer-term opportunity represent additional sector development potentials. The identified areas consist of relatively compact groups of people working in leading edge fields, new formative centers just recently pulled together, or established areas of expertise in which further investment in infrastructure and/or personnel are required to sustain or accelerate development momentum.

These four **longer-term** additional opportunity areas are

- **Host-Parasite Biology and Systems**—Examining the interaction and symbiotic beneficial relationships between hosts and parasitic organisms, with an initial emphasis on immunologic response.
- **Instrumentation, Devices and Sensors**—Using Iowa's skills in engineering, chemistry, biology and related fields to produce novel tools for instrumentation, analysis, invasive and non-invasive imaging, diagnostics, and biosensors.
- **Formation of a Cardiovascular Research Institute**—Mirroring Iowa's success with The University of Iowa's Comprehensive Cancer Center to build a similarly resourced and dedicated scientific institute for advancing cardiovascular and cardiopulmonary research and development.
- **Formation of a Free Radical Research Institute**—Cementing Iowa's existing world leadership position in free radical and oxygen biology research within a formal institute with associated facilities and funding.

Battelle's assessment of Iowa's position in the biosciences highlights a state that has significant promise to be among the nation's bioscience research leaders in selective fields. Iowa institutions have substantive strengths in the "three principal legs of the bioscience stool"— human, animal, and plant biosciences. In particular, the bioscience operations of both Iowa State University and The University of Iowa show fundamental bioscience technology platform strengths that can be further enhanced by increased collaborations between the institutions and with industry.[4]

Challenges in Realizing Iowa's Bioscience Potential

The primary goals of the research were to identify bioscience core competencies and determine key platforms for bioscience-based economic development in the State of Iowa. While not a primary research goal, this study also served to identify barriers and challenges to bioscience development in Iowa. The principal observed challenges are grouped by theme below:

Bioscience Visibility

It is important that all three legs of the bioscience stool be recognized as important to the future economic growth of Iowa, namely: human, animal and plant biosciences. Agricultural biosciences have much higher legislative and public visibility in the state than do human medical sciences. While it is good that agricultural bioscience is recognized for its significant value to the current and future health of the Iowa economy, attention also needs to be raised to the equally strong position of Iowa in human bioscience R&D.

Structuring for Bioscience Development

The primary research universities in the State are not on equal footing when it comes to organizational structure and support for bioscience development. Iowa State University has made important progress in forming new Institutes and Centers that correspond well in their focus and strengths to both the goals of technology-based economic development and the primary platforms recommended in this report. In addition to being well structured to progress bioscience development, Iowa State also benefits from a research foundation and technology transfer/commercialization operation that is adequately staffed and cutting edge in approach and partnering arrangements with industry. The University of Iowa is more traditional in its structure, with the bulk of its bioscience work still taking place in academic departments.

Table ES-4 compares Iowa universities on various metrics of technology transfer performance (as compiled by the Association of University Technology Transfer Managers [AUTM]). These data compare the performance of the University of Iowa and Iowa State University with the median and top quartile of U.S. universities on selective measures developed by Battelle. It should be noted that our study has focused on core competencies and that one important consideration in realizing economic benefits from these competencies and platforms is having the ability to transfer and commercialize discoveries from the research base into the commercial sector. This study did not involve an in-depth review of either the technology transfer function or technology commercialization gaps that need to be addressed, both subjects of a fuller bioscience development strategy.

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[4] Platforms are not intended to supplant or replace the existing structure of Iowa State University in its agbioscience work. Battelle notes that Iowa State University has established a well-structured suite of Centers under the umbrella of the Plant Sciences Institute and other formal Presidential initiatives, and recognition of this is shown in our analysis and recommendations on pages 89–92. It is highly important to Iowa's future in the BioEconomy that the ISU Plant Sciences Institute and its related centers continue to be funded and grown.

Table ES-4: Iowa Technology Transfer Performance

FY 2002 AUTM Licensing Data					
Metric	University of Iowa Research Foundation	Iowa State University	University of Northern Iowa	AUTM Median For Universities	AUTM Top Quartile for Universities
Sponsored Research Expenditures	$288,808,000	$212,100,000	$2,878,356	**$127,497,469**	**$285,697,000**
Invention Disclosures Received	88	100	1	**47**	**104**
Patent Applications Filed	77	64	1	**36**	**87**
Patents Issued	30	29	1	**10**	**26**
Licenses & Options Executed	37	287	0	**9**	**27**
Licenses Generating Income	115	416	3	**22**	**63**
Gross License Income	$7,932,531	$10,826,616	$23,500	**$851,155**	**$3,799,628**
Startups	3	2	N.A.	**1**	**3**
Disclosures per $10 M Sponsored R&D	3.05	4.71	3.47	**3.69**	**3.64**
Patents Issued per $10 M Sponsored R&D	1.04	1.37	3.47	**0.78**	**0.91**
Licenses Executed per $10 M Sponsored R&D	1.28	13.53	0.00	**0.71**	**0.95**
License Income per $10 M Sponsored R&D	$274,665	$510,449	$81,644	**$66,759**	**$132,995**
Average Revenue per License	$68,979	$26,026	$7,833	**$38,689**	**$60,312**
Startups per $10 M Sponsored R&D	0.10	0.09	N.A.	**0.08**	**0.11**
Startups per License Executed	0.08	0.01	N.A.	**0.11**	**0.11**

Bioscience Funding for Academe and Industry

While Iowa is performing quite well for its size in the attraction of federal bioscience funding, state government financial support has declined significantly during the past five years. The result has been program cuts, faculty salary freezes, an inability to invest in new technologies and infrastructure, and a general fear for the future among the Iowa education and scientific community. At a time when higher education research institutions represent a strong economic investment, Iowa has had to lower rather than increase investment. A lack of sufficient state funding could put at risk some of the core strengths and resulting technology platforms identified in this report as key. Faculty and scientists may be attracted to higher-paying jobs and more richly endowed laboratories and facilities in states where investments continue to be made in spite of revenue shortfalls.

On the commercialization front, financing for start-ups, spinoffs, and younger bioscience firms has been difficult to secure in Iowa. There is an evident lack of pre-seed, seed and venture capital available in Iowa to fund new ventures in the biosciences. Lack of local capital resources is limiting entrepreneurship on campuses and reducing the volume of innovation-based companies in the state. The scarcity of venture capital was confirmed in interviews with multiple start-up companies in the state.

Recent state initiatives to address capital gaps, including formation of a fund of funds, the Iowa Values Fund, and tax incentives for investors will be helpful, and will better position Iowa to secure sufficient funding for these biosciences ventures.

Bioscience Entrepreneurship

Bioscience-based economic development is understood by many in academia to be a key priority for the state. However, faculty in the state are confused as to what is expected of them in terms of faculty entrepreneurship, intellectual property generation, and idea commercialization. Many feel that their traditional research and teaching roles are threatened by a perceived requirement to start and run companies. Reassurance needs to be provided that while universities are expected to be economic development engines through the generation of discoveries and ideas, it is not necessarily the faculty themselves that must be the founders and managers of any resulting commercial enterprises. A set of policies is required that would relieve faculty of the burden of commercializing their concepts, whereby faculty can disclose their discoveries and have a team of commercialization experts assess marketability and ultimately form companies around the most viable concepts. Faculty should be free to be technical advisors to companies that their inventions promote, and to help move their research discoveries into the commercial realm. An appropriate rewards system for faculty engagement in applied and commercial research should also be encouraged at each university.

Limitations on Iowa's commercialization of bioscience also are imposed by an apparent lack of experienced bioscience entrepreneurs and managers who can fulfill management duties in new start-ups, or provide mentoring to new bioscience enterprises. Lack of experience makes new businesses a more high risk venture and makes the attraction of venture funds and capital that much more difficult.

Successful commercialization of bioscience discoveries and technologies in Iowa may require a comprehensive review of policies and relaxed return expectations at the IP-generating universities. By adopting policies that are more flexible for companies forming and operating in-state, the Regent universities may enhance the economic development potential. The research institutions are operating under reduced state funding and are limited in their ability to grant flexible arrangements in licensing with industry. An appropriate set of incentives may be needed to assist research universities in spurring enhanced company formation and local technology licensing.

Iowa's Commercial Bioscience Base

Iowa higher education institutions appear to be making good attempts to link their research to the needs of industry in the state. For example, Iowa State University has incorporated industry advisors and advisory boards as key components of its institutes and centers. However, these efforts are hindered somewhat by a lack of a commercial base in many areas of biotechnology, pharmaceuticals, medical devices and even food processing. Building a base in these areas will certainly not happen overnight and will place constraints on the pace at which bioscience development will progress in Iowa.

The one area of bioscience in Iowa in which short-term progress is being made in commercialization and new company formation is in the BioEconomy arena. BioEconomy companies generally need to be close to their required biomass inputs, and the agricultural richness of Iowa in combination with the strong university-based R&D in the field is producing results. The formation of the BIOWA Development Association with members from the corporate community, agriculture community, state universities and state agencies is a very positive step forward.

Certainly, barriers exist to realizing the full potential of these platforms, but none of them, in Battelle's opinion, are insurmountable. Other states—Arizona, Missouri, Georgia, Michigan—have developed a comprehensive state biosciences strategy that includes the economic analysis and core competencies identification contained in this report, as well as systematically identifying ways to position a state in technology and in talent and capital formation. Iowa may wish to build on this work with a similar effort to complete a biosciences roadmap for the state.

A formal development and funding strategy needs to be developed to provide a roadmap for offsetting and circumventing barriers and to provide a step-by-step path for achieving tangible and sustainable bioscience development results.

Conclusion: Bioscience is a Clear Target of Opportunity for Iowa

Iowa is strong and diversified in its bioscience R&D base and has a small but growing commercial base in certain related disciplines (most notably related to BioEconomy initiatives). The R&D basics are in place across agricultural-bioscience, animal science, and human/medical bioscience, and the leading universities are already working on collaborations to help advance their bioscience work.

Iowa's core competencies in the biosciences lend themselves to the development of several distinct development platforms, each of which has large-scale market potentials. These platforms include distinct opportunities in

- **The BioEconomy**—A platform for near-term investment and development in which university R&D and commercial strengths come together to generate great promise for the future.
- **Advanced Food Products**—Another near-term opportunity in which Iowa's expertise in agriculture, food production, and processing can be leveraged with a depth of expertise in genomic-sciences and nutrition to make important progress in functional foods and nutraceuticals.
- **Animal Systems**—Using the transgenics skills of Iowa State and The University of Iowa to establish a leadership position in transgenic animals and associated applications. This may have a longer development cycle than some of the other platforms.
- **Integrated Biosecurity**—Working to leverage Iowa's expertise in plant, animal and human diseases to produce integrated approaches and models to the protection of agro, food and bio-systems. An opportunity that should be considered near-term to take advantage of current homeland security funding and imperatives.
- **Drugs**—Investing in the near-term in The University of Iowa to create a drug discovery center that will complete an integrated pipeline from basic sciences research to discovery, trials, and production in an integrated academic environment. Also, investing in Iowa State will support biologics production facilities. This platform has the potential to generate a homegrown drugs and biologics industry in Iowa.
- **Post-Genomic Medicine**—Another highly important near-term opportunity to build upon the University of Iowa's strengths in bioinformatics, genomics, post-genomic sciences, health informatics, epidemiology, and clinical practice to accelerate discoveries in pharmacogenetics and the potential for personalized medicine.

Other investments and priorities may also be considered by Iowa, most notably the formation of institutes to enhance Iowa's leadership and expertise in cardiovascular research, free radicals research, host/parasite biology, and bioscience electronics, instrumentation, devices and sensors. In Iowa's future, it will be key to link near- and long-term platforms and the underlying research foundations with the development of a critical mass of firms connected to and improving their competitiveness through these research drivers and platforms.

Introduction: Biosciences

AN ERA OF THREATS AND ECONOMIC OPPORTUNITY

As the 21st century moves forward, fundamental forces are at work that severely impact the ability of states to maintain their normal economic *modus operandi*. The U.S. economy is facing a time of great change. In our nation, where states have the freedom to chart their own courses through the free market economy, the pace of change is likely to produce winners and losers as some make the correct decisions and investments while others make the wrong ones or fail to react at all.

For the past 200 years, the U.S. economy has sustained a general trend of economic growth and standard of living increases for its population; this progress largely has occurred through the innovation of Americans and ever higher levels of productivity in agriculture, industry, and commerce. Over the last decade, however, it has become increasingly apparent that America's economic leadership cannot be taken for granted. Global competition is intensifying and economic indicators are showing multiple disturbing trends:

- The United States has a growing and negative balance of trade. The nation is consuming many more goods produced by competing nations than it is selling overseas. For the 12 months ending in January, 2003, the United States recorded a goods trade deficit of $496 billion. Even the information technology sector is declining. The trade deficit is not a short-term anomaly; it is now a sustained trend.
- The United States is the world's largest debtor nation, with Bureau of Economic Analysis data showing an accumulated U.S. foreign debt of $3.3 trillion in 2002.
- Educational performance in grades K-12 has fallen behind that of most competing developed nations. In terms of educational performance per dollar spent, U.S. educational productivity has declined dramatically rather than increasing as it should.

At the heart of the problem is a nation that is consuming more than it produces, falling deeper into debt to foreigners to pay for its consumption, and lacking the education and workforce performance required to increase productivity and reverse the negative trends.

These same trends operate at the state level. Iowa's traditional economic base in agriculture and manufacturing is threatened. Commodity crops, such as soybeans, are facing increased competition from foreign producers, such as Brazil, while manufactured products face increased competition from Asian and European producers. Macro-economic trends have resulted in a significant State of Iowa budget shortfall which, according to Iowa State University economists, is the product of declining corporate tax revenue.

Within an environment of stiff and increasing competition, the State of Iowa must be able to make informed decisions regarding the right investments for its economic future. Therefore, the Iowa Department of Economic Development engaged Battelle's Technology Partnership Practice (TPP) to perform economic and core competency analyses of the biosciences in Iowa. **Research performed by the TPP indicates that the key determinant of the future wealth of U.S. states lies within their ability to innovate and produce economic output based upon that innovation.** Creating an economic structure conducive to innovation and more importantly, innovation *commercialization,* is increasingly central to the future sustainability of state economies.

The U.S. economy always has been nourished by inventiveness and creativity, so the "innovation economy" *per se* is not new; rather innovation has become the primary impetus of economic growth and competitiveness among developed nations. Two fundamental forces are driving technology and knowledge advancement as determinants of economic success:

- The rapidly accelerating pace of scientific discoveries and the technologies that are developed from these discoveries. For example, advances in genetics have accelerated dramatically the discovery process in the biosciences. The opportunity to accelerate the discovery and development processes, along with the ability to protect and profit from intellectual property, has led to an innovation race among competing countries, regions, and states.
- World markets are global and pressure is increasing on the United States to maintain its high-wage, high-skill employment base through technology gains and productivity increases.

THE BIO-CENTURY

Much attention has been paid in state economic development circles to the importance of biosciences as an engine for innovation and technology growth in the 21st century. Many states have developed bioscience plans, but much of the focus has been on applying bioscience to human health (e.g., pharmaceuticals, diagnostics, medical devices, instruments, and replacement tissue). *While applications of bioscience to human health hold significant economic potential, so too does the application of bioscience to agricultural productivity, agricultural and food products, companion animal health, and new materials, chemicals and biologics developed via biomass pathways.* The plant and animal biosphere contains a huge repository of genes; the novel combination, mining, and use of which has the potential to stimulate change in a broad range of industries, from medicinal and food products to advanced materials and energy sources. Traditional bioscience and bioengineering disciplines also have a great deal to contribute in new production and processing technologies, improved products from agricultural commodities and biological materials, and the novel application of bioresources to as yet undiscovered economic uses.

The presence and ongoing operation of bioscience research and development institutions in a state likely can provide a comparative advantage for growing its economy. Iowa has the opportunity to greatly enhance its economic performance and the future quality of life of Iowans through participation in all major sectors of the biosciences economy. Iowa's major research institutions have strengths in human, animal, and plant biosciences, and an industry base that can be leveraged for future economic growth and prosperity.

Competitive advantages will go to those countries, states, and regions that use interdisciplinary collaboration and technologies to drive cutting edge innovations. Iowa has an existing culture of interdisciplinary academic research, and an emerging culture of industry-university collaborations that can enhance growth and advancement.

In the following two sections of this report, Iowa's current economic base of private firms in the biosciences is described; the bioscience industries are defined; and trends in growth, comparisons to the nation, and identification of the key elements of Iowa's current bioscience complex are reported. Battelle has identified core research areas, "mega" research clusters, and the corresponding six technology platforms in which Iowa can excel based on its current and emerging research and applications endeavors. In the future it will be key to link both these platforms and the underlying research foundations with the development of a critical mass of firms in Iowa connected to and improving their competitiveness through these research drivers and platforms.

Economic Analysis

INTRODUCTION

Bioscience is a set of knowledge-based industry sectors that, together, form a cluster of established and emerging opportunities. This cluster is constantly altered and reinvented as scientists, engineers, and researchers gain new insights into the ways living organisms function. It is a set of industries with roots in academic and clinical discovery as well as engineering and ecological advancements. These technological breakthroughs take shape in new and innovative products used in everyday life. This explains, in part, the reason why public officials, private investors, and academic scholars have watched developments in bioscience with intense interest.

The industry's ability to reinvent itself continually indicates the potential that the biosciences have to spur new economic activity. The promise of new life-altering discoveries has made bioscience a high value-adding industry sector. Countless new commercial prospects emerge with every new breakthrough and discovery.

The innovative nature of the industry has positioned bioscience as a growing sector of the economy. The industry has given rise to new establishments and increasing employment. Over the past four years, bioscience industry has grown by 4.6 percent across the United States, adding close to 270,000 jobs nationally as defined in this study.[5] Continual technological research and product development has lead to new and pioneering products. New market opportunities have been created as a result of technology transfer and commercialization activities. Case studies have documented the links between research and development activity and economic growth.[6]

The inherent diversity of the bioscience sector is a strong factor contributing to the growing industry focus. The cross-cutting technologies embedded in the biosciences have led many companies to pursue market opportunities in associated technologies, from bio-engineered foods and fuels to advanced new botanical medicines, from breeding healthier animals to mapping the human genome—each contributing to the advancement of life science activities, whether related to plant, animal, or human health discoveries and opportunities.

The United States is a world leader in many areas of the biosciences—bioscience research, designing and producing new technologies, healthier agricultural and food commodities, new drugs and surgical procedures. Since interactions between researchers and practitioners are vital for continued advancement and progress within the sector, the biosciences have tended to concentrate in certain regional economies where such relationships are prevalent. Nevertheless, other areas also support substantial centers of bioscience activity and are engaging in promulgating, supporting, and enhancing this most promising set of industry segments.

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[5] The bioscience industry in this analysis includes the following sectors: agricultural services, agricultural processing, organic and agricultural chemicals, drugs and pharmaceuticals, agricultural machinery equipment, medical equipment and supplies, research and testing, and hospitals.

[6] The National Commission on Entrepreneurship examined the link between university R&D spending and new business starts. The authors found that the lag time between the investment of research and development dollars and economic growth is shorter than previously expected. A significant number of new firms spring up within the first year after the funding and the growth trend continues for at least five years, albeit at a lower rate after the first year. The full report can be found at: http://www.nasvf.org/web/allpress.nsf/pages/5415

The State of Iowa can develop its bioscience expertise and become a value-adding asset for the industry. The opportunity exists to support current emerging subsectors in the bioscience industry and reinforce existing specializations.

This economic analysis section examines the bioscience industry within the State of Iowa as it existed in 2002, describes the general performance of the bioscience sector in the last four years, and compares it with national trends. This analysis identifies emerging and existing subsector industry strengths which, along with the research core competencies analysis to be described later, provide the basis for linking research excellence to economic opportunity in Iowa.

WHY FOCUS ON THE BIOSCIENCES?

The bioscience industry is a strong driver for the U.S. and Iowa economies, diversifying the economic base, offering good, well-paying jobs, and contributing to overall economic productivity. However, with national and global competition intensifying, the state's performance within particular segments of the biosciences is not necessarily the pattern for the future. Therefore, it is appropriate that the private and public sectors jointly consider and address ways to ensure Iowa's competitive base and future in this biosciences industry cluster.

There are a number of reasons to target Iowa's bioscience industry for economic development:

1. The bioscience industry is a significant part of the Iowa economy. In 2002, bioscience employment accounted for 7.0 percent of total employment in Iowa, exceeding the national average of 5.6 percent of total private sector employment. The strength that Iowa demonstrates in this technologically advancing industry suggests that this sector of the economy is an asset for the state upon which to build.

Another way to observe the impact of the bioscience industry on the state economy is in the examination of the Gross State Product (GSP) of Iowa. Table 1 illustrates the important role that subsectors critical to bioscience play in the Iowa economy. The health services, food and kindred products, and chemical product subsectors comprising the bioscience sector account for large shares of Iowa's GSP. In fact, in Iowa, each subsector has a larger share of GSP compared with the United States.

Table 1: Bioscience Share of Gross State Product, 2001.

2001 Gross State Product	Iowa		United States	
Industry	(millions of current dollars)	Percent Share of Total GSP	(millions of current dollars)	Percent Share of Total GSP
Total Gross State Product	90,942	100.00%	10,137,190	100.00%
Farms	2,831	3.11%	80,596	0.80%
Ag. services, forestry, and fishing	623	0.69%	60,054	0.59%
Food and kindred products	3,788	4.17%	123,683	1.22%
Chemicals and allied products	2,880	3.17%	163,456	1.61%
Health services	5,653	6.22%	589,788	5.82%

Source: U.S. Bureau of Economic Analysis, 2001 Gross State Product by Industry Category, Released April 2003

2. The bioscience industry has a wide-ranging impact on industries not typically perceived to be linked with bioscience technology. Examining the bioscience industry from a macroeconomic perspective reveals that the industry is a broad-based sector of the economy. Industries increasingly are integrating new technologies in a variety of ways to raise productivity and product capabilities. The innovative nature of the bioscience industry has positioned it as a value-adding sector of the economy.

The diverse industrial applications of the biosciences can be attributed to the innovative capacity of the industry in both the agriculturally related and clinical related fields. New market opportunities have emerged as a result of scientific and technological innovations and discoveries. New food technologies have led to methods to control food-borne pathogens and enrich the nutritional value of crops (e.g., vitamin-A-enriched rice). Genetically modified crops resistant to insects and diseases produce higher yields, lower production costs, and reduce the use of pesticides and chemical fertilizers. Materials produced from maize are being used to create polylactide plastics, which are then used in clothing and packaging. New precision farming equipment is incorporating advanced electronic systems to monitor soil conditions to improve crop yields and reduce harmful environmental impacts.

Medical technologies also drive the biosciences. New electro-medical devices are used to monitor heart and brain activity. Bio-engineered drugs are manufactured to target specific human genes to prevent diseases such as Alzheimer’s or heart disease. Hospital and medical laboratories are investigating new ways to use the Internet to reduce medical costs and improve healthcare delivery. All of these advances demonstrate that the bioscience industry has the potential to stimulate new economic activity across several industry sectors.

3. The bioscience industry is a tremendous source of well-paying jobs. Compared with other major Iowa industries, bioscience is one of the highest paying industries in the state. The average wage of a bioscience worker in 2002 was more than $10,000 more than the statewide average annual wage and surpassed such sectors as manufacturing, information, construction, and finance, insurance, and real estate (FIRE) (Table 2). Because bioscience is a diversified industry, comprises a substantial share of state economic activity, and is a source of high-paying jobs, it is reasonable to support initiatives that focus on this industry.

Table 2: Average Iowa Annual Wages per Employee 2002.

Average Iowa Annual Wages per Employee 2002*	
Organic and Ag Chemicals	**$52,760**
Ag Machinery and Equipment	**$51,672**
Ag Processing	**$46,318**
FIRE	$40,471
Biosciences	**$39,253**
Wholesale Trade	$38,300
Manufacturing	$38,230
U.S. Total Private Sector	$36,517
Transportation and Utilities	$35,708
Information	$34,830
Construction	$34,777
Iowa Total Private Sector	**$29,158**
Professional Business Services	$28,630
Ag/Natural Resources and Mining	$25,364

*** Wages are based on 2002 ES-202 data from the Bureau of Labor Statistics (BLS) and the Iowa Workforce Development, Employment Statistics Bureau. 2002 Information for the U.S. was retrieved from BLS and is considered preliminary according to the Department of Labor.**

DEFINITION OF IOWA'S BIOSCIENCES CLUSTER

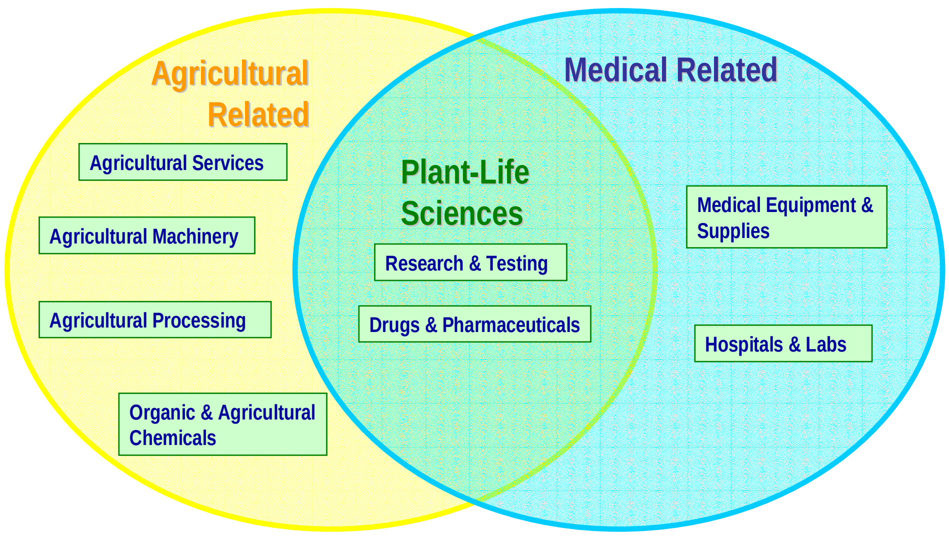
Varying industrial classifications could be used to define the bioscience sector of the economy. Currently there is no commonly accepted definition. Categorization is difficult due to the diversity of bioscience activity. The industry is dynamic and encompasses a wide variety of industrial applications. Continual innovation further complicates the industry definition. Bioscience advancements constantly are being applied in new and different ways, creating new industry segments such as genetically improved foods or alternate energy sources such as agriculturally based fuels.

To address the diversity of the bioscience industry in this analysis, it was divided into three sectors: agricultural, medical, and plant-life sciences. The agricultural sector consists of those industrial subsectors involved in developing, supporting, and manufacturing new farming and food production technologies for advancing health and nutrition. Four subsectors of the bioscience industry were identified as part of the agricultural sector: (1) agricultural services, (2) agricultural machinery and equipment, (3) agricultural processing, and (4) organic and agricultural chemicals. This area is one of the most difficult in which to establish boundaries and parameters. This area is one of the most difficult in which to establish boundaries and parameters. Battelle used Iowa's covered employment and wage (CEW, or ES-202 as it is sometimes referred to) data series to determine where individual firms were classified and to ensure that only those firms known to be agriculture biorelated were included.

The medical sector consists of those industrial subsectors involved in manufacturing and developing clinical techniques aimed at and directed toward advancing human health care. Two subsectors of the bioscience industry were identified as part of the medical sector: (1) medical equipment and supplies, and (2) hospitals and medical laboratories.

The plant-life sciences sector consists of those industrial subsectors involved in research, testing, developing, and manufacturing clinical and agronomic techniques and products for improving the functions of all living organisms. Two subsectors of the bioscience industry were identified as part of the plant-life sciences sector: (1) research and testing, and (2) drugs and pharmaceuticals. Figure 1 shows the three sectors and subsectors in the bioscience industry.

Figure 1: Broadly Defined Iowa Bioscience Industry.



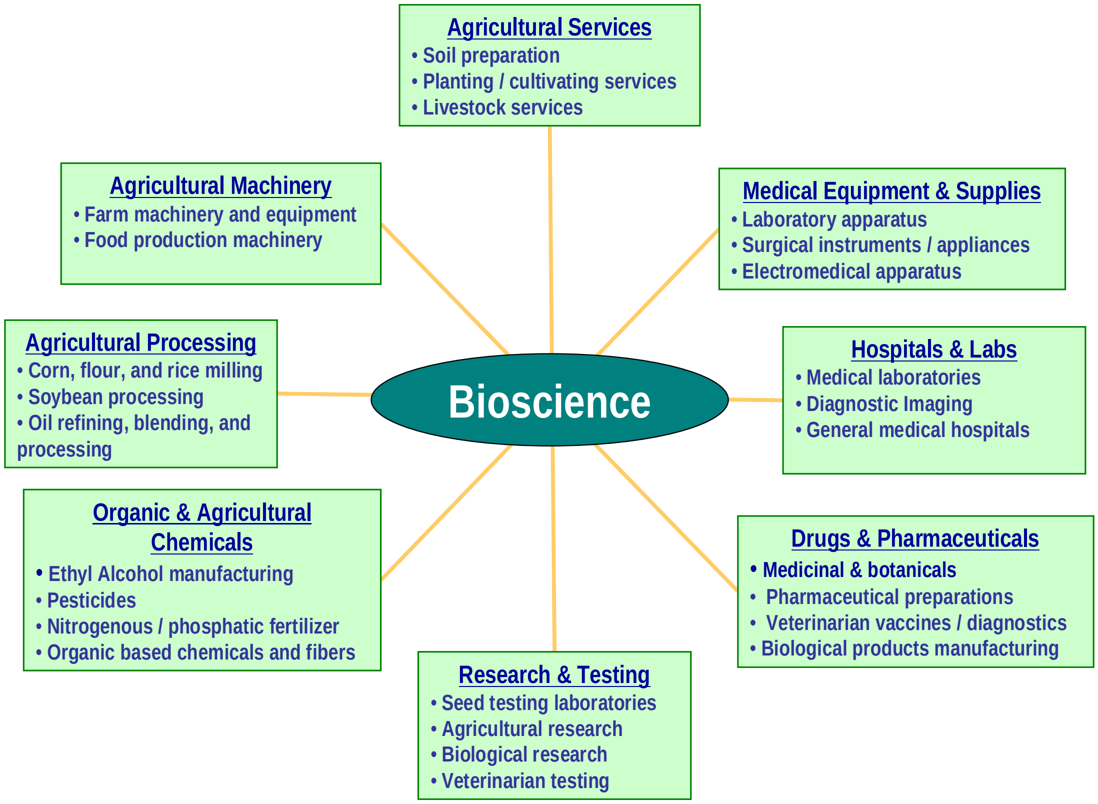
The North American Industrial Classification System (NAICS) was chosen as the most appropriate means to identify industry subsectors associated with bioscience activity. Based on an analysis of six-digit NAICS codes, 46 industries were selected and organized according to eight major subsectors of the bioscience industry.[7]

The eight major subsectors of the bioscience industry identified for this economic analysis report appear in Figure 2. The eight subsectors of bioscience activity each encompass a wide variety of industrial activity upon which Iowa is well situated to further build and strengthen its overall bioscience base.

Clearly, this definition of bioscience subsumes much of the supplier chain—a key characteristic of cluster analysis—including such subsectors as agricultural machinery, agricultural processing, and agricultural chemicals. In defining the cluster, not more narrow industry segments, it is possible that enclaves of economic activity related to the bioscience industry were not included in this list. NAICS does not fully incorporate the wide variety of industrial activity that falls within the scope of the bioscience industry. Characterizing an industrial sector solely on the basis of aggregated industrial data inevitably results in certain data gaps.

[7] A detailed list of the 46 NAICS codes used to define the Iowa bioscience industry can be found in Appendix B.

Figure 2: Detailed Description of Bioscience Industry Breakout.



It must be understood that no one data source can fully account for all economic activity related to a particular industrial sector. This analysis strived to select the best data system in which to characterize the bioscience industry and capture the largest portions of industry activity. The North American Industrial Classification System was chosen as the most appropriate data system.

Data and Methodology

This economic analysis report primarily examined the economic changes that took place between 1998 and 2002. Battelle used the CEW data series to examine changes that occurred in employment, establishments and wages.[8]

[8] Reported monthly employment data represent the number of covered workers who worked during, or received pay for, the pay period which included the 12th day of the month. Reported annual average employment is an average of the corresponding monthly employment levels. Reported number of establishments represents the number of establishments whose activities were reported to the Unemployment Insurance system for the quarter. An establishment is an economic unit, such as a farm, mine, factory, or store, which produces goods or provides services. It is typically at a single physical location and engaged in one, or predominantly one, type of economic activity for which a single industrial classification may be applied. Reported annual average number of establishments is an average of the corresponding quarterly number of establishment levels. Reported quarterly total wages are the wages paid by Unemployment Insurance covered employers during the calendar quarter, regardless of when the services were performed. Reported total annual wages are the sum of the total wages reported for the corresponding quarters. Total wage values reported in this database have been rounded and are reported in thousands of dollars.

The Iowa Workforce Development, Employment Statistics Bureau, was the primary source for gathering data relevant to the state. The United States Department of Labor, Bureau of Labor Statistics (BLS) was the primary source for gathering data relevant to the United States.

The CEW data, or ES-202 as it is sometimes referred to, is a cooperative program involving the BLS and State Employment Security Agencies (SESA). The QCEW program produces a comprehensive tabulation of employment and wage information for workers covered by state unemployment insurance (UI) laws and Federal workers covered by the Unemployment Compensation for Federal Employees (UCFE) program. Publicly available files include data on the number of establishments, monthly employment, and quarterly wages, by NAICS industry, by county, by ownership sector, for the entire United States. These data are aggregated to annual levels, to higher industry levels (NAICS industry groups, sectors, and supersectors), and to higher geographic levels (national, state, and Metropolitan Statistical Area [MSA]).[9]

Since 2001, ES-202 data has used the North American Industry Classification System. The new federally mandated classification system reflects recent changes in the economy. The new system was developed to better identify new and emerging industries. Industries that primarily create and disseminate a product subject to copyright, such as information technology, are now better identified under the new system.

Prior to 2001, ES-202 data was reported using the Standard Industrial Classification (SIC) system. Unfortunately, the NAICS and SIC systems do not directly correspond with one another. This makes it extremely difficult to translate one classification system into the other. Fortunately, the Iowa Employment Statistics Bureau has developed a computational methodology whereby the state calculated historic employment, establishment, and wage data. The state provided Battelle with data estimates for the selected NAICS codes.

Battelle used the County Business Patterns data series to calculate estimated national data for the years prior to 2001.[10] County Business Patterns data is one of the first publicly available data sets to report economic information according to NAICS for multiple years. County Business Patterns makes it possible to use the most up-to-date industry classification system and also examine changes over time dating back to 1998. Using this information, Battelle was able to calculate estimated employment, establishment, and wage data for the bioscience industry and its associated eight subsectors. The estimations made it possible to calculate changes that had occurred in the bioscience industry in the years preceding 2001.[11]

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[9] Major exclusions from UI coverage include self-employed workers, most agricultural workers on small farms, all members of the Armed Forces, elected officials in most states, most employees of railroads, some domestic workers, most student workers at schools, and employees of certain small nonprofit organizations.

[10] County Business Patterns is an annualized data set that provides sub-national employment, establishment, and payroll information. The data is assembled from several databases maintained by the Census Bureau and other Federal Government agencies. Data is extracted from the Business Register, the Annual Company Organization Survey, the Economic Census, the Annual Survey of Manufactures, and Current Business Surveys, as well as from the administrative records of the Internal Revenue Service (IRS), the Social Security Administration (SSA), and the Bureau of Labor Statistics (BLS). Relying on data collected by the government ensures a high degree of reliability and uniformity for comparison purposes.

[11] Battelle used employment, establishment, and annual wage information from the County Business Patterns data series for the years ranging from 1998 through 2001. Battelle analyzed data changes using 2001 as the base year. The assumption was that annual changes in the data for County Business Patterns would be proportional to ES-202. This is why the 2001 data was critical, because it was the one year in common to both ES-202 and the County Business data set. Understanding that the County Business Patterns data is a different data set than the ES-202 data series, but faced with the need for timely and accurate data to analyze the bioscience industry, Battelle was confident that by calculating the proportional relationship as opposed to using raw absolute numbers, a rough estimate of industry activity prior to 2001 was captured.

ECONOMIC ANALYSIS OF IOWA'S BIOSCIENCE CLUSTER

Overall, in the four-year period analyzed, the industry experienced a period of decline and then growth. In 2002, the Iowa bioscience industry employed 82,849 individuals across 1,856 establishments. Although this level of employment represents a drop from the 1998 level, the industry has demonstrated above average growth since 2000, despite the economic downturn that began in March, 2001.[12] Therefore, examining the Iowa bioscience industry performance between 1998 and 2002 requires a careful analysis.

> "New plant biotech firms and research facilities are being created throughout the United States. The number of agricultural and food scientists are increasing as workers are attracted to the biotech sector's above-average wages, and a large number of individual states are reaping the benefits of this investment and job-related activity. While 41 of 50 states had some type of biotech initiative by 2001, those that have aggressively adopted and invested in biotechnology are reaping the greatest rewards."
>
> *Dr. C. Ford Runge, director of the Center for International Food and Agricultural Policy and Distinguished McKnight University Professor of Applied Economics and Law.*

Despite Iowa's bioscience industry decline since 1998, recent trends since 2000 indicate a growth rate that is above the national average. Between 1998 and 2000, the industry experienced massive employment losses compared with the nation. Iowa's bioscience employment base dropped by more than 4,600 employees, representing a 10.1 percent decline. In sharp contrast, the industry at the national level grew. Although marginal, the nation experienced bioscience employment growth at a rate of 0.9 percent.

Above-average employment growth between 2000 and 2002 helped offset large employment losses between 1998 and 2000. The Iowa bioscience industry employment rebounded somewhat in the two years since 2000. Bioscience employment grew by 5.3 percent at the state level, regaining 4,179 jobs since 2000. Even more promising is that this growth rate was above the national average. The bioscience industry across the United States grew at a rate of 3.7 percent between 2000 and 2002. Table 3 illustrates the bioscience industry's overall performance in Iowa and the nation.

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[12] The National Bureau's Business Cycle Dating Committee maintains a chronology of the U.S. business cycle. The chronology identifies the dates of peaks and troughs that frame economic recession or expansion. The period from a peak to a trough is a recession and the period from a trough to a peak is an expansion. According to the chronology, the most recent peak occurred in March 2001, ending a record-long expansion that began in 1991. The most recent trough occurred in November 2001, inaugurating an expansion. http://www.nber.org/cycles/november2001/recessnov.html

Table 3: State and National Bioscience Comparison, 1998-2002.

Metric		IOWA		UNITED STATES	
		Biosciences	Total Private Sector	Biosciences	Total Private Sector
Establishments					
	1998	2,468	92,099	82,476	7,557,865
	2000	1,951	98,845	81,772	7,697,470
	2002	1,856	83,340	86,273	7,852,549
% Change	98-00	-20.9%	7.3%	-0.9%	1.8%
	00-02	-4.9%	-15.7%	5.5%	2.0%
	98-02	-24.8%	-9.5%	4.6%	3.9%
Employment					
	1998	87,517	1,186,935	5,803,281	102,708,722
	2000	78,670	1,217,722	5,855,230	108,358,433
	2002	82,849	1,185,668	6,072,130	107,618,787
% Change	98-00	-10.1%	2.6%	0.9%	5.5%
	00-02	5.3%	-2.6%	3.7%	-0.7%
	98-02	-5.3%	-0.1%	4.6%	4.8%
Employees per Establishment					
	1998	35	13	70	14
	2000	40	12	72	14
	2002	45	14	70	14
Location Quotient					
	1998	1.30	n.a	n.a	n.a
	2000	1.20	n.a	n.a	n.a
	2002	1.24	n.a	n.a	n.a
Wages					
	1998	33,682	25,670	37,663	31,923
	2000	36,127	27,570	41,165	35,470
	2002	39,253	29,158	44,199	36,517
% Change	98-00	7.3%	7.4%	9.3%	11.1%
	00-02	8.7%	5.8%	7.4%	3.0%
	98-02	16.5%	13.6%	17.4%	14.4%
Percent Share of Private Sector of Employment					
	1998	7.4%	n.a	5.7%	n.a
	2000	6.5%	n.a	5.4%	n.a
	2002	7.0%	n.a	5.6%	n.a

Source: Battelle calculations based on ES-202 data from the US Department of Labor, Bureau of Labor Statistics and Iowa Workforce Development, Employment Statistics Bureau

Even with the recent growth trend, the bioscience industry in Iowa declined overall during the 1998 to 2002 time span. Bioscience employment in Iowa has dropped by 5.3 percent since 1998. The growth experienced between 2000 and 2002 did not make up for the large losses between 1998 and 2000. Nationally, the 1998 to 2002 timespan represented a period of 4.6 percent growth for U.S. bioscience employment.

Although the bioscience employment base fluctuated over time, the industry has remained a sizable portion of Iowa's economy throughout the four years analyzed. Bioscience employment concentrations over the four-year period consistently accounted for a larger share of state private-sector employment than at the national level. Bioscience employment in Iowa is responsible for 7.0 percent of total state private-sector employment. Nationally, the bioscience industry accounts for 5.6 percent of total private-sector employment.

The current level of Iowa's bioscience employment concentration is considered to be regionally specialized. The location quotient is a common measure of the concentration of an industry within an economic region. When the location is significantly above average, a location quotient above 1.20, the region is said to possess a specialization in the industry. The fact that bioscience employment in Iowa accounts for a larger share of private sector employment than the industry does at the national level results in an above average location quotient for Iowa. Applying the formula in Figure 3 indicates that Iowa possesses a regional specialization in the bioscience industry that is currently 1.2, and this number has declined since 1998.[13]

Iowa's location quotient has fluctuated over time, following the ebbs and flows of employment. Examining the change in the location quotient over time must be analyzed carefully because of the nature of the formula. Location quotient change could be a result of change in total employment and/or industry employment at the local and/or national level.

Figure 3: Location Quotient Formula.

$LQ_{Ri} = (R_i / R_T) / (US_i / US_T)$
Where:
R_i = industry *i* employment for the region
R_T = total employment for the region
US_i = industry *i* employment for the nation
US_T = total employment for the nation

The data reveal that over the four-year period between 1998 and 2002, Iowa's location quotient in the bioscience industry eroded from 1.30 in 1998 to 1.24 in 2002. Bioscience employment at the state level fell at a faster rate than total state employment. Dwindling state employment in both the private sector and the bioscience industry contrasts with the national trend. The United States experienced employment growth across both the private sector and the bioscience industry. The decline of bioscience employment in Iowa is the main reason for the industry's decreasing employment concentration.

IOWA BIOSCIENCE CLUSTER SUBSECTORS

While the bioscience cluster industries are engaged in understanding living organisms and their functions, this understanding is mobile and applied across several platforms. This variety supports the importance of industry and technology convergence. It is critical to understand how convergence among different industry segments within and outside the cluster will affect the future of the biosciences. Bioscience convergence is especially relevant for traditional agricultural-oriented industries and clinical-oriented industries.

[13] Location quotients are a common measure of the concentration of particular industry in a region relative to the nation (reference area). The LQ consists of the ratio of the share of total regional employment that is in the particular industry and the share of total employment in the nation (reference area) that is in the particular industry. A LQ greater than 1.0 for a particular industry indicates that the region is relatively concentrated, whereas an LQ less than 1.0 signifies a relative under-representation. A location quotient of above 1.20 denotes employment concentration well above the national average. Throughout this report, LQs are used to report regional industry concentrations relative to the United States as a whole. The minimum concentration threshold for declaring a regional specialization is a matter of judgment and varies somewhat in the relevant literature. In this analysis, regional specializations are defined by LQs of 1.2 or greater.

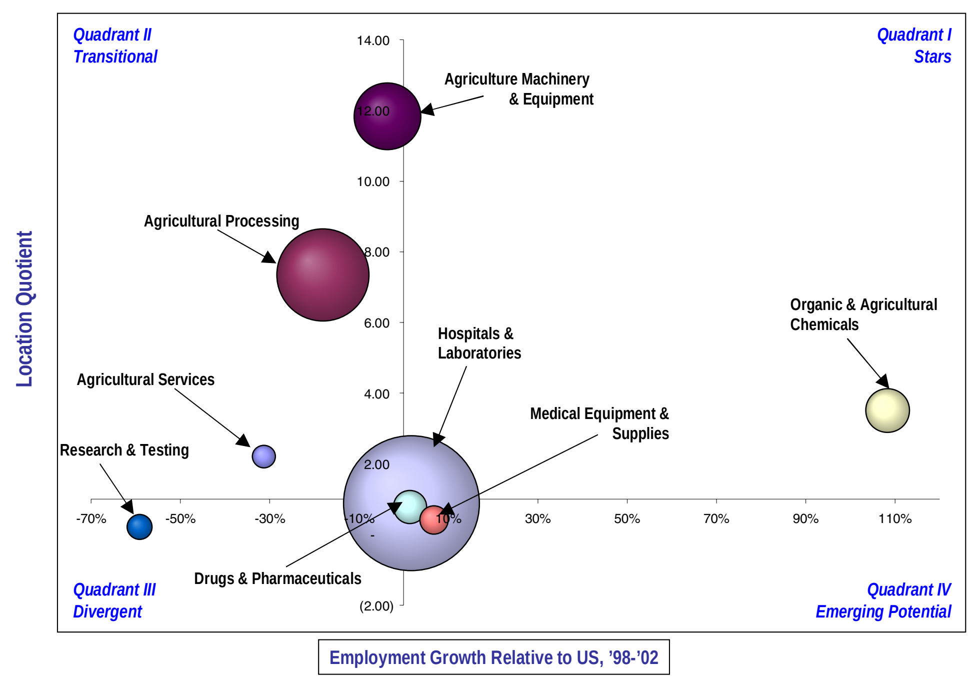
Therefore, the diverse nature of the bioscience industry requires an analytical approach that accounts for the numerous applications of agricultural and clinical technologies. Accurately depicting the bioscience industry requires examining both the underlying technologies and the products which enable and advance life-science knowledge. Examining each of these unique subsectors helps foster a better understanding of the overall industry. Dissecting the industry also helps identify specific areas of strength and opportunity to create synergies and facilitate future development potential for the entire industry sector.

Corn Belt states with higher adoption levels of biotech crops—South Dakota, Nebraska, Kansas, Minnesota and Iowa—have a greater proportion of agricultural and food science jobs than those with lower levels of adoption. For example, Iowa, one of the top five states in crop biotech adoption, has 50 agricultural and food science jobs per 100,000 jobs, more than lower adoption states. The average annual salary for these jobs in 2001 was $52,310—more than one and a half times the U.S. average of $34,020.

-- The Council for Biotechnology Information: www.whybiotech.com

Iowa's bioscience subsectors can be categorized into four classes based upon their performance from 1998 to 2002, as shown in Figure 4. The four categories are based on (1) the subsector's growth relative to U.S. growth and (2) the subsector's location quotient. The four classifications of subsectors are ***stars, emerging potential, transitional, and divergent***. Subsectors classified as stars or emerging are vital for the overall industry and its future development potential. These subsectors are often seen as the driving force behind the industry's success. Subsectors classified as transitional or divergent are in a declining state. Though not irreversible, these subsectors demonstrate current characteristics that may threaten the long-term viability of the industry in Iowa.[14]

Figure 4: Iowa Bioscience Cluster Subsector Performance, 1998-2002.



Note: Bubble size indicates the subsector employment size
Source: Battelle calculations based on ES-202 data from the US Department of Labor, Bureau of Labor Statistics and Iowa Workforce Development, Employment Statistics Bureau

[14] A detailed table of Iowa's bioscience subsector performance can be found in Appendix B.

Stars

The organic and agricultural chemicals subsector is the fastest growing subsector in Iowa relative to the United States and is regionally specialized. Between 1998 and 2002, the subsector almost doubled in size, adding more than 2,000 jobs. The subsector had an employment base of 4,416 in 2002 across 56 establishments. This employment increase is substantial considering that at the national level the subsector experienced a 15.3 percent employment drop. The phenomenal growth in Iowa has positioned the subsector well above the national employment concentration level.

The state's employment concentration in organic and agricultural chemicals is 2.5 times greater than the national average. This level of employment makes organic and agricultural chemicals in Iowa significantly specialized. In addition to the regional specialization, Iowa's employment level represents an increasing concentration. The subsector's fast-paced growth is a major reason contributing to the state's growing specialization.

Emerging Potential

The drugs and pharmaceuticals subsector is the second fastest growing bioscience subsector and outpaced growth of this industry at the national level. Over the four-year time period between 1998 and 2002, subsector employment in drugs and pharmaceuticals rose by 12.6 percent. The increase brought employment levels above 2,500 across 44 establishments. The growth that Iowa experienced in drugs and pharmaceuticals even surpassed the U.S. growth rate. Nationally, the drugs and pharmaceuticals subsector grew by 11.3 percent. The ability of drugs and pharmaceuticals to remain ahead of national employment growth rates has contributed to a rising employment concentration. However, the employment concentration level in Iowa remains 22 percent below the national average.

The medical equipment and devices subsector experienced the second fastest employment growth rate in Iowa relative to the United States. Though growth was only half as much as the drugs and pharmaceutical subsector, medical devices was second only to organic and agricultural chemicals in terms of relative growth compared to the nation. Iowa's employment base in the medical device subsector grew by 6.1 percent. Across the nation, subsector employment in medical devices decreased by 0.6 percent.

Despite the encouraging growth trend over the last four years, the medical device subsector in Iowa remains small. In 2002, the subsector employed 1,847. The employment concentration of the subsector is significantly below the national average. Iowa is 59 percent less concentrated than the nation is in the medical equipment and devices subsector.

The hospitals and laboratories subsector is Iowa's largest bioscience subsector and is growing. The Iowa hospital and laboratory subsector employed 41,882 in 2002. Although not often considered at the forefront in bioscience research or production, hospitals and laboratories are important contributors. In particular, health centers perform clinical trials and collaborate with companies on research and development.

Since 1998, this subsector grew by 6.1 percent in Iowa, above the national rate of 4.4 percent. The growth provides the Iowa hospital and laboratories subsector with an employment level slightly below the national average. Typically, employment in hospitals and laboratories across most states and regions possesses a location quotient equivalent to the national average. This is to be anticipated because hospitals and laboratories generally service the local healthcare market except where specialized and/or academic teaching hospitals serve a broader, multi-state market.

Transitional

The agricultural equipment and machinery subsector is the most specialized bioscience subsector in Iowa. In 2002, the subsector employed more than 10,000 workers across the state. This level of employment is far above the national level. The agricultural equipment and machinery subsector in Iowa possesses a location quotient of 11.83. This concentration level represents an employment base in the state that is more than 10 times the national level.

This subsector has experienced sizable employment losses since 1998 at both the state and national level. Across the United States, employment in the agricultural equipment and machinery subsector decreased by 19.2 percent. Subsector employment in Iowa fell at a somewhat faster rate of 22.9 percent. Though the loss of employment was rather large in Iowa, it can be expected that a state as concentrated as Iowa inevitably will mirror the national trend. In spite of this decline, Iowa remains highly concentrated, an indicator of the state's strength in the agricultural equipment and machinery subsector.

The agricultural processing subsector is the largest agriculture-related bioscience subsector in terms of employment size and the second most regionally specialized subsector in Iowa's bioscience industry. In 2002, the agricultural processing subsector employed 19,458 across 976 establishments within the state. The subsector's size is demonstrated by examining the average establishment size. The typical agricultural processing establishment in Iowa employs 22 individuals. Nationally, the average establishment employs 16 individuals.

In Iowa, the agricultural processing subsector typically more concentrated and is composed of larger firms. The state's employment concentration in the agricultural processing subsector is more than 7 times greater than the national average. The location quotient of 7.34 clearly represents a strong regional specialization.

Unfortunately, much like the experience of the agricultural equipment and machinery subsector, employment in the agricultural processing subsector has dropped in Iowa and across the country since 1998. Jobs in agricultural processing in Iowa fell by 21.0 percent between 1998 and 2002, compared with a 2.9 percent decline nationally. Even with this loss of employment, the subsector remains significantly more specialized in Iowa.

The agricultural services subsector is regionally specialized but experienced the second largest decline in employment. The agricultural services subsector is the smallest of all the bioscience subsectors, employing 1,187 in 2002. Although small in size, the subsector is significantly concentrated and is considered to be regionally specialized in Iowa. The subsector is more than twice as concentrated in Iowa versus the nation.

The level of employment specialization is threatened by sizable employment losses. Between 1998 and 2002, Iowa lost 31.8 percent of its employment base in agricultural services. The nation experienced a job loss that was far less severe. U.S. employment in agricultural services fell by only 0.5 percent.

Divergent

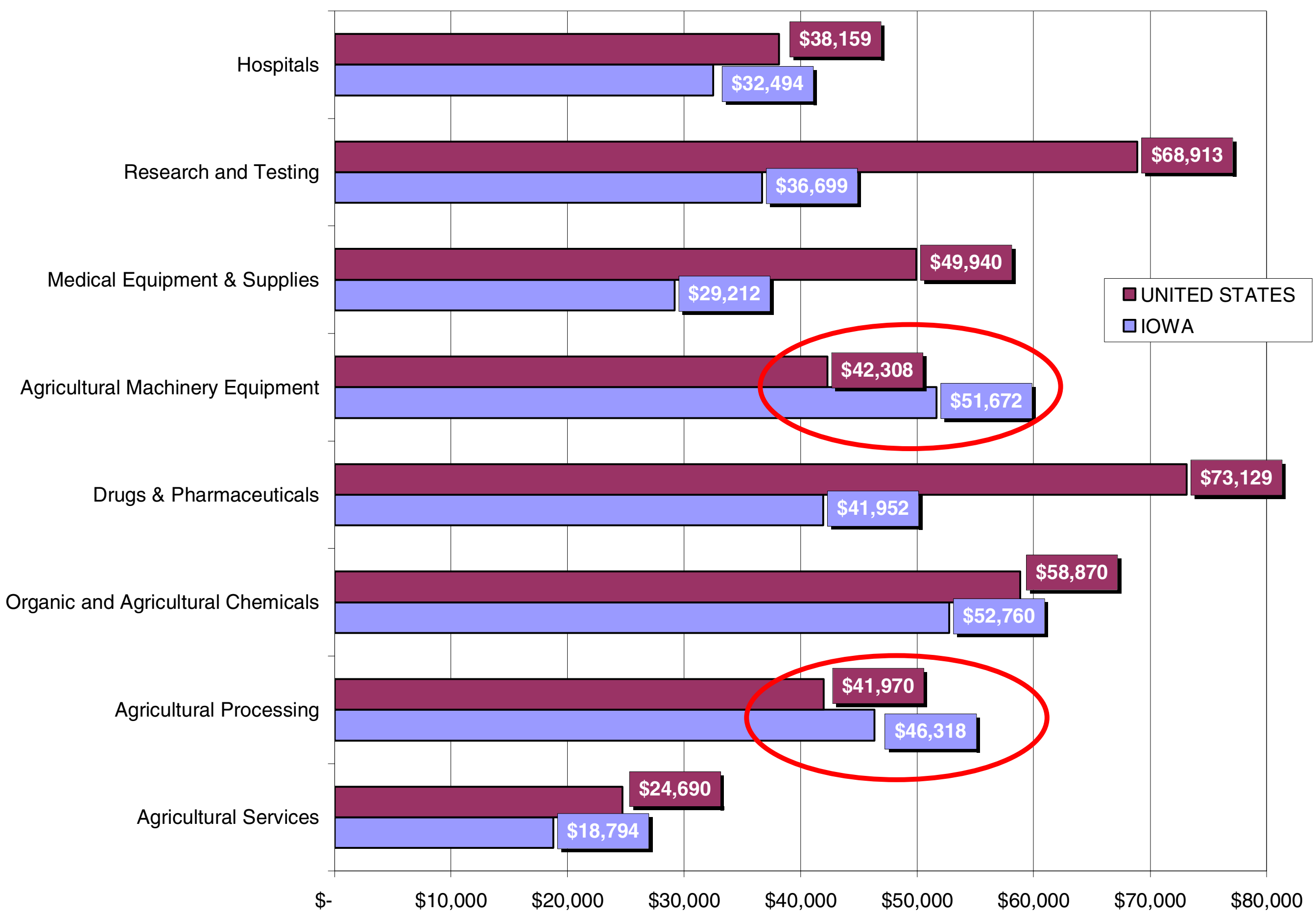
The research and testing subsector experienced the largest decrease in employment and is well below the national concentration average. Between 1998 and 2002, the subsector lost 37.3 percent of its employment base. This fast-paced decline contrasts sharply with strong growth at the national level. The U.S. research and testing subsector grew by 21.8 percent. Though not the smallest bioscience subsector in Iowa, the research and testing employment base is only slightly higher than agricultural services. In 2002, the research and testing subsector employed 1,429 across 186 establishments, making it Iowa's second smallest bioscience subsector.

The rapidly dwindling employment base has drastically reduced the level of employment concentration in the state. Research and testing is almost 80 percent less concentrated in Iowa than in the nation and is extremely small. This makes it more difficult to position the subsector as a platform on which to build the state's bioscience industry, even though research and testing is the industry subsector most closely identified with "biotechnology," as distinct from the "biosciences" industry segment.

Cluster Subsector Wages

Analyzing the average annual wage per employee is another way of identifying critically important bioscience subsectors. Pinpointing subsectors which provide relatively high wages is an indication that the subsector is a high value-adding segment. By targeting economic development initiatives and job-creating efforts at high-paying bioscience subsector positions, the state can concentrate its efforts on the highest value-adding segments and potentially raise the overall industry annual average wage per employee. Figure 5 illustrates the average annual wage per employee for each subsector in 2002.

Figure 5: Bioscience Cluster Subsector Average Annual Wage per Employee, 2002.



Source: Battelle calculations based on ES-202 data from the US Department of Labor, Bureau of Labor Statistics and Iowa Workforce Development, Employment Statistics Bureau

The graph clearly illustrates that agricultural machinery and equipment along with agricultural processing are major sources of current high-paying jobs in the biosciences in Iowa. These subsectors are well above the statewide average annual wage per employee, which stood at $29,158 in 2002. The subsectors are also above the bioscience average annual wage for the state and nation. ***The average annual wage per employee for agricultural machinery and equipment and agricultural processing is more than $4,000 above the national average wage within each subsector.***

Although employment has not grown since 1998, these two subsectors experienced average annual wage increases. Agricultural processing saw wages grow by 13.1 percent and agricultural equipment and machinery experienced an 8.4 percent growth in wages. Both growth rates are above U.S. growth rates. Above-average annual wages combined with strong regional specializations within Iowa position the agricultural machinery and equipment subsector along with the agricultural processing subsector as important subsectors for the state's future development efforts.

Detailed Cluster Subsector Strengths

While it is useful to further isolate particular strengths of these subsectors, industry-specific information should be approached cautiously. At such a detailed level, the data are often suppressed to avoid revealing information related to individual firms. The detailed analysis can also result in smaller absolute numbers, which exaggerate standard metrics and comparisons. In spite of these limitations, the disaggregated data can potentially reveal sources of subsector strength.

Figure 6 depicts the performance of key NAICS industries in the state of Iowa. The industries were chosen based on three criteria:[15]

- Industries with employment concentrations of 1.20 or more were considered regional specializations.
- Industries that grew above the national growth rate were considered high growth.
- Industries were classified as "large" based on employment size equal to or greater than 2,000.

Industries that fall within the confluence of all three circles are considered major bioscience cluster subsector strengths. These industries exhibited very large employment bases, significant specializations, and growth over the last year that surpassed U.S. growth rates. It is essential to target these industries. Table 4 presents the data for those NAICS industries that possess at least two of the criteria used to identify strong detailed industry segments.

Table 4 shows the industries that likely represent critical strengths of the Iowa bioscience sector. Each possesses a pair of critical characteristics from which the state can help bolster the entire bioscience cluster. Based on these metrics, these industries demonstrate the potential for the state to create new opportunities and niches in the bioscience industry that can be leveraged to jump-start other promising industry segments. The diversity of the bioscience industry within the cluster clearly indicates that advancements within particular subsectors can be leveraged to strengthen others. By focusing on its existing strengths, Iowa can build a promising future in the biosciences.

[15] To avoid overstating trends, only those industries with an employment level of at least 500 were analyzed.

Figure 6: Assessment of Iowa's Biosciences Cluster Detailed Industry Strengths.

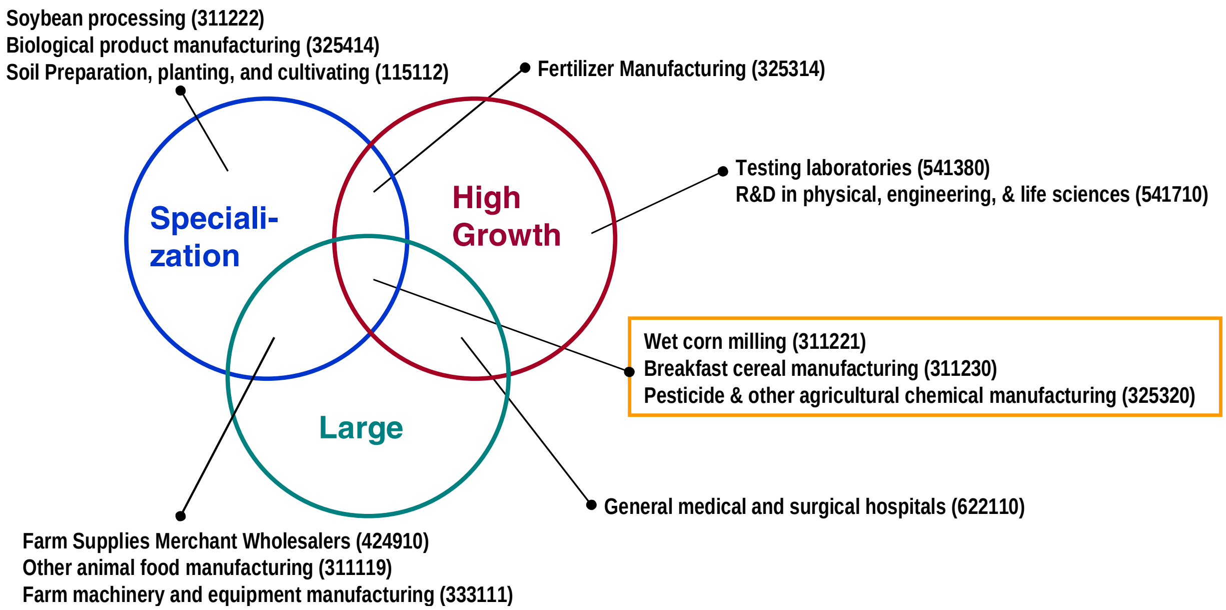


Table 4: Detailed Iowa Biosciences Cluster Industry Strengths.

Primary Target Industries - Large, Growing, and Regional Specialized		
325320	Pesticides & other agricultural chemical manufacturing	**Sizable:** Employment stands at 2,982 **High Growth:** Employment increased by 228% **Regionally Specialized:** LO stand at 14.39
311221	Wet corn milling	**Sizable:** Employs 2,947 **Growing:** Increased by 0.3% while US declined **Extremely Specialized:** LQ stand at 30.54
311230	Breakfast cereal manufacturing	**Employment:** 2,077 workers **Growth:** Employment rose by 5% **Specialized:** Iowa possesses an LQ of 13.65
Large Anchors - Large Employment and Regionally Specialized		
424910	Farm Supplies Merchant Wholesalers	**Large Employment:** 10,497 workers, the largest agricultural industry segment **Specialized:** 8.66 **Employment Growth:**
333111	Farm machinery and equipment	**Large Employment:** 9,656 workers **Specialized:** Maintains LQ of 15.36 despite losses **Growth:** Employment fell by 2.8%, less than US decline
311119	Other animal food manufacturing	**Sizable:** Employs 2,105 **Concentrated:** remained specialized with LQ of 5.82 **Employment Change:** Loss of 30.1% since '98
Emerging Industries - High Growth +		
622110	General medical and surgical hospitals	**Large Employment:** 40,675 workers **High Growth:** Employment grew by 6.3% **LQ:** Employment concentration is 5% below US average
325314	Fertilizer manufacturing	**Small:** Employment stands at 565 **High Growth:** Employment rose by 128% **Specialized:** Iowa is 6 times more specialized than US

Source: Battelle calculations based on ES-202 data from the US Department of Labor, Bureau of Labor Statistics and Iowa Workforce Development, Employment Statistics Bureau

CONCLUSIONS

The bioscience industry sector in Iowa is a large and regionally specialized sector of the state's economy. The sector has demonstrated successes and shown encouraging industrial potential. Though overall employment between 1998 and 2002 lagged behind the United States, the better than average growth exhibited between 2000 and 2002 suggests that the bioscience industry represents an economic development opportunity for Iowa. Development opportunities can have even more impact if industrial and academic initiatives are linked and focused around similar priorities.

The economic analysis of the Iowa bioscience economy indicates that the industry is dominated by the agricultural-related subsectors. In particular, three subsectors are well-positioned to be the foundation of a comprehensive economic development strategy (Table 5). Organic and agricultural chemicals are a sizable, growing regional specialization that is extremely well-positioned to benefit from increases in ethanol production (an organic chemical). Agricultural processing is the largest of the agriculturally based bioscience subsectors. Despite loss of employment, the subsector demonstrates a solid base that is significantly more specialized than the nation and possesses an average annual wage per employee that is higher than the national average. Similarly, agricultural machinery and equipment exhibits a solid employment base and high average annual wage.

Table 5. Key Iowa Bioscience Subsectors.

Key Iowa Bioscience Subsectors

Subsector	2002 Employment	Location Quotient	Employment Growth 1998 - 2002
Organic & Agricultural Chemicals	4,416	3.51	93.0%
Agricultural Processing	19,458	7.34	-21.0%
Agricultural Machinery & Equipment	10,115	11.83	-22.9%

The demonstrated success of these three subsectors positions the agricultural-related subsectors as vital existing strengths of Iowa's bioscience industry. State and regional stakeholders in the bioscience industry need to tailor development initiatives that specifically address these core strengths and further build the capacity to fully utilize these assets.

Medical-related subsectors, though not yet core strengths, demonstrate emerging characteristics that place these subsectors in the category of potential drivers. Above-average employment growth relative to the United States indicates that these subsectors can be a crucial part of the bioscience industry's future.

Though agricultural services and research and testing are subsectors that have not shown strong growth rates or high levels of employment concentration, these subsectors remain important pieces of the bioscience industry in Iowa. Agricultural services and research and testing represent key industry segments necessary to ensure the overall strength and stability of Iowa's biosciences sector. The diversity of the bioscience industry clearly indicates a high degree of interdependence among different industry segments.

To create a more durable and vibrant bioscience industry, the State of Iowa must target initiatives to support existing strengths and encourage and stimulate emerging subsectors. While Iowa must tailor initiatives to target those niches with the greatest promise of economic growth, the state must not lose sight of the inherent diversity of bioscience activity. The challenge that state leaders face is the need to balance initiatives between solidifying core areas within the biosciences and promoting new innovative industrial technologies that promise continual economic growth.

Biosciences Core Competency Assessment

One of the required platforms for creating an understanding of the potential for bioscience development is a rigorous analysis of the bioscience-related research competencies found within Iowa upon which future bioscience economic advances may be made. Each state's major research institutions have their own core research strengths and focus areas, and, as will be shown, Iowa is no exception.

Without a strong research foundation found at universities, it is difficult for any state or region to initiate or sustain major industry development related to the biosciences. Universities are leaders in basic and applied bioscience research. Increasingly, universities are bringing enabling technologies to the forefront, helping advance bioscience-related applications in imaging, analytical instrumentation, processing technology, diagnostics, therapeutics, and materials science. Research centers not only are the key to the basic research discoveries that generate product leads for bioscience companies; they also contribute to an environment in which bioscience companies can flourish.

Looking forward, the biosciences offer enormous potential for linking basic research innovations with new market opportunities. Table 6 describes the major potential breakthrough areas.

Table 6: Potential Bioscience Breakthrough Areas.

Human Biosciences	Plant Biosciences	Animal Biosciences
• The prevention of diseases with underlying genetic causes • The development of early stage disease diagnostics • The ability to detect genetic predisposition to disease and develop prevention and treatment regimens • The production of advanced imaging technologies to promote new discovery and enhance therapeutic delivery • The discovery and development of new drugs and biologics for enhanced treatment outcomes • Drugs and therapies targeted to individual genomic characteristics leading to greatly improved outcomes and reduced side-effects	• Pest and disease resistant crops • Increased crop yield and desirable qualities characteristics • Lengthened growing seasons via cold resistance or reduced light requirements • Enhanced shape, texture, flavor and processability characteristics • Technologies to reduce the required application of fungicides, herbicides and insecticides • Functional foods and nutraceuticals • Plant genetic resources for development of biologics, drugs and pharmaceuticals	• New approaches to animal disease diagnostics, prevention and treatment • Increased food animal meat yield and desirable quality characteristics • Improved technologies for food preservation and the prevention of spoilage and food-borne diseases • Genetic resources for development of biologics, drugs and pharmaceuticals for human and veterinary applications • Xenotransplantation and tissue engineering, providing organs and tissue for human medical applications via animal pathways • Development of engineered species, such as customized predator insects, to control pests and diseases

Table 6: Potential Bioscience Breakthrough Areas (continued).

Human Biosciences	Plant Biosciences	Animal Biosciences
• The development of replacement tissue and organ systems to replace those injured or failing • The biological integration of advanced technologies, such as nanotechnology, biomaterials and MEMS devices • Advanced bioinformatics and health informatics tools to drive knowledge-based medicine. • The ability to eradicate, inoculate against and more effectively treat established and emerging infectious diseases • Enhanced biosecurity	• Genetic resource (germplasm) preservation and storage technologies • Development of biosensors for industrial and commercial applications • "Biopharming" and the production of novel and useful chemicals via plant pathways • Development of sustainable bio-based fuels • Development of advanced biomaterials for use in construction and other industrial applications • Development of degradable plastics from plant starch, protein and fermentation-produced monomers • Bioremediation and environmental protection via plants • Enhanced biosecurity	• Development of biosensors for industrial and commercial applications • Bioremediation and environmental protection via microbial pathways • The use of animal waste and byproducts as renewable energy and chemical production resources • Enhanced biosecurity • The novel application of animal and plant genetic resources to new technologies such as biological computing

As a result of potential discoveries and innovations in these areas, multiple forms of economic development may take place around the biosciences, including but not limited to the following:

- The formation, growth and attraction of companies engaged in
  - Drug development and manufacturing
  - Biologics development and manufacturing
  - Vaccine production
  - Gene therapy development
  - Diagnostic test development and production
  - Diagnostics and imaging instrumentation manufacturing and development
  - Laboratory and diagnostics services and healthcare services
  - Medical implants and invasive devices
  - Tissue engineering and organ systems development
  - Seed and plant varietal development and production
  - Improved food animal species and enhanced animal health

- Agricultural and food processing technologies
- Biomaterials and biocomposites development
- Biofuels and bio-sourced chemicals
- Production of novel and useful compounds via plant pathways
- Agricultural equipment and precision agriculture devices
- Bioinformatics and health informatics tools and software
- Biosecurity
- Waste management and environmental clean-up and protection
- Nanotechnology and MEMS devices
- Other bio and bio-related commercial applications yet to be developed or imagined.

- The diversification of existing commodity producers, such as farms, into enhanced value-added products.
- Direct economic benefits from research itself, brought by the attraction of external research funds and the scientists and staff they support.
- Enhanced education and workforce development in and around biosciences and technology.

Because research is the driving force behind bioscience innovation and commercialization, it is imperative that Iowa's decisions regarding science and technology policy for advancing the biosciences be built upon a formal understanding of the state's bioscience research core competencies. To develop a profile for Iowa, Battelle performed a formal, in-depth assessment and evaluation of the state's bioscience core competencies and resulting technology platforms—a task that Battelle has undertaken for other states and universities.

Methodological Approach to Assessing Iowa's Core Research Competencies

Underpinning the successful translation of bioscience research strengths into economic development opportunities requires recognition of the importance of "market-driven" processes. The traditional model of commercialization assumes a "research-driven" approach to commercialization. This research-driven commercialization process proceeds in a pipeline fashion from basic research leading to a major scientific breakthrough, to applied research leading to product development, and ending with industrial manufacturing and marketing. The shortcomings of the research-driven approach are that it is too divorced from commercialization and product development needs and has uncertain economic value. The market-driven approach recognizes that commercialization is a highly interactive process involving close ties between research activities and business development activities. Success depends, as the Council on Competitiveness points out, "on a team effort that includes carefully focused research, design for manufacturing, attention to quality and continuous market feedback."[16]

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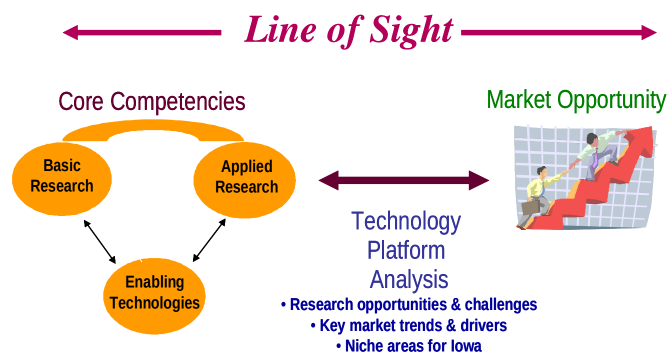
[16] Council on Competitiveness, *Picking Up the Pace: The Commercial Challenge to American Innovation* (Washington, DC: Council on Competitiveness), pp. 9-10.

As seen in Figure 7, the components of a core competency area can bring together basic research, enabling technology, and applied research activities with a "line of sight" that moves seamlessly to address clinical needs and market opportunities, and can form robust technology platforms. Core competency areas that lack this linkage and connection to needs and market opportunities offer more limited development opportunities.

Figure 7. Line of Sight.



Defining Core Competencies

There is no one single source of information that serves to identify core research competencies and focus areas. Rather, a variety of integrated and complementary analyses are required to help identify an institution's current position and areas of focus that may lead or contribute to Iowa's future bioscience growth.

In identifying core research focus areas in the biosciences, Battelle's objective was to identify those fields where there is an ongoing critical mass of activity along with some measure of excellence. This does not mean, however, that other fields of bioscience excellence may not be present within Iowa institutions. What it does mean is that these other bioscience strengths are found in relatively limited pockets and so offer more limited opportunities upon which to build—but may still contribute in some manner.

To take the analysis further, Battelle chose to apply an industrially focused core competency definition that is widely used by technology-based firms. As defined by Hamel and Prahalad, in "Competing for the Future,"[17] a competence is a bundle of skills and technologies, rather than a single discrete skill or technology. It represents the sum of learning across individual skill sets and individual organizational units.

Three tests can be used to identify a core competency:

1. Is it a significant source of competitive differentiation? Does it provide a unique signature for the state?
2. Does it transcend a single business? Does it cover a range of businesses, both current and new?
3. Is it hard for competitors to imitate?

Approach to Identifying Iowa's Bioscience Research Core Competencies

Battelle identified core research focus areas using both quantitative and qualitative methods (see also Figure 8):

- Quantitative assessment uses statistical information on extramural grants, publications, and patent activities—as well as application of Battelle's proprietary software tool "Starlight™" to identify research clusters—to develop an understanding of the trends and characteristics of bioscience research within Iowa institutions.

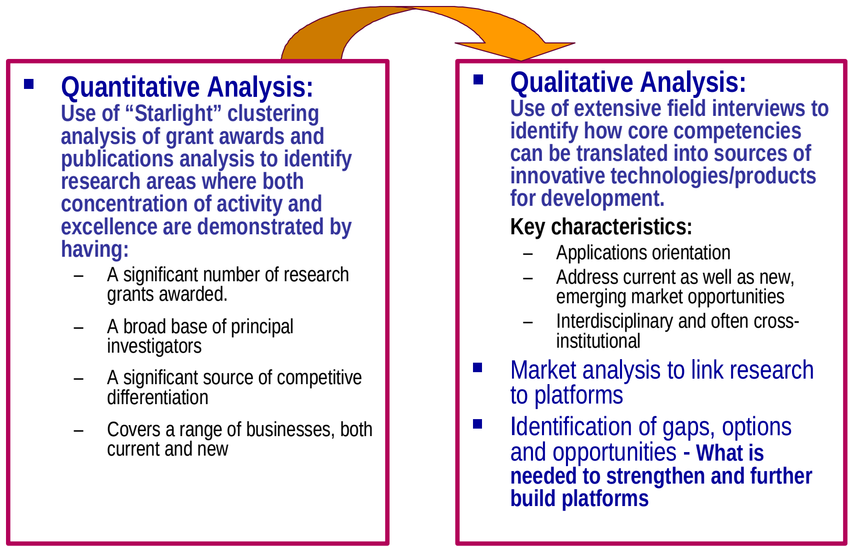
[17] Hamel, G. and Prahalad, C. K. 1994. Competing for the Future. Harvard Business School Press: Boston, MA.

- Qualitative work includes extensive field-work interviews with key administrators, scientists, and researchers across the research drivers found in Iowa institutions.

The questions that the Battelle team explored in the core competency assessment focused on the following:

- What is Iowa's overall volume of bioscience research and what trends, positive or negative, are being demonstrated?

Figure 8: Quantitative/Qualitative Analysis.



- In which fields of bioscience and related activities are Iowa R&D institutions receiving significant levels of funding, especially funding from "gold standard" sources such as the National Institutes of Health (NIH), the U.S. Department of Agriculture (USDA), National Science Foundation (NSF), etc.?
- In what bioscience and related fields do Iowa academic institutions demonstrate a substantive and influential record of publication?
- In what bioscience areas is Iowa generating patents and intellectual property?
- What areas of bioscience and related fields do Iowa's institutions self-identify as core competencies?
- Based on identified core competencies, what development opportunities can be identified for the near-term (over the next five years) for growing the biosciences and related industries and technologies in Iowa?
- Which bioscience core competencies show the most promise for becoming growth poles for incorporation into Iowa's statewide technology and economic development policy?
- Which core areas of bioscience focus require additional investment in order to realize their development potential?

In evaluating the answers to these questions, the Battelle team can provide insights into the Iowa biosciences research base and draw implications as to how these research strengths may best intersect with the state's industry and economic base, economic competitiveness factors, and market trends.

Quantitative Assessment of the Iowa Bioscience Base: Trends and Developments

As a first step in assessing the biosciences position of Iowa, Battelle reviewed published statistics that allow the position of Iowa institutions to be compared to those of other leading bioscience institutions. Several sources of information typically are accessed by Battelle in assessing comparative bioscience positioning:

- External, national research funding sources, including NSF, USDA, and NIH grant funding
- Institute for Scientific Information (ISI) science publications citation index statistics
- Proprietary Battelle Starlight™ analysis tools for mining research abstract information and patent abstract information for clusters of research expertise and focus.

For purposes of this study Battelle used the latest comparative data available on all 50 states from federal agencies. While individual universities in Iowa have later data, it could not be used because it would not allow us to make comparisons with the nation and other states. In addition, this analysis is affected by the disproportionate federal research investments in human/medical research compared to plant, animal and related agriculture research. Because of the disproportionate amount of federal research dollars flowing through NIH, as compared to, for example, USDA, the reader should not conclude that the University of Iowa, whose medical school is the state's primary recipient of NIH funds, is more successful than Iowa State, where USDA has a much smaller research budget to allocate to research universities.

Size of the Iowa Bioscience Research Base

In terms of total university-based R&D activity, Iowa stands 24th in the nation, with $439.8 million in total research funding across seven research universities (as recorded by the NSF for 2001, Table 2). This level of R&D in Iowa outpaces the state's overall ranking in population, which stands at 30th.

Iowa historically has performed relatively well in terms of academic biosciences R&D. In 2003, 66 percent ($291 million) of the $439.8 million in total Iowa university-based research was within the biosciences—placing Iowa 21st in the nation. Also, Iowa has sustained a strong position, relative to its population base, in multiple areas of bioscience R&D, with national rankings as follows:

- 19th in "medical sciences" ($138 million)
- 20th in "agricultural sciences" ($50 million)
- 22nd in "biological sciences" ($84 million).

Table 7: Iowa Biosciences-Related Funding.

R&D Funding at Iowa Universities (Rank of State of Iowa vs. Other States - For 7 Iowa Colleges & Universities)			
Field	**FY 2001**	**% U.S.**	**Rank**
TOTAL OF ALL ACADEMIC DISCIPLINES	**$ 439,810**	**1.3%**	**24**
LIFE SCIENCES TOTAL	**$ 290,912**	**1.5%**	**21**
Agricultural Sciences	$ 49,993	2.2%	20
Biological Sciences	$ 84,185	1.4%	22
Medical Sciences	$ 137,689	1.4%	19
Other Life Sciences	$ 19,045	2.5%	15
OTHER CRITICAL SCIENCES			
Chemical Engineering	$ 3,558	0.9%	32
Chemistry	$ 9,625	1.0%	30

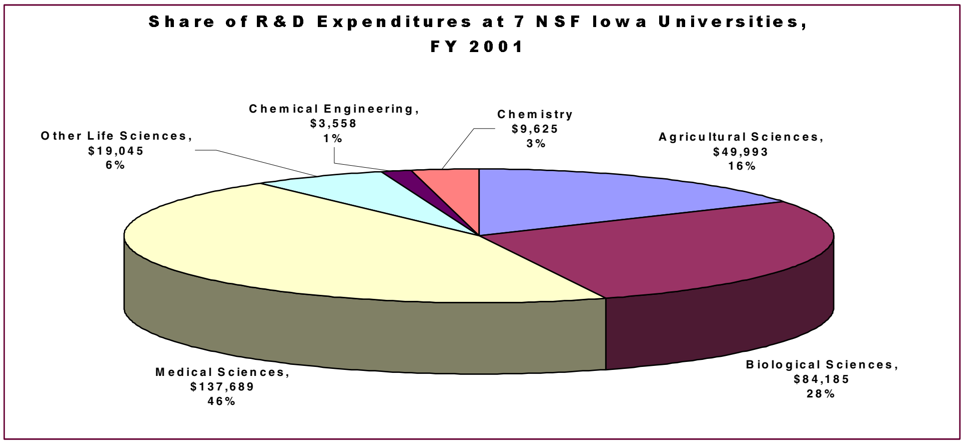
Iowa's ability to attract research funds is reflected in an overall rank of 24th for all academic disciplines combined, compared with Iowa's population ranking of 30th. In Bio/Life-Science disciplines the state performs particularly well, while it also achieves a ranking appropriate for its size in chemistry and chemical engineering (two disciplines of great importance in current and future BioEconomy initiatives).

As the pie charts in Figure 9 illustrate, the percent of each type of bioscience and associated sciences R&D in Iowa is quite similar to that within each field in the nation as a whole except that Iowa has a significantly higher than average concentration in agricultural sciences (16 percent versus 11 percent nationally).

While Iowa has performed comparatively well in bioscience research in relation to its size, it has started falling off the national pace. Since 1996, Iowa has experienced a slowly declining share of U.S. academic biosciences R&D funds. This trend is illustrated in Figure 10.

Key data relating to Iowa's recent performance in the biosciences is highlighted in Table 8 and further explains how Iowa has not kept pace with national bioscience research funding trends. The data show that Iowa has a greater concentration of total academic R&D in the biosciences than the national average, and also that bioscience academic R&D spending per capita is considerably above the U.S. average. ***This comparative concentration in bioscience is declining somewhat as Iowa's growth in bioscience R&D funding has not kept pace with the growth rate of U.S. bioscience research.*** To put it another way, if Iowa's bioscience R&D increase from 1997 to 2001 kept pace with overall U.S. growth, Iowa would have received approximately $8 million more in bioscience R&D funding in FY 2001.

Figure 9: Share of Bioscience-Related R&D for Iowa and the U.S.



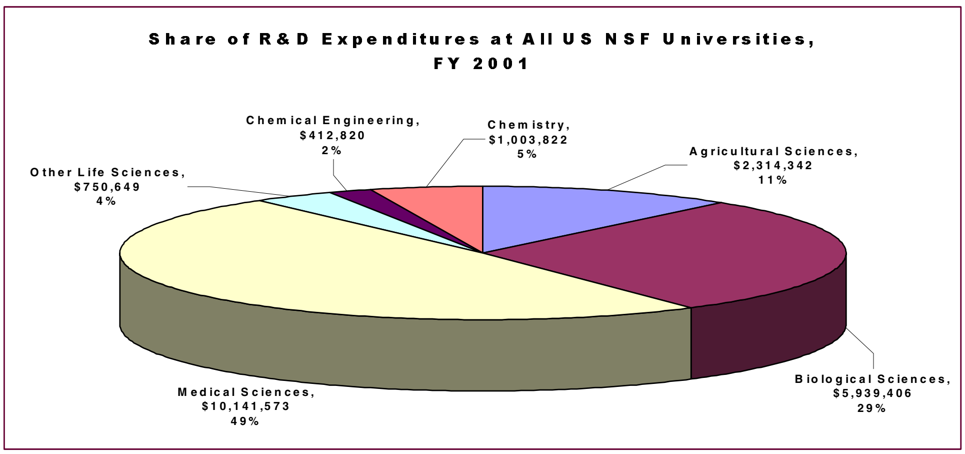


Figure 10: Academic R&D in Iowa as a Percentage of U.S. Academic R&D.

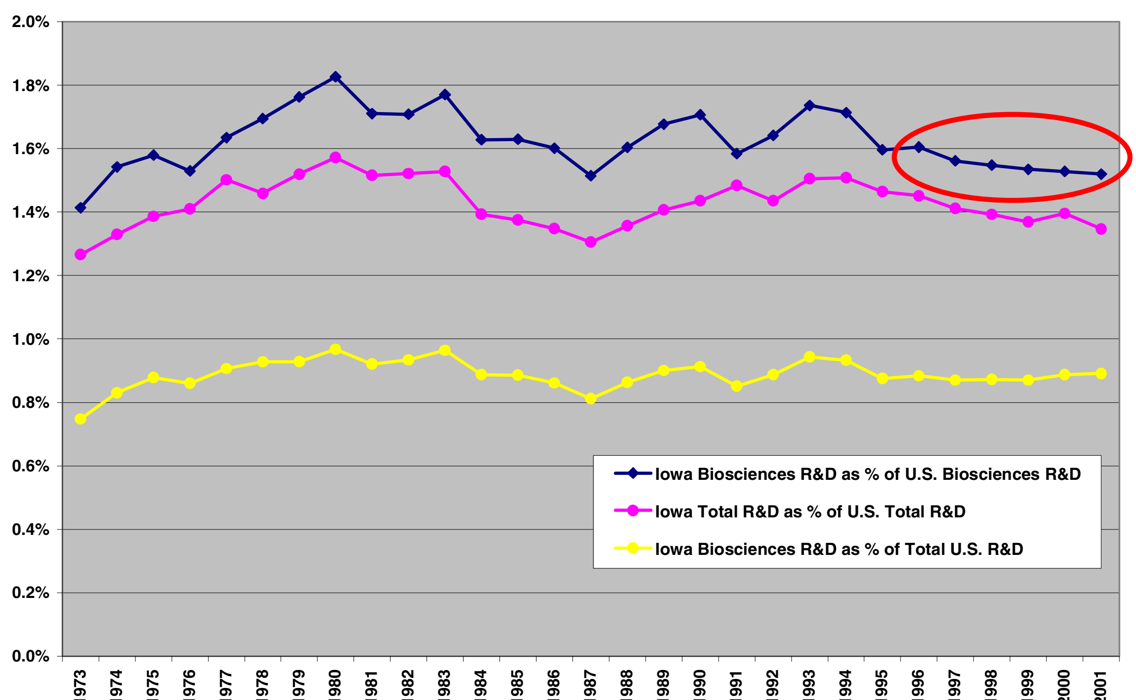
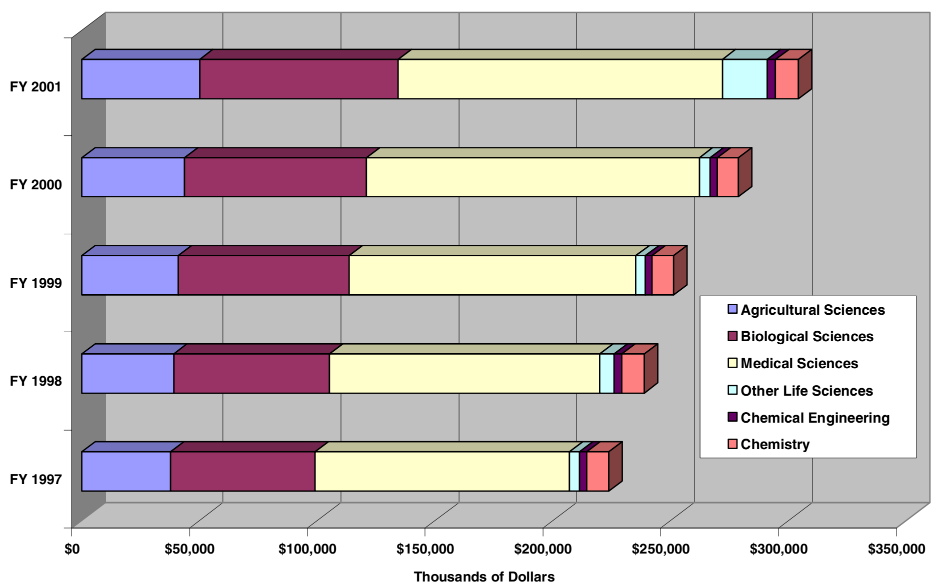


Table 8: Recent Bioscience Performance in Iowa and the U.S.

Metric	Iowa	United States
Total Academic R&D, FY 2001	$439,810,000	$32,652,261,000
Total Bioscience R&D, FY 2001	$290,912,000	$19,145,970,000
Bioscience as a % of All Academic R&D	66.1%	58.6%
Annual Academic Bioscience R&D Per Capita, FY 2001	$99.22	$67.10
% Increase in Academic Bioscience R&D, FY '97-01	37.7%	41.5%

To further examine this issue, Figure 11 depicts life science funding to the seven Iowa institutions included in the NSF data, by general category (including bioscience funding and funding in chemistry and chemical engineering), for 1997 through 2001.[18] The figure shows that in each category, Iowa has achieved an increase in the level of R&D spending at its academic institutions during this period.

Figure 11: Academic Life Sciences R&D Spending at 7 Iowa Institutions, FY 1997-2001.



A more detailed examination by federal agency of the funding trends is shown in Figure 12 (most recent available data is from 1996 to 2000). Figure 12 shows that actual declines in U.S. Environmental Protection Agency (and DOE) funding, slower growth in NSF funding, and *much* slower growth in USDA funding,[19] all contributed to the overall slower bioscience research funding growth rate for the state. However, in HHS (NIH) funding, Iowa's growth continued to outpace that of the nation.

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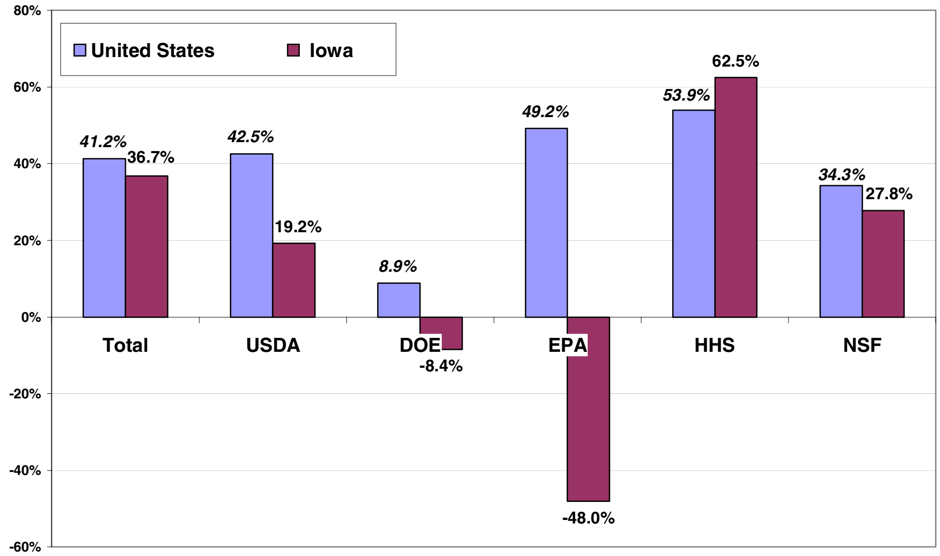
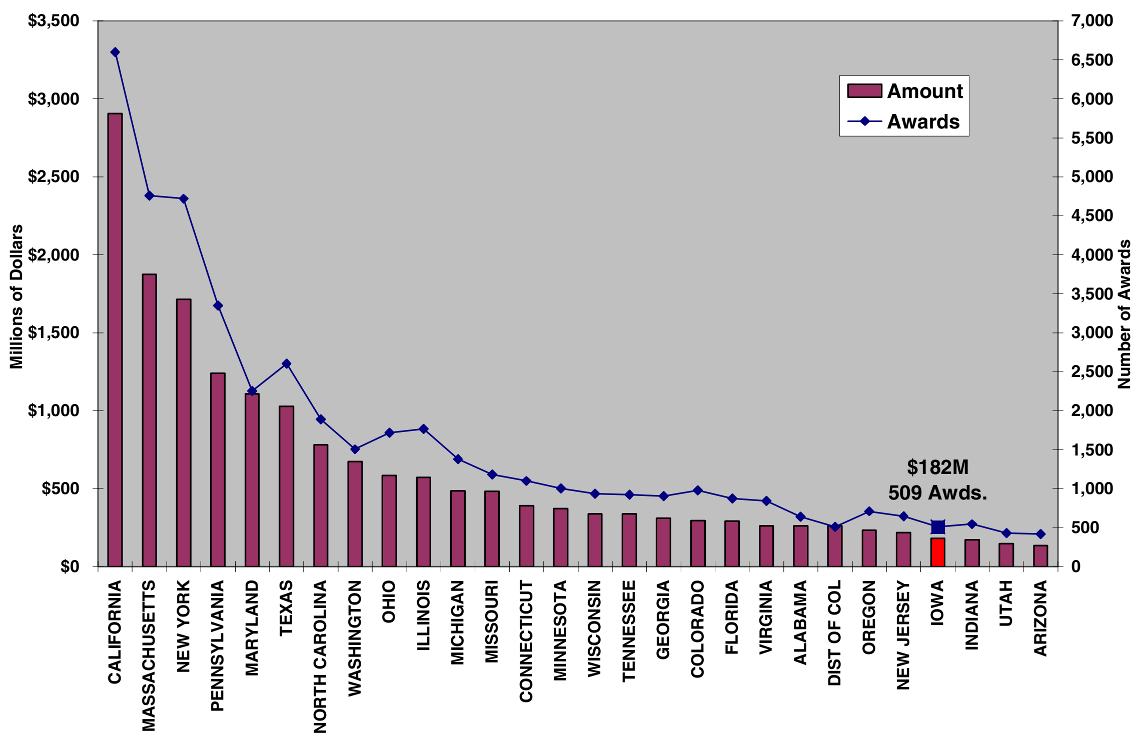
[18] The 7 institutions include Iowa State University, University of Iowa, University of Northern Iowa, Drake University, Grinnell College, Maharishi University of Management, and Des Moines University-Osteopathic Medical Center.
[19] It should be noted that USDA funding tends to fluctuate considerably from year to year.

Figure 12: Percentage Change in Federal Agency R&D Funding at Universities and Colleges in Iowa and the U.S., FY 1996-2000.



Iowa's overall position in one of the "gold standards" of bioscience funding, the National Institutes of Health, shows that Iowa ranks 25th in total NIH awards (Figure 13). This performance exceeds the state's population ranking (where it stands at 30th).

Figure 13: Total NIH Funding and Number of Awards, FY 2002.



Quantitative Assessment of the Iowa Bioscience Base: Identification of Potential Core Competency Areas

The previous section highlighted basic trends in academic bioscience R&D activity within Iowa. In this section, the analysis is extended to examine the specific areas of bioscience and bioscience-related activities that are receiving extramural funding. The volume of funding and numbers of investigators are used to indicate the most active bioscience fields in Iowa's research institutions. NIH, USDA, and NSF data are primarily used for this analysis.

In addition, the ISI Citations database—a source providing detail on research "output" in terms of number of papers published, by discipline, and the average number of citations received per paper—was used. ISI maintains a detailed database of U.S. scientific papers and associated citations, allowing Iowa's academic paper output in biosciences and related disciplines to be compared with national norms and indexed for relative impact. ISI data also allows for the calculation of the relative concentration of individual bioscience fields within institutions against national norms.

These statistical sources were used to derive an overview of research core competencies and to give a more specific description of the bioscience expertise within Iowa academic R&D institutions. An area is identified as a core competency area when it has the following:

- A significant number of bioscience-related research grants awarded through rigorous peer-review processes such as those at the NSF, USDA and NIH
- A broad base of principal investigators, along with prominent biomedical researchers who hold multiple peer-review grants
- A substantial level and impact of publications.

RESEARCH CORE COMPETENCY AREAS SUGGESTED BY FEDERAL FUNDING DATA

Examining NIH, USDA and NSF funding more closely, at the department level, suggests specific areas of strength in Iowa.

Table 9 summarizes the national ranking of departments within Iowa institutions that are recipients of NIH funding (with The University of Iowa separated into the College of Medicine versus other departments aggregated across the University). Table 10 shows the number of awards by department (for those receiving 10 or more awards) between FY 1997 and FY 2003.

Table 9: NIH Awards Rank by Department.

Institution	Department	NIH Rank (Within Top 30)
Among Medical Schools (FY 2002)		
The University of Iowa College of Medicine	Orthopaedics	3
	Public Health & Preventative Medicine	5
	Otolaryngology	5
	Pediatrics	8
	Anesthesiology	10
	Biostatistics & Other Math Sciences	11
	Urology	12
	Radiation-Diagnostic/Oncology	13
	Anatomy/Cell Biology	23
	Internal Medicine/Medicine	24
	Psychiatry	25
	Neurology	30
	Dermatology	30
Among Universities (FY 2000)		
The University of Iowa	Pediatrics	7
	Orthopedic Surgery	9
	Anesthesiology	11
	Nursing (2002 Data)	11
	Otolaryngology	13
	Radiology	14
	Public Health & Preventative Medicine	15
	Dermatology	16
	Anatomy	19
	Medicine	25
	Neurology	26
	Other Health Professions	26
	Dentistry	27
	Psychiatry	27
Iowa State University of Science and Technology	Social Sciences	3
	Zoology	14
	Nutrition	25

Table 10: NIH Awards by University Department.

The University of Iowa	Awards
Anatomy And Cell Biology	36
Biochemistry	45
Biological Sciences	34
Cardiovascular Center	11
Chemistry	22
Dows Institute For Dental Research	12
Epidemiology	12
Internal Medicine	274
Microbiology	39
Neurology	26
Orthopaedic Surgery	14
Otolaryngology	15
Pathology	28
Pediatrics	78
Pharmacology	18
Physiology And Biophysics	35
Preventative Medicine & Environmental Health	43
Psychiatry	56
Psychology	49
Radiation Research Laboratory	11
Radiology	27
Speech Pathology And Audiology	16
Iowa State University of Science & Technology	**Awards**
Biomedical Sciences	11

While the NIH is the largest funder of bioscience research in the U.S., both the NSF and the USDA also provide significant bioscience R&D funds. The USDA funding is, of course, particularly important to land grant institutions, such as Iowa State University, who have a substantial R&D infrastructure supporting animal and plant biosciences. Table 11 summarizes NSF awards in Iowa, while Table 12 shows awards by the USDA.

Table 11: NSF Awards by NSF Program Areas (Those with 10 or More Awards).

The University of Iowa	Awards	Iowa State University	Awards
Bioengineering & Environmental Systems	10	Biological Infrastructure	16
Molecular and Cellular Biosciences	16	Environmental Biology	20
		Integrative Biology and Neuroscience	18
		Molecular and Cellular Biosciences	21

Table 12: USDA Awards by Federal Center or University Department *(Those with 10 or More Awards Provided to Iowa Institutions).*

United States Department of Agriculture (USDA)*	Awards	Iowa State University	Awards
Agricultural Research Service	20	Agronomy	18
National Animal Disease Center	30	Animal Science	20
		Plant Pathology	10
		Veterinary Medicine	80

**USDA Has Only Different Centers, Not Departments*

The NIH data show that The University of Iowa College of Medicine ranks in the top 10 in the nation in terms of

- Orthopaedics (#3)
- Public Health and Preventative Medicine (#5)
- Otolaryngology (#5)
- Pediatrics (#8)
- Anesthesiology (#10)

The University of Iowa College of Medicine also has a strong placing in biostatistics and other math sciences, an important area of modern biomedical research (ranking 11th in the nation).

In terms of NSF awards, Iowa State University is a strong performer with awards spread across biological infrastructure, environmental biology, integrative biology and neuroscience, and molecular and cellular biosciences. Iowa State also is a major recipient of funding from the USDA, especially in the areas of Veterinary Medicine and Animal Sciences.

Tables 10 to 12 also provide insight into the overall research funding strengths of the State of Iowa. No departments or institutions other than Iowa State University and the University of Iowa received more than 10 federal R&D awards in the FY 1997 to FY 2003 period.

Core Competency Research Areas Suggested by ISI Citations Data

ISI provides specific insight regarding the volume of publications produced by departments and the influence, in terms of citations, that each department's work is having within its field. Battelle used the

ISI data, in addition to extramural funding data, Starlight™ analysis, and in-depth interviews, to provide an overview of where institutional strengths in science and technology may lie.

Battelle accessed the ISI data for 1997 through 2001. In determining areas of strength within the biosciences, the focus was on bioscience and related fields where the institution has published at least 50 papers that meet either or both of the following ISI indices parameters:

- The relative impact of the published papers should be 1.25 or higher, where 1.0 equals the average impact of a U.S. paper in the field. "Relative Impact" represents the institution's citation impact in the field (number of citations its papers receive in a field divided by its total number of papers) divided by average national impact of a paper in that field. A number above 1.0 can be read as a percentage, i.e., 1.25 equates to a 25 percent higher-than-average impact, while a 0.9 impact is 10 percent lower than average.
- The publication quotient or citation quotient of 2.0 or higher indicates a concentration of effort in the area within the institution. The ratio measures the degree of concentration in a field within an institution versus the U.S. average. A ratio of 1.0 equals the national average, while greater than 1.0 indicates a higher concentration in Iowa versus the nation.

ISI data were only available for Iowa State University, The University of Iowa and the Ames Laboratory. Table 13 illustrates the areas of strength suggested by the ISI data within bioscience fields in Iowa:

Table 13: Overall Iowa Bioscience Publication Strengths.

Top Fields in Publications, FY 1997-2001 (Citation or Publication Quotient Greater than 2.0 or Relative Impact Greater than 1.25)					
Field	Citations	Publications	Citation Quotient	Publication Quotient	Relative Impact to US
Agricultural Chemistry	555	185	2.85	2.79	0.94
Agriculture/Agronomy	929	387	5.80	3.56	1.50
Anesthesia & Intensive Care	638	119	1.20	0.77	1.42
Biotechnology & Applied Microbiology	602	106	1.63	1.61	0.93
Clinical Immunology & Infectious Diseases	3,481	308	3.15	1.70	1.71
Dentistry/Oral Surgery & Medicine	721	263	3.29	2.76	1.09
Entomology/Pest Control	365	140	1.58	1.14	1.27
Food Science/Nutrition	654	209	1.66	1.59	0.95
Microbiology	6,750	718	2.03	1.79	1.04
Ophthalmology	721	176	2.14	1.64	1.20
Otolaryngology	571	187	2.85	2.04	1.29
Veterinary Medicine/Animal Health	801	308	2.17	1.79	1.12

The ISI data indicate that Iowa is generating significant impact relative to the U.S. as a whole in terms of R&D in

- *Clinical Immunology and Infectious Diseases* (1.71 relative impact)
- *Agriculture and Agronomy* (1.50)
- *Anesthesia and Intensive* Care (1.42)
- *Otolaryngology* (1.29)
- *Entomology/Pest Control* (1.27).

Also of note is *Ophthalmology* in which Iowa achieves a relative impact of 1.2.

The *Agriculture and Agronomy* field also has strong citations and publications quotients (at 5.8 and 3.56 respectively). Also of note for high citations and publication quotients are *Agricultural Chemistry*, *Clinical Immunology and Infectious Diseases*, *Dentistry, Oral Surgery and Medicine*, *Microbiology*, *Ophthalmology*, *Otolaryngology* and *Veterinary Medicine/Animal Health*.

Because of the comparative differences in bioscience focus of The University of Iowa (primarily human biomedical focused) and Iowa State University (primarily plant and animal bioscience focused), the ISI citations data were separately analyzed for each. Table 14 illustrates the results for the University of Iowa, while Table 15 shows Iowa State University. (Research fields that are part of the overall state strengths shown in Table 13 are represented in orange in Tables 14 and 15.) These results clearly illustrate the different focus areas of both universities, with each having their respective and separate strength areas that contribute to Iowa's quite broad expertise in human, animal and plant bioscience.

Table 14: Bioscience Publication Strengths of the University of Iowa.

Top Fields in Publications for University of Iowa, FY 1997-2001 (Citation or Publication Quotient Greater than 2.0 or Relative Impact Greater than 1.25)					
Field	Citations	Publications	Citation Quotient	Publication Quotient	Relative Impact to US
Anesthesia & Intensive Care	638	118	1.44	1.10	1.44
Clinical Immunology & Infectious Diseases	3,383	297	3.68	2.36	1.72
Clinical Psychology & Psychiatry	1,266	162	2.01	1.85	1.20
Dentistry/Oral Surgery & Medicine	718	262	3.93	3.97	1.09
Environment/Ecology	735	153	0.52	0.44	1.31
Immunology	5,733	342	1.41	1.15	1.36
Microbiology	5,776	545	2.09	1.96	1.18
Oncogenesis & Cancer Research	2,526	190	0.93	0.79	1.30
Oncology	2,120	170	1.11	0.97	1.27
Ophthalmology	720	175	2.57	2.36	1.20
Otolaryngology	571	187	3.42	2.94	1.29
Research/Lab Med. & Med. Tech.	1,604	163	1.31	1.15	1.26

Note: Field names in orange are fields that are part of a combined statewide strength.

Table 15: Bioscience Publication Strengths of Iowa State University.

Top Fields in Publications for Iowa State University, FY 1997-2001 (Citation or Publication Quotient Greater than 2.0 or Relative Impact Greater than 1.25)					
Field	Citations	Publications	Citation Quotient	Publication Quotient	Relative Impact to US
Agricultural Chemistry	362	128	11.53	6.62	0.88
Agriculture/Agronomy	899	379	34.85	11.94	1.48
Animal & Plant Sciences	848	143	6.14	4.11	0.76
Animal Sciences	550	262	6.47	3.97	0.83
Biology	648	124	4.04	2.47	0.83
Biotechnology & Applied Microbiology	255	56	4.29	2.92	0.75
Entomology/Pest Control	349	131	9.39	3.67	1.30
Environment/Ecology	910	336	3.33	2.29	0.74
Food Science/Nutrition	546	187	8.58	4.89	0.89
Plant Sciences	1,519	366	7.13	4.24	0.85
Veterinary Medicine/Animal Health	629	289	10.57	5.74	0.93

Note: Field names in orange are fields that are part of a combined statewide strength

One research area of particular note is the Environment/Ecology field (highlighted in gray in both Table 14 and Table 15). Interestingly, this field is considered a strength for each of the two universities separately—The University of Iowa for relative impact (1.31) and Iowa State University for citation quotient and publication quotient (3.33 and 2.29 respectively), yet it fails to meet the publications and citations strength criteria for the state as a whole.

Battelle's ISI citations analysis highlights several factors relating to the biosciences in Iowa:

- There is significant institutional depth in a broad range of bioscience, biomedical and related disciplines. Both Iowa State University and The University of Iowa contribute to this depth.
- Iowa has strengths in the three primary components of bioscience—human medicine, veterinary medicine and animal health, and plant sciences/agricultural science.
- The University of Iowa is particularly strong and productive in Clinical Immunology and Infectious Diseases, Immunology, Otolaryngology, Ophthalmology, Anesthesia and Intensive Care, and Clinical Psychology and Psychiatry.
- Iowa State University has demonstrated impact in Agriculture/Agronomy and Entomology and Pest Control. The University also has a strong concentration in Agricultural Chemistry, Animal and Plant Sciences, Veterinary Medicine and Animal Health, Food Sciences, and Nutrition.

RESEARCH CORE COMPETENCY AREAS SUGGESTED BY STARLIGHT™ CLUSTER ANALYSIS

Battelle, through its research at the Pacific Northwest National Laboratory (PNNL), has developed proprietary pattern recognition and clustering software that provides unique insight into research strength areas. The clustering tool, known as Starlight™, uses pattern recognition algorithms to cluster research fields into grouped strength areas. Starlight™ is valuable because it allows free association of words and phrases, rather than forcing clustering on preselected key words—thus, there is no a priori bias to the clusters identified.

Battelle has performed the Iowa Starlight™ analysis on both patent and research abstract data. This provides perspective on key Iowa strength areas from a corporate and academic patent perspective, in addition to investigating research grant themes. The performance of the clustering analysis involves the following steps depicted in Figure14:

Step 1—Content Development: Developing a data set with sufficient descriptive content, such as patent abstracts or grant abstracts. Starlight™ cannot work with only titles or single sentence descriptions.

Step 2—Pattern Recognition: The analysis generates clusters where patents or grant activity have apparent relationships and produces a series of words to describe and link these cluster areas.

Step 3—Interpretation and Grouping by Expert Review: the identification of key themes and groupings that result for Starlight™ require an experienced research analyst to interpret and explain the types of technologies and specific activities that are represented in the cluster items.

Figure 14.
Method for Using Starlight Cluster Analysis

The Iowa grants analysis dataset contained detailed abstract information for 1,880 grants, including grant data from the following agencies for FY 1997 through to Nov. 2003:

- NIH—1,416 grants
- USDA—319 grants
- NSF—145 grants (only bio/agriculture-oriented grants)

The majority of the grants were issued to the state universities:

- The University of Iowa—1,302 (69 percent)
- Iowa State University—432 (23 percent)
- All other entities—146 (8 percent)

Starlight™ output is provided to the analyst in both graphical and spreadsheet table formats. This allows for visualization of key cluster areas and deeper investigation of the actual grants or patent information contained within each apparent cluster. Figures 15 and 16 illustrate the resulting graphic for grants activity, with grants included from NIH, NSF and USDA federal funding sources.

Figure 15: Starlight™ Research Clusters—Grant Data by Agency.

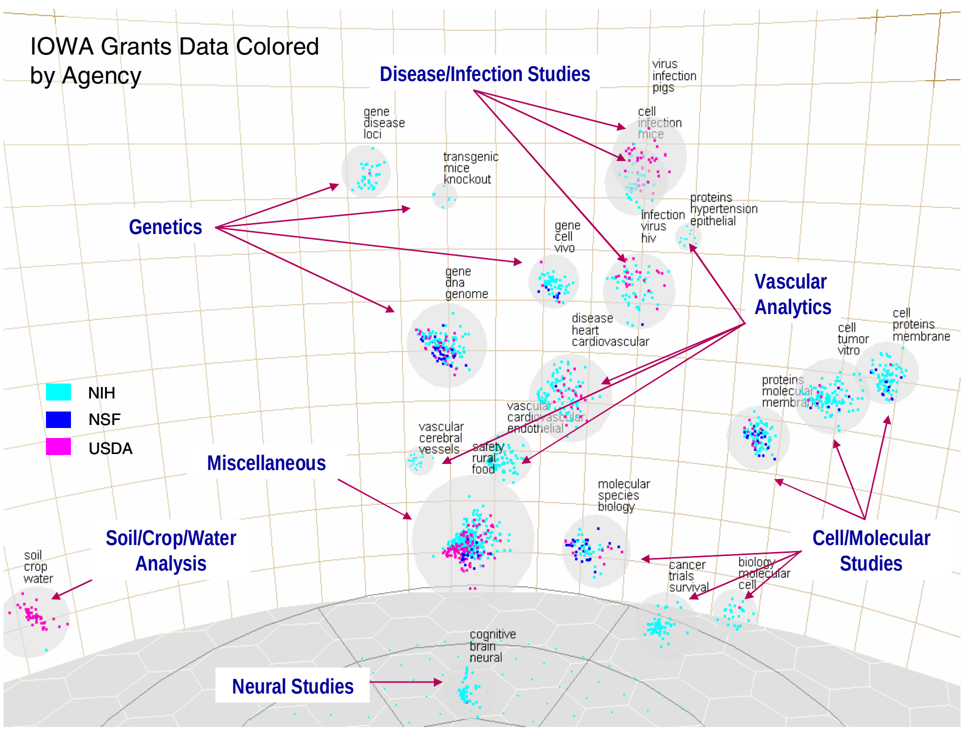
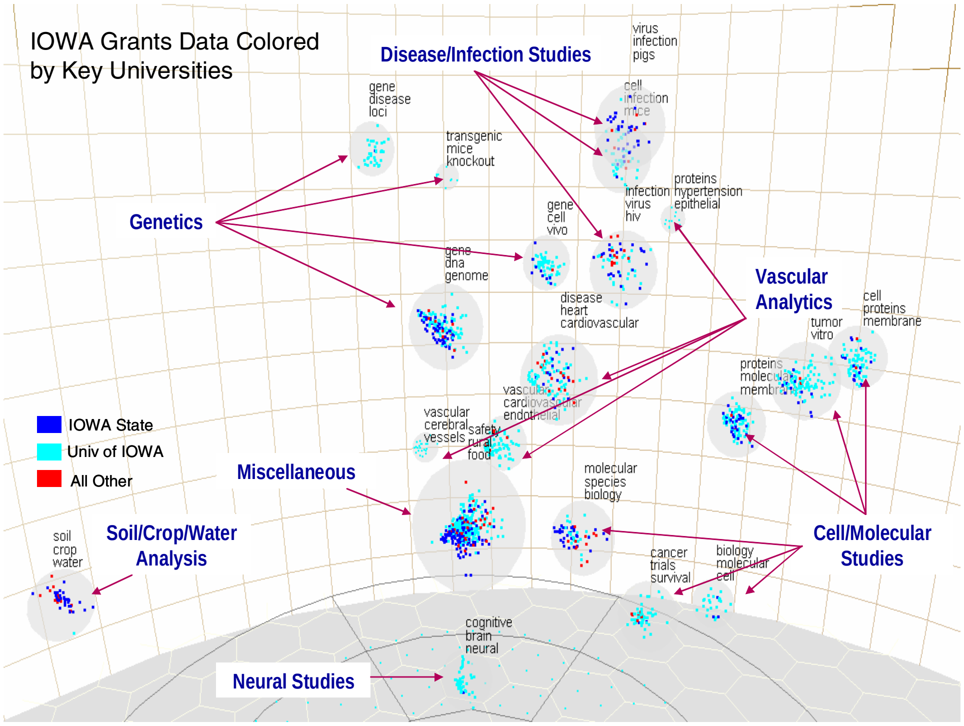


Figure 16: Starlight™ Research Clusters—Grant Data by Universities.



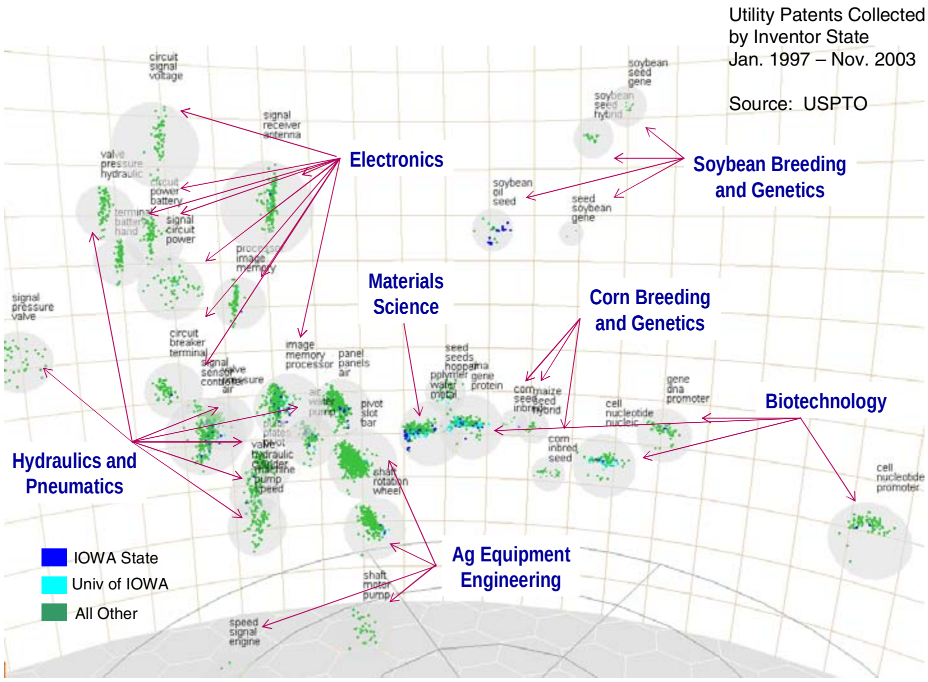
The grants cluster analysis indicates that R&D strengths are present most notably within the two largest state universities, Iowa State University and The University of Iowa. Key federal grant funded research cluster areas are identified in Table 16.

Table 16: Details of Starlight™ Meta Clusters of Federal Research Grant Strengths.

Grant Clusters				
Meta Cluster Title	# of Ind. Cluster	# of Grants	# of Grants by Institution	# of Grants by Agency
Cell/Molecular Studies	7	510	UI = 370, ISU = 112, ARS/NADC = 6, Other = 22	NIH = 404, NSF = 64, USDA = 42
Crop/Soil Analysis	1	49	ISU = 36, ARS/NADC = 7, UI = 1, Other = 5	USDA = 47, NIH = 1, NSF = 1
Disease/Infection Studies	2	96	ISU = 48, UI = 32, ARS/NADC = 14, Other = 2	USDA = 50, NIH = 45, NSF = 1
Genetics	4	259	UI = 177, ISU = 72, ARS/USDA = 2, Other = 8	NIH = 174, NSF = 46, USDA = 39
Neural Studies	1	51	UI = 50, ISU = 1	NIH = 50, USDA = 1
Vascular Analytics	4	225	UI = 186, ISU = 18, ARS/NADC = 9, MUM = 7, Drake U = 2, Other = 3	NIH = 200, USDA = 23, NSF = 2
Miscellaneous Non-Descript Cluster	1	473	UI = 288, ISU = 136, ARS/NADC = 13, MUM = 2, Drake U = 2, Other = 32	NIH = 326, USDA= 117, NSF = 30

Battelle also investigated patent data for the State of Iowa to examine the key areas of R&D that are resulting in potentially commercializable intellectual property. Patents were collected by *Inventor State* of Iowa with a total of 5,129 patents clustered in the Starlight™ analysis (Figure 17).

Figure 17: Starlight™ Clusters—Patent Data by Universities and Other Patent Holders.



Patent data show that the seed/agriculture and engineering sectors have been most productive in the generation of patents in Iowa. It is also evident that the great majority of patents generated in the state are coming from non-academic IP generation sources—companies such as Pioneer in seed development and John Deere in agricultural equipment and associated engineering disciplines. Iowa State University is noticeably active in the materials science and plant breeding/genetics areas, while The University of Iowa is evident in the biotechnology cluster around the descriptors "cell, nucleotide and nucleus."

The Starlight™ analysis is notable in that it shows a disconnect between some of the primary research grant focus areas and those areas generating patents. Within the biosciences in Iowa, only a comparatively small number of patent clusters emerge from the analysis; namely, corn and soybean plant breeding, genetics, and cell, nucleotide and protein biotechnology. Areas of distinct focus in the research arena, such as animal sciences, diseases and infection studies, neural studies and vascular analytics, for example, have not yet resulted in substantial intellectual property generation in Iowa. It should be noted, however, that on a national basis the private sector holds 97 percent of all patents (a logical situation given the importance of progress and innovation to the private sector). Iowa State University, in particular, demonstrates strong performance in intellectual property generation, with a recent ranking in *Nature* of 4th nationally in biotech related IP.

CORE COMPETENCY RESEARCH AREAS SUGGESTED BY REPUTATION

Examining publications or research grants (either through funding levels or context, as in the case of Starlight™ analyses) provides a perspective for establishing a state's or university's core competencies. However, given that some unique strengths also may exist without a strong direct tie to research publications or funding mechanisms it is important to look beyond these types of analyses to determine such strengths. One method is to use third-party-based reputation analyses, such as the *U.S. News & World Report's* Graduate School Rankings and Best Hospitals Rankings.[20] These rankings, while typically geared more toward the general public, often help establish areas of strength in the less research intensive areas.

Table 17 details the rankings of Iowa institutions that appeared in published reputation rankings (most recent, typically 2002). The agricultural strength of Iowa State University is shown through a rank of 10th in agricultural engineering and 17th in veterinary medicine. Many of the University of Iowa's medical school and health discipline strengths are detailed. Through this analysis some specific non-research intensive strengths appear, including physician assistant (2nd), nursing (8th), and primary care (9th). Additionally, the University of Iowa's overall strength in otolaryngology is demonstrated by combined strengths in audiology (1st) and speech-language pathology (1st).

Table 17: Iowa Bioscience-Related Academic Reputation.

Iowa's Institutions US News & World Report Graduate Ranking and Peer Assessment Score			
Field	**Institution**	**Rank**	**Peer Assessment Score** (out of 5 - if applicable)
Biological Sciences	University of Iowa	45	3.4
Engineering - Agricultural Engineering (2003)	Iowa State University	10	N/A
Health Disciplines - Audiology	University of Iowa	1	4.5
	University of Northern Iowa	58	2.6
Health Disciplines - Clinical Psychology	University of Iowa	12	3.9
Health Disciplines - Health Services Admin.	University of Iowa	11	3.4
Health Disciplines - Nursing	University of Iowa	8	4.2
Health Disciplines - Nursing: Anesthesia	University of Iowa	25	3.2
Health Disciplines - Nursing Specialties: Nursing Service Admin.	University of Iowa	1	N/A
Health Disciplines - Nursing Specialties: Nurse Practitioner-Pediatric	University of Iowa	11	N/A
Health Disciplines - Nursing Specialties: Nurse Practitioner-Gerontological/Geriatric	University of Iowa	2	N/A
Health Disciplines - Physical Therapy	University of Iowa	3	3.8
	Des Moines University (Osteopathic Medical Center)	74	2.5
Health Disciplines - Physician Assistant	University of Iowa	2	4.1
	Des Moines University (Osteopathic Medical Center)	48	2.7
Health Disciplines - Public Health	University of Iowa	18	2.5
Health Disciplines - Rehabilitation Counseling	University of Iowa	3	4
	Drake University	48	2.6
Health Disciplines - Speech-Language Pathology	University of Iowa	1	4.7
	University of Northern Iowa	51	3
Health Disciplines - Veterinary Medicine	Iowa State University	17	2.8
Medical Schools - Primary Care	University of Iowa (Roy J. & Lucille A. Carver)	9	3.5
Family Medicine	University of Iowa (Roy J. & Lucille A. Carver)	11	N/A
Internal Medicine	University of Iowa (Roy J. & Lucille A. Carver)	18	N/A
Rural Medicine	University of Iowa (Roy J. & Lucille A. Carver)	4	N/A
Medical Schools - Research	University of Iowa (Roy J. & Lucille A. Carver)	24	3.7
Note: Bold represents a major category. Indented Field is a Sub discipline of a larger category.			

[20] *U.S. News & World Report* methodology for identifying "America's Best Hospitals" was devised in 1993 by the National Opinion Research Center at the University of Chicago, which carries it out and refines it each year. The U.S. News Index accounts for reputation cited by a random sample of board-certified physicians in each specialty area over the past three years as well as data from an annual survey of hospitals by the American Hospital Association, generally covering extensiveness of services.

Table 18 details the rankings of Iowa hospital and clinical care institutions.

Table 18: Iowa Bioscience-Related Hospital/Clinical Care Reputation.

Iowa Hospitals US News & World Report Ranking and Reputational Score				
Field	Institution	Rank	U.S. News Index	Reputational Score
Ear, Nose, And Throat	University of Iowa Hospitals and Clinics	3	70.0	31.3%
Eyes/Opthalmology	University of Iowa Hospitals and Clinics	6	-	22.9%
Gynecology	University of Iowa Hospitals and Clinics	50	31.4	1.3%
Hormonal Disorders	University of Iowa Hospitals and Clinics	29	29.3	1.8%
Neurology And Neurosurgery	Mercy Medical Center	48	28.9	0.0%
Orthopedics	University of Iowa Hospitals and Clinics	8	39.6	10.3%
Psychiatry	University of Iowa Hospitals and Clinics	14		7.2%
Respiratory Disorders	University of Iowa Hospitals and Clinics	25	29.9	2.8%
Rheumatology	University of Iowa Hospitals and Clinics	48	33.3	1.6%
Urology	University of Iowa Hospitals and Clinics	21	32.4	4.4%

Again the strength of the University of Iowa's research and care in otolaryngology is demonstrated by the hospital receiving a rank of 3rd. Other top 10 strengths include eyes/ophthalmology (6th) and orthopaedics (8th).

Summary of Core Competency Areas Suggested by Quantitative Analysis

The quantitative data sources (grants data, ISI citations data and cluster analysis data) provide considerable insight into the R&D strengths of Iowa in the biosciences and related fields. Contained within these data are broad themes that serve as "direction finders" to the state's bioscience core competencies (both broadly based and human medicine/health specific).

Among the broadly based R&D core focus areas are

Plant Breeding and Genetics—Significant programs in soybean and corn/maize breeding and genetics in conjunction with other plant genetics and sequencing expertise.

Biotechnology and Applied Microbiology—Broad areas, with applications in cellular and molecular studies associated with plants, animals, and human medicine.

Immunology and Infectious Disease—Substantial programs in human, animal, and plant based disease studies, disease prevention, and treatment.

There are other areas of expertise in the state suggested by the quantitative data sources. These include

- Agricultural Equipment Engineering (mostly conducted in commercial R&D settings, with some support at state universities)
- Food Safety and Nutrition
- Materials Science
- Agricultural Chemicals
- Entomology and Pest Control
- Veterinary Medicine and Animal Health.

Table 19 details each of the broadly based core focus areas and expertise areas suggested by the quantitative data.

Table 19: Broadly Based Core Focus Areas Suggested by Quantitative Data.

Core Focus Areas	Federal Research Grants			Publication & Citation Strength	Starlight Cluster Analysis		Academic Reputation
	NIH	NSF	USDA	(ISI Data)	Grants	Patents	(U.S. News & World Report Rankings)
Plant Breeding and Genetics		✓	✓		✓	✓	
Biotechnology and Applied Microbiology	✓	✓	✓	✓	✓	✓	
Immunology and Infectious Disease	✓		✓	✓	✓		
Agricultural Equipment Engineering			✓			✓	✓
Food Safety and Nutrition	✓		✓	✓			
Materials Science						✓	
Agricultural Chemicals			✓	✓			
Entomology and Pest Control		✓	✓	✓			
Veterinary Medicine and Animal Health		✓	✓	✓			✓

Among the human medicine/health-specific research and clinical strengths, the core focus areas include

Cancer, Oncology and Oncogenesis—Led by The University of Iowa's Holden Comprehensive Cancer Center.

Cardiovascular research and vascular analytics—The University of Iowa's Cardiovascular Center has received more than $325 million in extramural support since its founding in 1971.

Otolaryngology—A world renowned research program and clinical practice at The University of Iowa ranked 3rd in the nation by *U.S. News & World Report.*

Ophthalmology—The 6th ranked program in the country by *U.S. News & World Report.*

Neurosciences—Expertise maintained at both Iowa State University and The University of Iowa, and high quality research and clinical practice at The University of Iowa in neurology and neurosurgery.

Public Health and Preventative Medicine—Ranked 18th in the nation at The University of Iowa by *U.S. News & World Report,* and 15th in NIH funding.

There also are other areas of human health/medical expertise in the state suggested by the quantitative data sources. These include

- Anesthesiology
- Audiology
- Nursing
- Orthopaedics
- Pediatrics
- Radiology and radiation diagnostics

Table 20 details each of the human medicine/health-related core focus areas and expertise areas suggested by the quantitative data.

Table 20: Human Medicine/Health Core Focus Areas Suggested by Quantitative Data.

Core Focus Areas	*Federal Research Grants*			*Publication & Citation Strength*	*Starlight Cluster Analysis*	*Academic Reputation (U.S. News & World Report Rankings)*	*Best Hospitals (U.S. News & World Report 2003 Rankings)*
	NIH	NSF	USDA	*(ISI Data)*	Grants		
Anesthesiology	✓			✓		✓	
Audiology	✓					✓	
Biostatistics	✓						
Cardiovascular	✓				✓		
Neurosciences, Neurology & Neurosurgery	✓	✓			✓		✓
Nursing						✓	
Oncology				✓	✓		
Ophthalmology				✓			✓
Orthopaedics	✓						✓
Otolaryngology	✓			✓			✓
Pediatrics	✓						
Public Health & Preventative Medicine	✓					✓	
Radiology & Radiation Diagnostics	✓						

The core focus areas resulting from the quantitative analysis are used to direct the focus of field-work interviews for additional investigation, and identify core competencies and technology platforms.

The following section details Battelle's findings from the qualitative interview research conducted with Iowa bioscience institutions. Both the quantitative and qualitative findings are evaluated by Battelle experts to determine core technology platforms upon which bioscience development may be built. The technology platforms are discussed in detail beginning on page 83 of this document.

Qualitative Assessment of the Iowa Bioscience Base: Interview and Fieldwork Findings

The analysis of grant, publishing, and patent data sets a context for understanding where Iowa's core competencies in bioscience research are focused. To further investigate these fields and deepen our understanding of the core bioscience focus areas in Iowa, extensive interviews were conducted with university administrators, faculty, scientists, clinicians, industry executives, and development agencies in the state. These interviews are essential in developing an understanding of how the data on publications and grant awards translate into on-the-ground focus areas in Iowa.

In total, face-to-face interviews individually or in small group sessions were conducted with more than 225 individuals. These included interviews with more than 200 academic scientists and faculty at Iowa State University, The University of Iowa, and the University of Northern Iowa, together with over 25 interviews conducted with commercial bioscience-related companies and associated industry promotion and economic development groups.

The interviews, for the most part, confirmed the areas of specialization in Iowa identified in the quantitative analysis. They also, however, highlighted several new and emerging areas of R&D focus and some key theme areas that were not readily apparent within the quantitative datasets. One challenge in using quantitative data is the rapid rate of change in scientific enterprise. Peer review systems—whether used for federal grant awards, citation analysis, or in reputation rankings—tend to lag emerging new fields of inquiry, recognizing younger and new scientific talent. One objective of the qualitative interviews was to capture emerging areas, faculty, and fields of inquiry at each of the three universities.

The analysis synthesized the core content of the fieldwork interviews and highlighted key areas of strength and focus. Both these qualitative interviews and the quantitative research are of substantial importance in determining core competencies—they go hand-in-hand to facilitate identification of

- Where Iowa is heading in terms of building upon and leveraging its core bioscience strengths, and in terms of developing and enhancing new and emerging areas of bioscience focus
- What the current pipeline of bioscience R&D activity is within academic research institutions in the state
- Which areas of bioscience are generating patents and intellectual property that can lead to commercial opportunities for Iowa.

The field interviews provide information relevant to each of these question categories, but they are most important in providing an in-depth understanding of current and emerging R&D strengths and opportunities.

Based on the interviews, findings are organized into three key levels:

Established Strengths in which Iowa has considerable strength through at least two of the following:

- A significant number of well-funded researchers, scientists and/or clinician scientists working in basic, applied, or clinical research.
- Recognized clinical expertise.
- Applied science R&D assisting critically important current and/or emerging commercial sectors.

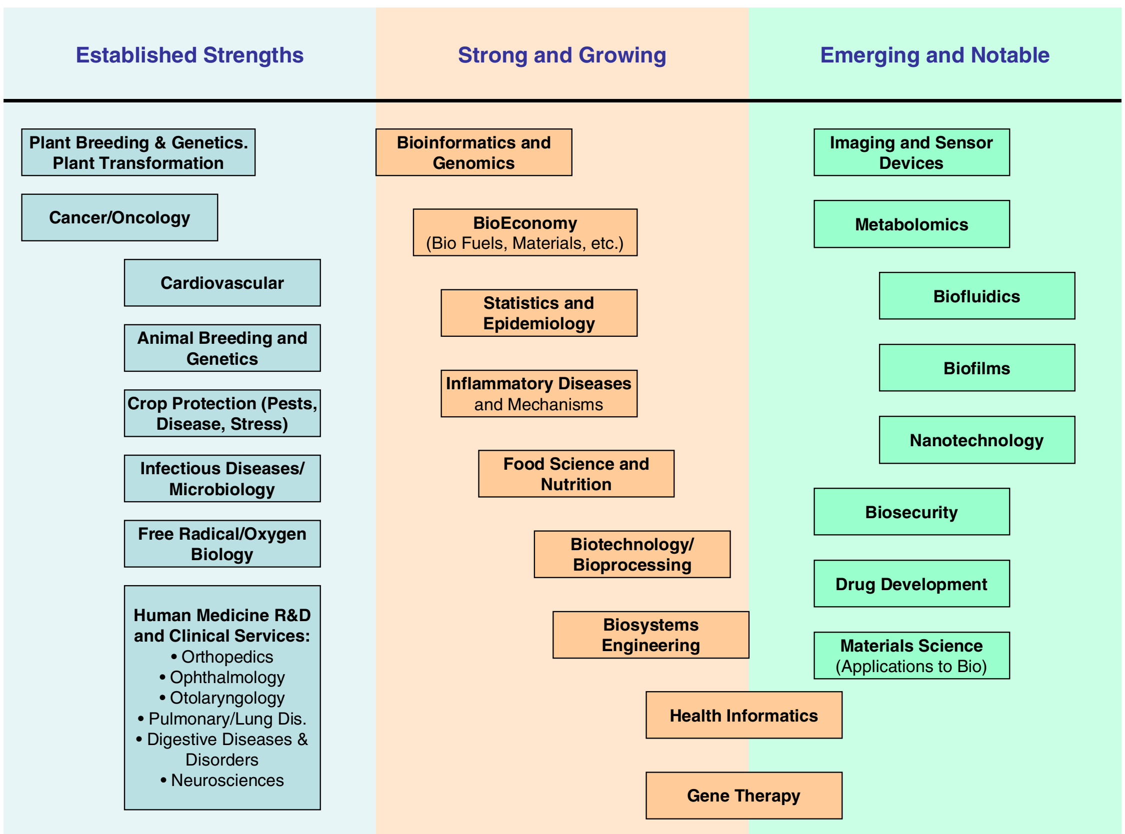
- A number of commercial enterprises with R&D or production facilities working on the delivery of products or services.

Strong and Growing focus areas in which Iowa has demonstrated strengths that are more focused on one dimension or which have lower levels of research activity, clinical expertise, or commercial enterprises, or have a more niche focus of activity. In many instances, these include focus areas that are required to support other areas of strength, or to form platforms for economic development from the biosciences. As such, these are highly important strengths to continue building.

Emerging and Notable are smaller or embryonic programs that show significant potential for bioscience development in the State of Iowa.

Based on these general parameters, the team identified the focus areas summarized in Figure 18.

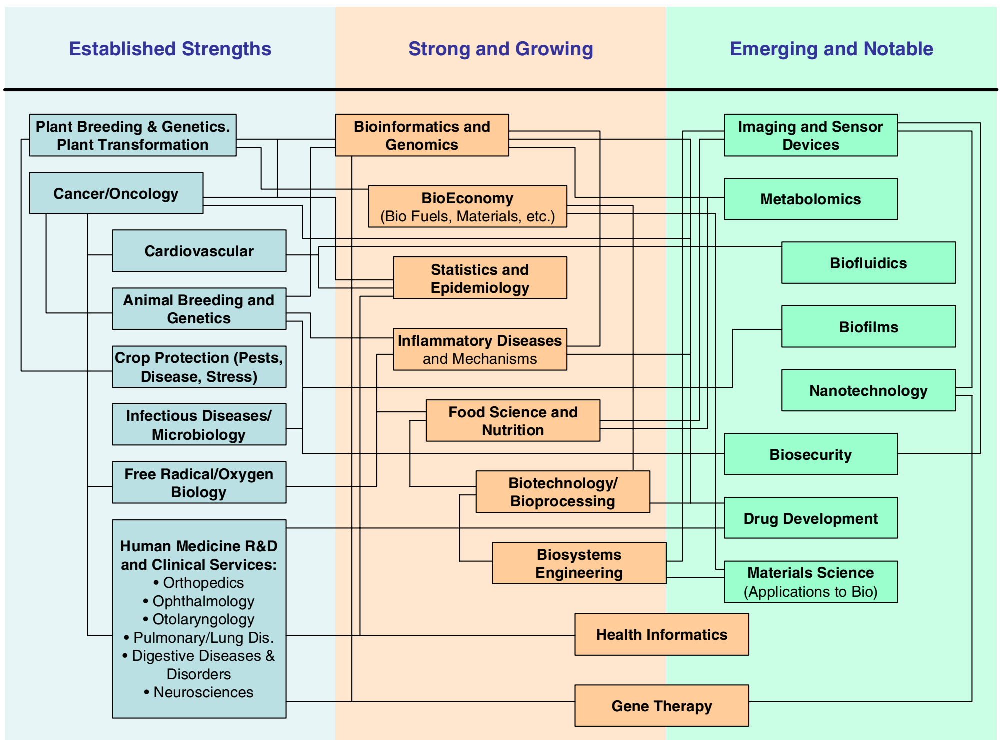
Figure 18: Focus Areas Based on Qualitative Assessment.



Bioinformatics and genomics are strongly positioned in Iowa at both the University of Iowa and Iowa State. However, genomics and post-genomic sciences are the basic pillar upon which much bioscience progress will be made. Other states are investing heavily in initiatives to enhance their genomics, proteomics, metabolomics, and bioinformatics infrastructure and bolster their position in these critically important fields. While this field is a key strength in the state and was classified as “strong and growing” in Iowa, it is an area of great competition and growth and momentum must be maintained.

In the modern biosciences, seldom does an area of focus stand on its own. Rather, biosciences should be viewed as a system of interrelated disciplines and areas of study that support and assist in the advancement of one another. For this reason, the NIH and similar organizations are focusing increasing grant-making attention on multidisciplinary institutes, centers, and research teams. Figure 19 illustrates some of the interrelationships and supporting links that exist between established, building, and emerging strength areas in Iowa bioscience. These and other links are explored in detail in the analyses that follow regarding technology platforms and opportunities.

Figure 19: Interrelationships Among Iowa's Interview-Identified Bioscience Strength Areas.



The links between strength areas are critical to the emergence of bioscience core competencies in Iowa. As in any system, a change in one of the parameters (strength areas) is likely to affect the operation of others. For example, an enhanced center for the support of drug development with associated pilot facilities likely would increase the attention of various medical and veterinary disciplines on drug discovery activities. Equally, such an enhancement could spur biosystems engineering work on bio-processing activities for drugs or lead to an increased nanotechnology focus on drug delivery. Each of these strength areas is discussed below, and the reader should bear in mind the linkages and interrelationships that may exist.

ESTABLISHED STRENGTH AREAS

Each of these qualitatively identified areas of strength and competency are examined in further detail in Tables 21 through 50. In each table, Battelle provides:

- A definition of the field or specialty area
- Details regarding the strengths in Iowa identified by interviewees
- Supporting quantitative statistics (where available)
- The name of the primary engaged institutions in Iowa.

Table 21: Iowa Established Strength Areas: Plant Breeding and Genetics

<table>
<tr><th colspan="2">Plant Breeding and Genetics</th></tr>
<tr><td>Field Definition</td><td>Acquiring fundamental knowledge in plant sciences and using it to develop enhanced crop cultivars and new economic uses for Iowa crops.</td></tr>
<tr><td>Interview Identified Strengths</td><td>
Iowa State University has a substantial history and track record in the development of new plant cultivars in key cash crops such as corn and soybean.
The ISU Plant Sciences Institute is operating to “generate knowledge and develop practices for the creation of valuable traits in crops important to Iowa using the power of genomics and bioinformatics.” Multiple centers operate under the umbrella of the Institute, including:
Center for Designer Crops (molecular research)
Center for Plant Genomics (understanding plant genes and whole plant genome discovery)
Center for Plant Transformation and Gene Expression (transgenics)
Baker Center for Plant Breeding (enhancing cultivars via breeding methods and germplasm enhancements)
Center for Crops Utilization Research (new uses for Midwestern crops)
Center for Designing Foods to Improve Human Nutrition (functional foods, nutraceuticals, etc.)
Center for Plant Responses to Environmental Stresses (stress research and tolerance enhancement)
Baker Center for Bioinformatics and Biological Statistics (genomic data analysis and support)
Seed Science Center.
ISU is focusing its substantial resources in plant biosciences to push forward multiple R&D platforms for the state, including:
Enhancing the nutritional (and economic) value of plants in animal and human diets
Creating a plant biofactories/biopharmaceutical production industry for Iowa
Unlocking the potential of plant genomics and transgenics
Generating applications for crops in biorenewable resource projects
Protecting crops from natural and man-made threats.
The Plant Sciences Institute comprises over 220 faculty affiliates across 32 departments in 7 ISU colleges.
45,000 sq.ft. Carver Co-Lab opened to facilitate interaction between University and industry scientists in plant sciences.
</td></tr>
<tr><td>Supporting Statistics</td><td>
Almost $24 million in external research funding generated in 2001 by affiliated faculty –$17.2 million from federal agencies.
Over 400 graduate students working on plant sciences at Iowa State University.
Genetics cluster at Iowa State University confirmed by Starlight™ analysis.
ISU 177 federal grants in genetics.
</td></tr>
<tr><td>Key Institutions</td><td>Iowa State University</td></tr>
</table>

Table 22: Iowa Established Strength Areas: Cancer (Oncology)

Cancer (Oncology)	
Field Definition	The study or science dealing with the physical, chemical, and biologic properties and features of tumors including causation, pathogenesis, and treatment.
Interview Identified Strengths	• Holden Cancer Center at The University of Iowa is an NCI-designated Comprehensive Cancer Center. • Key expertise in Lymphoma (SPORE[21]), Head and Neck Cancer, and Urologic Cancers (prostate and bladder). Additional focus areas in GI malignancies, orthopedic tumors, and breast cancer. • Research areas designated as a focus by the Cancer Center include: o Cancer Epidemiology (running the Iowa Cancer Registry, a SEER[22] program) o Cancer Immunology and Immunotherapy o Cell Signaling and Developmental Pharmacology o Free Radical/Oxidative cancer events (pioneers in this field) o Cancer Genomics o Molecular and Tumor Virology o Molecular Mechanisms of Metastasis o Prostate Cancer Research o Tumor Imaging • Strong core resources in: o Biostatistics o Central Microscopy o Clinical Trials Support o DNA Core o Free Radical Research o Flow Cytometry o Gene Transfer Vectors o Large Scale Digital Cell Analysis o Small Animal Imaging o Tissue Culture Hybridoma o Tissue Procurement o Health informatics. • Work in a number of translational areas, including for example: small molecule and potential drug candidate research and development, cancer imaging, and gene therapy. • Clinical trials infrastructure in place. • Good and expanding resources in radiation oncology.
Supporting Statistics	• 153 cancer researchers and clinicians in 37 departments and six colleges at The University of Iowa • 170 published papers between 1997-2001 in Oncology with a relative impact of 1.27, and 190 papers in Oncogenesis and Cancer Research with relative impact of 1.3. • 56 NIH-NCI grant awards in 2003. • Cluster confirmed by Battelle Starlight™ analysis.
Key Institutions	• The University of Iowa

[21] SPORE = Specialized Programs of Research Excellence (a NIH designation).
[22] SEER = Surveillance, Epidemiology, and End Results (a program of the National Cancer Institute).

Table 23: Iowa Established Strength Areas: Cardiovascular

Cardiovascular	
Field Definition	The branch of medicine dealing with the heart and blood vessels. Also includes the cardio-pulmonary field examining the heart and lungs as a system.
Interview Identified Strengths	• The Cardiovascular Center at The University of Iowa has a significant track record in science dating back to the early 1970s and has performed pioneering work on arteriosclerosis, lipids and cholesterol. The Center has brought in $350 million in grant funding to Iowa since its formation in 1974. • Current research expertise in: o Resuscitation including wave forms and reduction of free radical injury o Vascular structure and function, including work on free radicals involved in signaling and injury, inflammation, and the innate immune system of the vascular wall o Thrombotic mechanisms contributing to cardiovascular disease and stroke o Inherited diseases of the heart muscle o Neural pathway effects on hypertension o Neurobiology of cardiovascular regulation o Basic causes of hypertension o Cardioelectrophysiology including studies of atrial defibrillation and arrhythmia management o Pediatric cardiovascular diseases (genetic links) o Fatty acids, lipoproteins and hypertension. • Recognized for research in neuro control, lipids, imaging, free radicals, vector physiology, and ion channels. • Opportunity to move research program into a more applied and translational focus (drug discovery, targeted drugs, gene tests, etc.), but need resources and an organized center to do this.
Supporting Statistics	• The University of Iowa's cardiology and cardiovascular research includes 180 scientists, from various departments and colleges across campus. The Cardiovascular Division of the Department of Internal Medicine has over 30 faculty, with more than half heavily engaged in research. • Major program project grants/SCOR's[23] from NIH • Four interdisciplinary training programs supporting 15 predoctoral and multiple postdoctoral trainees. • 635 papers published in Cardiovascular and Hematology research and Cardiovascular and Respiratory research between 1997 and2001. Relative impact of 1.19 in Cardiovascular and Respiratory. • Cluster confirmed by Battelle Starlight™ analysis.
Key Institutions	• The University of Iowa

[23] SCOR = Specialized Center of Research (a NIH designation).

Table 24: Iowa Established Strength Areas: Animal Breeding and Genetics

Animal Breeding and Genetics	
Field Definition	The development of animals with optimized characteristics for use by humans. Includes the genetic improvement of livestock and other animal species

Interview Identified Strengths	• In terms of livestock and comparative genomics ISU considered to be in the top 3 in the world.
	• In terms of livestock animal breeding, ISU is generally regarded as one of the top (if not the top) institutions in the world.
	• ISU has the top animal genetics and genomics group in the U.S. and is considered a world leader in porcine, bovine and avian genomics. ISU has internationally recognized strengths in microbial genomics and infectious disease.
	• Very strong in animal science and meat science.
	• New Center for Integrated Animal Genomics goes considerably beyond livestock and is broad in terms of bioinformatics capabilities and work on companion animals. Used the term "integrated" to denote work on livestock, companion animals and across into microbial.
	• Deep expertise in pigs (because of importance to Iowa agricultural sector). This shows great promise for human linkages, since the pig is a very useful human model.
	• 50 faculty within the Center for Integrated Animal Genomics.
	• The Center provides a forum to bring together people from across the ISU campus to advance animal genomics, microbial genomics, comparative genomics and bioinformatics—ultimately with the goal to enhance the health of animals and people.
	• Within animal genomics ISU has considerable depth in quantitative genomics, and good strengths also in molecular.
	• Directly working as major contributors on the chicken and pig genome projects.
	• Deep resources and facilities for basic science and applied research. Good support in instrumentation, genomics cores, proteomics, confocal and electron microscopy.
	• Specific goals in the Center for Integrated Animal Genomics:
	  o Genetic improvement of livestock species
	  o Improved food safety and reduction in the use of antibiotics
	  o Development of vaccines and anti-microbial agents
	  o Development of designer animals for specialized animal products to improve human health
	  o Deduction of possible bioterrorism threats through the food chain
	  o Economic development of the animal genomics industry in Iowa.
	• The University of Iowa is also active in animal transgenics and operates a state-of-the-art transgenic animal (mice) facility.

Supporting Statistics	• 262 papers published in Animal Sciences between 1997-2001 with citation quotient of 6.5. • Genetics cluster at ISU confirmed by Starlight™ analysis.
Key Institutions	• Iowa State University • The University of Iowa

Table 25: Iowa Established Strength Areas: Crop Protection (Pests, Diseases, and Stress)

Crop Protection (Pests, Diseases, and Stress)	
Field Definition	Approaches to the protection of economic crops from damage and economic losses caused by plant diseases, pests, and environmental stresses.
Interview Identified Strengths	• Strong in field crop entomology, with additional strengths in medical entomology and disease prevention. Main entomology focus is on insecticide development, with little work being done in molecular engineering. • Taking approach of integrated pest management to reduce and optimize the use of pesticides, fungicides, and insecticides. • The Center for Plant Responses to Environmental Stresses (CPRES) performs fundamental research on how plants detect and respond to biotic and abiotic stresses in their environment. Biotic stress research studies the molecular mechanisms used by viruses, bacteria, fungi, and nematodes to incite disease and by plants to resist infection. Research on abiotic stresses includes molecular mechanisms by which plants resist unfavorable conditions such as drought, flooding, chilling, excess salts, toxic metals, and pollutants. • Plant Health and Protection is offered as an interdepartmental major administered by the departments of Plant Pathology, Entomology, Agronomy, Horticulture, and Forestry. The program emphasizes a holistic approach to plant health maintenance encompassing soil fertility and plant nutrition, genetics and plant breeding, cultural practices, and protection from pests such as insects, weeds, and the microorganisms that cause plant diseases. • 16 full-time faculty in the Department of Plant Pathology. • Research focus areas in corn and soybean diseases, plant viral diseases, fungi, host-parasite interactions, quantitative pest management, soybean cyst nematodes, seed infections, and the emergence of new plant diseases.
Supporting Statistics	• ISI citations data for Iowa State University show the following levels of paper publication between 1997-2001: Agricultural Chemistry (128 papers), Agriculture/Agronomy (379), Entomology and Pest Control (131) and Plant Sciences (366). • Iowa State University's focus on crops confirmed by Battelle Starlight™ analysis.
Key Institutions	• Iowa State University

Table 26: Iowa Established Strength Areas: Infectious Diseases

Infectious Diseases	
Field Definition	Includes acquired diseases caused by infectious agents such as viruses, bacteria, myco-bacteria and prions.
Interview Identified Strengths	• Focus of research within the College of Veterinary Medicine at ISU, with research in: o Traditional production animal diseases o Foreign and exotic animal diseases o Preharvest food borne diseases o Antimicrobial resistance o Zoonotic diseases (West Nile Virus and Nipah) o Immunology and inflammatory diseases • Strong focus of research at The University of Iowa from both a clinical infectious diseases standpoint and via microbiology. • Deep and expanding expertise in human respiratory diseases and respiratory pathogens. $3.3 million per year NIH contract in the field (funded for seven years at the University of Iowa). Examining pathogenic mechanisms in common human respiratory diseases such as pneumonia. Also studying how human cells respond to pathogens in the airway. • University of Iowa also working on CMV (cytomegalovirus), inflammation and enteric pathogens (such as salmonella and shigella). Expertise in viral pathogenesis and viral regulation of genes. • University of Iowa virologists and virologists within Iowa State University (primarily the College of Vet Medicine) cooperate well—with University of Iowa contributing strengths in mammalian virology. • Vaccine and vaccine delivery systems research at The University of Iowa. • Strong inflammation program at The University of Iowa housed in 11,000 sq.ft. of new lab space at Oakdale campus. Work in microbial pathogenesis, and on the development of immunosuppressive and immunopromultory protein endotoxins. • University of Iowa expertise is mostly focused on viral and bacterial diseases—far less work on fungal and parasitic diseases. • Somewhat held back in infectious diseases research at The University of Iowa because of lack of BSL3 facilities. • The Center for Emerging Infectious Diseases, recently established in The University of Iowa College of Public Health, employs laboratory technologies, advanced epidemiological methods and clinical evaluations to better understand emerging infectious diseases. Pathogens under study include: human adenovirus, human metapneumovirus, influenza A, prions, SARS, West Nile Virus and Varizella-zoster virus. • At the University of Northern Iowa, researchers are investigating technologies for integrating bacteriophagy of anthrax and other pathogens, remote detection, and decontamination and therapeutics.
Supporting Statistics	• 12 faculty in Iowa State University College of Veterinary Medicine whose labs are focused on infectious diseases.
Key Institutions	• Iowa State University • The University of Iowa • University of Northern Iowa

Table 27: Iowa Established Strength Areas: Free Radical/Oxygen Biology

Free Radical/Oxygen Biology	
Field Definition	Free radical biology is the study of the interaction of free radicals within biological material. Free radicals are atoms or molecules with at least one unpaired electron, and are being found to be agents in a large number of diseases and pathological states.
Interview Identified Strengths	• The University of Iowa has, without a directed effort, become the top place in the world for attracting free radical researchers. Currently the University has more than 50 faculty involved in the study of free radicals. • Has the first ever PhD granting program in free radical biology (10 graduate students enrolled). • Other universities such as Alabama, Wisconsin, Oklahoma, and Emory have created and funded formal free radical centers. Iowa's is not so supported and so risks losing its leadership advantage. • The University of Iowa has a broad platform in the field, incorporating study of free radicals by multiple scientists in: o Cancer o Cardiac disease and vascular disease o Hypertension o Diabetes o Premature birth o Inflammation and infectious diseases o Aging o Neurodegenerative diseases o Bone disease o Lou Gehrig's disease. • Because of advanced state of The University of Iowa's research in the field, they are beginning to move into translational work and are submitting a SPORE on head and neck cancer and free radicals. • One Iowa project is moving into clinical trials based on Vitamin E anti-oxidant affects after aneurisms. • This is a relatively new field of study that uses good basic science to lead to pragmatic clinical results. The University of Iowa has a lead that may warrant preserving with funding of a formal center with associated facilities and support.
Supporting Statistics	• 27 current NIH grants in which the study of free-radicals is a major cited component. • Concentration confirmed by Battelle Starlight™ analysis.
Key Institutions	• The University of Iowa

Table 28: Iowa Established Strength Areas: Orthopaedics

Orthopaedics	
Field Definition	Orthopaedics is the medical specialty devoted to the diagnosis, treatment, rehabilitation, and prevention of injuries and diseases of the body's musculoskeletal system.
Interview Identified Strengths	• University of Iowa orthopaedics operates the Biomechanics Laboratory where major areas of investigation include total joint arthroplasty (hip, ankle, knee), osteonecrosis of the hip, high-energy fracture comminution, fracture fixation, cell culture mechanostimulus, joint kinematics, and articular contact stresses as they relate to joint degeneration. • The Ignacio V. Ponseti Biochemistry and Cell Biology Laboratory at The University of Iowa conducts basic and applied biological research investigating the normal structure and function of the musculoskeletal system. Other areas of investigation include normal skeletal growth and development, tissue regeneration, tissue aging and cell-matrix interactions. Current areas of investigation include the molecular biology of intervertebral disc development, aging of articular cartilage, osteoarthritis, spondylo-epiphyseal dysplasias, chondrocyte-matrix interactions, response of chondrocytes to cartilage matrix proteins and age-related changes in chondrocyte function. • Research and development work is taking place in total wrist replacement. • The University of Iowa maintains a SCOR in arthritis • Biomechanical engineering work for orthopaedic devices and total joint replacements (e.g. total hip). • Major clinical practice in orthopaedics and orthopaedic surgery. • Multiple industry relationships with Zimmer, Smith and Nephew, DePuy and Genzyme Biosurgery. • Working collaboratively with Iowa State University on bi-ped animal model for arthritis (using the Emu). • Interdisciplinary center at the University of Northern Iowa (RERC), in combination with a prosthesis company, working to develop a new prosthesis and/or orthotic for resting diseased or wounded extremities.
Supporting Statistics	• Department of Orthopaedics and Rehabilitation at The University of Iowa ranked in the top 10 by U.S. News. Ranked 8th in orthopaedic surgery. • 28 MD's and 9 PhD research staff • 170 papers published between 1997-2001, with citations quotient of 1.3 • 3rd in the U.S. in NIH funding (behind Case and Yale)
Key Institutions	• The University of Iowa • Iowa State University • University of Northern Iowa

Table 29: Iowa Established Strength Areas: Ophthalmology

<table>
<tr><th colspan="2">Ophthalmology</th></tr>
<tr><td>Field Definition</td><td>Ophthalmology is the medical specialty relating to the treatment of diseases and disorders of the eye</td></tr>
<tr><td>Interview Identified Strengths</td><td>
Major research programs at The University of Iowa in:
Eye pathology (F. C. Blodi Eye Pathology Laboratory)
Ocular Melanoma
Glaucoma, with an emphasis on the potential adverse effects of Beta-Blockers
Macular degeneration
Molecular ophthalmology
In macular degeneration, The University of Iowa operates The Center for Macular Degeneration with 14 faculty working in the field. It has been one of the leaders in the diagnosis, treatment, and research of macular degeneration for over 20 years, and now is studying macular degeneration at the cellular and molecular levels. Have identified the locations of genes that cause three different types of hereditary macular degeneration and have discovered over 100 specific macular-disease-causing mutations. In addition, The University of Iowa has investigated the disease at the cell and tissue level and have identified important molecules and biological processes involved in the development of macular degeneration.
In molecular ophthalmology have made major contributions through discoveries related to
Macular Degeneration
Retinitis Pigmentosa
Glaucoma
Hereditary Obesity - Bardet Biedl Syndrome
Corneal Dystrophy
Vitreoretinopathy
Uveitis - ADNIV
Optic Neuropathy
Discoveries facilitated by the Molecular Ophthalmology Laboratory (MOL)
Also operate the Carver Laboratory for Molecular Diagnosis which is dedicated to providing non-profit genetic testing for rare eye diseases. Most of the diseases studied are so rare that commercial tests would be unlikely to be viable.</td></tr>
<tr><td>Supporting Statistics</td><td>
The University of Iowa ranked 6th in the nation in ophthalmology by U.S. News
14 clinicians rated in Best Doctors in America
13 NIH grants through the NIH National Eye Institute.
175 published papers between 1997-2001, with relative impact of 1.2 and citation quotient of 2.6</td></tr>
<tr><td>Key Institutions</td><td>The University of Iowa</td></tr>
</table>

Table 30: Iowa Established Strength Areas: Otolaryngology

<table>
<tr><th colspan="2">Otolaryngology</th></tr>
<tr><td>Field Definition</td><td>Otolaryngology is the branch of medicine concerned with the diagnosis and treatment of disorders and diseases of the ears, nose and throat (ENT).</td></tr>
<tr><td>Interview Identified Strengths</td><td>
The University of Iowa Department of Otolaryngology-Head and Neck Surgery is one of the most comprehensive ENT programs in the world.
Considerable strengths at The University of Iowa in:
Cochlear implants—where Iowa is a leader in clinical research and development
Genetics/etiology of hearing loss
Head and neck cancer
Speech pathology
Engineering for ENT needs, including assistive devices
Multiple research areas, with resources focused through:
Auditory Physiology Research Lab—conducting basic and applied research to better understand how the cochlea and auditory nerve function, as well as how cochlear implants function
Cleft Palate-Craniofacial Research—Iowa has a long history in cleft palate research and clinical treatment
Head and Neck Oncology Research—works with disorders of the head and neck within the anatomic limits determined by the structures between the dura and the pleura. Work includes the oral cavity, the larynx and pharynx, the nose and sinuses, the thyroid and parathyroid glands, the lymphatics, muscle and bone of the head and neck.
Iowa Cochlear Implant Research Center—have implanted over 150 children and over 250 adults with every type of cochlear implant available in the U.S. and have a substantial database following some of these patients for as long as 12 years.
Molecular Otolaryngology Research Lab—The lab offers genetic testing at the DNA level for several types of inherited hearing impairment. This is one of the few laboratories in the nation to make this service available to families.
Strong relationships with industry in the development and testing of devices, especially auditory and speech devices.</td></tr>
<tr><td>Supporting Statistics</td><td>
The University of Iowa ranked second in ENT by U.S. News.
187 papers between 1997-2001, with a relative impact of 1.29 and citations quotient of 3.4
21 faculty
26 grants from the NIH National Institute for Deafness and Other Communication Disorders (NIDCD)</td></tr>
<tr><td>Key Institutions</td><td>The University of Iowa</td></tr>
</table>

Table 31: Iowa Established Strength Areas: Pulmonology/Lung Diseases

Pulmonology/Lung Diseases	
Field Definition	Pulmonology is the medical practice pertaining to the lungs and respiratory system.

Interview Identified Strengths	• The University of Iowa is considered to be the equal of National Jewish in Colorado in terms of status, and has three times the amount of epithelial biologists. Main difference is the basic science emphasis of Iowa, versus the industry collaborations that National Jewish and UNC Chapel Hill enjoy.
	• The University of Iowa has developed expertise in multiple environmental lung diseases. The agricultural working environment creates lots of dusts and allergens that promote respiratory disorders, such as asthma.
	• Iowa's strengths in inflammation research directly link into environmental and other respiratory/lung disorders.
	• Performing fundamental immunologic research and vaccine based immunotherapies.
	• Major lung work being performed in:
	  o Cancer
	  o Asthma
	  o Emphysema
	  o Cystic Fibrosis
	  o Inflammatory Lung Disease
	  o Fibrotic Lung Disease
	  o Pulmonary Hypertension.
	• Pulmonary division said to be one of the largest and most influential in the country.
	• Strengths in lung infectious diseases, immunology and genetics form a triad that is perhaps hard to duplicate elsewhere.
	• Have one of only a handful of clinical exposure facilities in the U.S. for delivering and assessing physiologic reactions.
	• Receive many calls from drug companies interested in working with them on drug delivery via the lungs.
	• Pulmonary rehabilitation is also a focus area.

Supporting Statistics	• 29 faculty working within Internal Medicine on pulmonary diseases and disorders. • 256 papers published in Cardiovascular and Respiratory Systems with a 1.19 relative impact, plus 107 papers in Environmental Medicine and Public Health with a 1.17 relative impact. • 25 current NIH grants related to the lung and respiratory systems. • Cluster confirmed by Battelle Starlight™ analysis.
Key Institutions	• The University of Iowa

Table 32: Iowa Established Strength Areas: Digestive Diseases and Disorders (Gastroenterology)

Digestive Diseases and Disorders (Gastroenterology)	
Field Definition	Gastroenterology is the field of medicine concerned with the function and disorders of the digestive system.
Interview Identified Strengths	• Leading research thrust at The University of Iowa is on the development of immune modulators. • Research has led to a breakthrough discovery that is relevant to a wide variety of autoimmune disorders, not just GI disorders (e.g. asthma, arthritis, lupus, dermatitis, inflammatory bowel disease, Crohn's disease). This immune research is led by an immunoparasiteologist and has generated a patent on the use of all helminths (a worm) and derivatives from them for the treatment of human diseases. Likely to result in a new path of immune disorder treatment producing helminth egg therapies or drugs based on genetic/biochemical characteristics of the worm. Link between The University of Iowa and Iowa State University because host animal for producing the helminths is pigs. Double blind studies showing great effectiveness from this parasite introduction and treatment. • Also strong in GI device work including tools for advanced endoscopy, drainage stents (wedge stents for draining malignant strictures), operating instruments and cauterizing guide wire devices. • Expertise in neuro gastroenterology, primarily leading to clinical research developing investigative techniques for pain in the gut. Also probes and training devices for people with anal-rectal dysfunction and extreme constipation. • Program in pediatric gastroenterology. • Multiple recent publications in the American Journal of Gastroenterology and other journals. • Somewhat held back in total research volume by heavy clinical demands placed on gastroenterologists since this discipline tends to be a significant revenue generator for hospitals/practice plans.
Supporting Statistics	• 19 faculty in the division at The University of Iowa. Comparatively large and would place them in the Top 20 in terms of rank. (Largest player is Mayo Clinic with 70) • 10+ major NIH grant awards • 69 papers in Gastroenterology between 1997-2001
Key Institutions	• The University of Iowa

Table 33: Iowa Established Strength Areas: Neurosciences

Neurosciences	
Field Definition	The discipline concerned with the development, structure, function, chemistry, pharmacology, clinical assessment, and pathology of the nervous system.
Interview Identified Strengths	• A major research focus within the College of Veterinary Medicine at Iowa State University. Focus areas include: Parkinson's disease (especially environmental factors); Alzheimer's disease; Eye Disorders (with an emphasis on the retina); Pain, and Prion Diseases. • University of Iowa researchers are leaders in brain imaging and neurosciences, muscular dystrophy, and Huntington's disease. • Focus within the Department of Biological Sciences at The University of Iowa with 8 faculty concentrating in neurobiology. • The neurosciences program at The University of Iowa has strengths in molecular and cellular neuroscience, developmental and systems neuroscience and cognitive and behavioral neurosciences. • Within Neurology at The University of Iowa, research is being conducted in: o Alzheimer's Disease o Autonomic Dysfunction (including Neurobiology of Cardiovascular Regulation) o Cognitive Neuroscience of Human Emotion and Behavior o Epilepsy o Experimental Neuroanatomy o Human Factors Studies (including Driving Safety) o Movement Disorders (including Parkinson's Disease and Huntington's Disease) o Neurochemistry and Neurobiology o Neurodegenerative Diseases o Neuroergonomics o Neuromuscular Diseases (including Amyotrophic Lateral Sclerosis and Peripheral Neuropathy) o Sleep disorders o Stroke o Visual Function • Neuro expertise within The University of Iowa extends across into neurosurgery. Iowa neurosurgeons have developed state-of-the-art magnetic guided neurosurgery systems.
Supporting Statistics	• Iowa State University College of Veterinary Medicine has 7 major principal investigators funded in neuroscience. Have multiple RO1's from the NIH. • 43 faculty and fellows within University of Iowa department of neurology, 8 in neurosciences within the College of Biological Sciences and 7 faculty in the Division of Neurosurgery (within the Department of Surgery) • The University of Iowa has 56 NIH grants through the NIH National Institute for Neurological Disorders and Stroke (NINDS)—53 grants from the National Institute for Mental Health (many with major neurological research content). • Neural studies confirmed as a distinct cluster in Iowa by Battelle Starlight™ analysis.
Key Institutions	• The University of Iowa • Iowa State University

STRONG AND GROWING

Table 34: Iowa Strong and Growing Areas: Bioinformatics and Genomics

Bioinformatics and Genomics	
Field Definition	Bioinformatics involves the application of computer technology to the management of biological information. Specifically, it is the science of developing computer databases and algorithms to facilitate and expedite biological research, particularly in genomics. Genomics is the study of genes and their function.

Interview Identified Strengths	Note: Bioinformatics and Genomics are very strong at both Iowa State University and the University of Iowa. They are, however, listed in the "strong and growing" category because of their extreme importance to bioscience R&D and future clinical practice. Other states are investing heavily in these fields, and because of this, continued growth in these fields in Iowa is highly important and forms the basis for advancement of multiple recommended bioscience platforms.
	• Iowa State University has multiple centers working in bioinformatics and genomics, especially as they relate to plants and animals. These centers include:
	  o Center for Plant Genomics
	  o Center for Plant Transformation and Gene Expression
	  o Baker Center for Bioinformatics and Biological Statistics
	• Iowa State's bioinformatics and biostatistics program has research initiatives taking place in bioinformatics and biostatistics (10 PI's); systems biology (5 PI's), functional and structural genomics (20 personnel), genome evolution (5-6 personnel), and macromolecular structure and function (15-20 personnel).
	• The Center for Plant Genomics provides technical support for research projects that require high-throughput data collection and analysis (such as large-scale EST sequencing, mRNA and protein profiling, and genetic & physical mapping). The Center also partners to develop, adapt and/or evaluate novel technologies for genomics and proteomics research through its Microarray and Proteomics facilities.
	• The Center for Plant Transformation and Gene Expression is a pragmatic institution working to develop efficient methods for producing transgenic plants that will be safe for human health and the environment, and to develop gene expression technologies to ensure that transgenes are stably expressed in the desired parts of plants and under the correct conditions.
	• The University of Iowa also has considerable strength in bioinformatics and genomics, both from a basic science level and into active support of major clinical research programs in cancer, cystic fibrosis, macular degeneration, rare inherited disorders, cardiovascular disease and other fields.
	• The University of Iowa cemented its growth in bioinformatics with the formal establishment of the Center for Bioinformatics and Computational Biology (CBCB). The CBCB encompasses 26 funded PI's and supports 9 full-time computational scientists. External funding is derived from both public and private sources and totaled $17.6 million as of December 2003. The Center has 16 labs from 17 departments and 5 colleges.
	• The University of Iowa's research initiatives are focused on:
	  o Gene therapy
	  o Disease gene understanding and therapeutic targeting
	  o Genomic and transcriptional resource generation
	  o Animal models of disease
	  o Bioinformatics - providing the information science techniques necessary to integrate data from research in genomics, molecular evolution and macromolecular structure/function relationships to provide understanding of biological systems.
	  o Functional and Structural Genomics (also includes collaborations with ISU faculty involved in genomics initiatives with plants, animals and microbes).
	  o Genome Evolution - with expertise in molecular evolution with emphasis on whole genome analyses and on understanding patterns and processes of change that occur among genes and genomes over time. (Includes collaboration with ISU faculty).
	  o Macromolecular Structure and Function
	  o Computational Biology
	  o Metabolic and Developmental Networking
	  o Mathematical Biology and Biological Statistics
	• Joint bioinformatics workshop held by Iowa State and The University of Iowa to showcase respective strengths and encourage collaboration.

Bioinformatics and Genomics	
	• Expertise at both universities in whole genome sequencing, including active participation in the human genome project.
Supporting Statistics	• Cluster concentration in Iowa confirmed by Battelle Starlight™ analysis. • ISI citations analysis shows a significant volume of papers from both Iowa State (160 papers in Molecular Biology and Genetics and 36 in Cell and Developmental Biology) and The University of Iowa (373 papers in Molecular Biology and Genetics and 172 in Cell and Developmental Biology) • 70 plus bioinformatics related faculty at Iowa State.
Key Institutions	• Iowa State University • The University of Iowa

Table 35: Iowa Strong and Growing Areas: BioEconomy

BioEconomy	
Field Definition	The BioEconomy is an economy where the basic building blocks for industry and the raw materials for energy are derived from plant-based (renewable) sources.
Interview Identified Strengths	• Major push at Iowa State University and a concerted strategic effort to make a significant impact on the Iowa economy. One of the formal ISU Presidential Initiatives. • Focus on industrial applications of bio-resources (mainly plant materials) including: Chemicals, Fuels, Fibers, and Energy. • BioEconomy operations are organized around "platforms" that bring people from diverse disciplines to focus on pragmatic problems and opportunities. Platforms include: o <u>Lignocellulosic feedstock development</u>—using grasses and tree fiber crops to produce high quality fibers that can be used in biocomposite materials such as fibermat and fiberboard. o <u>Syngas fermentation</u>—working with crops and other plant materials to break them down into gas and then synthesize from gas phase into liquids. Main thrust on the production of polyesters and hydrogen (5+ year horizon) o <u>Vegetable lipids</u>—mostly involves chemistry and chemical engineering moving double bonds in fatty acids. Results can be as diverse as increased food shelf life through to polymerization for making plastics. o <u>Expression of recombinant proteins</u>—requires a bioprocessing facility and involves using plants (such as corn) to produce recombinant proteins for industrial and pharmaceutical applications. o <u>Metabolic engineering of new fermentation products</u>—Idea here is to identify biocatalysts to improve fermentation technology (trying to improve fermentation yields and broaden the organic acid and alcohol products of fermentation). o <u>Biofuels</u>—such as the production of ethanol from corn or biodiesel from soybeans. • Key resources in Iowa include the BECON facility for biomass energy conversion (with DOE Energy of the Future program), Plant Sciences Institute coordinating scientific research, Center for Plant Genomics, Center for Crops Utilization Research, Center for Plant Transformation, Ag Biosystems Engineering, IPRT Center for Catalysis, Chemical Engineering, Institute for Combinatorial Discovery, etc. • Companies already formed in Iowa related to BioEconomy, which constitutes a growing cluster. • The University of Iowa is also actively involved and operating the Center for Catalysis and Bioprocessing—50 faculty associated with this well equipped pilot scale facility. 18 staff, Good Laboratory Practice (GLP) structure and 16,000 sq.ft. of space. • The ABIL center at the University of Northern Iowa has been performing leading edge work in bio-based lubricants since its establishment in 1990. The UNI program has recently been awarded funding from the USDA to move towards a national center for ag-based product testing and advocacy. Spin-off company, Environmental Lubricants Manufacturing, now commercializing products successfully. • The University of Northern Iowa's RRTTC Center is assisting those who to desire to use recycled or biomass-based materials for manufactured products. • Ames DOE Lab focused on materials sciences and may be leveraged into more of a biomaterials focus.
Supporting Statistics	• Cluster specialization confirmed by Battelle Starlight™ analysis on Iowa patents. • ISI data confirms some of the important strengths, including Materials Science and Engineering with 239 papers at Iowa State University, 37 at The University of Iowa and 124 from Ames Lab. Intensity

BioEconomy	
	also in Organic Chemistry and Polymer Science (229 ISU, 125 U of I and 42 from Ames Lab).
Key Institutions	• Iowa State University & Ames Lab • The University of Iowa • University of Northern Iowa

Table 36: Iowa Strong and Growing Areas: Statistics and Epidemiology

Statistics and Epidemiology	
Field Definition	Statistics is a branch of applied mathematics concerned with the collection and interpretation of quantitative data and the use of probability theory to estimate population parameters. Epidemiology is the scientific study of diseases; includes analyzing the occurrence and distribution of diseases and the factors that govern their spread.
Interview Identified Strengths	• National strengths at The University of Iowa in cancer epidemiology and neurological disease epidemiology. Cancer work is greatly facilitated by strong cancer registry with good funding and a high capture rate. • The University of Iowa has NIH funding in the field. • Epidemiology centered within the Department of Public Health at The University of Iowa looking at the epidemiology of chronic diseases such as: o cancer o cardiovascular disease o mental illness o diseases caused by the environment. • Epidemiology at The University of Iowa cooperative within the university and also across into close working relationship with the College of Veterinary Medicine at Iowa State University. • Strengths in zoonotic diseases and their relationship to food animal worker and slaughter/meat processing environments. • Strong applied work with industry and other researchers in vaccine trials. Working with CDC in monitoring adeno viruses in the immunocompromised patient. • Good support from mathematics in terms of modeling and complex models for infectious diseases. • Iowa State University recognized as having one of the strongest statistics programs in the U.S.. • Iowa State operates the Statistical Laboratory—a research and service institute developing and applying statistical methodology to support research throughout the University and beyond. • Iowa State statistics active with computational biology on the genetics side of statistics, and also with epidemiology and public health applications. • Strong mathematics base for quantitative support and modeling at The University of Iowa and Iowa State University.
Supporting Statistics	• University of Iowa Math and Stats with 274 papers and 1.14 relative impact, and Iowa State University with 217 papers and a 1.42 relative impact.
Key Institutions	• The University of Iowa • Iowa State University

Table 37: Iowa Strong and Growing Areas: Inflammatory Diseases and Mechanisms of Inflammation

Inflammatory Diseases and Mechanisms of Inflammation	
Field Definition	Inflammation is a fundamental response of virtually all multicellular organisms to infection and injury. Essential functions of the inflammatory response include detection and response to invading microbes and to cellular damage, control of microbial proliferation and of microbial material, and repair of tissue injury.

Interview Identified Strengths	• Inflammation is formally established as a research group at The University of Iowa and operates from 11,000 sq. ft. of new space at the Oakdale campus. The University created the Inflammation Program as an interdisciplinary program comprised of independent investigators who share a common interest in understanding the cell and molecular biology of inflammation, its causes and consequences. The overall goal of this interactive group is to provide insights into cellular and molecular events of host defense within the context of inflammation.
	• Three major pushes related to inflammation:
	  o Microbial pathogenesis
	  o Arteriosclerosis (which has an inflammation component)
	  o Malignant disease.
	• Investigators in the Inflammation Program are actively engaged in fundamental research on several cellular elements of the innate immune system, as well as soluble factors (*e.g.* cytokines, products of arachidonic and metabolism, and coagulation factors).
	• Designed to complement established programs in Immunology and Bacterial Pathogenesis.

Supporting Statistics	• ISI data show Immunology (no direct category for inflammation) having published 342 papers between 1997-2001 with a relative impact of 1.73. • There are 38 current NIH grants to The University of Iowa in which inflammation is a component of study.
Key Institutions	• The University of Iowa

Table 38: Iowa Strong and Growing Areas: Food Science and Nutrition

Food Science and Nutrition	
Field Definition	Nutrition involves the study of the food and liquid requirements of humans or animals, consisting of the taking in and metabolism of food materials whereby tissue is built up and energy liberated.
Interview Identified Strengths	• Signature focus of Department of Food Science and Nutrition at ISU is in soy—working from breeding through to functional properties. • Working to understand the basic mechanisms by which soy imparts health benefits (such as lowered cholesterol, improved bone density, cancer prevention). • Iowa State University is operating a Botanical Center that is NIH funded for investigating medicinal/nutraceutical effects of herbs. Current focus on Echinacea and St. John's Wort—working to identify bioactive components and novel compounds. $7 million in NIH funding for this research, with The University of Iowa also collaborating on the project (total of 20 labs engaged, 18 at ISU and 2 at The University of Iowa). Expect to bring soy in as an additional study plant. This is one of six NIH-funded botanical supplement centers in the U.S. and the only one associated with a Food Science and Nutrition department. • Anticipate work with herbs will lead them on a path to anti-viral and immunity enhancement as a broad focus or theme. • Department at Iowa State University is also focused on functional food components, flavinoids, and folate nutrients. • Iowa State operating the Center for Designing Foods to Improve Nutrition, with a focus on improving the quality of food and developing food products that may help offset the obesity epidemic.
Supporting Statistics	• Iowa State University published 187 papers in food science and nutrition between 1997-2001with a citation quotient of 8.6. • The University of Iowa published 21 papers in the field.
Key Institutions	• Iowa State University • The University of Iowa

Table 39: Iowa Strong and Growing Areas: Biotechnology and Bioprocessing

Biotechnology and Bioprocessing	
Field Definition	Biotechnology involves the scientific manipulation of living organisms, especially at the molecular genetic level, to produce useful products. Gene splicing and use of recombinant DNA (rDNA) are major techniques used. More broadly it includes a set of biological techniques developed through basic research and now applied to research and product development. In particular, biotechnology refers to the use by industry of recombinant DNA, cell fusion, and new bioprocessing techniques.

Interview Identified Strengths	• Biotechnology and bioprocessing are a focus at both The University of Iowa and Iowa State University.
	• Iowa State operates a formal Office of Biotechnology to facilitate research and development in the field.
	• Iowa State is focusing biotech work in three broad areas:
	  o Increasing the value of current agricultural raw materials through bioprocessing techniques
	  o Increasing the efficiency, profitability, and sustainability of plant and animal production
	  o Genetic modification of plants, animals, and microbes to produce more diverse products of greater economic value.
	• Iowa State University involved in statewide education initiatives to support biotechnology and raise public understanding.
	• Strong facilities in support of biotechnology research at Iowa State, including:
	  o Animal Gene Transfer Facility
	  o Microscopy facilities , including electron microscopy
	  o Analytical services—providing resources for atomic absorption spectro-photometry, automated analysis, gas chromatography, carbon analysis.
	  o Cell facility with flow cytometry and cell sorting.
	  o Chemical Instrumentation facility with Magnetic resonance, mass spectrometry, x-ray diffraction, spectrophotometry and elemental analysis.
	  o Confocal microscopy facility
	  o DNA sequencing and synthesis facility
	  o Fermentation facility
	  o Hybridoma facility
	  o Image analysis facility
	  o Microanalytical instrumentation
	  o Microarray facility
	  o NMR Facility, with a 500MHz NMR spectrometer
	  o Plant transformation facility
	  o Protein facility conducting amino acid analysis, peptide synthesis, protein/peptide sequencing, HPLC, mass spectrometry, electroblotting and proteomics
	  o Proteomics facility
	  o Soybean molecular marker facility.
	• Bioprocessing and its relation to biotechnology is also a major focus of the Center for Biocatalysis and Bioprocessing—this center has a 20 year operating history and is one of very few places in academia equipped with large-scale biotechnology piloting facilities, GLP lab operations, and BL2 facilities for large scale work.
	• The University of Iowa Center for Biocatalysis and Bioprocessing is primarily focused on: biocatalyst fundamental properties, bioremediation, bioprocessing, new biocatalyst discovery, novel biocatalyst applications, biosensing technology, and reactive agent development.
	• Iowa State University in the late planning stages for a bioprocessing facility at their research park.

Supporting Statistics	• ISU has over 283 “biotechnologists” from 26 departments in five colleges. University of Iowa Center for Biocatalysis and Bioprocessing has 59 faculty members and 300 researchers. • The University of Iowa published 48 papers between 1997-2001 in Biotechnology and Applied Microbiology with a relative impact of 2.13, while Iowa State published 56 papers with a 1.34 relative impact.
Key Institutions	• Iowa State University • The University of Iowa

Table 40: Iowa Strong and Growing Areas: Biosystems Engineering

Biosystems Engineering	
Field Definition	Biosystems Engineering includes the study and development of engineering solutions to agricultural, environmental, and related problems and needs. It is closely related to the traditional discipline of Agricultural Engineering.
Interview Identified Strengths	• Biosystems Engineering thrust is in multiple areas at Iowa State University: o Environmental and natural resource engineering, examining complete hydrology and soil water landscape system and biosystems approaches to decontamination and sustainability. Use lakes, wetlands, etc. as bioreactors to naturally use biomicrobes to clean up chemicals. o Antibiotics and pharmaceuticals—working on biosystems engineering approaches to removal of growth hormones, antibiotics, etc. that enter the ecology. Most of the grants from USDA. o Homeland security, monitoring and environmental genomics. o Advanced machine systems—tractors, combines, chemical applications, tankers, clean up of manure handling systems, etc. Work for meat packing industry in automation. Also work to look at systems for farm safety (how should they be secured and monitored). John Deere concerned that machines are properly cleanable and contamination removable. Need to build in biosafety to machines. o Livestock industry—big facility design issues, efficiency, animal welfare, smell control etc. Observation of animal stress factors—heat, humidity, air circulation—plus the effects on the health of the livestock industry's workforce. o Food safety and food engineering—getting more and more into bioengineering. Storage of grains (air circulation), transportation, grain handling and grain quality assurance. Working with sensors to test fat, carbohydrate, protein content etc. in a rapid way (ISU developed the first of these instruments). Plus new issues of bioterrorism and contamination of the food chain. • At The University of Iowa related engineering work is taking place within the well established Optical Science and Technology Center. Expertise is particularly strong in infrared monitoring devices and oxygen sensor devices.
Supporting Statistics	• 26 faculty: 8 in environmental biosystems, 4 in machine systems, 7 on animal environmental engineering, 5 in food and process engineering, and 1 attached to the BioEconomy Initiative. • $4.8 million in annual research expenditures. • State commercial focus in agricultural machinery and processing equipment confirmed by Battelle Starlight™ analysis of patents.
Key Institutions	• Iowa State University

Table 41: Iowa Strong and Growing Areas: Health Informatics/Nursing

Health Informatics/Nursing	
Field Definition	Health informatics is an evolving scientific discipline that deals with the collection, storage, retrieval, communication and optimal use of health related data, information and knowledge. The discipline uses the methods and technologies of the information sciences for the purposes of problem solving and decision-making.
Interview Identified Strengths	• The College of Nursing at The University of Iowa is using health informatics as a core tool in several projects. Studies have examined outcomes and quality of care and developed normative rating scales for care. Considerable focus on care of the elderly—a direct issue for Iowa which has an older population than most states. • Health informatics in the College of Nursing draws on database management skills, research design, statistical analysis, and knowledge of the patient population. • The College of Nursing operates a research dissemination core that is in its 11th year of funding and provides knowledge to practitioners on the care of older adults to help improve care delivery (30,000 protocols disseminated by this program). • The University of Iowa has the only P30 from the NIH in gerontology nursing. • Operates a genetics track in master's and doctoral programs, including genotyping and phenotyping work. • Operates an interdisciplinary program in health informatics. Has built capacity in knowledge representation (building text representations of patient interaction, clinical effectiveness coding systems). Is developing protocols and scoring systems for nursing quality management that are being developed into software by an outside vendor (with University of Iowa retaining the property rights). • Believes it has the opportunity to have more than 60+ organizations feeding data into it for processing and analysis—it could serve as a central clearinghouse and electronic processing center for clinical outcomes data. This could form the core of a data warehouse system it could sell, plus be a tool to link medical and nursing research. It believes it is the only place in the country with a nursing (as opposed to medical) outcomes focus.
Supporting Statistics	• Currently ranks 10th in NIH funding with $5 million annually. • Also has highest volume of T32 nursing training grants in the country (focused on gerontology, genetics, outcomes measurement and effectiveness). • 16 current NIH grants from National Institute for Nursing Research. • ISI data show University of Iowa with 64 papers in Healthcare Science and Services between 1997-2001.
Key Institutions	• The University of Iowa

Table 42: Iowa Strong and Growing Areas: Gene Therapy

Gene Therapy	
Field Definition	Gene Therapy is a group of approaches to preventing and/or treating disease by replacing, removing or introducing genes or otherwise manipulating genetic material. Genes may be introduced by direct injection or using a viral vector to deliver genes into cells.
Interview Identified Strengths	• The Iowa Center for Gene Therapy, established in the fall of 1998 through joint funding by NIH/NIDDK and the Cystic Fibrosis (CF) Foundation, is one of three such centers in the United States. The purpose was to create an organized center at the University of Iowa for promoting research and training on gene therapy approaches for treating CF and other serious inherited diseases. • The Gene Therapy Center supports four research core facilities: the Vector Core, the Animal Models Core, the Cell Morphology Core, and the Cells and Tissue Core. • Due to an increasing need for CF lung tissue in basic research, the University of Iowa formed a Midwest Regional CF Lung Tissue Acquisition Program as part of this Center for Gene Therapy of CF and Other Genetic Diseases at the university. The goal of this consortium is to create a frozen repository of viable primary cells and lung tissue specimens for basic research. • The University of Iowa has a long-standing history as a leader in the field of CF research and applied gene therapies for this disorder. The University of Iowa has several funded CF research programs, including a Research Development Program (RDP) funded by the CF Foundation, a CF Scientific Center of Research (SCOR) funded by NHLBI, and a Gene Therapy for CF program project grant (PPG) funded by the NIH. • Developing some good strengths in animal modeling (including the cloning CF ferrets). • CF total of 10 main lead researchers. Broad funding. All of them are generating patents and intellectual property (IP). • Developing strong expertise in biofilms as a result of CF work.
Supporting Statistics	• The Gene Transfer Vector Core was established with approximately $1.1 million provided by the College of Medicine and the Carver Trust. The Transgenic Animal Facility, built in 1992 at a cost of $2.4 million, is at the Oakdale Research Park. Total CF funding at $8 million to $12 million annually. • 26 NIH grants related to gene therapy and cystic fibrosis. • Cluster confirmed by Battelle Starlight™ analysis.
Key Institutions	• The University of Iowa

Emerging and Notable

Table 43: Iowa Emerging and Notable Areas: Imaging and Sensor Devices

Imaging and Sensor Devices	
Field Definition	Imaging is the capture, storage, manipulation, and display of visual information or data, which in the biosciences may be achieved through a variety of means such as microscopy, x-rays, PET scans, fluoroscopy, magnetic resonance images, etc. Sensors can include a variety of chemical, biological or electronic means for detecting the state or change in a biosystems (e.g. temperature change, presence of invading microorganisms, increased biofluid flow, heart arrhythmia, etc.)
Interview Identified Strengths	• Both The University of Iowa and Iowa State University have strengths in imaging and sensor R&D and the application of these technologies. • The University of Iowa College of Engineering Imaging Group (CEIG), for example, provides a collaborative environment for medical image processing, analysis, research, and education. Contributing departments include Electrical and Computer Engineering, Biomedical Engineering, and Radiology • The University of Iowa College of Medicine has particular imaging strengths in advanced physiological imaging, down to the sub-millimeter level. The College is also taking a leading role in the development of volumetric imaging tools and techniques. Particular emphasis is being placed on imaging for cardiovascular and pulmonary applications through the Center for Advanced Imaging Research. • The University of Iowa is home to some of the leading experts on medical image processing, analysis, and machine vision. • The Department of Agricultural and Biosystems engineering at Iowa State University is placing an emphasis on research in biosystems engineering through the use of biosensors, image analysis, and biological systems modeling. • Both Iowa State University and The University of Iowa are also leaders in the application of imaging to the creation of virtual reality environments for use in training and research. • Biosensors are also a focus of research in the Iowa State University entomology department, whose recent emphasis involves development of miniature biosensors for detection and location of sources of compounds of importance to defense and precision agriculture. • Iowa State University is also taking a leading role in the development of environmental monitoring sensors and systems, and developing biosensor applications for food safety monitoring and biosecurity.
Supporting Statistics	• Cluster of more than 25 faculty and research scientists engaged in The University of Iowa's Center for Advanced Imaging Research. • Multiple awards from government agencies in biosciences engineering and related disciplines.
Key Institutions	• The University of Iowa • Iowa State University

Table 44: Iowa Emerging and Notable Areas: Metabolomics

Metabolomics	
Field Definition	Metabolomics uses genomics to understand metabolism—the network of chemical reactions organisms use to maintain life.
Interview Identified Strengths	• Iowa State University has been equipping a $1 million lab for metabolomics funded by the W. M. Keck Foundation. Termed the Metabolomics Research Laboratory, it will facilitate the study of metabolites to provide clearer understanding of the function of genes. • At Iowa State the focus of metabolomics initially will be on plants. Work is taking place on starch metabolism, genes that direct seed oil production, and analysis of the herbs Echinacea and St. John's Wort. The work in metabolomics at Iowa State is central to the University's Center for Designer Crops, a component of the Plant Sciences Institute. • Metabolomics research will be fundamental to many of the goals of Iowa State in terms of adding value to plant crops. The science may lead to enhanced oils, plant morphology changes, color manipulation, functional foods, and other desirable characteristics. • Strength at Iowa State is ability to link from model systems (Arabidopsis) across into crops and the know-how of growing the crops. They then take genomics and focus it on the understanding of metabolism. Rapid identification of lipids and other metabolite classes will be useful in a variety of applications, such as plant and animal breeding, the characterization of transgenic crops, and basic research. • At The University of Iowa metabolomics will also be an outgrowth of genetics and proteomics research. Metabolomics brings a different and complementary perspective to biomedical research and therapeutic development. Metabolites are measurable, directly responsible for health, and changeable through intervention. By definition, the concentrations of metabolites are the direct reflection of metabolism, and by measuring changes in metabolite concentrations, the full range of biochemical effects induced by a therapeutic intervention can be determined. • In a clinical setting, metabolomics can be used to diagnose or predict disease, stratify patient populations by their specific metabolism, or to determine the safety or efficacy of a therapeutic intervention. Metabolomics is useful in most aspects of biomedical research, and it is likely to evolve into an essential component of the drug discovery and development process.
Supporting Statistics	• Iowa State has 14 faculty specializing in designer crops, a manager of the metabolomics lab, and an assistant for the center. Roughly $1-2 million range of grant funding.
Key Institutions	• Iowa State University • The University of Iowa

Table 45: Iowa Emerging and Notable Areas: Biofluidics

Biofluidics	
Field Definition	Biofluidics involves the modeling of biological fluids, such as arterial haemodynamics or respiratory systems. It is being facilitated by advances in high performance computing.
Interview Identified Strengths	• The University of Iowa may be well positioned to progress science in biofluidics. Expertise in lung imaging and modeling, and expertise in the cardiovascular system, both have direct relevance to biofluidics—and biofluidics models may be useful in the analysis of infections, diseased tissue locating, post-surgery prognosis modeling, artificial organ and tissue development, and detection of cardiovascular abnormalities (such as aneurisms). • Strong computational modeling expertise, coupled with medical imaging expertise, is critical to progress, and both exist at The University of Iowa.
Supporting Statistics	• No data
Key Institutions	• The University of Iowa

Table 46: Iowa Emerging and Notable Areas: Biofilms

Biofilms	
Field Definition	Also known as "microbial mats," biofilms consist of layered groups or communities of microbial populations. Biofilms are produced by microorganisms and consist of a sticky rigid structure of polysaccharides and other organic contaminants. This slime layer is anchored firmly to a surface and provides a protective environment in which microorganisms grow.
Interview Identified Strengths	• The University of Iowa is taking a leading role in the new field of biofilms and claims to have become <u>the</u> center for medical biofilms research. Much of the work is taking place within the Cystic Fibrosis Center, but it is broader than just CF (although it is a model biofilm disease). Work is fundamental and the next ten years will see molecular level work, gene correlation to antibiotic resistance and then a move into clinical applications. Lots of patents being generated. Some small pharmaceutical and large biotech companies are starting to become players in biofilms disease and treatment. • Physicians prescribe antibiotics to treat bacterial infections; however, such treatment is generally ineffective if bacteria cluster in biofilm colonies. Now the Iowa scientific community is focusing attention on developing therapeutic agents to combat biofilm infections. • University of Iowa researchers have identified a subset of genes in a bacterium that behave differently when the organism exists as a biofilm. These findings may lead to an understanding of the genetic causes of increased antibiotic resistance in biofilms. By examining the list of genes that were differentially activated or repressed in biofilms, the researchers have found other genes that have also been linked to the ability of non-biofilm cells to withstand lower concentrations of antibiotics.
Supporting Statistics	• 5 main NIH grants identified with the term "biofilms" in them at The University of Iowa.
Key Institutions	• The University of Iowa

Table 47: Iowa Emerging and Notable Areas: Nanotechnology

Nanotechnology	
Field Definition	Nanoscience is the study of the principles of molecules and structures with at least one dimension between 1 and 100 nanometers (one nanometer is one billionth of a meter). Nanotechnology is the application of the unique properties of such objects to materials, devices and biological systems.
Interview Identified Strengths	• Nanotechnology appears to be a growing field at both The University of Iowa and at Iowa State University • The Optical Science and Technology Center at The University of Iowa is working on novel optical components to gather bio information via imaging, both noninvasive and invasive. Working with personnel in cancer, and able to work at the single molecule level. • 15+ groups on The University of Iowa campus would consider themselves working in Nanotechnology. • Joint work with University of Colorado in photopolymerization. Work is in nano-structures/ordered-structures using photo polymerization. • Researchers at The University of Iowa are conducting research to see how plants handle nano-sized particles and what would be some of the risks attached. Biomimicry is one of their basic science investigative areas. Plus remediation aspects of technology - working on environmental aspects of nanotechnology. • At Iowa State University, scientists in materials sciences and within chemistry are active in nanotechnology. Work within chemistry has focused on mesoporous spheres as catalysis promoters (mesoporous silica bioreactors), non-invasive cell identification tools, drug delivery tools and as artificial gene therapy vectors. • The Iowa State University Materials Science and Engineering Program has a focus in nanomaterials and nanotechnology. • Iowa State University Research Park now home to a nanotechnology company, Bioforce Nanosciences, which is a developer of ultra-miniaturized nanoarray technologies for solid-phase, high-throughput biomolecular analysis. • The Mechanical Engineering Department at Iowa State University has a world-class laboratory that provides facilities for experimentation to investigate the fundamental and feasibility concepts of laser advanced manufacturing, microelectromechanical systems (MEMS), and nanotechnology. • Materials scientists at Ames Laboratory are performing experiments to characterize materials, modeling the systems at the atomic level using some of the world's fastest supercomputers, and developing theoretical models to explain these properties. • IPRT at Iowa State features the new Microanalytical Instrumentation Center, with clean room facilities designed to facilitate nanotechnology research. Facility is unique in being designed for use by chemists in developing nano-scale instrumentation.
Supporting Statistics	• No data
Key Institutions	• The University of Iowa • Iowa State University

Table 48: Iowa Emerging and Notable Areas: Biosecurity

Biosecurity	
Field Definition	Biosecurity encompasses work to ensure that ecologies sustaining either people or animals are maintained. Biosafety encompasses the science of prevention of large-scale loss of biological integrity, focusing both on ecology and human health.
Interview Identified Strengths	• Iowa has multidimensional strengths in biosafety and biosecurity that have not yet been pulled into a formal program, institute, or center. However, Federal support for a biosecurity initiative has come in the form of a planning grant. • Iowa State University has specific strengths in biosecurity as it relates to agrosecurity, food and animal safety and infectious disease threats. The University also has expertise in water, soil and other ecosystem sustainability and security fields. • Iowa State has organized food security and public health security under the Center for Food Security and Public Health with the mission of increasing national preparedness for accidental or intentional introduction of disease agents that threaten food production or public health. • The University of Iowa has a strong program in infectious diseases, with an emphasis on respiratory diseases and zoonotic diseases. This is an interest shared with Animal Sciences and the College of Veterinary Medicine at Iowa State University. • Good virology expertise at The University of Iowa and Iowa State. • Lack of BL3 facilities limiting progress somewhat. • Opportunity for an integrated approach to biosecurity between Iowa institutions including: humans, animals, food, agricultural production and processing, engineering, and ecological/environmental monitoring and protection. • Collaborations being developed with other Midwestern universities in a consortium approach to biotechnology (University of Kansas and Wichita State University, for example). • Iowa State University is operating the Biosafety Initiative for Genetically Modified Products using science based risk/benefit analysis.
Supporting Statistics	• No data
Key Institutions	• Iowa State University • The University of Iowa

Table 49: Iowa Emerging and Notable Areas: Drug Development

Drug Development	
Field Definition	Drug development (as opposed to drug discovery) involves the various procedures, formulation, trials, and studies that must be undertaken to satisfy Food and Drug Administration requirements for drug approval and marketing.
Interview Identified Strengths	• The Center for Advanced Drug Development (CADD) at The University of Iowa is ten years old and mostly performing analytical development, pre-formulation and stability research. The Center provides a fee-for-service operation to researchers and corporations. It performs 350 batches of pharmaceutical dosage forms a year, and can do more than one project per day. 85% of projects are for clinical trials for humans, while the rest are development and stability batches. CADD has 6,500 sq.ft. and 17 people. • The Division of Pharmaceutical Services occupies the whole ground floor of the College of Pharmacy at The University of Iowa. It began as a manufacturing department for the pharmacy of the university hospitals, and was upgraded to comply with GMP specifications to help faculty with accessing grants from the federal government. Now the institution has a considerable track record in contract work for pharmaceutical companies (extremely unusual for an academic institution). • 85-90% of the Division of Pharmaceutical Services' work is with smaller pharmaceutical companies and start up pharma companies who cannot afford to set up their own small GMP facilities. Conducts formulation and analytical development—and mostly manufacture for Phase I and II in all forms (except soft gelatin capsules, aerosols and transdermals). Have 24,000 sq.ft. and 56 staff members. • Kentucky has a similar pharmaceutical services operation but it is smaller; Maryland's is newer but more limited; and Purdue is just starting one. Linking into a cGMP biologics facility will make Iowa unique. • Iowa State University is in the late planning stages for the development of a biotechnology processing facility for protein production and purification at their Research Park in Ames. • Drug formulation is also a distinguishing feature of The University of Iowa's expertise in pharmaceutics. Many new drug products will not necessarily involve new chemical entities (drug discovery). Modified compound formulations may be designed to more effectively balance conveniences, efficacy, and toxicity using improved delivery techniques.
Supporting Statistics	• No Data
Key Institutions	• The University of Iowa • Iowa State University

Table 50: Iowa Emerging and Notable Areas: Materials Science (Applications to Bioscience)

Materials Science (Applications to Bioscience)	
Field Definition	Materials Science includes those parts of chemistry, physics, geology, and even biology that deal with the physical properties of materials. It is usually considered an applied science, in which the properties under study have some industrial purpose. Biomaterials are any substance (other than drugs) or combination of substances synthetic or natural in origin, which can be used for any period of time, as a whole or as a part of a system which treats, augments, or replaces any tissue, organ, or function of the body.
Interview Identified Strengths	• The Department of Biomedical Engineering at The University of Iowa has a concentration in biomaterials, especially implant biomaterials. • Work in Biomedical Engineering's Biomaterials Laboratory involves the modification of ultra high molecular weight polyethylene (UHMWPE) to be chemically adhered to the polymethylmethacrylate bone cement for better fixation of implants made of UHMWPE such as the acetabular cup of the hip and tibial plateau of the knee joint. Another area of research is the use of thermal seeds to heat prostate tissues. The development of PdCo alloy seeds and testing of the seeds in various conditions have moved into the clinical trial stage. • Developing expertise in biofilms may be directly relevant to future biomaterials and biocompatibility issues. There is also work in tissue engineering at The University of Iowa. • At Iowa State University there is a very strong tradition of materials science tied to the work of the Ames Laboratory. Work on campus in biomaterials is progressing, with examples including the synthesis and design of new biopolymeric materials for protein stabilization, tissue engineering, and controlled and targeted delivery of DNA, drugs, and genetically engineered proteins and peptides. • Iowa State's expertise in materials science, chemistry and chemical engineering is being applied to the BioEconomy initiatives in addition to biotechnology. Polymers, biocomposite materials, adhesives, and other materials are being developed and tested by Iowa State. • Opportunity may exist to leverage the reputation and expertise of the Ames Lab into further research tied to biomaterials and to the BioEconomy initiatives in the state.
Supporting Statistics	• No data
Key Institutions	• Iowa State University and Ames Laboratory • The University of Iowa

Summary

The above tables provide significant insight into the bioscience core competencies and specific areas of focus in Iowa. Conclusions regarding these competencies and strengths are incorporated, together with the findings of the quantitative analysis, to develop and refine "technology platforms" upon which a bioscience economy may be built in Iowa. The specific recommended platforms, and the research core competencies to leverage in building them, are discussed in detail in the next section.

Iowa Paths to Biosciences Development: Leveraging Core Research Competencies and Technology Platforms

The purpose for gaining an understanding of Iowa's research core competencies is not only to identify the key research strengths and drivers for biosciences. To ensure economic impact the key technology platforms must be identified that move this research toward commercialization around products, processes, and market-driven niches. Core competencies identification also helps focus on the state's specific possibilities for becoming a bioscience growth center around major niches and opportunities. Of particular importance is the ability of a state to have specific areas for near-term (within the next two to five years) development that takes advantage of core research strengths that will contribute to economic growth. It is these near-term areas for development that identify how the state can be a thriving center for the biosciences and can provide the foundation for further, more longer-term investments needed to establish broader core competencies for growth in the longer term.

Given the close linkages of research and industry development in the biosciences and the extensive reliance on research for new bioscience products, it is helpful to focus on areas of primary research for near-term development. But research alone is insufficient to ensure bioscience development. The most likely areas for bioscience development can be found where research intersects with a state's industry base, competitive advantages, and market opportunities.

The criteria for selecting near-term opportunities for technology development include areas in which there are

- Existing research focus strengths
- Bases of commercial activity emerging or established within the state, or a genuine opportunity to create a base in the near future
- Distinct opportunities to leverage Iowa's comparative advantages to create competitive marketplace advantages
- Significant product market potential
- Links to, or reinforcements of, other bioscience strengths and core research competencies, thereby helping to enhance other fields as it expands.

Based on these criteria, the following technology development platforms are identified for near-term development, focus, and investment in Iowa:

- **BioEconomy Platform**
- **Integrated Drug Discovery, Development, Piloting, and Production Platform**
- **Advanced Food Products Platform**
- **Integrated Post-Genomic Medicine Platform**
- **Animal Systems Platform**
- **Integrated Biosecurity Platform.**

These six platforms represent the base from which a significant R&D, business base, and bioscience economy may be built. They each specifically draw upon Iowa's institutional expertise in multiple fields, since it is multidisciplinary research that is increasingly gaining importance in driving new study areas, technologies, and commercializable innovations and discoveries. The assembly of multidisciplinary platforms is likely to increase the opportunity for winning federal agency grant awards. It is also a specific match to the type of cross disciplinary institute structure being formally adopted by Iowa State University and more informally used within The University of Iowa.

In addition to the main platforms, Battelle also identified several additional areas of opportunity that represent longer-term or less broad bioscience sector development potentials. The identified areas consist of relatively compact groups of people working in leading edge fields, new formative centers just recently pulled together, or established areas of expertise in which investment in infrastructure and/or personnel are required to sustain or accelerate development momentum. These additional opportunity areas include

- **Host-Parasite Biology and Systems**
- **Instrumentation, Devices and Sensors**
- **Formation of a Cardiovascular Research Institute**
- **Formation of a Free Radical Research Institute.**

Each of the main bioscience platforms and opportunity areas noted above are linked to multiple centers of bioscience excellence and related disciplines within Iowa's academic R&D institutions. Figure 20 summarizes the competency areas identified through quantitative research (the column of disciplines on the left) and those identified through the in-depth qualitative interviews (the column of disciplines on the right). The center column depicts the main technology platforms and opportunity areas that can result from the integration of these qualitative and quantitative strengths.

Figure 21 shows how Iowa's bioscience research strengths, determined and validated through both quantitative and qualitative analyses, lead to the recommended six specific technology platforms. Each of these six platforms, as well as the four emerging opportunity areas, are described in the following narratives. Each narrative includes a figure designed to show the specific linkages between the quantitatively based and qualitatively based core competency disciplines and recommended platforms and opportunity areas. The figures graphically illustrate the way in which these platforms are reinforced by the R&D talent across a wide range of strength disciplines in Iowa.

Figure 20: Quantitative and Qualitative Core Competencies and Resulting Biosciences Technology Platforms.

Quantitative

- Plant Breeding/Genetics
- Biotechnology & Applied Microbiology
- Immunology & Infectious Diseases
- Ag. Engineering
- Food Safety & Nutrition
- Materials Science
- Agricultural Chemicals
- Entomology & Pest Control
- Veterinary Medicine & Animal Health
- HM: Anesthesiology
- HM: Audiology
- HM: Biostatistics
- HM: Cardiovascular
- HM: Neuroscience
- HM: Nursing
- HM: Oncology
- HM: Ophthalmology
- HM: Orthopaedics
- HM: Otolaryngology
- HM: Pediatrics
- HM: Public Health
- HM: Radiology

Notes:
HM = Human Medicine

Core Platforms

- BioEconomy Platform
- Advanced Food Products Platform
- Animal Systems Platform
- Integrated Biosecurity Platform
- Integrated Drug Discovery, Development Piloting & Production Platform
- Integrated Post Genomic Medicine Platform

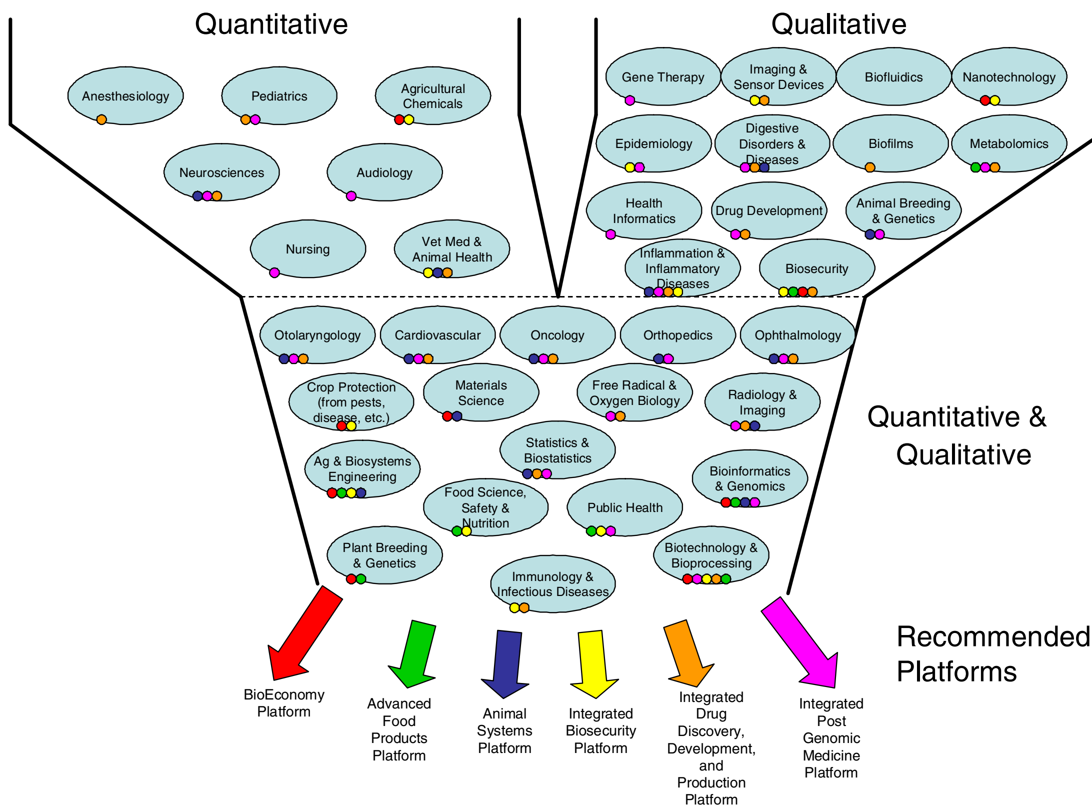
Additional Opportunities

- Host-Parasite Biology & Systems
- Instrumentation, Devices & Sensors
- Cardiovascular Research Institute
- Free Radical Research Institute

Qualitative

- Plant Breeding, Genetics & Plant Transformation
- Cancer/Oncology
- Cardiovascular
- Animal Breeding & Genetics
- Crop Protection
- Infectious Diseases & Microbiology
- Free Radical & Oxygen Biology
- Additional Human Medicine Focus Areas
- Bioinformatics & Genomics
- BioEconomy
- Statistics/Epidemiology
- Inflammation & Inflammatory Diseases
- Food Science & Nutrition
- Biotechnology & Bioprocessing
- Biosystems Engineering
- Health Informatics
- Gene Therapy
- Imaging & Sensor Devices
- Metabolomics
- Biofluidics
- Biofilms
- Nanotechnology
- Biosecurity
- Drug Development
- Materials Science

Figure 21: Iowa's Validated Research Strengths Leading to Recommended Platforms.



IOWA'S TECHNOLOGY PLATFORMS

In the pages that follow each of the six identified platforms are described and analyzed and gaps and opportunities discussed.

BIOECONOMY PLATFORM

Iowa's research institutions and industry already have aggressively moved forward in the platform area of "BioEconomy"—a term coined to describe the application of biosciences and biological resources to the production of biorenewable resources and products. The BioEconomy stands as distinct from biotechnology in that biotechnology can be defined as work on technologies targeting human, animal, and plant health, while **the BioEconomy is focused on the commercial application of bioresources to the production of energy, industrial commodities, and specialty products.** Examples include

- Biofuels (such as Ethanol, Biodiesel, Methane Gas)
- Biocomposite Materials (such as construction materials, insulation, sound deadening panels)
- Specialty Chemicals (such as plastics, adhesives, lubricants, catalysts) via bioresource pathways
- Fibers (for carpeting, clothing and other applications)
- Environmental Remediation and Protection Systems (such as microbes for toxic waste disposal).

The use of biorenewables has received considerable attention in Europe where the European Community-sponsored "Interactive European Network for Industrial Crops and Their Applications" (IENICA) has undertaken significant analysis of potential markets for biorenewables. IENICA segments the potential market into five main areas:

- Oils
- Fibers
- Carbohydrates (sugars, starches, glycogen)
- Specialty Products
- Proteins.

IENICA's research concludes that the first three of these (oils, fibers and carbohydrates) will have the greatest potential impact on agriculture because **they will require large production land acreage**. Independent of fuel production (such as ethanol and biodiesel), IENICA predicts that the main oil market opportunities will be in

- Bio-lubricants
- Bio-printing inks
- Bio-solvents
- Linoleum
- Surfactants
- Polymers
- Paints and Surface Coatings.

In terms of fiber applications, the Europeans predict opportunities in

- Matting based products (filters, growth media, textiles)
- Biocomposites (such as materials for use in vehicle manufacturing)
- Insulation products
- Wood-based panel substitution with annual constituents (such as straw)
- Paper and pulp manufacturing.

Non-food carbohydrates markets, especially those for starches, represent approximately 50 percent of total starch use in the European Community. These non-food uses are primarily in

- Paper and cardboard manufacturing
- Plastics and detergents
- Fermentation and technical uses
- Specialty areas including water purification, cosmetics, toiletries, pharmaceuticals, paints, and agrochemicals.

Proteins are predicted to have major applications (outside of food) in packaging and labeling industries, pharmaceutical and chemical production, adhesives, and cosmetics.

It is therefore evident that considerable opportunities exist for the commercial exploitation of biorenewables. Much of the future for these products depends on the development of processing technologies that will generate products at a price competitive to alternative (usually petroleum based) production pathways.

As noted previously, Iowa has, through the Industries of the Future program, already identified the BioEconomy as a component of the future world economy in which Iowa can gain an early and sustainable leadership position. Iowa State University research, sponsored by the U.S. Department of Energy, Iowa Department of Natural Resources, and the Iowa Energy Center, resulted in the Fall of 2002 publication entitled "Biobased Products and Bioenergy Vision and Roadmap for Iowa." The Roadmap provides a vision statement for Iowa's potential position in the BioEconomy stating that by 2020:

> *Iowa leads the nation in developing the BioEconomy. Growth of the BioEconomy had led to an unprecedented period of sustained economic growth in the state and has allowed Iowa to develop abundant amenities and a quality of life rated among the highest in the United States. Iowa biorefineries*[24] *enjoy widespread support from Iowans because they consistently*
>
> - *Produce superior products*
> - *Capture significant value for all segments of bioproduct value chains*
> - *Provide high rates of return to investors*
> - *Attract local and outside capital*
> - *Provide exciting, challenging and lucrative jobs*
> - *Improve environmental conditions and ecological diversity.*

The Iowa State University report for Industries of the Future specifically outlines the science and technology focus areas that need to be addressed to assure advancement of the BioEconomy and Iowa's leadership position within it. The science and technical focus areas include

- **Plant Science**—improving processing functionality; expression of desirable characteristics; plant vigor; durability of feedstocks; manure characteristics; uniformity of raw material; pest resistance; optimized yields; environmental impact; and genomics, bioinformatics, and metabolomics capabilities.
- **Production**—improving understanding of the impact of crop residue removal; developing best management practices; expanding planting and harvest windows; developing cost effective methods of harvesting, transporting, and storing biomass; adoption of appropriate farm policies; and developing a marketing system for crop residues and specialty crops.
- **Processing—**improving plant component separation; conversion processes; management and financing systems that reduce feedstock costs; quality and availability of feedstock; and developing decentralized preprocessing technologies.
- **End Use—**designing biorefineries that enhance functionality/performance of local biomass resources; exploiting specific markets for local/regional biobased products; adopting policies that encourage domestic consumption of biobased products; establishing certification programs that verify biobased content and product performance.

[24] The Iowa State University report defines biorefineries as "integrated processing plants that yield numerous products."

Focus products of the Iowa BioEconomy are anticipated to include

- Industrial Chemicals
- Ethanol
- Enzymes
- Biodiesel
- Hydrogen
- Carbohydrate-based chirals
- Building materials such as fiber board, ceiling tiles, etc.

While there are considerable scientific, technical and market hurdles to overcome, efforts are already underway for Iowa to implement this platform, with its advocates noting it has the opportunity to become a major contributor to the state's economic health. Indeed, the BioEconomy in Iowa is not some long-term dream; it is already becoming a reality as R&D advances in the state result in new companies being formed in the field. Iowa is already home to a growing biorefineries industry.

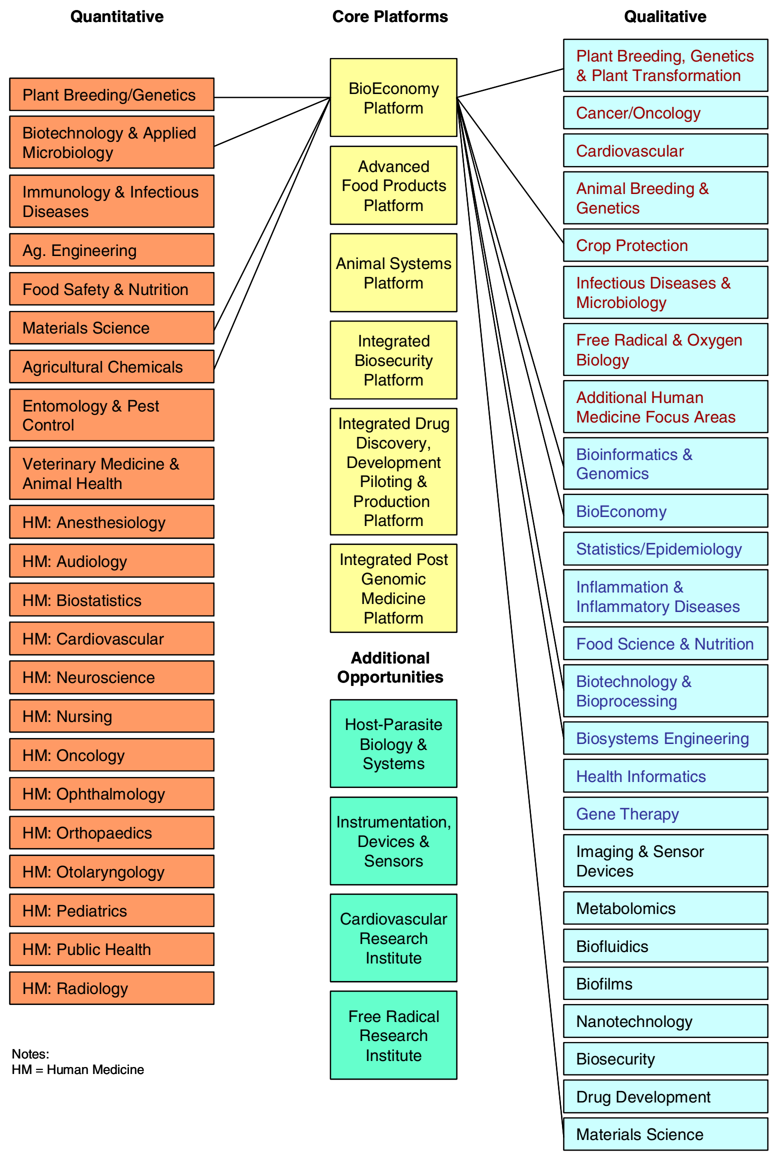
Figure 22 illustrates the key linkages between quantitative and qualitative core competency disciplines and the BioEconomy platform. This figure shows the importance of many core research areas to the success of this platform and the widespread expertise that will be needed to position Iowa to succeed in this arena.

Iowa State University is certainly central to the state's initiatives in the BioEconomy. **The University has put in place a structure of institutes and R&D centers that positions it well as the leader in driving the science and technology of the BioEconomy forward.** *The following components of Iowa State University are key elements in BioEconomy technology platform development:*

***The Plant Sciences Institute*—**an umbrella organization comprising nine research centers and three task forces. Each of these centers and task forces has a role to play in the BioEconomy—but chief among them are six centers that in combination provide a vertically integrated chain of discovery, research and development:

- **Laurence H. Baker Center for Bioinformatics and Biological Statistics—**developing methods, programs, and algorithms for acquiring genomic data and analyzing it for use by plant scientists.
- **Center for Plant Genomics**—developing and using genomic technologies to provide the genetic understanding of plant resources that will form the underpinning of control over plant growth, development, and inherent characteristics.
- **Center for Plant Transformation and Gene Expression**—working to develop methods to efficiently insert and transfer genes in order to efficiently generate transgenic plants and assure their safety.

Figure 22: Quantitative and Qualitative Core Competencies and Resulting BioEconomy.



- **Center for Designer Crops**—working to understand and control the plant production of metabolites that produce useful applications (such as starch, oils or drug compounds).
- **Center for Plant Responses to Environmental Stresses**—working to help modify plants to withstand wider ranges of biotic and abiotic stress.
- **Raymond F. Baker Center for Plant Breeding**—integrating breeding techniques and germplasm enhancements to develop plant cultivars to meet the expression needs and plant characteristics as BioEconomy feedstocks.

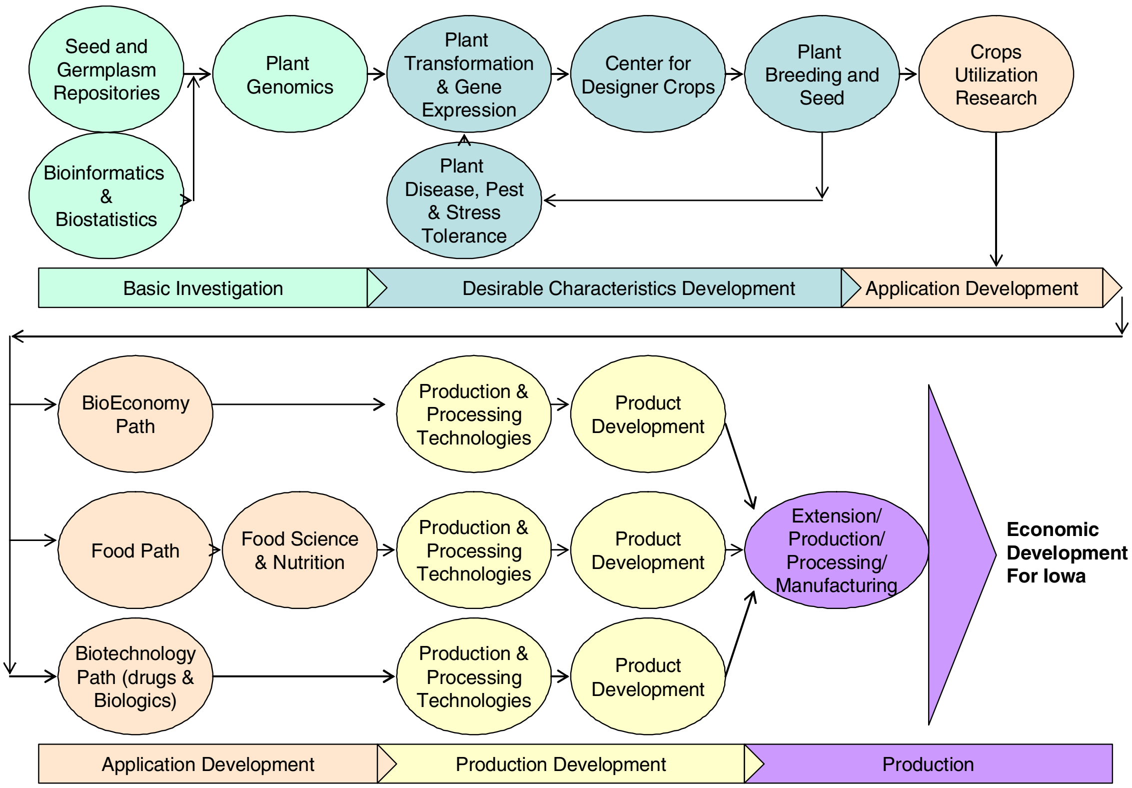
The above centers provide a pathway of basic and applied science from fundamental genomic discoveries through to the exploitation of these discoveries expressed through new, optimized plant cultivars. Thus, there exists at Iowa State a basic fabric of interrelated research centers providing an applied and highly focused research and development engine for the BioEconomy. The work of the R&D scientists is further supported by additional centers and research institutes at Iowa State that can take the science output and direct it for optimal use in developing the BioEconomy. Examples of such pragmatic centers and supporting programs at Iowa State include

- **Center for Crops Utilization Research**—facilitating basic and applied mission-oriented research to find new uses for Midwestern crops and identify uses for potential crops (both food and non-food uses). The Center operates a Crop Products Pilot Plant including:
    - Wet pilot plant facilities
    - Dry pilot plant facilities
    - A hazardous solvents pilot plant
    - Fermentation facility
    - Sensor evaluation laboratory
    - Process development laboratory
    - Analytical services laboratory
    - Technology transfer pilot plant.
- **Center for Catalysis—**working on the catalytic chemistry of converting green feedstock's into BioEconomy products such as plastics and lubricants.
- **Center for Sustainable Environmental Technologies**—developing and demonstrating sustainable energy and environmental technologies, including the study of biomass-derived chemicals, fuel, and power. The Center has resources to specifically assist in the evaluation and scale-up of sustainable technologies, including
    - Fermentation reactor
    - Biomass gasifier, using biomass resources to generate heat and power
    - Virtual pilot plant (through ISU's Virtual Reality Application Center)
    - Biomass Energy Conversion Facility (BECON), a 12,000 sq. ft. research facility dedicated to pilot-scale testing of biomass-energy technologies.

These centers are interdisciplinary in their research and staffing and benefit not only from Iowa State's strong position in genomics and plant biosciences, but also the University's departmental strengths in chemistry, biochemistry, chemical engineering, and biosystems engineering. *The same pathway of basic through applied BioEconomy products also works at Iowa State for developing advanced food and nutrition products.*

The integrated approach to BioEconomy, Biotechnology, and Food Products R&D in Iowa is illustrated in Figure 23. It is evident that Iowa State University has put in place a structure well-suited for moving from basic science research to pragmatic commercializable products (assuming that the system is adequately funded, staffed, equipped, and organized).

Figure 23: Integrated Approach to BioEconomy, Biotechnology, and Food Products R&D in Iowa.



Within this basic structure of BioEconomy development in Iowa, both The University of Iowa and the University of Northern Iowa have contributions to make and expertise that should be engaged and integrated. The University of Iowa has considerable strengths in the biological sciences, bioinformatics, genomics, and proteomics. It also has the Center for Biocatalysis and Bioprocessing with skills and facilities directly relevant to the BioEconomy and biotech technology development paths, in addition to medical and health scientists with applicable skills to food science and nutrition. The Center for Biocatalysis and Bioprocessing at The University of Iowa is a unique facility and provides expertise relevant to both BioEconomy opportunities (in chemical catalysts and associated chemistry fields) and biotechnology opportunities (given established knowledge of, and facilities for, cGMP processes and practices).

Likewise, the University of Northern Iowa is making important contributions related to the BioEconomy. This is especially notable in the area of bio-based lubricants, where UNI operates the ABIL (Ag-Based Industrial Lubricants) research program. ABIL has more than a decade of operating experience in research and development of hydraulic and other industrial lubricants from soybean and other vegetable oils. The program receives support from state, federal, and private industrial partners. ABIL serves as a microcosm of the type of progress that may result in Iowa through BioEconomy research, development, and investment. Since its founding, ABIL discoveries have led to a portfolio of products commercialized by private industry, including

- Multi Grade Hydraulic Fluid
- Industrial Hydraulic Fluid

- Food-Grade Hydraulic Fluid
- Fifth Wheel Grease
- Chain Bar Oil
- Rail Curve Grease
- Food Grade Grease
- Cotton Picker Spindle Grease
- Viscosity Modifier/Property Enhancer
- Optimized Soybean Base Oils.

INTEGRATED DRUG DISCOVERY, DEVELOPMENT, PILOTING, AND PRODUCTION PLATFORM

Iowa has established piloting and production facilities within an academic research setting—The University of Iowa—that may form the basis of an integrated suite of piloting and production services for academia and industry. There is an opportunity to make this a more widely known and used technology platform as it represents a unique resource for bringing new drug discoveries from testing to market. Currently, there is a worldwide shortage of GMP quality facilities for the production of mid-scale volumes of drugs and biological preparations—the volumes required for clinical trials and for the production of orphan drugs. While there are contract commercial entities that service this market, there is likely to be an expanding shortage of facilities based on the large pipeline of compounds, drugs, and biologics starting to move into clinical trials.

The University of Iowa's Center for Advanced Drug Development (CADD) and the GMP production facilities of the Division of Pharmaceutical Services are fairly unique facilities in academe. Together these resources provide a substantive resource for drug development and production that is primarily used on a contract basis by small pharmaceutical and biotechnology companies located outside Iowa.

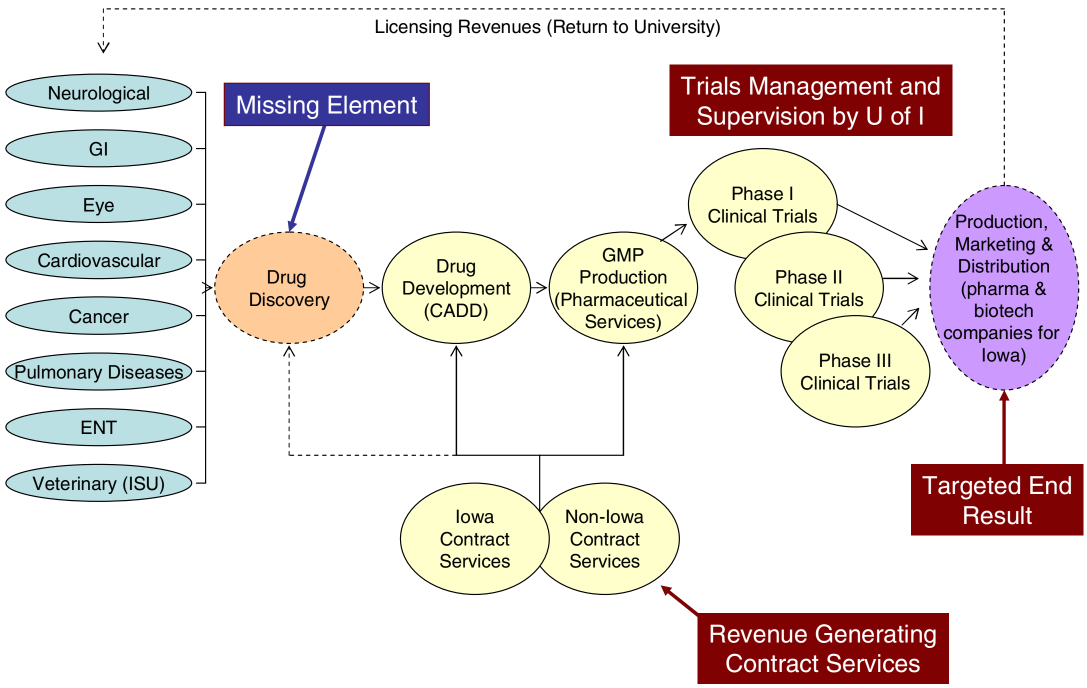
At the other end of the drugs pipeline, The University of Iowa has considerable breadth and depth in basic sciences research in a variety of medical disciplines. Work in cardiac and vascular systems, cancer, gastroenterology, neurology, and pulmonology, for example, could lead to discoveries of biological mechanisms that would be suited to drug screens.

The University of Iowa may be able to form an integrated pipeline of R&D for new drugs and biologics. It has the basic science, drug development, GMP production, and clinical trials structure required to conduct complete in-house projects. This would increase the likelihood of pharmaceutical and biotechnology companies forming and staying in the state. **One key element of an integrated pipeline, however, is missing —The University of Iowa lacks a drug discovery facility.**

By establishing a Drug Discovery Center, The University of Iowa would be equipped with a continuous model structure for facilitating the movement of basic science discoveries from the bench to the bedside. In combination with the University's identified strengths in genomics, and emerging strengths in proteomics and metabolomics, Iowa has almost all of the key required elements in place.

This is an area considered by The University of Iowa to be ripe for integration and collaboration across several departments and colleges, including chemistry, biochemistry, pharmacology, and medicinal and natural products chemistry. Figure 24 lays out this drug pipeline concept and shows how filling the gap with a drug discovery center leads to a more fully integrated model.

Figure 24: Concept for Integrated Drug Discovery, Development, Piloting, and Trials Pipeline.



An integrated model on this scale would be very expensive and difficult for competing academic institutions to set up. Having direct commercial experience in drug development services and in GMP production, as Iowa has, would be a great challenge for another institution to duplicate. It takes years of experience and training to achieve the credentials to be licensed by the FDA for GMP production, and a multiyear track record of uninterrupted success in GMP production in order to be trusted by external commercial biotechnology and pharmaceutical companies with their production: ***The University of Iowa has already achieved this.***

The concept for establishing a Drug Discovery Center at The University of Iowa has been proposed by the Department of Pharmacy members Gerald Gebhart, Ph.D., and Johannes Hell, Ph.D.[25] The Battelle field project team met with the Pharmacy staff to discuss the concept, the development of which is expected to require three primary components:

1. **Personnel**—Initially estimated at three full-time positions including one full-time position for a faculty member who would direct the Center, with oversight by a steering committee (ideally composed of both University of Iowa and industry representatives).

[25] Letter to Dr. Jean Robillard (Dean of the University of Iowa College of Medicine) from Gerald F. Gebhart, Ph.D. (Professor and Chair, University of Iowa Department of Pharmacology) and Johannes W. Hell, Ph.D. (Associate Professor, University of Iowa Department of Pharmacology). October 12, 2003.

2. **Instrumentation**—for performance of high throughput screens.
3. **Compound Libraries**—including a classic chemical library of 50,000 to 500,000 compounds, peptide libraries to be custom-made by the Center, and biological libraries to be pioneered by the Center.

As Professors Gebhart and Hell note:

> *Basic research as performed in many laboratories at The University of Iowa continuously uncovers new biological mechanisms that would offer themselves for drug screens (e.g. discovery of a new ion channel), but does not take advantage of such novel scientific insight. The Center (for Drug Discovery) would catalyze the desirable bench-to-bedside approach by facilitating drug discovery and by bringing together basic and clinical researchers. It also holds the promise to generate income for UI through patents in the future and to foster the establishment of biotechnology-oriented companies in Iowa, thereby improving the infrastructure and economy in our state. It would be a long-term investment with far-reaching benefits.*

The development of a Drug Discovery Center at The University of Iowa is a clear and logical step in completing a thorough and difficult-to-replicate suite of services designed to develop basic science discoveries into new drugs, biologics, and therapeutics.

The Pharmaceutical Service Division at The University of Iowa is a Food and Drug Administration-registered pharmaceutical manufacturing facility, occupying approximately 24,000 square feet on the ground floor of The University of Iowa College of Pharmacy building. The division manufactures, under contract, clinical supplies of most types of pharmaceutical dosage forms for clinical testing. These dosage forms include sterile injectable solutions, emulsions, and suspensions; sterile lyophilized (freeze-dried) preparations; tablets (film-coated and uncoated) and capsules; topicals (ointment, creams, gels); and oral liquids (solutions, suspensions, emulsions). The division is also licensed with the DEA and can manufacture dosage forms containing schedule I-V actives. Pharmaceutical Service typically serves over 65 client organizations per year. CADD performs a wide range of assays to obtain data for pre-approved active pharmaceutical ingredients, new molecular entities, drug products, and excipients.

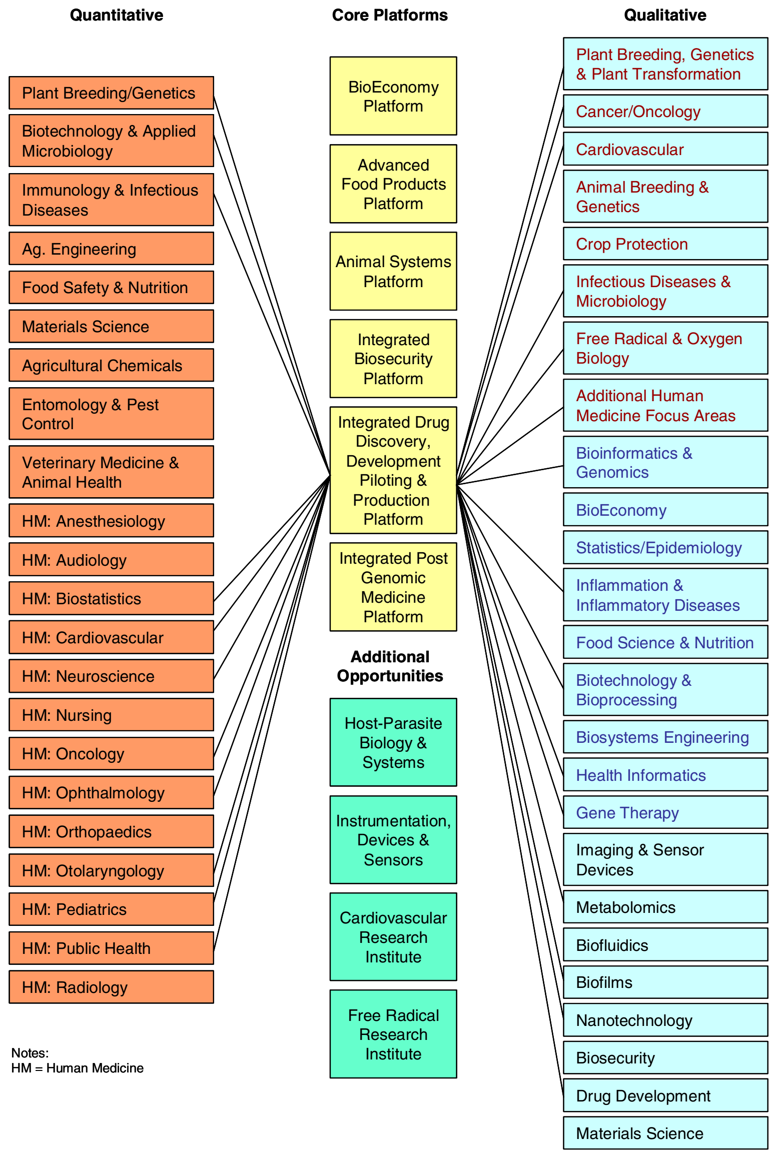
Iowa State University has important elements of the drug pipeline that should be integrated into the platform. Iowa State can provide a similar basic science through testing and production pathway on the veterinary medicine side, and has considerable expertise in combinatorial chemistry, which may be integrated into the drug discovery system. The Iowa State University College of Veterinary Medicine's work on companion animal medicine may prove to be a means to achieve early trials and market introductions of drugs on a timeline shorter than that required for human medicines.

The Center for Biocatalysis and Bioprocessing (CBB) at The University of Iowa has a 20-year track record in combining scientific faculty with modern facilities to research and develop new technologies for chemical, pharmaceutical, nutritional, and agrochemical industries. The CBB consists of 59 faculty members and more than 300 researchers, including graduate and undergraduate students, postdoctoral scientists, technicians, and visiting faculty and industrial scientists. Principal areas of CBB study include biocatalyst fundamental properties, bioremediation, bioprocessing, new biocatalyst discovery, novel biocatalyst applications, biosensing technology, and reactive agent development. During FY2003, the CBB laboratory collaborated with more than 60 industrial companies and institutions and more than 90% of the CBB laboratory's contract income is from the private sector. Some examples of industry collaborations include production of vaccines, antibiotics, anticancer drugs, polymers, BL2-LS pathogens (used to develop diagnostics and vaccines), biochemicals, enzymes, pharmaceutical intermediates, and derivatives of bioactive compounds.

Iowa State University also has plans to develop a biologics facility on their research park—a facility focused on protein recovery and purification. Such a facility would complement the facilities at The University of Iowa and provide a resource for production of products for use in biotechnology, pharmaceuticals and nutraceuticals. It would also provide a resource for protein extraction related to potential BioEconomy applications.

Figure 25 illustrates the key linkages between quantitative and qualitative core competency disciplines and the drug discovery, development, piloting, and production platform.

Figure 25: Quantitative and Qualitative Core Competencies and Resulting Integrated Drug Discovery, Development, Piloting, and Production Platform.



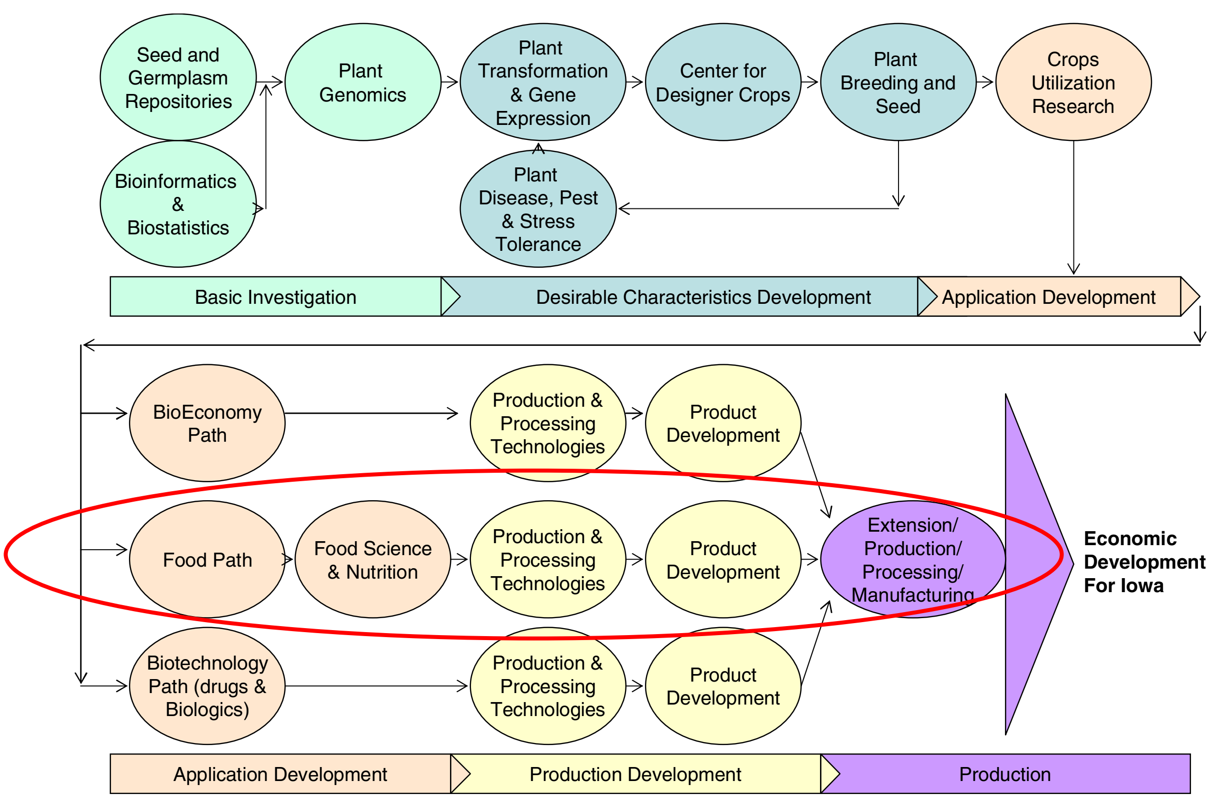
ADVANCED FOOD PRODUCTS PLATFORM

Many of the same scientific disciplines and skills that will power the BioEconomy initiatives will also be broadly applicable to developing advanced food products. Such products may include:

- **Functional Foods**—The Institute of Medicine defines functional foods as "any food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains." Functional foods can be either plant- or animal-based.
- **Nutraceuticals**—The definition given by the Iowa State University Extension is that a nutraceutical is "any substance that may be considered a food or part of a food and provides medical or health benefits, including the prevention or treatment of disease."
- **Phytochemicals**—Nutritionists use the term phytochemical when referring to naturally occurring components of plants that have physiological effects on humans. Such physiological effects might include enhanced immune system activity, chemoprevention, and reduced cholesterol.

As shown in Figure 26, the same vertically integrated system of scientific R&D that will contribute to Iowa's leadership in the BioEconomy has a food path that could lead to an advanced foods economy in the state.

Figure 26: Potential Path for Advanced Food Economy in Iowa.



Iowa State University and The University of Iowa have much to contribute to advanced foods development. Already the two universities, in collaboration, have attracted a $6 million, 5-year NIH grant to study and isolate active chemicals in the commonly used herbs Echinacea and St. John's Wort. This work represents a significant step in phytochemical discovery, an area of research that others within Iowa State have been actively engaged in—such as work to uncover the antiviral properties of "hypericin," a phytochemical present in St. John's Wort.

At its core, work in advanced food products addresses one of the economic development missions in the state—that of generating products that have added value. Work to identify, isolate, and prove the health and nutrition benefits of various plant and animal components may lead to

- Transgenic corn or soy expressing enhanced levels of beneficial nutrients, vitamins and phytochemicals (as with Golden Rice). Such crops will have increased value in world commodity markets.
- Traditional crops expressing beneficial nutrients, vitamins, and phytochemicals that are then separated from the crop to produce processed supplements and nutraceuticals.
- New crops, produce, herbs, fruits, and animal varieties for production by Iowa farmers that will have advanced food characteristics and the ability to command a premium price.
- A base of nutraceutical and chemical extraction R&D and production companies leveraging the expertise or Iowa universities in various related disciplines.
- Food processing technologies and companies using advanced techniques that maintain the functional and beneficial qualities in advanced plant and animal products.

The work to identify active chemicals and compounds in foods may also generate a logical link into the drug discovery and development pipeline discussed previously. Identifying and analyzing a chemical in St. John's Wort that has anti-depressive qualities, for example, may lead to the development of a more traditional pharmaceutical product, rather than simply consumption of the herb. Thus, the advanced foods initiative may be an additional branch pipeline for discoveries related to pharmaceuticals and biologics. Much of the work related to beneficial chemicals in advanced foods will have logical links into the strongest areas of medical research at The University of Iowa. Examples might include

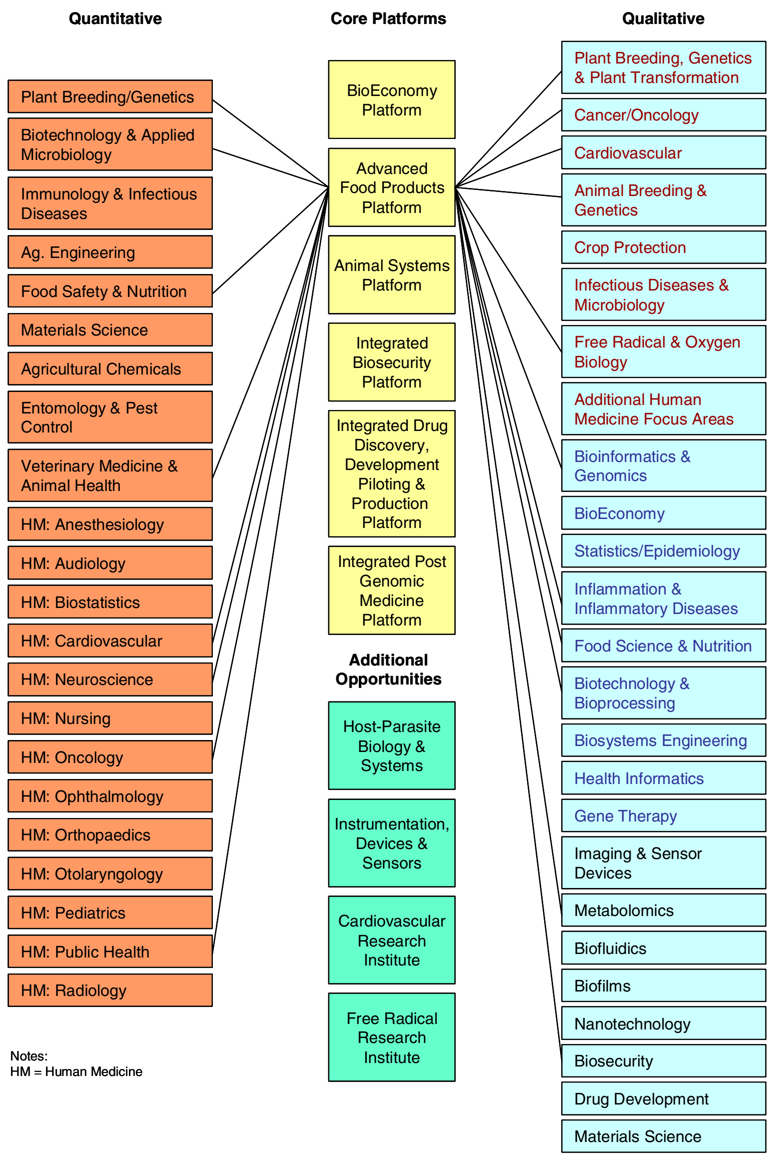
- Cancer Research—with the discovery of immunopromultory or immunosuppressive chemicals, chemoprevention agents, etc.
- Cardiovascular Research—with development of low saturation oils, cholesterol reducing chemicals, nutrients that reduce blood pressure, etc.
- Free Radical Research—where vitamins have already been identified at The University of Iowa that have highly positive activity during oxidative events, helping to reduce free radical damage.
- Neurological Research—with the potential discovery of chemicals and nutrients having a positive effect on neurodegenerative diseases.

Much of the expertise is in place at both Iowa State University and The University of Iowa to make significant progress in advanced food research and applications possible. Iowa State operates a substantial Food Science and Human Nutrition program and has the basic science bases largely covered in terms of genomics, proteomics, metabolomics, chemistry, and biochemistry. The University also has the required strengths in gene expression (and insertion) and plant and animal breeding to advance initiatives in the field.

Iowa State University may also make important contributions in advanced food initiatives through the Institute for Food Safety and Security, helping to assure the safety of genetically modified or otherwise modified food products resulting from advanced food initiatives.

Figure 27 illustrates the key linkages between quantitative and qualitative core competency disciplines and the advanced food products platform.

Figure 27: Quantitative and Qualitative Core Competencies and Resulting Advanced Food Products Platform.



INTEGRATED POST-GENOMIC MEDICINE PLATFORM

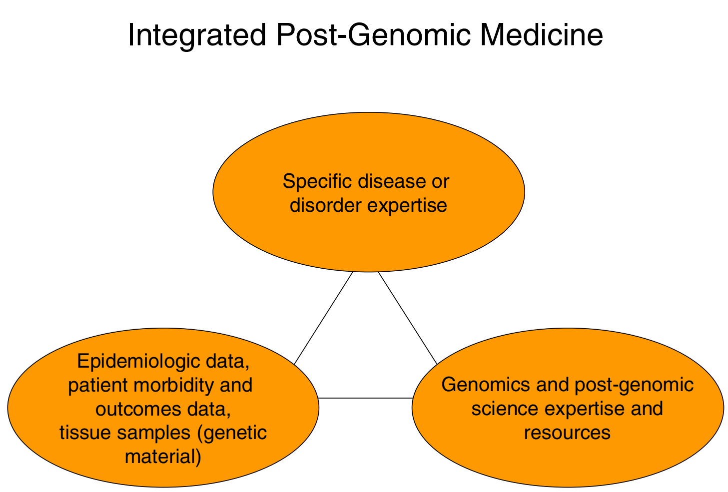
The importance to medicine of the decoding of the human genome, and indeed the future of humanity, is hard to overstate. DNA underlies every aspect of human health, both in terms of function and dysfunction. In many respects, the genomic revolution is moving the practice of medicine from a mix of art and science into a purely quantitative scientific realm.

While there is still a vast landscape of medical discovery ahead of the world's scientists, the decoding of the genome has been the first step into that new landscape. Obtaining a detailed picture of how genes function, how they express proteins, and how they interact with environmental factors ultimately will change the way in which disorders are diagnosed, treated, and prevented. This will bring forth revolutionary changes in clinical and public health practices and have a profound effect on health care, one of the largest components of the U.S. and individual states' economies.

While the decoding of the human genome represents a tremendous scientific accomplishment, it is perhaps most significant as a starting point for new discoveries that will take place in comparatively new life science fields, such as functional genomics, proteomics, pharmacogenetics, human genomic epidemiology, and bioinformatics. The genome provides something akin to a national highway map—it points scientists in general directions, but new and deeper investigations are required to fill in the city, neighborhood, and street-level detail. It is at this detailed local level that functional genomics and proteomics come into play, but these have to be further supported by strong epidemiological and patient outcomes data.

In the future, it is likely that many of the most significant medical discoveries and advances will be made at those institutions that are able to combine ***clinical disease or disorder expertise***, together with large-scale ***epidemiology and outcomes databases*** related to the diseases or disorders, and which have ***strong genetic research*** capabilities to look for genes related to the disease or disorder epidemiology being observed (see Figure 28).

Figure 28: Integrated Post-Genomic Medicine.



The rise in importance of bioinformatics, biostatistics, and health informatics is being advanced by the data-driven nature of quantitative post-genomic bioscience. In 21st century medical research, it is likely that those institutions that control the largest and most comprehensive datasets will have a comparative advantage in making important discoveries. In a knowledge economy, data is king, and Iowa has some advantages already evident.

The University of Iowa has the main components needed to provide solutions in post-genomic medicine. It has

- Access to a comparatively stable population base in Iowa, where patient records have substantive longevity and the potential to be maintained into the future
- The ability to track patient disease or disorder morbidity through time
- A strong clinical practice providing health care to patients with a broad variety of diseases and disorders
- The ability to examine patients for genomic characteristics that appear to be related to disease susceptibility, progression, outcomes or resistance.

At the University of Iowa, clinical research, pathology, gene expression, and epidemiologic and outcomes data can be brought together to rapidly advance post-genomic medicine and associated discoveries.

Ophthalmology is one area at the University of Iowa in which the concept of an integrated post-genomic medicine platform could be advanced fairly rapidly. Iowa's ophthalmologists have, for decades, stored photographs in a database of each patient seen. This rich data resource of eye pathology data, in combination with a very stable population base, can enable disease epidemiology and outcomes to be studied. Data mining directs ophthalmologists and geneticists to examine specific patients for genes that may be related to the development, progression, or non-progression of a given eye disease. Advances using such an integrated system have already been made at The University of Iowa in glaucoma and macular degeneration. Recognition of Iowa's leadership in the field has helped expand the dataset, as ophthalmology programs around the world have started to share samples with Iowa. Iowa now has 40,000 human samples from nearly all countries in the world, with 700 of the samples demonstrating the rarest of eye diseases.

Once genes are identified, researchers can move into animal models to express the gene. Then scientists are able to look at pathophysiology, plus start work on prevention. Ophthalmology researchers have stratified macular degeneration phenotypically, discovering that it actually represents multiple diseases. The macular degeneration team has begun to discover causative genes. Next steps could incorporate work on drugs to slow progression of the disease together with population genetic testing. **Such a basic structure for gene discovery and pathophysiology studies would naturally extend into drug discovery initiatives, linked to the drug discovery/development technology platform previously discussed.**

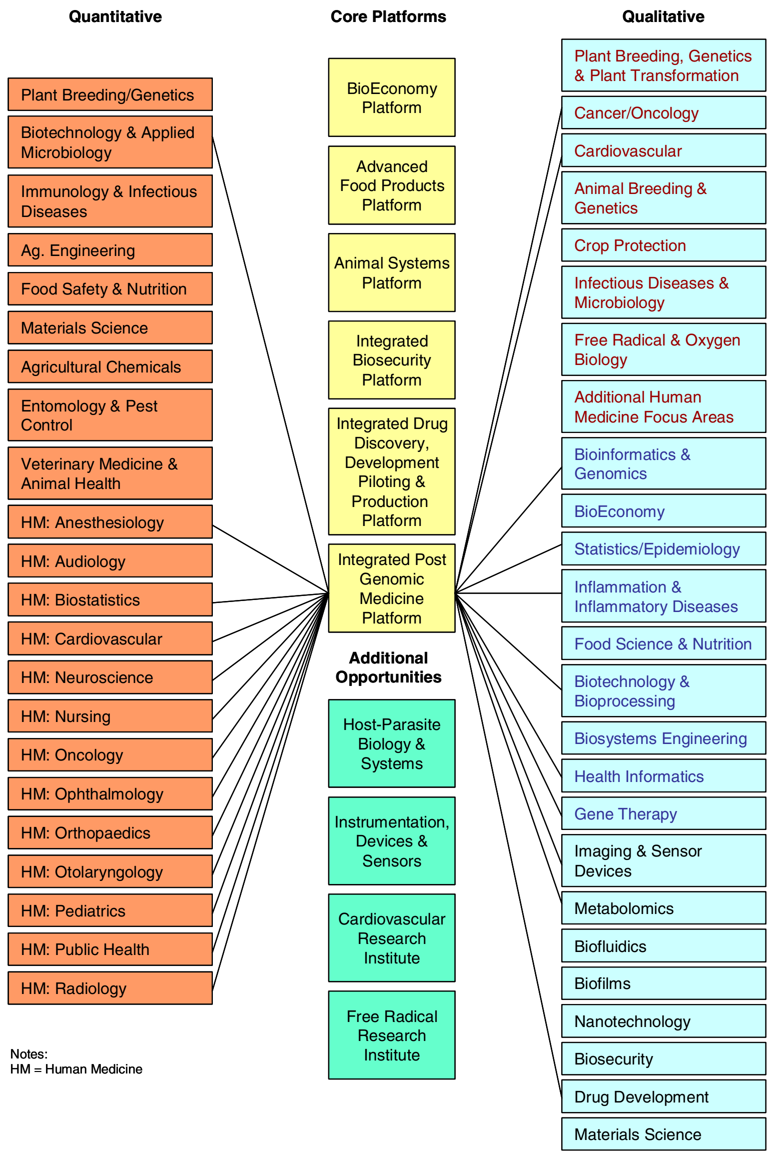
This integrated approach of "clinical practice→ data gathering → data mining → gene discovery" may be applied in Iowa in a number of medical areas. For example, the **longitudinal Muscatine cardiovascular study** has a large dataset associated with it, and the Cancer Center likewise has longitudinal data, tissue and runs the Iowa Cancer Registry—a component of the NCI's Surveillance, Epidemiology, and End Results (SEER) program. Similar opportunities are presented in other strength fields at the University of Iowa, including otolaryngology, pulmonology, gastroenterology, and neurosciences.

The key to integrated post-genomic medicine platform development is generating data that combines clinical, pathology, and gene expression into one database system. University of Iowa researchers secured NCI funding for additional work on this challenge. Additional funding is needed for further physical infrastructure, resources, and faculty to advance database development and its clinical applications. This approach represents a basic platform concept which may be linked to multiple medical disciplines; it is also a platform best suited to an academic medical center operating with a stable patient base and having formal patient follow-up processes (i.e., The University of Iowa model).

The success of such an integrated approach depends on population enrollment for longitudinal studies. The University of Iowa Hospitals would be well served by setting up a patient enrollment center in the University Hospital lobby, following the model already successfully employed by Washington University in St. Louis, Missouri.

Figure 29 illustrates the key linkages between quantitative and qualitative core competency disciplines and the integrated post-genomic medicine platform. It shows that the vast majority of clinical discipline strengths in Iowa can fit into and contribute to this platform.

Figure 29: Quantitative and Qualitative Core Competencies and Resulting Integrated Post-Genomic Medicine Platform.



ANIMAL SYSTEMS PLATFORM

Except in the economic use of manure by-products, BioEconomy opportunities largely have been discussed in terms of renewable resources from plant biomass. F**ocusing only on plant biotechnology and BioEconomy initiatives, however, misses another large scale aspect of the biosphere—animals.**

There are likely to be significant economic opportunities for Iowa related to animal biosciences, through developments such as the following:

- **Transgenic Animals**—animals that carry a foreign gene that has been deliberately inserted into the animal's genome. The foreign gene is constructed using recombinant DNA technology. In addition to a structural gene, the DNA usually includes other sequences to enable it to be incorporated into the DNA of the host and to be expressed correctly by the cells of the host. Transgenic animals present many opportunities:
    - Promoting meat quality, tenderness, fat content, rate of development, or other desirable characteristics in livestock
    - Preventing genetic diseases through genome manipulation
    - Imparting the ability to express foreign proteins through the milk, or other body fluids, of animals such as sheep, goats, or cows
    - Synthesizing proteins, including human proteins, in the white of eggs produced by transgenic chickens
    - Using transgenic animals in research, such as transgenic mice or pigs that can be used as model systems for human medicine experiments
    - Producing organs and tissue for xenotransplantation via animals such as pigs.
- **Chimeric animals**—"new" animals created to have useful traits through the combination, or "fusing together," of multiple species. The commonly cited example is the "Geep," a goat-sheep chimera produced in the United Kingdom by fusing embryo cells from a goat and a sheep.
- **Animal Cloning**—creating identical copies of an animal, potentially one with ideal commercial characteristics, thereby removing variability from the livestock system and enhancing its economics.

To some, these concepts may read like science fiction—but for the most part they are already realities in limited forms. Some examples serve to highlight the possibilities:

- Genzyme Transgenics created a transgenic goat carrying a gene that produces BR-96, a monoclonal antibody useful for the delivery of conjugated anti-cancer drugs.
- PPL Therapeutics generated a cow whose milk contains alpha-lactalbumin, a human protein that provides essential amino-acids.
- Scottish scientists have created the first cloned mammal, a sheep (the famous, and now deceased, "Dolly").
- Australian scientists produced sheep that grow 30 percent faster than "natural" varieties.
- Animal genes have been transferred into plants to impart positive characteristics, such as the transfer of the "antifreeze gene" from an arctic flounder into tomatoes, to increase cold stress tolerance.

There should be little doubt that research will continue to advance in transgenics, chimerics, and cloning. These new arenas of science show promise for generating significant benefits, such as the introduction of completely predictable meat animal quality, inexpensive modes of protein and other chemical expression via animal pathways, and greatly increasing the availability of organs and tissue for transplantation purposes. These are areas of R&D with very large revenue generation probabilities, and they are the subject of much bioscience and biotechnology research. However, societal unknowns may factor into the ultimate potential of these fields. European boycotts of transgenics, bans on cloning and stem cell research, and potential ethical and moral issues in animal use and genome manipulation may substantially affect progress.

There remain many challenging scientific and technical issues related to advanced animal systems. The research and development opportunities available to Iowa institutions are significant. Much work can be done in the following:

- Gene discovery—genomics, proteomics and metabolomics
- Gene transfer and expression
- The passing of transgenes to animal progeny
- Cloning of various animal species
- Novel combinations of chimeric animals for beneficial use
- The study of animal retrovirus risks in xenotransplantation
- Immune system modulation for xenotransplantation
- Commercial livestock production practices for transgenic animals
- Transgene risk evaluation and biosafety.

Iowa has many of the required skills within its Regent universities. Key components are in place:

The Center for Integrated Animal Genomics (CIAG) at Iowa State University—a center developing and using techniques in computational, molecular, and cell biology to improve animal and human health. CIAG is building on Iowa State's existing strengths in animal and microbial genetics, bioinformatics, animal sciences, biotechnology, veterinary medicine, and the life sciences. CIAG expresses its goal as "to enhance the breadth of animal research activities at Iowa State University, increase basic and translational research, and foster economic development and growth in Iowa's biotechnology industries." CIAG predicts that potential outcomes of their work could include

- Genetic improvements of livestock species
- Development of designer animals for specialized animal products and improving human health
- Improvements in food safety and the reduced use of antibiotics
- Development of safe and effective vaccines and anti-microbial agents
- Reduction of possible biotechnology threats through the food chain
- Increased harmony of animal agriculture with Iowa's natural resources.

The Center currently brings together over 40 faculty from three colleges at Iowa State University to conduct animal systems and animal agriculture research.

Animal Sciences Department—Recognized throughout the world and highly regarded for its work in meat science, pork, beef, and poultry. The meat industry ranks Iowa State University number two in meat science, number one in pork processing technology, and number two in beef processing. ISU's meat laboratory is 30,000 sq.ft. with comprehensive slaughter and processing capabilities.

Animal Gene Transfer Facility—The facility provides a variety of services to scientists who wish to use transgenic animals in their research. The facility maintains equipment necessary for creating transgenic animals via microinjection or blastocyst injection procedures.

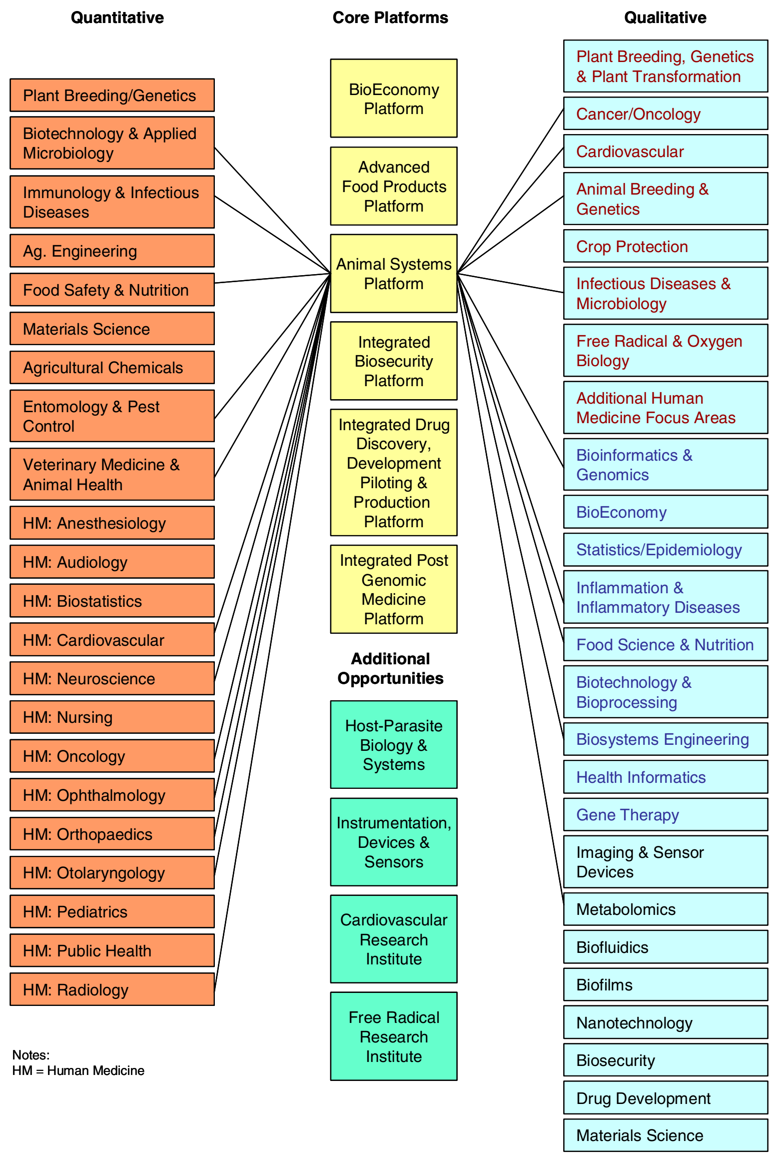
College of Veterinary Medicine—the oldest public college of medicine in the country and home to a variety of animal health programs and research initiatives.

Iowa State University also is highly active in whole genome sequencing projects, with active participation in the pig, cow, and chicken genome projects. This research leadership provides Iowa scientists with early stage insight into genetic characteristics and properties of these important species.

Expertise in animal models, systems, and transgenics also is maintained at the University of Iowa, which operates the Transgenic Animal Facility as a component of the College of Medicine. The transgenics facility provides centralized instrumentation and expertise in the generation, breeding, and analysis of transgenic animals in support of research. The main goal of the facility is to generate and subsequently identify transgenic mice requested by research investigators at both the University of Iowa and Iowa State University. The Transgenic Animal Facility also provides a service in the rederival of transgenic strains from other institutions. Further investment in animal facilities is anticipated at the University of Iowa with major space being allocated within the new Carver Biomedical Research Building.

Figure 30 illustrates the key linkages between quantitative and qualitative core competency disciplines and the animal systems platform.

Figure 30: Quantitative and Qualitative Core Competencies and Resulting Animal Systems Platform.



INTEGRATED BIOSECURITY PLATFORM

The federal government is taking the threat of bioterrorism and the need for enhanced biosecurity extremely seriously. The events of September 11th, 2001, awakened the nation to the extreme cunning and viciousness of international terrorists. The World Trade Center attack leaves no doubt that al-Queda or other terrorist networks likely would have no hesitation in using any weapon of mass destruction (WMD) that fell into their hands; indeed, the CIA warns that the al-Queda network has made obtaining WMD capability a very high priority.[26]

The threat comes from multiple potential weapons, including nuclear bombs, radiologic bombs, chemicals, and biological weapons. The threat is also to multiple potential targets including humans, livestock, and agricultural resources. While the threat of a nuclear bomb or chemical weapon must be taken seriously, many terrorism experts note the technical difficulties involved in acquiring, developing, transporting, and detonating/dispersing such weapons[27]—whereas, an individual with smallpox in the contagious phase can deliver a "bioweapon" simply by visiting crowded areas.

Bioterrorism thus presents a very real danger for the United States and the federal government is acting swiftly to fund programs that may act to counter the threat. The threat is posed by multiple potential diseases and biological agents including

- Anthrax
- Botulism
- Plague
- Smallpox
- Tularemia
- Viral Hemorrhagic Fevers (Ebola, Yellow Fever, Rift Valley Fever, etc.)

Compounding the threat of these known disease agents is the potential that genetic engineering technologies could be used to

- Enhance/expand the transmission (infection) characteristics of the infectious agent
- Increase an infectious agent's resistance to known antidotes or antibiotics
- Bioengineer new infectious agents through recombinant DNA technology.

As noted above, humans do not have to be the target for terrorists to cause the "terror" of substantial economic and social disruption. Hence there is also a concern that food sources, either livestock or crops, could be targeted. The outbreak of foot and mouth disease in the United Kingdom caused tremendous economic and social damage, as did the later outbreak in Canada. A similar outbreak in the U.S. ranching community could be devastating. More distant as a threat, but still a potential, is the fact that if genes can be introduced to food crops to produce pharmaceuticals, so might they be introduced to produce toxins.

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[26] Bowman, Steve. "Weapons of Mass Destruction: The Terrorist Threat". Congressional Research Service Report for Congress. March 7, 2002.
[27] Bowden, Ibid.

Iowa has relevant strengths in human and veterinary medicine and plant sciences related to the detection, diagnosis, treatment, and prevention of both natural and man-made biosecurity threats. As biotechnology and the BioEconomy move forward, the increasing convergence and integration of bioresources will be central to the U.S. economy. Biorenewable resources are likely to underpin increasingly large sectors of the economy, including, for example

- Food production and processing
- Drugs and biologics for human and animal health
- Chemicals from plant resources
- Biocomposite materials
- Energy resources.

The biotech century, as it has been called, will see dramatic advances in both traditional and non-traditional applications of biomass and biological materials. As the U.S. economy builds upon this new science base and reaps significant economic opportunities from it, bioresources will be realized as inherently fragile and more susceptible than other economic sectors to severe damage through accidental or deliberate contamination, transgene pollution and terrorist acts. **In a bio-driven economy, biosecurity is not only an issue of human health, it also is an issue of economic and societal structural security.**

Iowa, with its expertise in human and animal infectious diseases plus plant diseases, may be well placed to take a leadership role in the development of an integrated and holistic biosecurity approach. Iowa's initial application to the federal government for the formation of a Biosecurity initiative was integrated inherently in that it emphasized lung and enteric diseases—leading causes of illness and death in both humans and domestic animals and livestock. Several of the diseases in which Iowa has expertise are zoonotic; that is, they are able to transfer from animals to humans or vice versa. With strengths in human, animal, and plant health sciences, Iowa may be able to leverage work in one field into others. Examples include

- Devices invented for detecting bacteria and other pathogens in a human environment may be applied to detecting pathogens that may harm or destabilize an industrial bioprocessing operation or a livestock operation.
- Approaches to detecting and decontaminating pathogens or toxins introduced to water system reservoirs may be adapted to monitoring agricultural irrigation water or industrial process waters to prevent the introduction of alien substances.
- Approaches to infectious disease treatment in animals may be applied more rapidly than they can be in human trials; once proven effective, they can be accelerated into human trials.
- Approaches to preventing transgene migration and pollution in agricultural crops may be applied to ornamental plants as well as into food animal gene expression.
- Work in the expression of chemicals through plant pathways can be extended into the rapid production of vaccines and drugs, as required, through plants, and delivery via advanced food products.

Iowa may be successful in developing a smaller biosecurity initiative based on respiratory diseases, but this opportunity could be expanded into an Institute for Integrated Biosecurity that would tackle the large-scale system issues in biosecurity such as the food chain, water supply and use,

industrial bioprocessing, zoonotic disease emergence and transmission, etc. To the extent possible, all three Iowa Regent universities should be engaged in this initiative. An Institute, shared and operated among all three universities, might begin by concentrating on one of the systems, then apply its learning and methodologies to others. The likely result would be a broad suite of potentially commercializable discoveries in areas such as the following:

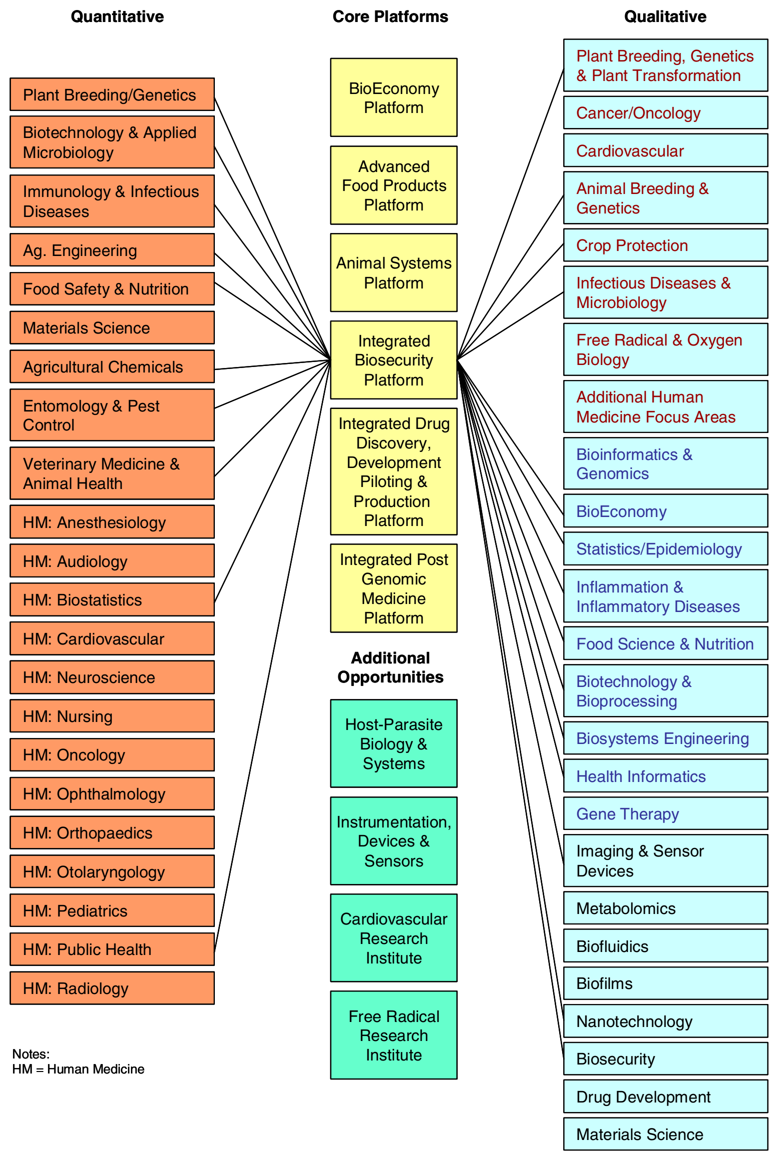
- Monitoring devices and sensors
- Detection instrumentation and diagnostic tests
- Security and monitoring software
- Models and protocols for incident response and containment
- Production and processing equipment designed to prevent tampering, alert to tampering, or facilitate decontamination
- Decontamination equipment and protective equipment
- Microbes bioengineered to conduct decontamination or provide signaling/monitoring
- Vaccines and other therapeutic approaches to bioattacks or disease outbreaks
- Consulting services in facility and systems design for biosecurity.

Iowa already is making progress on biosecurity initiatives and associated planning. The University of Iowa, Iowa State University, and collaborating universities in Kansas have received a National Institute of Allergies and Infectious Diseases (NIAID) planning grant for a biodefense center. There also is major NIH support at The University of Iowa for research related to respiratory pathogens—agents of great concern in both human and animal biosecurity.

Iowa's positioning for integrated biodefense may be further facilitated by the extremely close relationship between the state's hygienic laboratory and the state university system. The University Hygienic Laboratory (UHL) is located on the campus of The University of Iowa with considerable collaborations and areas of cooperation between the two institutions. The laboratory is particularly well-suited to work in integrated biosecurity since it works with both diseases and environmental issues.

Figure 31 illustrates the key linkages between quantitative and qualitative core competency disciplines and the integrated biosecurity platform.

Figure 31: Quantitative and Qualitative Core Competencies and Resulting Integrated Biosecurity Platform.



LONGER-TERM BIOSCIENCE POTENTIALS FOR IOWA

Battelle identified a number of potential technology platforms that represent longer-term bioscience sector development potentials. The identified opportunity areas mainly consist of relatively compact groups of people working in leading-edge fields, new formative centers just recently pulled together, or established areas of expertise in which investment in infrastructure and/or personnel are required to sustain or accelerate development momentum.

Longer-term potential technology platforms include

- **Host-Parasite Biology and Systems** –Both The University of Iowa and Iowa State University have initiatives that examine host-parasite/host-microbe interactions. This area of science was highlighted in its importance by the helicobacter link to human ulcers, but at Iowa's institutions even more basic and exciting discoveries are being made. Work at The University of Iowa, for example, is demonstrating substantial immunologic health benefits imparted to humans by helminths (a form of worm)—work that is showing significant promise for therapeutic approaches to a wide range of autoimmune system disorders such as Crohn's disease, inflammatory bowel disease, and asthma. Other fundamental discoveries have been made regarding symbiotic relationships between plants and bacteria. Bacteria are being found expressed in plant seed and play an important role in the absorption of plant nutrients. Fundamental discoveries, such as the above two examples, may lead to multiple new clinical therapies and commercial opportunities. The creation of a Host-Parasite Institute at The University of Iowa, with links into plant and animal biology at Iowa State University, may be area for future attention and focus.
- **Instrumentation, Sensors and Devices**—Iowa's universities contain multiple academic departments and centers engaged in the development of instrumentation, sensors, and devices. These range from the development of high throughput gene sequencing equipment, to non-invasive optical sensors and diagnostic instruments, environmental monitoring systems, and invasive medical instrumentation and systems. Several faculty inventors of devices expressed that a clear model for facilitating research, development, prototyping, testing and commercialization of instruments, sensors, and devices does not yet exist. An opportunity may exist to create a more formal structure to facilitate interactions and collaborative projects within and between Iowa institutions, with programs in engineering, optics, materials science, clinical diagnostics, imaging, and human and veterinary surgery.
- **Cardiovascular Research Institute**—The University of Iowa has a considerable track record in advanced cardiovascular research. Since 1971, the "Cardiovascular Center" at The University of Iowa has obtained $324 million in external grant funding (an average of $10 million per year) and this funding has led to fundamental discoveries and contributions to cardiovascular science and clinical practice by Iowa cardiovascular scientists in areas such as neuro control, lipids, imaging, free radicals, vector physiology, and ion channels. Despite the contributions made by the cardiovascular team at Iowa, the Center has not received the level of formal funding support to match leading centers in other states. An opportunity exists to strengthen the assembled team and promote increased progress and interaction through the establishment of a formal Cardiovascular Research Institute, with dedicated research and practice space similar to the Comprehensive Cancer Center at The University of Iowa. The benefits of developing a research institute include preventing erosion of faculty skills; attracting NIH funding (which is increasingly being steered to major "institutes"); enhancing and integrating the clinical program to become more engaged in translational and applied medicine; and

providing the laboratory and clinical resources required to attract top quality faculty into weaker areas such as cardiac surgery and catheterization. Testimony for the attractiveness of the concept is provided by the recent Reynolds Foundation grants for cardiovascular centers, in which Iowa was a finalist against other top centers in the country, but, ultimately lost the project in the last round, when two out of four finalists were funded.

- **Free Radical Institute**—The University of Iowa is a leader in research on the health impacts of free radicals (atoms or molecules with at least one unpaired electron). Even without a concerted institutional mission, The University of Iowa has grown to become the leading world location for free radical researchers and biologists. Iowa now has the first Ph.D.-granting degree program in free radical biology, and is incorporating free radical research into a broad range of medical fields including cancer, cardiac disease and vascular disease, hypertension, diabetes, premature birth, inflammation and infectious diseases, aging, neurodegenerative diseases, bone disease, and Lou Gehrig's disease. Free radicals research is a relatively new field of study that employs basic science to lead to pragmatic clinical results. Iowa's lead in free radical research may warrant preserving it with funding of a formal center with associated facilities. Indeed, other states have begun to see the opportunities and have funded formal free radical research centers in Alabama, Wisconsin, Oklahoma, and Georgia. As with the Cardiovascular Institute concept, a Free Radical Institute would facilitate interaction between multiple groups of researchers, provide access to core facilities, and more firmly root the existing base of researchers in Iowa for the future.

Illustrations of the linkages between quantitative and qualitative core competencies and the additional opportunity areas listed above are provided in Figures 32 through 35.

Figure 32: Quantitative and Qualitative Core Competencies and Resulting Host-Parasite Biology and Systems Opportunity.

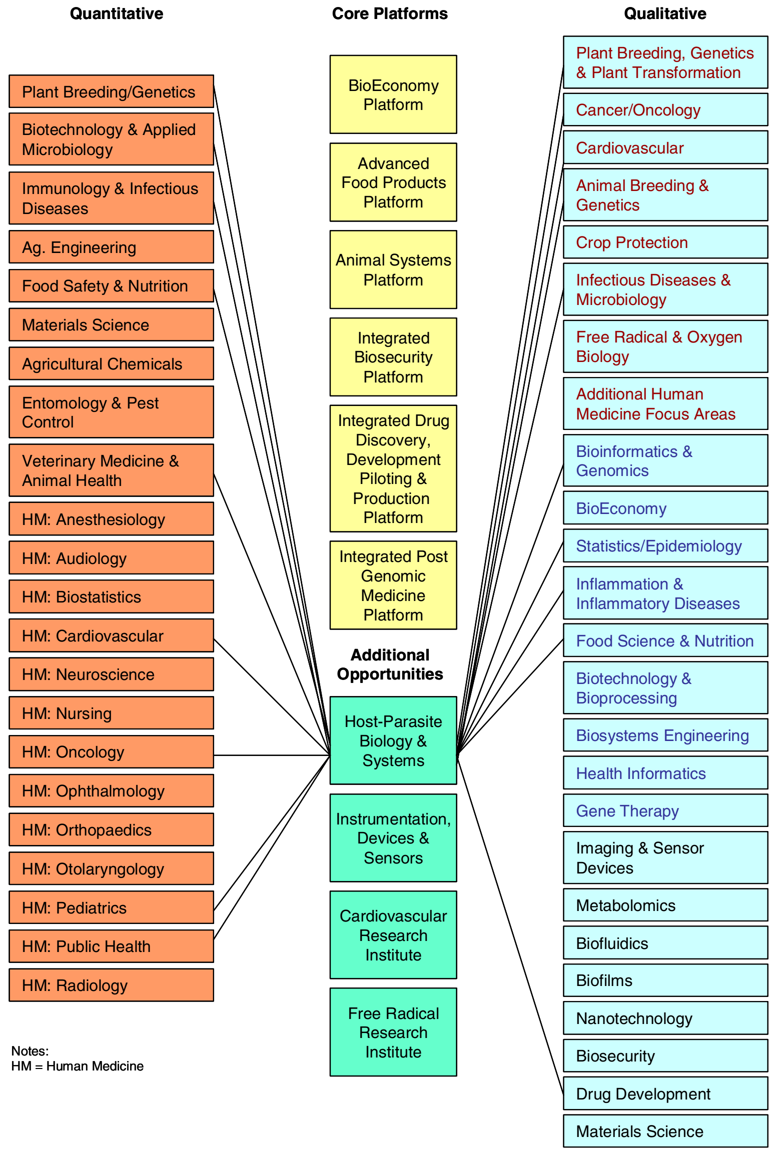


Figure 33: Quantitative and Qualitative Core Competencies and Resulting Instrumentation, Devices, and Sensors Opportunity Area.

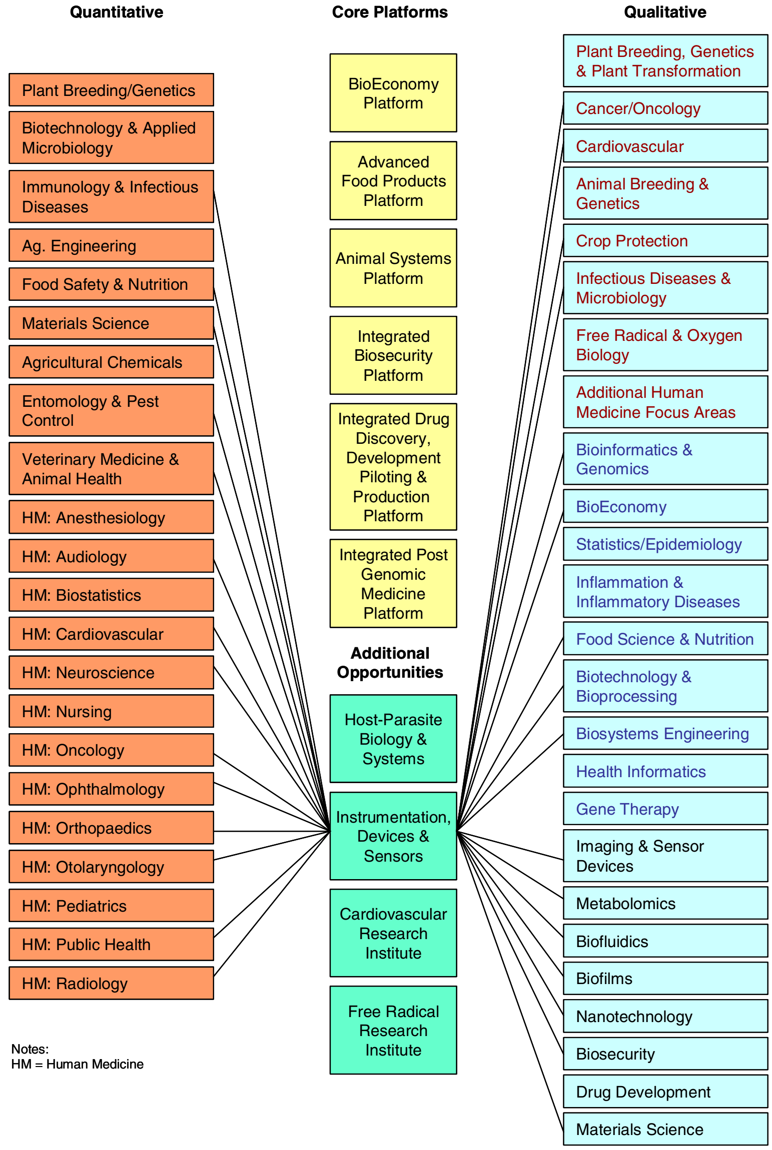


Figure 34: Quantitative and Qualitative Core Competencies and Resulting Cardiovascular Research Institute Opportunity Area.

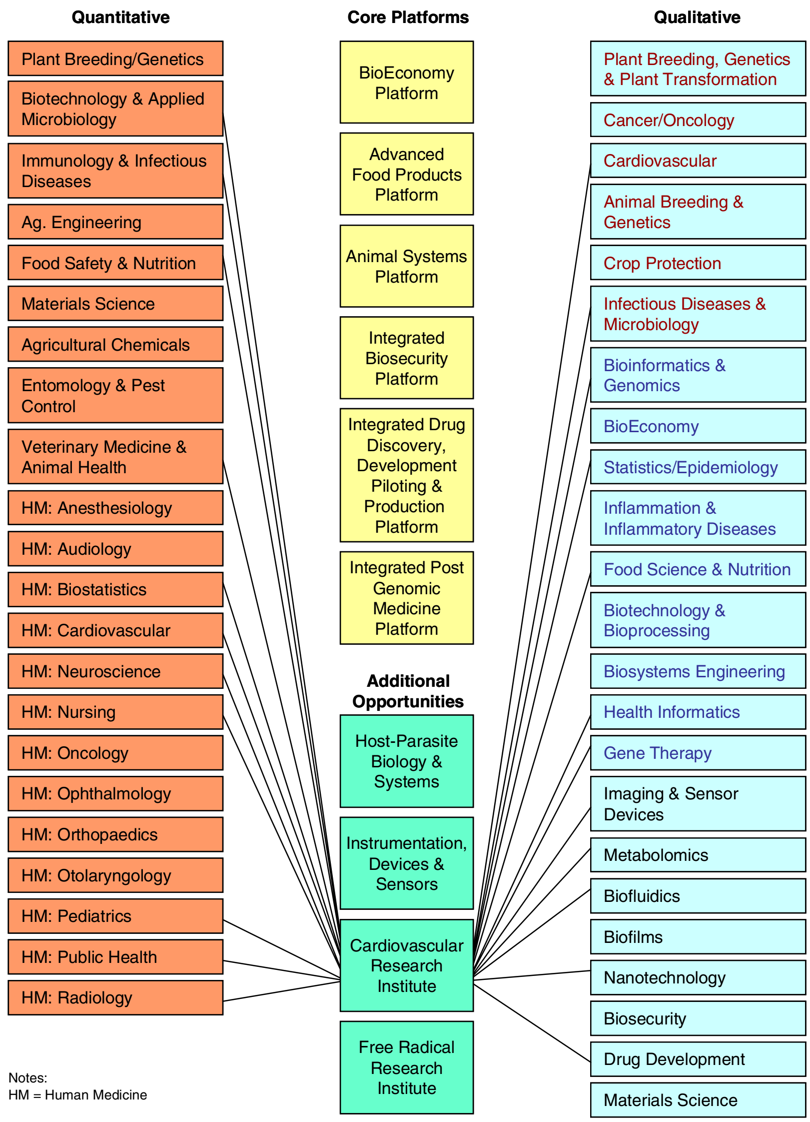
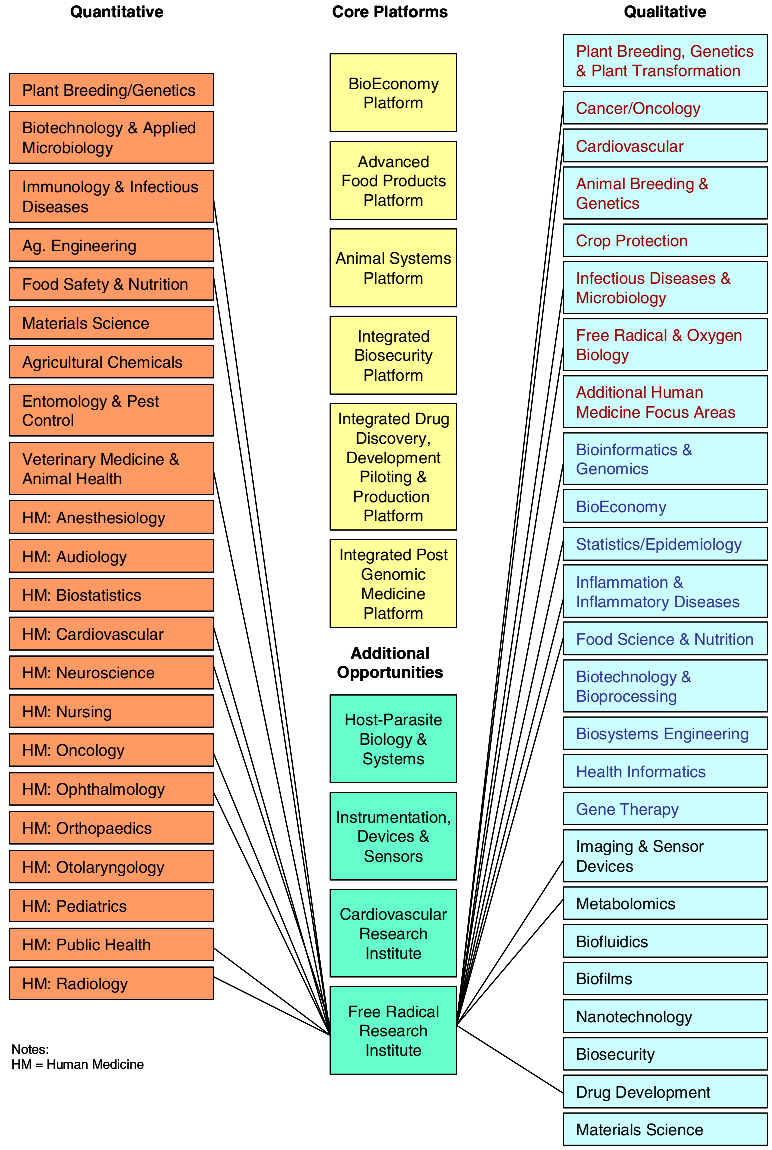


Figure 35: Quantitative and Qualitative Core Competencies and Resulting Free Radical Research Institute Opportunity Area.



MARKET ANALYSIS

The ultimate goal for the State of Iowa in supporting the development of bioscience platforms is **economic development**. R&D, in and of itself, ***is*** economic development in that millions of dollars flow into Iowa each year from federal and other external funding sources to support research. These dollars, in turn, create jobs and income for Iowans in, and related to, the R&D sector. The goal of technology-based economic development, however, is to move into an integrated model where local research feeds a local commercialization and production cluster, thereby capturing increased value-added economic gains for the state from its R&D work. It is important, therefore, that the development of platforms be made with an eye to markets and commercialization opportunities related to each platform.

In this section, Battelle examines basic market forces and trends related to each of the key Iowa bioscience platforms.

Market Trends in the BioEconomy

The BioEconomy has been recognized by Iowa within its Iowa Industries of the Future program. The opportunity to convert agricultural crops and residues into biobased products and bioenergy presents entirely new value-added pathways for agriculture and industry in Iowa. Much of the opportunity for Iowa in the field has been detailed in the October 2002 report titled "Biobased Products and Bioenergy Vision and Roadmap for Iowa."[28] This report outlines potential markets for Iowa's biomass resources and sets realistic goals for progress. The BIOWA Development Association, an association composed of representatives from agriculture, industry and academe, has been formed to support and promote the growth and development of Iowa's Bioeconomy, an important step forward in generating progress in the sector.

Iowa is wise to pursue the opportunities presented in the BioEconomy. The Office of the Chief Economist at the USDA notes that biobased products potentially can compete in some truly huge markets.[29] For example,

- Lubricant sales is a $5.1 billion market
- Composite materials are a $14.6 billion market
- Paints and coatings represent a $43 billion market
- Plastics have a $77 billion market.

As the USDA notes, if the agricultural sector could capture between 5 and 10 percent of each of these markets, it would mean major gains in farm income and rural development in the United States. The above markets, of course, represent only part of a far larger opportunity for biorenewable resources in fuels and energy applications.

Power consumption has risen steadily in the United States during the past 50 years. According to the U.S. DOE, in 2001, the nation consumed 96.94 quadrillion Btu's of energy (approximately 18 times more than

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[28] Iowa State University. "Biobased Products and Bioenergy Vision and Roadmap for Iowa." October, 2002. Available online at: http://www.ciras.iastate.edu/iof/pdf/IABioVisionRoadmap.pdf.

[29] Conway, Roger. "The USDA's Contribution to the President's Bioproduct and Bioenergy Initiative." Office of Energy Policy and New Uses. Office of the Chief Economist at the United States Department of Agriculture. Available online at: http://www.agbiotechnet.com/reports/nabc/nabc12/Conway.pdf.

consumed in 1950).[30] Energy consumption is projected to increase substantially by 2025, to 136.48 quadrillion Btu's. Consumption in 2003 was 98.08 quadrillion Btu's, of which only 5.98 quadrillion Btu's came from renewable energy sources (including biomass, hydroelectric power, solar power, wind power, and other renewable sources such as landfill gases and municipal wastes). Clearly there is a great opportunity, and national imperative, to reduce reliance on imported energy sources, which in 2003, was 30.53 quadrillion Btu's (over 25 quadrillion Btu's comprising crude oil and petroleum products).

Thirty-six percent of total energy consumption in the United States is used for manufacturing and other industrial purposes, 27 percent for operating the nation's transportation system, 20 percent for powering homes, and 16 percent for general businesses. Of all the oil consumed in the world in 1999, the United States accounted for 25.5 percent, according to the DOE. The powerful U.S. economy depends disproportionately on energy consumption, with the United States consuming

- 25.5 percent of world oil
- 26.9 percent of world natural gas
- 25.5 percent of world coal
- 30.4 percent of world nuclear energy.

The amount of power mined from fossil fuel sources in the United States is enormous, yet it is not enough to satisfy U.S. energy demand. For example, in 2000, Americans consumed 27.2 quadrillion more Btu's of fossil fuels than the United States produced. Crude oil, used for gasoline, diesel fuel, and a host of other products, is the most common form of energy imported into this country. Moreover, while energy demand is increasing in the United States, it also is projected to grow significantly throughout the world. The DOE's International Energy Outlook 2001 projects an increase in world energy consumption of 59 percent by 2020 (with much of the increase in demand occurring in developing nations).[31]

Eventually, the world's fossil fuels will run out, but before that happens the demand and supply curves will cross and price increases will force alternative energy sources to become more prominent. When these events will happen is the subject of considerable economic debate, but it eventually will happen and those economies that can supply renewable energy resources and technologies will be well-positioned for economic growth.

Freedonia Group foresees U.S. demand for fermentation chemicals to surpass $9 billion in 2007, with volume exceeding 30 billion pounds.[32] In terms of value and volume, the bulk of fermentation products is composed of ethanol for fuel usage, with production driven by environmental regulation, tax incentives, and the future ban on MTBE. While fuel is expected to remain the largest market segment for chemical fermentation products, other areas of bio-fermentation are also expected to grow:

- 1,3-propanediol (PDO) is an emerging new fermentation product for plastics and fibers
- Demand for Erythritol, a fermentation chemical used as an artificial sweetener in foods and beverage, is also expected to grow

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[30] U.S. Department of Energy. "Energy Consumption by Sector and Source." Available online at: http://www.eia.doe.gov/oiaf/aeo/pdf/aeotab_2.pdf.
[31] Energy Information Administration (EIA). "Annual Energy Outlook 2001." DOE/EIA-0383(2001) (Washington, DC, December 2000).
[32] Freedonia Group. "Fermentation Chemicals to 2007 - Market Size, Market Share, Demand Forecast and Sales." Study #: 1662. May, 2003.

- Fermentation-based lactic acid (a primary feedstock) production is expected to grow with the rise in demand for polylactic acid-based biopolymer manufacturing
- Plastics and fibers are also predicted to experience double digit rapid growth through 2007
- Polylactic acid polymers reached the market in 2002, and POD polymers are forecasted to reach commercialization by 2007
- Natural polymer demand in the United States will grow by 6.4 percent annually through 2005.

According to the United Nations, the impact of the BioEconomy will increase in forthcoming years, spreading from the farm to the manufacturing sector.[33] Many of the products we currently touch, wear, and see are already produced, in one way or another, using biotechnology-derived reagents. The development of genetic engineering and recombinant DNA technology will lead to higher levels of productivity and economic viability.

The benefits of assuming leadership in the BioEconomy may be substantial for Iowa. According to the Institute for Decision Making at the University of Northern Iowa, a cluster of 10 biorefineries in the state would create 22,000 jobs, have an $11.6 billion economic impact, and generate $367 million in taxes.[34] These statistics are reinforced by the conclusions of BioEconomy Partners in New York, who found that one bioeconomy development initiative in California created more than 13,000 jobs, commercialized 250 new products, and led to the start-up of 45 new companies within a 5-year period.[35]

Market Trends in Advanced Food Products (Functional Foods and Nutriceuticals)

According to Decision Resources Market Research, by almost every measure, the markets for functional foods (defined as disease-fighting, whole or processed food products) and nutraceuticals (defined as bioactive ingredients and dietary supplements) are flourishing.[36] National Health Interview surveys show that retail sales of dietary supplements in the United States exceeded $10 billion in 1996, and consumption grew from 71 million users ten years ago to between 94 million and 130 million users by the close of the century.[37] Functional foods are far outpacing growth in the total food market; with nutritionally improved products accounting for 78 percent of total growth in more than 35 major food categories, according to Decision Resources Market Research.

Fry Foods International estimates the total market for functional foods in Japan, the United States, and Europe at approximately $38 billion.[38] Growth over the next five years has been estimated conservatively at 15 percent annually, while some predict the market will double. Functional foods is currently the largest growth area in the food industry.

The U.S. market for functional foods is still developing and also is evolving in a different way from Europe and Asia. Of particular interest are products that may improve the functioning of the immune

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[33] United Nations Conference on Trade & Development. “The New BioEconomy—Industrial and Environmental Biotechnology in Developing Countries.” Ad Hoc Expert Group Meeting. Palais de Nations, Geneva. November, 2001.
[34] Iowa State University. “Biobased Products and Bioenergy Vision and Roadmap for Iowa.” October, 2002. Available online at: http://www.ciras.iastate.edu/iof/pdf/IABioVisionRoadmap.pdf.
[35] BioEconomy Partners. http://www.bioeconomypartners.com/index.htm.
[36] Decision Resources Market Research. http://www.dresources.com/home.asp.
[37] Ibid.
[38] Fry Food Technologies International. “International Food Industry Trends—Functional Foods and Nutriceuticals.” Available online at: http://www.fryfoodtech.com/images/trends.pdf.

system, reduce cancer risks, or help prevent cardiovascular disease and lower cholesterol. Consumer interest has been growing in botanical or herbal fortified beverages, including green-tea-based beverages. Sales of vitamin and mineral fortified juices (primarily vitamins E and calcium) also have grown. Additionally, soybean products, including soy milk, have increased in popularity, due to perceived health benefits. Sales of fiber- and vitamin-fortified food products, such as cereals, have grown, particularly those with reduced fat content. The U.S. market for dairy products containing probiotics has not grown or expanded as in other parts of the world. Broadly interpreted, the U.S. market for functional foods is currently estimated at $15 billion.

Similar figures are put forth by Sloan Trends and Solutions in Food Technology.[39] They identified the world market for functional foods as $47.6 billion (having grown from $30 billion in 1995). The U.S. component of the functional foods market is estimated at $18.25 billion. The largest product subsector in functional foods is beverages, followed by breads/grains, prepared foods, dairy, snacks, and condiments. Sloan Trends and Solutions identified the following top trends in functional foods:

1. Increasing nutrient and specialty foods fortification
2. Marketing for specific physical conditions
3. Lifestyle enhancing products, as in energy, immunity, and mental performance
4. Crossover products from sports nutrition
5. Children’s health
6. Marketing toward gender, age, and ethnicity
7. Weight reduction, satiety, and appetite suppression
8. Functional snacks
9. Natural ingredients such as those containing essential fatty acids, herbals, and probiotics
10. Nontraditional food markets, including eye health, oral health, and the medical foods market.

One of the most innovative sectors in the rapidly growing functional foods market is the so-called “performance” functional foods that affect mood and mental and physical performance. An important issue in ensuring long-term growth in this sector is to consolidate research on the complex links between nutrition and functional ingredients such as herbs, mood and cognitive performance (an area in which both Iowa State University and The University of Iowa are researching). Scientists are finding interactions between food, stress and mood, looking, for example, at the role of carbohydrates. Bioscience researchers are examining the impact of a number of nutrients and herbal ingredients on mood and cognitive performance, including herbs such as St. John’s wort and kava kava.

The global nutraceutical market grew by 7 percent annually between 1999 and 2002, increasing from $38.2 billion to $46.7 billion. Between 2002 and 2007, researchers anticipate that the nutraceuticals market may increase an average of 9.9 percent annually, reaching $74.7 billion by 2007 (BCC March 2003[40]).

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[39] Sloans Trends and Solutions in Food Technology. http://www.cargilldci.com/news/pdf/top10.pdf.
[40] Business Communications Company, Inc. “Functional Foods and Beverage Market.” February, 2000. Available online at: http://www.bccresearch.com/editors/RGA-109.html.

- Herbal and non-herbal extracts are expected to provide the strongest growth opportunities
- Nutrients and functional food additives will generate above-average growth and sustain new product developments, expanding end-use applications. Soy and fiber compounds for liquid meal substitutes, energy drinks, sport beverages, and fortified foods will be among the fastest growing segments within the nutrients market.
- Minerals and vitamins will generate slower growth in nutraceutical applications due to expected pricing competition. (Freedonia June 2002[41])

The U.S. and European probiotics markets are expected to grow rapidly in coming years despite widespread consumer ignorance about what probiotics are and how they can benefit the human body, according to a Frost & Sullivan report.[42] Probiotics are "friendly" bacteria that contribute to the health of the intestinal tract and, as such, link the advanced foods products platform and the host-parasite biology and systems sub-platform Battelle recommends. Frost & Sullivan estimate the U.S. market will reach $400 million by 2010 from a current level of $144 million. In the same period, European sales will more than triple, from $40 million to $138 million.

Foods that are simply genetically modified (GM), rather than functional or nutraceutical, are already a staple in the American diet. According to RocSearch, 60 percent of all processed foods in U.S. grocery stores contain GM ingredients from corn, soy, or canola.[43] In 2002, the GM food market was worth approximately $60 billion, according to Research and Consultancy Outsourcing Services.[44] GM foods are forecasted to grow by 7 to 8 percent by 2010, versus 1 to 3 percent growth for conventional foods; but, this growth will very much depend on consumer acceptance.

Market Trends in Animal Systems

Under the Animal Systems platform, Battelle envisions opportunities for Iowa from multiple applications:

- Marketable model animal systems and transgenic animal bioreactors
- Cloning and transgenic animal production systems
- Molecular farming—using livestock to produce medicines, nutraceuticals, and tissues for xenotransplantation purposes
- Transgenic animals with enhanced production characteristics, such as increased meat or fiber yield.

Transgenic animals, also called bioreactors, allow the effects of various factors on a gene's function to be tested in a whole animal rather than merely in a test tube or cell. By inserting human DNA into an animal such as a mouse, medical researchers learn important information that may help them in their efforts to conquer human disease.

According to Drug and Market Development, the use of transgenic animals in models of human disease has never been greater.[45] In the United Kingdom, the use of transgenic animals increased by 27 percent in

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[41] Freedonia Group. "Fermentation Chemicals to 2007 - Market Size, Market Share, Demand Forecast and Sales." Study #: 1662. May, 2003.
[42] Frost & Sullivan. "Probiotics Manufacturers Battle Low Consumer Awareness; Raising Consumer Education is Priority." October, 2003.
[43] RocSearch. "Genetically Modified Food: Markets, Issues and Implications." January, 2003.
[44] Research and Consultancy Outsourcing Services. http://www.rncos.com/research.htm.
[45] Drug and Market Development Publishing. "Transgenic Animals—Market Opportunities Now a Reality." October, 1999.

1998, representing 17 percent of all animal experiments, and leading to the first increase in total animal usage since 1976. Many diseases and disorders with a high level of unmet need can be treated successfully with drugs created from transgenic animals. The world market for recombinant proteins has been estimated at $12.8 billion in 1998, and the world market for antibodies exceeded $1 billion in 1998. Transgenic protein production offers significant economic and technological advantages over traditional methods of protein production; therefore, the market is highly likely to experience substantial growth. Advantages include reducing capital expenditures, lowered direct production cost per unit, and reducing the risk of transmission of human viruses and other adventitious agents (Drug and Market Development). For some drugs, a herd of 600 transgenic animals potentially could supply worldwide demand. Although laboratory manipulation of genes in animals, plants, and bacteria accounted for less than one percent of world supply of human therapeutic proteins in 1998, that one percent was valued at $12 billion, or 50 percent of a then $24 billion global market for human proteins.

As the number of transgenic and cloned transgenic animals increases, it is likely that the numbers of proteins that can be produced in animals also will increase as the cost of creating the initial founder animals decreases. The cloning of sheep, mice, goats and cows likely will allow companies to expand their production herds for transgenic therapeutics even faster, while reducing cost.

Global demand continues to grow for human proteins and vaccines. These proteins serve numerous therapeutic purposes, such as treatments for cystic fibrosis, hemophilia, osteoporosis, arthritis, malaria, and HIV. Transgenic animals also can produce monoclonal antibodies (antibodies specifically targeted towards disease proteins) that are used in vaccine development.

Transgenic animals are costly to produce and they have high value. The cost of making one transgenic animal ranges from $20,000 to $300,000, and only a small portion of attempts succeed in producing a transgenic animal. A Wisconsin firm that clones transgenic calves for human pharmaceutical production, however, estimated that one transgenic animal can produce, in its lifetime, $200 to $300 million worth of pharmaceuticals.[46]

In addition to the enhancement of therapeutics, transgenic animals provide opportunity in other areas:

- increased meat and dairy production
- increased wool/fiber production
- improved aquaculture production
- increased availability of organs for transplantation.

Public opinion and regulatory concerns are likely to impose initial limitations on the growth of the animal transgenics market. Many ethical issues are associated with genetically engineered foods and animals, with food safety being perhaps the most obvious area of potential impact from genetic engineering as it affects agricultural animals. In addition, xenotransplantation causes concern and uneasiness for many individuals and there are potential risks to the public from cross-over infections from animals to humans (zoonotic diseases). The history of science, however, is one in which the “genie is rarely returned to the bottle”—so rather than stopping bioscience progress through transgenics, public and regulatory concerns are more likely to simply slow progress.

[46] Center for Emerging Issues. “Animal Pharming: The Industrialization of Transgenic Animals.” December 1999. Available online at http://www.aphis.usda.gov/vs/ceah/cei/animal_pharming.htm.

Market Trends in Biosecurity

The biosecurity threat comes from multiple potential weapons, including nuclear bombs, radiologic bombs, and chemical and biological weapons and diseases. Multiple potential targets are threatened, including humans, livestock, and agricultural resources. While the threat of a nuclear bomb or chemical weapon must be taken seriously, many terrorism experts note the technical difficulties involved in acquiring, developing, transporting, and detonating/dispersing such weapons—whereas an individual with smallpox in the contagious phase can deliver a "bio-weapon" simply by visiting crowded areas. Bio-terrorism thus presents a very real danger for the United States and the federal government is acting swiftly to fund programs that may act to counter the threat. The threat is posed by multiple potential diseases and biological agents including the following:

- Anthrax
- Botulism
- Plague
- Smallpox
- Tularemia
- Viral Hemorrhagic Fevers (Ebola, Yellow Fever, Rift Valley Fever, etc.).

Compounding the threat of these known disease agents is the potential that genetic engineering technologies could be used to

- Enhance/expand the transmission (infection) characteristics of the infectious agent
- Increase an infectious agent's resistance to known antidotes or antibiotics
- Bioengineer new infectious agents through recombinant DNA technology.

As noted above, humans do not have to be the target for terrorists to cause substantial economic and social disruption. Hence there also is a concern that food sources, either livestock or crops, could be targeted. The outbreak of foot and mouth disease in the U.K. caused tremendous economic and social damage; a similar outbreak in the United States ranching community could be devastating. More distant as a threat, but still a potential, is the fact that if genes can be introduced to food crops to produce pharmaceuticals, so could genes be introduced to produce toxins.

Because of the breadth of bioweapon threats, the federal government is funding multiple counter terrorism initiatives. States also are spending money preparing for biosecurity threats and incidents. Homeland security thus represents a rapidly expanding market for a host of technologies in detection, prevention, preparation, treatment, and decontamination. The total homeland security market is estimated by Richard K. Miller & Associates to approach $100 billion.[47] The component of homeland security that comprises biosecurity initiatives is significant. Front Line Strategic Consulting estimates biodefense spending at $6 billion in 2003, and the NIH, CDC, DOD, and other federal agencies are budgeting several billion dollars for research and development programs.[48]

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[47] Miller, Richard K. & Associates. "Market Opportunities in Homeland Security." Norcross, GA. 2003.
[48] Front Line Strategic Market Reports. "Biodefense, An Analysis of Strategic Opportunities." San Mateo, CA. March, 2003.

According to the Department of Homeland Security, since September 11, 2001, the Bush Administration has spent or budgeted $12.9 billion to prepare and protect the nation from a bioterror attack, including $5.2 billion in the Fiscal Year 2004 budget.[49] This is 15 times the $305 million spent in Fiscal Year 2001.

President Bush's Fiscal Year 2005 budget request includes a $274 million Bio-Surveillance Program Initiative designed to protect the nation against bioterrorism and to strengthen the public health infrastructure.[50] The initiative will enhance ongoing surveillance programs in areas such as human health, hospital preparedness, state and local preparedness, vaccine research and procurement, animal health, food and agriculture safety, and environmental monitoring and integrate those efforts into one comprehensive system. The integration is an important point, since bio-attacks have implications across multiple interrelated systems (e.g., plant toxicity, water contamination, food animal contamination, and human infection in a connected system).

Agrosecurity is an important component of the nation's overall biosecurity. "Agrosecurity" is a term that was coined to address issues related to the vulnerability of the United States' food and fiber system to acts of terrorism. Agrosecurity issues are focused on gaining a better understanding of the nature of potential threats to plant and animal production, marketing, and processing. In responding to these threats, the United States needs to continue developing resistant varieties of plants and animals, pesticides, as well as comprehensive educational programs. Iowa State University is a key component of biosecurity for the State of Iowa with scientists examining the growth, development, and transportation of plant and animal diseases and pathogens.

The defense appropriations act, signed in January, provided an additional $328 million in USDA funding for homeland security.[51] The USDA proposed $2.37 billion in the fiscal year 2003 budget to fight sabotage and protect the nation's food supply from plant and animal disease, a $146 million increase in the budget. A $48 million increase was sought for animal health monitoring by the department's Animal and Plant Health Inspection Service. An additional $19 million will go to support agricultural quarantine inspection programs, which will provide additional inspectors, canine teams, and high definition X-ray machines at high-risk ports of entry.

Market Trends in Drug Discovery, Development, and Production

In 2000, according to IMS Health, the worldwide pharmaceutical market was valued at $317 billion and projected to grow to $3 trillion by 2020.[52] Capturing only a fraction of a percent of such a huge market can still amount to a major economic gain at a state level.

Traditional drug production focuses on small molecule, chemical agents. This is a mature market in which pharmaceutical companies have excellent core competencies. Nevertheless, there is major restructuring underway based on the need by drug companies to reduce costs and become more efficient. Contract drug development services are growing strongly, involving clinical evaluations of drug safety, drug disposition, drug evaluation, and toxicology studies that reach above $4 billion, as well as contract manufacturing efforts amounting to more than $12 billion. Among the contract services/outsourcing companies serving the pharmaceutical industry highlighted by Contract Pharma—the industry's trade organization—

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[49] Department of Homeland Security. http://www.dhs.gov/dhspublic/.
[50] The *Washington Times*. Article available online at: http://www.washtimes.com/upi-breaking/20040129-055250-8746r.htm.
[51] http://www.usda.gov/homelandsecurity/homeland.html.
[52] IMS. "World Review." Available at: http://www.ims-global.com//products/sales/review.htm.

were those located in San Antonio (TX), Albany (NY), Canada, Baltimore (MD) and Puerto Rico.[53] The University of Iowa already is a well-established contract formulation and drug production provider.

Other key market niches arising from traditional small-molecule chemical agent pharmaceuticals industries involve efforts to identify novel chemical agents. A particular source of novel chemical agents are natural product chemicals derived from plants. This market is expected to grow by more than 9 percent annually and reach nearly $4.5 billion by 2008. Natural product chemicals not only are important for new pharmaceutical chemical agents, but also for herbal supplements and nutraceuticals, which bring health benefits through diet (see the advanced food products market assessment).

Advances in biotechnology research has resulted in a growing number of new drug therapies produced by live, genetically modified microbial or animal cells, referred to as biologics. Genetic Engineering News (August 2002) reports that the current total pharmaceuticals market is $390 billion, of which biologics represents 7 percent.[54] By 2006, the total pharmaceuticals market is expected to increase to $550 billion, of which biologics will account for $70 billion—implying a growth rate for biologics of 15 to 20 percent per annum. Moreover, approximately one-third of the entire new drug pipeline is composed of biologics.

The manufacturing of biologics involves complex and expensive scale-up manufacturing processes and requires years of construction. The complexity and expense derives from the need to express the protein; purify cell lines; fill, label, and package; and maintain quality control over a very lengthy process. Currently the processing of biologics is much less efficient than that of traditional small-molecule agent drugs. Also, scaling up biologics production often requires significant process changes from earlier production of small quantities of the biologics used in research and development efforts. The capabilities at the University of Iowa in GMP biologics production, in addition to a major planned biologics production facility at Iowa State University, will give the state particular strength in this field.

Freedonia predicts that U.S. demand for biologics will advance almost 12 percent annually to more than $56 billion in 2006.[55] New product introductions evolving from advances in recombinant DNA and monoclonal antibodies will stimulate growth. Demand for applications in the treatment, prevention, and diagnosis of complex viral, malignant, and autoimmune disorders is expected to see the strongest gain as a result of the safety and performance shortcomings of available conventional products. Recombinant proteins are projected to remain the top-selling group of biologic products through 2006. Expanding knowledge and understanding of human genomics and proteomics likely will lead to a wealth of new disease targets as well as discovering in vivo substances with potential commercial value. Broad adaptation to protein production, coupled with safety and efficacy advantages over conventional preparations, will boost the range of therapeutic applications served by recombinant DNA technology. However, competition from small-molecule drugs developed through combinatorial chemistry and related methods will decelerate growth in overall demand for recombinant protein producers.

Freedonia further predicts that sales of monoclonal antibody products will increase the most among all biologics through 2006, and that because of advances in recombinant proteins and monoclonal antibodies,

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[53] Contract Pharma. "Top Contract Service and Outsourcing Companies." http://www.contractpharma.com/aug001.htm.
[54] *Genetic Engineering News*. "Biopharmaceutical Manufacturing." August 1, 2002. Available online at: http://www.genengnews.com/backissues/backissue.asp?issue_id=22&criterias=august,%202002.
[55] Freedonia Group. " Biologics to 2006 - Market Size, Market Share, Demand Forecast and Sales." Study #: 1618. November, 2002.

conventional biologics will provide below average growth opportunities.[56] Conventional vaccines based on live and inactivated viruses may provide the best sales prospects, reflecting trends promoting greater preventive medicine activities. By contrast, competition from recombinant DNA and monoclonal antibody products will weaken the market potential of whole blood, plasma derivatives, and semisynthetic protein drugs.

Hospitals, ambulatory health facilities, and pharmacies will likely comprise the largest markets for biologics as the treatment of complex diseases and disorders remains the leading application served by these products.

Key industry analysts expect a serious mismatch between who controls capacity to produce biologic-based pharmaceuticals and who needs the capacity. An analysis by USBancorp Piper Jaffray estimates that four biopharmaceutical companies—Amgen, Biogen, Boehringer-Ingelheim, and Genentech—will control more than half of the world's biologics production by mid-decade.[57] This leads USBancorp Piper Jaffray to conclude: "our analysis showing that there will be excess capacity does NOT imply that specific companies will not be left without production capacity for their products … the bulk of the manufacturing capacity will be a handful of companies, most of which are NOT contract manufacturers." The August 2002 issue of Genetic Engineering reinforces the concern about access by quoting the Chief Manufacturing Officer of Applied Molecular Evolution based in San Diego: "There appears to be lots of capacity at larger companies, but production space is in short supply at smaller companies, where the action is and at contract manufacturers."[58]

Market Trends in Post-Genomic Medicine

Increasingly, the tools of biotechnology are incorporating advanced computer-aided modeling, algorithms, statistical analysis, and pattern discovery to understand the structure and function of genes and proteins and to identify new potential targets of intervention for diseases. In addition, biotechnology is advancing the ability to design medications based on an individual's genetic makeup rather than on educated guesses or trial and error. This genetic-enabled approach to medical care is technically referred to as pharmacogenetics or pharmacogenomics, and more popularly known as personalized or individualized medicine. Frost and Sullivan, a leading market research firm, sees pharmacogenomics as having the potential to revolutionize gene-based diagnostics, helping that market grow by $3.5 billion by 2005.[59] The combined revenues for pharmacogenetic services and gene-based diagnostics could reach nearly $6 billion.

Reuters Business Insight performed recent research on the post-genomic medicine market and found that

- Small-molecule drug discovery increasingly is being driven by functional proteomics and the focus has shifted to targeting intracellular gene regulating proteins and disrupting protein pathways. Early target validation has become a key priority and many different approaches are being explored.
- Current approaches to increasing the efficiency of drug discovery include integrated use of technologies, especially chemical genomics, SNP scoring, rational drug design, early detection of drug toxicity, and bioinformatics.

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[56] Freedonia Group. " Biologics to 2006 - Market Size, Market Share, Demand Forecast and Sales." Study #: 1618. November, 2002.
[57] Battelle Memorial Institute, Technology Partnership Practice. "St. Louis Technology Cluster Strategies: Positioning St. Louis in Advanced Manufacturing Clusters." June, 2003. Page 18.
[58] *Genetic Engineering.* August 2002. Capacity Mismatch for Production of Monoclonals.
[59] Frost & Sullivan. "U.S. Pharmacogenomics Markets." June, 2001.

- The dominance of small-molecule drugs in the marketplace will be challenged by promising emerging biotherapies, which include antisense therapies and gene therapies.
- Theranostic tests, which predict drug response in individual patients, already are finding applications in many therapeutic areas, including infectious disease, cancer, and cardiovascular disease.[60]

Reuters further notes that

- Proteomics and other post-genomic technologies may revolutionize small molecule drug discovery.
- The successful integration of post-genomic technologies will be essential for small-molecule drug discovery to reach its fullest potential.
- Novel biotherapies could challenge the traditional dominance of small molecule drugs.
- Predictive diagnostics hold the key to preventive medicine.
- Closer linking of diagnostics and therapeutics will transform personalized medicine.[61]

According to Fuji-Keisai Corporation, proteomics is projected to grow from a $565 million market in 2001 to more than $3.3 billion in 2006.[62] This represents an average annual growth rate of over 40 percent. The fastest growing segment of the proteomics market is the protein chip segment that is expected to increase from $65.7 million in 2001 to more than $723 million in 2006. This represents an 11-fold increase in market size in a six-year period and an average annual growth rate approaching 62 percent. Demand for proteomics services is expected to be strong throughout this time period with an average annual growth rate of over 50 percent. The rate of growth in this market segment is expected to slow after 2004 when next generation proteomics platforms are introduced. The proteomics platform market segment will remain the largest with a growth from $311 million in 2001 to approximately $1.7 billion in 2006.

Following the release of the first full draft of the human genome, the spotlight in biomedical research is shifting from genomics to proteomics as the key technology to transform information into pharmaceutical products. The need to improve the speed and efficiency of drug discovery is the primary driver of proteomics. Current step-wise screening and chemical optimization methods are both time-consuming (averaging 10 to 12 years from discovery to market) and expensive (estimated costs range from $500 million to $750 million). In addition, there is a high rate of failure in the clinical trials process due to toxicity or low efficacy of selected drug targets resulting in an increased interest in identification of biomarkers suitable to use in therapeutic planning and individualized medicine. It is hoped that both the rate of drug development and the rate of discovery of novel, informative biomarkers will dramatically improve using emerging proteomics platforms.

Drug and Market Development notes that post-genomic medicine is being driven by new technologies and scientific insight that provide

- Fundamental new ways to understand the molecular pathology of disease
- Identification of genes associated with complex diseases for discovering new therapeutic targets

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[60] Reuters Business Insight. "Future Growth Strategies: Drivers of sustainable development within the biotech, specialty and major pharma sectors." Available online at: http://www.bioportfolio.com/cgi-bin/acatalog/Reuters_2003.html.
[61] Ibid.
[62] Fuji-Keisai Corporation. http://www.fuji-keizai.com/j/report/proteomics.html (in Japanese).

- Validation of genetic markers for predicting the risk of disease susceptibility, differential diagnosis, and monitoring therapeutic progress
- Use of genetic markers to select optimal drugs and doses for individual patients and reduce individual therapeutic experimentation
- Examination of natural genetic variation between and within populations and its impact on health and disease.[63]

Other states and universities are taking note. The University of Minnesota and the Mayo Clinic recently announced a state-funded collaboration called the Minnesota Partnership for Biotechnology and Medical Genomics—a project designed to further enhance and leverage the more than $400 million already spent at the two institutions in genomics. Indeed, the Minnesota Partnership states that "medical genomic solutions will rank among the most important scientific breakthroughs in history." Ohio and The Ohio State University are likewise placing an emphasis on post-genomic medicine and in defining the scope of the OSU Program in Pharmacogenomics they considered the following assumptions and predictions:

- Numerous new drug targets (genes and their encoded proteins) will lead to a wave of drug discovery, exploiting the availability of genomic sequences of multiple organisms. Yet, the number of human genes that can serve as suitable drug targets for treating complex diseases is limited. Moreover, biological complexity is likely to limit therapeutic success when treating with drugs aimed at specific targets. Most of the major diseases and chronic illness of old age are complex multigenic disorders. Therefore, new drug discovery alone is insufficient to optimize future therapy.
- Genetic variability among individuals will emerge as a major determinant of a patient's response to drug therapy. Use of genetic information promotes individualized therapy, if applied together with conventional clinical data.
- The outcome of drug therapy in an individual patient is likely to depend at least in part on genetic variations in multiple relevant genes. These include those that encode proteins in direct contact with the drug (transporters, metabolizing enzymes, receptors, and target enzymes), genes encoding proteins downstream in drug signaling pathways or metabolic cascades, and lastly, disease susceptibility genes.
- Over the coming decade, we will learn about numerous variant genes predisposing an individual disease. Frequently, the same disease phenotype (e.g., hypertension) is associated with distinct genetic variant profiles as the underlying cause—each profile potentially requiring a different type of drug therapy. Moreover, recognition of disease susceptibility genes will permit early treatment or even prevention of disease, requiring novel but potentially much more effective therapeutic strategies.
- Computational biology will permit the modeling of complex systems, eventually leading to prediction of drug effects in vivo.
- Vast databases on biomedical, genetic, and clinical information will become broadly accessible, requiring an informatics approach for optimizing drug therapy. This information must be further digested so as to become accessible to health care practitioners and patients alike.

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[63] Drug and Market Development Publishing. "Functional Genomics - Turning Promise into Profits." November, 2002.

Tripp Umbach Healthcare Consulting, Inc. has examined the numerous paths by which post-genomic science may affect a revolution in medicine.[64] The paths show the substantial market changes in medicine and healthcare delivery likely to result from genomics, proteomics, and associated sciences. Some of the most notable predictions are for

- **Pharmacogenomics**—Drug treatments will be tailored to fit the precise genetic makeup of individual patients. In effect, this will start to shut down the "one size fits all" therapeutics. An individual's enzyme function affects his or her response to drugs and drug dosage. Future advances will allow rapid testing of the patient's genotype such that drug type and dosage can be customized to the individual. How important is this? Currently, more than 100,000 deaths, and more than 2.2 million serious complications, are caused by adverse reactions to medications. In addition, millions of people likely receive little benefit at all from their prescribed medications because the drug or its dosage does not fit their genotype. Pharmacogenomics will drastically increase the effectiveness of prescribed medication and greatly reduce hospitalizations caused by adverse drug reactions.
- **Drug Development**—Most drugs today are based on about 500 molecular targets. Knowledge of the genes involved in diseases, disease pathways, and drug response sites may lead to the discovery of thousands of new targets. Hundreds of new drugs will emerge, aimed at specific sites in the body and at particular biochemical events leading to disease. Through enhanced targeting, these drugs will be more effective than today's "general population" drugs, and they will cause fewer side effects.
- **Genetic Tests**—Genetic tests already are in use and have been among the first applications of genetic discoveries. Tests can be used to diagnose disease, confirm diagnoses, provide prognostic information about the course of a disease, confirm the existence of a disease in asymptomatic individuals, and predict the risk of future disease in healthy individuals and their blood relatives. Several hundred genetic tests are already in clinical use and the introduction of new and more effective tests is expected to escalate rapidly.
- **Gene Therapy—**Genes themselves may be used to treat disease or enhance genetic traits that can help fight or ward off disease. Through gene therapy, normal genes may be introduced to replace defective genes or to bolster normal functions, such as immunity. This field, therefore, has the potential to deliver effective therapies for genetic acquired diseases such as cancers and AIDS. While gene therapy is still a new and emergent field, in 2001, more than 500 clinical trials were already underway worldwide (with 78 percent based in the United States).

The prospects for bioinformatics are inseparable from the prospects and market structure of biotech. Bioinformatics plays a key role in functionalities such as gathering, storing, classifying, analyzing, and distributing biological information derived from sequencing and functional analysis. It is the application of bioinformatics and informatics applications that leads to the potential to drive growth in the worldwide pharmaceuticals drug market from the $240 billion today to $3 trillion by 2020.

It is clear that each of the major recommended Iowa platforms operate in sectors with large scale market opportunities. As the State moves forwards in its bioscience planning and strategy development, further market investigation should be performed.

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[64] Simon Tripp, Paul Umbach and Susan Fisher. "Opportunities and Challenges Facing Mayo Clinic and the State of Minnesota in the Post-Genomic Era." Tripp Umbach Healthcare Consulting, Inc. Private report to the Mayo Clinic Board of Governors. 2003.

Summary of Iowa's Bioscience Technology Platform Opportunities

Table 51 provides a summary of the six near-term, major technology platforms and the four longer-term/niche emerging opportunity areas upon which to build Iowa's bioscience base. As shown in Table 51, each of the six technology platforms and four emerging opportunity areas are derived from the state's foundational strengths in basic research areas enhanced through specific enabling technologies and applied research. Each platform and opportunity area is then more fully defined and described through a brief summary of technology-based applications and examples of products that may stem from the research efforts. Finally, through the market analysis task, specific markets are linked to these platforms and opportunity areas—markets that are able to take advantage of these new products and spur the development of additional applications.

Table 51: Technology Platform Linkages from Core Competencies to Markets.

Areas Judged by Battelle to Have Near-Term Growth Potential (Next Five Years)

Basic Research	Enabling Technology	Technology Platform	Applications and Products	Markets
• Genomics • Proteomics • Biology • Chemistry	• Plant transformation and genomics • Crops utilization research • Plant breeding • Chemical engineering • Biochemistry • Bioprocess engineering • Catalysis and piloting facilities • Environmental engineering • Bioinformatics and biostatistics • Metabolomics	BioEconomy	• Biofuels • Biomaterials and biocomposites • Chemicals • Polymers • Plastics • Oils • Starches • Adhesives • Enzymes • Fiber	• World energy demand is expected to increase by 59% by 2020. • By 2004 Freedonia Group forecasts that U.S. demand for fermentation chemicals will reach 15 billion pounds and be valued at $5.4 billion. Markets targeted will be feed, fuel, and pharmaceuticals (Freedonia July 2000). • Starch and fermentation products will lead gains based on heightened demand for feedstock (Freedonia September 2001).

Basic Research	Enabling Technology	Technology Platform	Applications and Products	Markets
• Multiple medical basic science disciplines	• Genomics • Proteomics • Pharmacy • Pharmaceutical sciences • Combinatorial chemistry • Drug development services • GMP production services • Biologics production facilities • Clinical trials infrastructure • Bioinformatics and Biostatistics	**Drug Discovery, Development, Piloting and Trials**	• Drugs • Biologics • Potential for gene therapy agents and vaccines	• In 2000 according to IMS Health, the worldwide pharmaceutical market was valued at $317 billion and projected to grow to $3 trillion by 2020. • U.S. demand for biologics will advance almost 12 percent annually to over $56 billion in 2006. New product introductions evolving from advances in recombinant DNA and monoclonal antibodies will spur growth. • Recombinant proteins will remain the top-selling group of biologic products through 2006. • Sales of monoclonal antibody products will see the strongest gains among all biologics through 2006. • Advances in recombinant proteins and monoclonal antibodies will provide below-average growth opportunities for conventional biologics. Conventional vaccines based on live and inactivated virus will provide the best sales prospects, reflecting trends promoting greater preventive medicine activities. • Fermentation and cell culturing services will generate the largest outsourcing revenues based on the complex manufacturing and high investment require-ments of recombinant proteins and monoclonal antibodies. (Freedonia November 2002) • Freedonia predicts that U.S. demand for combinatorial products and services will grow by more than 12% through 2006. In 2003 industry estimated value was $2.2 billion. • Personalized medicine is expected to take off and reach $3.5 billion by 2005.

Basic Research	Enabling Technology	Technology Platform	Applications and Products	Markets
• Plant and animal sciences	• Plant genomics • Plant transformation • Plant breeding • Animal genomics • Animal breeding • Food science • Nutrition • Chemical engineering • Bioprocess engineering • Bioinformatics and biostatistics • Metabolomics	**Advanced Food Products**	• Functional foods (via both plant and animal pathways) • Nutraceuticals • Value added Iowa processed products	• 60% of processed foods in supermarkets contain genetically modified (GM) ingredients such as soy, corn, and canola (RocSearch May 2003). • GM foods initially forecasted to grow by 7% to 8% by 2010 versus 1% to 3% growth for conventional foods—but given recent market trends and consumer fears, forecasts have been toned down (Research & Consultancy OutSourcing Svcs, February 2003). • In 2002 GM food market was worth approximately $60 billion (Research & Consultancy OutSourcing Svcs, February 2003). • The global nutraceutical market grew at an annual rate of 7% between 1999 and 2002 increasing from $38.2 billion to $46.7 billion. Between 2002-2007 nutraceuticals are predicted to grow by an average annual rate of 9.9%, reaching $74.7 billion by 2007 (BCC March 2003). • Worldwide demand for nutraceutical chemicals will increase by 6.2 % annually reaching $8.6 billion by 2006. • The functional food market in the U.S. was valued at $18.5 billion in 2002 (Nutrition Business Journal April 2002).
• Multiple medical disciplines + genomics	• Genetic screening & phenotyping • Proteomics • Tissue banks • Pathology • Health informatics • Epidemiology • Bioinformatics and biostatistics • Trials enrollment and management • Longitudinal follow-up	**Integrated Post-Genomic Medicine**	• Leading centers of excellence in multiple disease areas (research and clinical practice) • Marketable informatics data • New drugs, biologics, therapeutics, vaccines, etc., passing into integrated pipeline.	• Pharmacogenomics market anticipated to approach $3.5 billion by 2005. Pharmacogenetic services and gene-based diagnostics could reach $6 billion. • Functional genomics market was estimated to be worth $940 million in 2002 and projected to grow to $2.2 billion by 2007; with an annual growth rate of 18%. • Proteomics is projected to grow from a $565 million market in 2001 to over $3.3 billion in 2006. This represents an average annual rate of growth of over 40%. • Application of bioinformatics/ informatics applications has the potential to drive growth in the worldwide pharmaceuticals drug market from the $240 billion today to $3 trillion by 2020. The forecast value for the worldwide informatics market in the life science sector is between $1.7 and $7 billion by 2007.

Basic Research	Enabling Technology	Technology Platform	Applications and Products	Markets
• Animal biology	• Genomics • Transgenics • Animal breeding • Bioinformatics and biostatistics • Visualization, modeling, and imaging	**Animal Systems**	• Marketable model animal systems • Transgenic animals • Marketable systems and protocols • Cloning and production technologies	• Many diseases and disorders with a high level of unmet need can be successfully treated with the use of drugs created from transgenic animals. The world market for recombinant proteins has been estimated at $12.8 billion in 1998, and the world market for antibodies was expected to exceed $1 billion in 1998.
• Microbiology	• Immunology and infectious diseases (humans, animals and plants) • High-level biocontainment • Microbial pathogenesis • Microbiology • Virology • Toxicology • Sensors and instrumentation • Bioprocessing • Environmental sciences • Risk assessment	**Biosecurity**	• Vaccines • Diagnostics • Drugs and therapeutics • Biodecontamin-ation microbes • Environmental monitoring products	• According to Front Line Strategic Consulting Inc., since 2001 biodefense funding has risen considerably. Spending in 2003 was projected at $6 billion. Proposed White House 2004 budget calls for a $5.2 billion spend. • Several billion dollars expected to be spent by the NIH and DOD on research into detection technologies, improved vaccines, and new treatments for victims of biological warfare (Front Line March 2003). • Demand for bioterrorism equipment and services is projected to grow by 16% annually through 2008, reaching $10 billion. Vaccines are predicted to be the fastest growing segment, rising from 54% annually from $286 million in 2003 to $2.5 billion by 2008. The second fastest growing segment will be biodetection equipment, increasing from $345 million in 2003 to $1.9 billion in 2008, averaging an annual growth rate of 41% (PBR September 2003). • USDA's proposed 2004 budget includes $2.4 billion for agrosecurity and food supply safety.

Areas Judged by Battelle to be Opportunities for Future Development

Basic Research	Enabling Technology	Technology Platform	Applications and Products	Markets
• Microbiology	• Parasitology • Immunology • Helminth biology • Genomics • Bioinformatics and biostatistics • Imaging	**Host-Parasite Biology and Systems**	• Immuno-therapeutics • Drugs and biologics • Parasite treatments • Diagnostics and clinical services	• One market is in live microbial feed supplements (probiotics), which benefit the host animal by improving its intestinal microbial balance. In humans, lactobacilli commonly are used as probiotics, either as single species or in mixed culture with other bacteria. Other genera that have been used are bifidobacteria and streptococci. • The probiotic market, including food and dietary supplements, accounted for $1.86 billion in revenue in 2000 and is expected to grow to $3.5 billion by 2007. The annual revenue growth rate is expected to increase from 7.4% in 2000 to 10.5% in 2007 and continue in the same manner. The probiotics dietary supplement segment represented $97.5 million at the manufacturer level in 2000, with similar expectations for future growth. (Nutraceutix Probiotics www.nutraceutix.com) • U.S. and European probiotic markets are projected to grow rapidly in upcoming years. The U.S. market is expected reach $400 million by 2010. The EU market will triple increasing from $40 million to $138 million (Functional Foods & Nutraceuticals January 2004).

Basic Research	Enabling Technology	Technology Platform	Applications and Products	Markets
• Engineering	• Mechanical and electrical engineering • Materials science • Biomedical engineering • Optical science • Mathematics • Computer science • Statistics • Medical imaging • Radiology • Rapid prototyping • Surgery	**Instru-mentation, Sensors and Devices**	• Imaging devices • Biosensors • Implantable devices • Surgical systems and instruments	• As drug development increasingly becomes focused on high-throughput drug screening technologies, bio-chip and microarray technology will become increasingly important. • The total market for microarrays is expected to experience strong growth to reach over $1.6 billion in 2008 as a result of industry consolidation, standardization of array data, establishment of robust databases, and the development of clinical diagnostics. The current estimated worldwide market breakdown is: U.S. at 65%, Europe at 25%, Japan at 10%, and the rest of the world at 5%. (Front Line Strategic Consulting May 2003) • The total biochip market size in 2002 is about $1.1 billion and is projected to grow to about $2.7 billion in 2007 with a CAGR of 19.5%. (Fuji-Keizai July 2003)

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Basic Research	Enabling Technology	Technology Platform	Applications and Products	Markets
• Cardiovascular Sciences	• Cardiovascular research • Pulmonary research • Hematology • Free radical biology • Imaging and radiology • Microbiology • Genetics • Proteomics • Bioinformatics and biostatistics	**Cardiovascular Research Institute**	• Analytical instruments • Measuring devices • Surgery and invasive diagnostics • Advanced biomedical imaging	• The global cardiovascular market was valued at an estimated $71 billion in 2001, an 8.2% increase over the 2000 value of $66 billion. The cardiovascular market remains the largest therapeutic segment of the pharmaceutical market; however, as key blockbuster products reach maturity, the competitive dynamics are changing, with factors such as generic competition and lifecycle management becoming as important as product innovation. (Research and Market) • Blockbuster drug revenues are set to experience an annual growth rate of 5.2% through 2008, topping at $158 billion. o Reliance on blockbuster revenues is increasing but pipelines appear weak. Cardiovascular and CNS therapy areas dominate the market segment. o Cardiovascular and CNS sales are forecasted to rise to $67 billion in 2008, accounting for 43% of total blockbuster sales(Datamonitor August 2003). • Cardiovascular devices are a $12.8 billion global industry that will grow on average of 12% per year through 2006, when it will be worth $22.6 billion. • BCC in 2001 predicted sales of cardiovascular drugs to reach $76.5 billion by 2005. Hypertension treatment would be the largest market segment accounting for $25 billion.
• Free radical biology	• Free radical biology • Radiology • Biochemistry • Biophysics	**Free Radical Institute**	• New therapeutics • Nutraceuticals • Drugs and biologics • Diagnostics	• Several free radical scavengers presently exist in the market in the form of dietary, vitamin, and mineral supplements. o These free radical scavengers are substances that influence the course of chemical reactions by seeking unstable and highly reactive molecules that contain one or more unpaired electrons. o Antioxidants are a major type of free radical scavengers presently in the market, they are synthetic or natural substances added to products to prevent or delay their deterioration. • According to the Nutrition Business Journal, the U.S. nutritional supplement market grew by 34% between 1997 and 2002 and is expected to reach $20.8 billion by 2005 (Detroit Free Press December 2003).

To take full advantage of these technology platforms, Iowa's universities, private sector, and state government will need to address several gaps as well as seize opportunities outlined in the table below

Table 52: Platforms and Gap-Filling Needs and Opportunities.

Platform	Gap Filling Needs and Opportunities
BioEconomy Platform	• Fund, and scale up, the operations of the BIOWA Development Corporation. Build BIOWA into a fully staffed industry development association, linking o Iowa and non-Iowa BioEconomy industries o Existing and potential end-user companies for biorenewable commodity products and specialty products o Academic R&D and associated resources at Iowa State University, University of Northern Iowa, and The University of Iowa. • Develop, within BIOWA, subcommittees devoted to specific product line opportunity areas (markets), including but not limited to o Industrial Chemicals o Ethanol o Biodiesel o Hydrogen o Enzymes o Fibers o Carbohydrates (sugars, starches, glycogen) o Proteins. • Dedicate additional support and funding to the Iowa State University Plant Sciences Institute as the core driver of ag-based biomass development for the State. Director of the Plant Sciences Institute to be a BIOWA Executive Board member. • Place additional emphasis on R&D related to new processing technologies and projects to reduce the cost of bio-renewable products to be competitive with competing products (such as those that are petroleum based). Dedicate support and funding to Iowa State University to develop a BioEconomy Institute to serve as the umbrella organization for steering applied R&D in processing, engineering, product design, and production technologies. Place the key related ISU centers (Center for Crops Utilization Research, Center for Catalysis and Center for Sustainable Environmental Technologies) as core components of the Institute. Director of the ISU BioEconomy Institute to be a BIOWA Executive Board member. • Actively engage ISU ag-extension in BioEconomy production consulting with the Iowa farm sector, and in industrial extension consulting with potential processors and users of bio-renewable resources. Director of Iowa State Extension to be a BIOWA Executive Board member. • Invite and encourage relevant University of Iowa and University of Northern Iowa centers, institutes, and departments to be members of the Iowa BioEconomy Institute at ISU. It is especially important to include the expertise contained in UNI's Ag-Based Industrial Lubricants (ABIL) program and The University of Iowa's Center for Biocatalysis and Bioprocessing.

Platform	Gap Filling Needs and Opportunities
	• Develop and refine state incentive policies to encourage the active development of Biorefinery clusters in Iowa. • Actively promote Iowa as America's leader in biorenewables and BioEconomy development through a State-led marketing and promotions campaign and high visibility at key industry trade shows. • Organize a Midwestern States lobby for BioEconomy development purposes in lobbying the federal government. • Seek to develop a formal relationship with Canada's leading bio-renewables research and industry cluster in Saskatoon to leverage North American skills against growing European, Asian, and Latin American competition.
Integrated Drug Discovery, Development, Piloting and Production Platform	• Dedicate additional support and funding to build upon core strength areas at The University of Iowa, including the Center for Advanced Drug Devel-opment (CADD) and the GMP production facilities of the Division of Pharmaceutical Services. • Fund the development of a new Drug Discovery Center at The University of Iowa, thereby plugging a current resource gap and completing an integrated system for moving discoveries from bench to bedside. Iowa may be unique in having the opportunity to have a fully integrated "pipe-line" of basic science research → drug discovery → drug development → pilot production → clinical trials → and drug production: all in-house at one major university. • Initial requirement for the new Drug Discovery Center is estimated at three full-time positions, plus instrumentation and equipment resources and development of compound libraries. • The University of Iowa may wish to appoint a Director of Pharmaceuticals and Biologics Development to guide the operations of The University of Iowa integrated drugs platform and further build and maintain close pharmaceutical and biotechnology industry linkages. • Areas of directly relevant strength at Iowa State University should be linked into The University of Iowa "pipeline." This would initially include ISU's expertise in veterinary medicine and combinatorial chemistry and the planned biologics production facility at the ISU research park.

Advanced Food Products Platform	• Iowa State University may wish to formalize its work in functional foods, nutraceuticals, and phytochemicals under a formal center or institute linked to existing platforms in plant and food animal sciences. Key programs to include would be Plant Genomics, Plant Transformation and Gene Expression, the Center for Designing Foods to Improve Nutrition, the NASA Food Technologies Commercial Space Center, and Food Science and Nutrition.
	• An Advanced Food Products Institute, based on Iowa's strengths, should likely concentrate on
	  o Value added Iowa transgenic crops expressing enhanced levels of beneficial nutrients, vitamins and phytochemicals
	  o Agricultural processing, separation and purification technologies for extracting beneficial nutrients, vitamins and phytochemicals from Iowa crops

Platform	Gap Filling Needs and Opportunities
	- o New advanced food products from crops, produce, herbs, etc. with enhanced commercial value for introduction on Iowa's farms - o Food processing technologies designed to maintain or enhance functional characteristics of food and food ingredients during processing, cooking and packaging. • The Institute should seek to establish relationships between the Iowa functional foods R&D platform and producers and distributors of functional and nutraceutical food products. • State funding and incentive mechanisms should be investigated to assist in founding and attracting functional food, nutraceutical, and associated agricultural and food processing companies. • R&D should also be performed to advance Iowa's key food animal sectors (especially Pork, Beef and Poultry/Eggs) in terms of functional characteristics and nutrient/chemical expression.
Post-Genomic Medicine Platform	• It is imperative that the State of Iowa continue investing in and building Iowa's strong position in bioinformatics, genomics, proteomics and metabolomics—together with associated programs in epidemiology and health informatics. Enhanced funding streams should be considered that would o Retain and anchor existing faculty in these fields, especially at The University of Iowa and Iowa State University o Attract additional faculty and investment in resources to continue Iowa's growing momentum in these critically important fields for bioscience progress. • The University of Iowa may wish to consider forming the Post-Genomic Medicine Institute dedicated to the formation of multi-disciplinary teams and the coordination of resources to capitalize on key opportunities in: o Ophthalmology o Cardiology o Oncology o Otolaryngology o Pulmonology o Gastroenterology o Neurosciences • Iowa should open discussions with the State of Minnesota, the University of Minnesota, and the Mayo Clinic to explore the potential to integrate and build upon Iowa's strengths in this area in collaboration with the new Minnesota Partnership for Biotechnology and Medical Genomics. Sharing access to clinical and epidemiological data in Minnesota and Iowa likely would strengthen programs for both states and speed platform development. • Iowa should fund ongoing development of computational resources and software/database systems development to support work in the Post-genomic Medicine Platform. Patient record data, demographics, imaging data, and genomics data should be linked under a unified software and data mining platform.

Platform	Gap Filling Needs and Opportunities
	• The University of Iowa should establish a clinical research patient recruitment center in the main lobby of the University Hospital and within the key departments linking their research into the post-genomic initiatives. Iowa should seek to increase patient enrollment rapidly, where possible, in longitudinal clinical and epidemiological studies.
Animal Systems Platform	• Maintaining Iowa's leadership position in certain food animals and associated meat products may increasingly require a solid foundation in animal transgenics—working to enhance food animal characteristics, productivity and value. Iowa State University should, to the extent possible, coordinate transgenics and animal systems research across key groups such as those contained in ISU Animal Sciences, the ISU Beef Center, Iowa Pork Industry Center and the Meat Export Research Center. The University of Iowa's expertise at the Transgenic Animal Facility also should be incorporated via collaborations. • Key transgenic animal systems pathways to pursue in the near term for Iowa may include o Enhanced meat production and meat quality predictability o Expression of valuable proteins and other chemicals via animal pathways (such as milk, eggs, blood, semen or urine). • Iowa should seek means to build upon the existing Center for Integrated Animal Genomics at Iowa State University, leveraging it to focus on the most relevant and near-term applications of transgenics, cloning and chimerics in food and fiber producing animals. • Iowa should also seek to leverage its expertise in mouse transgenics (at The University of Iowa) and pig transgenics (at Iowa State University) to build and expand upon opportunities in the production and sale of transgenic animals for R&D purposes.
Biosecurity Platform	• Iowa State University and The University of Iowa should consider forming a joint Institute for Integrated Biosecurity, working on whole systems approaches to biosecurity and agrosecurity. • Emphasis of initial R&D programs should likely be dedicated toward o Agrosecurity—protecting the food and biorenewable resource production and processing chain o Threat Diseases—with an initial focus on emerging and established respiratory diseases and emerging zoonotic diseases. • Within the Institute, Iowa may seek to establish interdisciplinary working groups to focus R&D on o Detection and analytical devices o Approaches to, and systems for, decontamination of production and processing facilities and equipment o Infectious disease protection, prevention, and treatments o Rapid production of vaccines via plant and animal pathways. • The market opportunity for biosecurity is large enough that state funds should be directed to support initial development of the platform. By showing state commitment to an integrated biosecurity approach (the main goal of Homeland Security), Iowa will be more likely to attract significant levels of federal biosecurity R&D funding.

Platform	Gap Filling Needs and Opportunities
	• Industry memberships in an Institute for Integrated Biosecurity should be encouraged, to help the potential development of a biosecurity industry cluster in Iowa. Initial focus should be on agricultural and processing equipment manufacturers and BioEconomy-related industry sectors.
Additional Gap Filling Activities & Opportunities	• Formation of a Host-Parasite Institute at The University of Iowa, linked to animal and plant biology expertise at Iowa State University could help build upon the emerging leadership of Iowa in this interesting medical and scientific field. • Formal funding should be considered for constructing and equipping a Cardiovascular Research Institute at The University of Iowa. This would anchor the strong base of existing research and development expertise of the University in cardiology, vascular systems, neuro-control and other related fields. A formal facility, allowing co-location of research scientists and clinician scientists along the lines of Iowa's Comprehensive Cancer Center, could foster significant advances. • A Free Radical Institute should be considered to formalize and facilitate interactions between the large base of scientists at The University of Iowa who are working in free radical biology. A few other states, such as Oklahoma, recently have recognized the importance of the study of free radicals and have formed formal centers. Iowa needs to cement its leadership position in the field and use an Institute to gain additional support and retain faculty excellence.

SUMMARY OF IOWA'S BIOSCIENCE TECHNOLOGY PLATFORM OBSERVED WEAKNESSES

While the goal of the core competency was to identify the key core research and technology competencies and platforms in biosciences, this review also served to highlight weaknesses and gaps that will also need to be addressed. The following were observed as general issues during the course of this study:

- Agricultural biosciences appear to have much higher legislative and public visibility in the state than human medical sciences. While it is good that agricultural bioscience is recognized for its significant value to the current and future health of the Iowa economy, attention also needs to be raised to the strong position of Iowa in human biosciences (where it actually holds higher rank in terms of research funding than it does in agriculture).
- Iowa higher education institutions appear to be making good attempts to link their research to the needs of industry in the state. However, these efforts are held back by a lack of a commercial base in many areas of biotechnology, pharmaceuticals, medical devices and even food processing.
- Research institutions vary in approaches to technology development, with Iowa State University demonstrating great flexibility in developing formal, institution-supported cross-disciplinary research institutes and centers—the type of structure best suited to modern scientific advancement and external funds attraction. The University of Iowa has developed a more traditional approach.
- State support for the Regent institutions has declined significantly during the last five years. The result has been predictable in terms of program cuts, faculty salary freezes, an inability to invest in new technologies and infrastructure and a general fear for the future among the Iowa education and

scientific community. At a time when higher education research institutions represent the best investment for a state, Iowa, for budgetary reasons, has had to lower, rather than increase, investment.

- There is an evident lack of pre-seed, seed and venture capital available in Iowa to fund new ventures in the biosciences. Lack of local capital resources is limiting entrepreneurship on campuses, reducing the volume of new innovation based companies in the state, and causing some of the companies that do spin-out of Iowa's universities to move out of the state closer to venture funding sources on the coasts.
- There is a lack of experienced bioscience entrepreneurs and managers who can fulfill management duties in new start-ups, or provide mentoring to new bioscience enterprises.
- There appears to be considerable variability in the level of commercialization and intellectual property protection services offered by Iowa's universities to their faculty. This variability in the ability to provide technology transfer support results from the fact that technology transfer services typically are funded by retained earnings from licensing successes or other "indirect" sources. Given the importance of technology transfer and commercialization operations to the future economic success of Iowa, it is very important that the major Iowa universities engaged in bioscience have sufficient resources to facilitate high performance in this area.
- Faculty in the state are confused as to what is expected of them in terms of faculty entrepreneurship, intellectual property generation and idea commercialization. Many feel that their traditional research and teaching roles are threatened by a perceived requirement to start and run companies. Reassurance needs to be provided that universities are expected to contribute to economic development as research and talent engines through the generation of commercializable discoveries, ideas, and a future work-force—not necessarily that the faculty themselves must be the founders and managers of any resulting commercial enterprises. A structure at each university is required that would relieve faculty of the burden of commercializing their concepts, whereby faculty can disclose their discoveries and have a team of university commercialization experts evaluate it, assess marketability, and ultimately form companies around the most viable concept. Faculty should be free to be investors and technical advisors to companies that their inventions promote, and to be as engaged in operations and management as their interests allow.
- The University of Northern Iowa is in a somewhat different position. The Iowa Board of Regents has agreed that UNI must actively participate in research related to academic niches, and the state provides $600 to faculty members each year to support their research. And, UNI has invested in facilities and scientific equipment. But the challenge for an institution like UNI, whose faculty have full-time teaching loads, is to find the time and resources to secure federal grants in the way other universities support their faculties' bioscience efforts. Iowa may want to consider providing incentive or "glue" funds to bioscience-related faculty at UNI that would allow them to leverage additional outside research dollars for financial support for bioscience research. A small amount of research funding annually for biotechnology, e.g., $300,000 made available on a competitive basis, might stimulate large potential returns for UNI.

THE COMMERCIALIZATION CHALLENGE: TRANSLATING CORE COMPETENCIES INTO IOWA ENTERPRISE

Critical to the translation of identified core competencies into the Iowa economy are the external elements that are participated in, but not controlled by, the universities. If maximum yield for the state's investment is to be achieved then it is important to understand and integrate these additional external elements. It will be important to evaluate strengths and weaknesses and make appropriate investments to fill in gaps. The issues and challenges are many.

Observations on Current Status—Interviews with start-up companies in Iowa indicate that venture capital is scarce. Further, many early stage companies are run by inventors who have little experience in managing or growing a biotech company. The key to success in a start-up biotech, biomed or ag-biotech company, or any company, is knowing what to do. If the CEO does the wrong thing in a start-up company it often causes the company to fail. There is little room for error when money is tight. The past two years in the U.S. have been difficult times for acquiring investment capital. Previously it was easier to obtain funding and entrepreneurs had more room to move around and learn while they were building their business. Those circumstances may return, but for now investors require clear product pathways with proven management leadership to obtain funding. CEOs that have experience and have guided this process successfully before have little reason to move to Iowa unless they are given adequate incentives. One strategy may be to search for alumni who have been successful entrepreneurs elsewhere. It may be possible to recruit them to return to the state where they grew up or were educated. Investors will have a particularly difficult time believing that the biotech or pharmaceutical industries can grow and flourish in Iowa until several successful companies emerge and are able to grow in the state.

Human Therapy Product Companies—The biotech facts of life are that human therapy product companies (generally this is pharmaceuticals or biomedical devices) command ten times more attention from investors than agricultural biotech companies because of the huge potential product sales. Even though the pathway for products generally includes long regulatory approvals, there is potential for investors to realize a large multiple on their investment when the drug or device comes to market or when a large pharmaceutical company acquires the company. A skilled CEO in the bio arena can use significant events or milestones to attract more and more funding into a promising, growth company. No real history of human therapy product companies exists in Iowa. Some start-ups are located in the state but are failing to grow at an acceptable pace due to lack of investment capital or inexperienced management. If there is a strong desire to change that dynamic it will require skillful and patient investment by the universities involved, by the private sector, and by state and local governments.

Ag Biotech Companies—There is great opportunity in Iowa for this kind of technology-based business. The challenge in this market sector is finding a technology that has a compelling enough story to command investors' attention. The key here is size and accessibility of markets as well as how quickly products can be brought to market. Iowa has the potential to dominate in commercialization of the BioEconomy Platform that has been identified. The products from this platform can fill the pipeline for new start-ups and existing mid-sized and even large companies. Universities will have to become closer in relationships to industry and be willing to work out new relationships that will benefit both. The bio-fuel, biomaterials, and bio-based lubricants products that are being commercialized now in Iowa are examples of this kind of activity. These entities could provide early successes that the State of Iowa needs in order to develop a track record.

All three universities (Iowa State, The University of Iowa and the University of Northern Iowa) have new initiatives to build stronger bridges to the private sector. Iowa State has strong liaison personnel at the Research Park and the Carver Co-Lab. The University of Iowa has made new commitments to economic development (including a special economic development appointment within the College of Medicine), while the University of Northern Iowa has a skilled economic development advisor to the President who has developed several important initiatives. All of these efforts are timely and commendable, but need bolstering and further financial support if the hope of the state is to convert the products of its core competencies into economic value for Iowa.

Real estate is a small component of a successful start-up business plan (often in the form of incubators). What is much more important is the quality of management that can be attracted, or the quality of business mentoring that can be made available to less experienced entrepreneurs. There is also no substitute for money. Lack of capital will starve any activity that is started in biotechnology commercialization. The Pappajohn Centers are excellent but are insufficient by themselves.

Present Status of Technology Transfer—Start-up companies exist around all three Regent universities in the state. To be successful in creating more start-up companies in the future will require that the universities be rewarded for licensing to start-ups.

One larger Iowa company (350 employees) has spun out of The University of Iowa's Biochemistry Department and a former professor of biochemistry runs the company today. This is a good start, but the future will require many of these successes to convince investors to invest in Iowa biomedical start-ups. Platform technologies in Drug Discovery, Development, Piloting, Trials and Production and in Integrated Post-Genomic Medicine may create patents that can be licensed to a new group of start-ups. Infrastructure for this kind of economic development is yet to be put in place in Iowa.

In interviews, larger bio-related companies in the state have indicated a strong reliance on Iowa's universities for recruiting new employees. Many of these companies also sponsor research programs in the universities. Most are funding graduate student research as good corporate citizens—not anticipating that they will benefit directly. One company indicated that they had built a major division of their operations in Iowa because of the expertise of Iowa State University and the College of Veterinary Medicine. Another company had a highly proprietary project being funded at Iowa State because of the expertise of the principal investigator.

Competition in Bioscience Development

Other states and regions are aggressively pursuing life science development.

Other states are investing aggressively in a comprehensive range of bioscience programs to promote research and commercialization. A number of states also are aggressively pursuing bioscience development strategies, including strengthening research, increasing university-industry collaborations, and enhancing their business development support.

Examples of bioscience investments over the last few years include the following:

- California is investing $100 million in a bioengineering and biotechnology institute, and $500 million in pension funds toward the California Biotechnology Program.
- Pennsylvania has committed to invest $2 billion over a 20-year period in the biosciences including $100 million specifically for the Life Sciences Greenhouses initiative.

- Michigan, through its Life Sciences Corridor initiative, initially planned to invest $1 billion in the biosciences over a twenty-year period. However, this investment level may be scaled back due to programmatic modifications and budgetary concerns.
- Georgia has invested more than $300 million over a ten-year period to build core research facilities and to attract Eminent Scholars, the majority of whom are in the biosciences; and has created a $1 billion Georgia Cancer Coalition designed to make Georgia a national leader in cancer prevention, treatment, and research.
- Texas appropriated $800 million for seven new or expanded health science research centers.

Other states and regions of the country have allocated more state funding and secured significant federal dollars as the NIH budget has nearly doubled in the last several years. For example, as many as 41 states report technology initiatives that support the development of bioscience research and/or bioscience companies.[65]

[65] See Biotechnology Industry Organization, *State Initiatives in Biotechnology 2001*, September 2001.

Conclusion

The biosciences have been identified as the underlying technology platform for the growth of state and regional economies in the coming decades. States are realizing that their traditional economic bases may undergo significant change and increasingly are embracing the biosciences as a path to future economic progress. States such as Michigan, Pennsylvania and Wisconsin have recognized the opportunity to leverage their academic and non-profit bioscience research institutions to form growth hubs of innovation in this dramatically advancing field.

Significant bioscience economic activities in several specific technology platform areas are already showing promise—some of which have already begun to be mobilized as formal initiatives in the state and others that need to be further supported and built-up. These **near-term platforms** include:

- **BioEconomy—**Designing initiatives to make Iowa a leader in the application of bio-renewable resources to industrial commodities, products, and energy.
- **Drug Discovery, Development, Piloting, Trials and Production**—Leveraging Iowa's basic science and applied clinical research expertise in human medicine (and perhaps veterinary medicine) and proven track record in drug development and production services, into a vertically integrated pipeline of discovery and commercialization.
- **Advanced Food Products**—Leveraging skills in informatics, genomics, genomic transformation, metabolomics, nutrition, and food science to attain a leadership position in functional foods, phytochemicals, and nutraceuticals.
- **Integrated Post-Genomic Medicine**—Leveraging informatics, genomics, epidemiology and pathology, in combination with specific disease strengths, to create centers of excellence based on quantitative discovery and longitudinal data.
- **Animal Systems**—Using Iowa's skills in transgenics, animal genomics, food animal science, and biological sciences to develop a platform for the development and production of designer animals for gene/protein expression, xenotransplantation, and improved meat quality and productivity.
- **Integrated Biosecurity**—Building upon Iowa's proven strengths in plant, animal, and human infectious diseases, together with broad skills in agronomy, environmental sciences, engineering and other disciplines, to develop a holistic approach to the biosecurity of entire systems.

Additional **long-term** opportunities have been further identified in the following areas:

- **Host-Parasite Biology and Systems**
- **Instrumentation, Sensors and Devices**
- **Cardiovascular Institute**
- **Free Radical Institute.**

This assessment of Iowa's position in the biosciences highlights a state that has significant promise to be among the nation's bioscience leaders in selective fields. Iowa institutions have quite substantial strengths in the "three legs of the bioscience stool"— human, animal, and plant biosciences. In particular, the bioscience operations of both Iowa State University and The University of Iowa show fundamental bioscience technology platform strengths that can be further enhanced by increased collaborations between the institutions and with industry.

Appendix A:
Detailed Iowa Bioscience Subsector Performance

Table A-1: Iowa and National Bioscience Subsector Comparison, 1998 to 2002

IOWA	Agricultural Services	Agricultural Processing	Organic and Agricultural Chemicals	Drugs & Pharmaceuticals	Agricultural Machinery Equipment	Medical Equipment & Supplies	Research and Testing	Hospitals
Establishments								
2002	148	976	56	44	129	139	186	178
98-00	-41.2%	-29.5%	-1.5%	17.1%	-12.0%	14.5%	1.4%	9.6%
00-02	-14.9%	-2.5%	-12.5%	7.3%	-7.2%	-7.3%	-11.8%	4.1%
98-02	-50.0%	-31.2%	-13.8%	25.7%	-18.4%	6.1%	-10.6%	14.1%
Employment								
2002	1,187	19,458	4,416	2,515	10,115	1,847	1,429	41,882
98-00	-22.2%	-21.4%	-17.5%	2.0%	-22.3%	9.9%	-47.9%	2.6%
00-02	-12.3%	0.5%	134.0%	10.5%	-0.8%	-3.4%	20.4%	3.4%
98-02	-31.8%	-21.0%	93.0%	12.6%	-22.9%	6.1%	-37.3%	6.1%
Location Quotient								
1998	3.07	8.60	1.47	0.73	11.82	0.37	0.40	0.83
2000	2.67	6.95	1.32	0.74	10.64	0.41	0.19	0.88
2002	2.21	7.34	3.51	0.78	11.83	0.41	0.21	0.89
Wages								
2002	$ 18,794	$ 46,318	$ 52,760	$ 41,952	$ 51,672	$ 29,212	$ 36,699	$ 32,494
98-00	13.2%	5.2%	34.3%	6.3%	4.5%	18.8%	195.3%	11.0%
00-02	17.2%	7.5%	-16.5%	12.3%	3.8%	-12.1%	12.0%	12.3%
98-02	32.7%	13.1%	12.2%	19.4%	8.4%	4.5%	230.7%	24.7%
Percent Share of Private Sector								
1998	0.15%	2.07%	0.19%	0.19%	1.11%	0.15%	0.19%	3.33%
2000	0.11%	1.59%	0.15%	0.19%	0.84%	0.16%	0.10%	3.33%
2002	0.10%	1.64%	0.37%	0.21%	0.85%	0.16%	0.12%	3.53%
UNITED STATES								
Establishments								
2002	7,893	15,231	2,004	2,542	2,058	15,090	24,246	17,209
98-00	-7.7%	-2.8%	-1.9%	1.0%	-4.1%	-3.0%	3.2%	1.3%
00-02	12.7%	-2.1%	-1.1%	0.9%	-6.9%	-0.4%	7.9%	16.1%
98-02	4.0%	-4.8%	-3.0%	1.9%	-10.7%	-3.4%	11.3%	17.7%
Employment								
2002	48,860	240,623	114,263	293,314	77,598	407,044	607,255	4,283,173
98-00	-8.1%	0.1%	-5.7%	3.6%	-11.2%	1.6%	11.9%	0.0%
00-02	8.4%	-3.0%	-10.2%	7.5%	-9.0%	-2.2%	8.9%	4.4%
98-02	-0.5%	-2.9%	-15.3%	11.3%	-19.2%	-0.6%	21.8%	4.4%
Wages								
2002	$ 24,690	$ 41,970	$ 58,870	$ 73,129	$ 42,308	$ 49,940	$ 68,913	$ 38,159
98-00	3.8%	4.2%	4.6%	-3.5%	6.3%	8.8%	28.2%	6.4%
00-02	11.4%	6.8%	1.2%	10.2%	3.1%	7.1%	-3.5%	10.2%
98-02	15.7%	11.3%	5.8%	6.4%	9.6%	16.5%	23.7%	17.3%
Percent Share of Private Sector								
2002	0.05%	0.22%	0.11%	0.27%	0.07%	0.38%	0.56%	3.98%

Source: Battelle calculations based on ES-202 data from the US Department of Labor, Bureau of Labor Statistics and Iowa Workforce Development, Employment Statistics Bureau

Appendix B:
Detailed Iowa Bioscience Industry Definition

Table B-1: Detailed List of NAICS codes found within the Iowa Bioscience Industry.

NAICS Code	NAICS Description
Agricultural Services	
115112	Soil Preparation, Planting, and Cultivating
115210	Support Activities for Animal Production
Agricultural Processing	
311119	Other Animal Food Manufacturing (pt)
311211	Flour Milling
311212	Rice Milling
311213	Malt Manufacturing
311221	Wet Corn Milling
311222	Soybean Processing
311223	Other Oilseed Processing (pt)
311225	Fats and Oils Refining and Blending (pt)
311230	Breakfast Cereal Manufacturing
311613	Rendering and Meat Byproduct Processing
311822	Flour Mixes and Dough Manufacturing from Purchased Flour
311930	Flavoring Syrup and Concentrate Manufacturing
Organic & Agricultural Chemicals	
325191	Gum and Wood Chemical Manufacturing
325192	Cyclic Crude and Intermediate Manufacturing
325193	Ethyl Alcohol Manufacturing
325199	All Other Basic Organic Chemical Manufacturing
325222	Noncellulosic Organic Fiber Manufacturing
325311	Nitrogenous Fertilizer Manufacturing
325312	Phosphatic Fertilizer Manufacturing
325314	Fertilizer (Mixing Only) Manufacturing
325320	Pesticide and Other Agricultural Chemical Manufacturing
Drugs & Pharmaceuticals	
325411	Medicinal and Botanical Manufacturing
325412	Pharmaceutical Preparation Manufacturing
325413	In-Vitro Diagnostic Substance Manufacturing
325414	Biological Product (except Diagnostic) Manufacturing
Agricultural Machinery	
333111	Farm Machinery and Equipment Manufacturing
333294	Food Product Machinery Manufacturing
Medical Equipment & Supplies	
339111	Laboratory apparatus & furniture mfg
339112	Surgical & medical instrument mfg
339113	Surgical appliance & supplies mfg
339114	Dental equipment & supplies mfg
339115	Ophthalmic goods mfg
339116	Dental laboratories
334510	Electromedical apparatus mfg
334516	Analytical laboratory instrument mfg
334517	Irradiation apparatus mfg
Research & Testing	
541380	Testing laboratories
541710	R&D in physical, engineering & life sciences
Hospitals & Labs	
621511	Medical laboratories
621512	Diagnostic Imaging centers
622110	General medical & surgical hospitals
622210	Psychiatric & substance abuse hospitals
622310	Other specialty hospitals