Vision 2020 High Performance Computing Committee Report

High Performance Computing

- Computing applications requiring:
  - Large amounts of processing capacity
  - Optimization of processing, parallel computing
  - Customized computational solutions
  - Handling of very large input data sets or output data sets

Applications of High Performance Computing

- Analysis of large data sets (medical and biological images, economic and climate data)
- Modeling of new products or manufacturing processes
- Modeling of biological processes (drug-target interactions) in drug discovery
- Operational modeling of prototypes and new components

Private Sector Applications of High Performance Computing

- Aircraft design
- Human and animal health
- Natural resources exploration and utilization (oil, gas, water)
- Scientific research
- Climate and crop yield analysis
- Advanced manufacturing
- Economic modeling and workforce analysis

Critical Features of High Performance Computing

- Computing infrastructure
- Networking infrastructure
- Storage infrastructure
- Advanced computational science expertise

Rationale for State Investment in High Performance Computing

- Large established firms have access to high performance computing
- Smaller and emerging firms struggle to obtain high performance computing
- High performance computing can make a difference between being cost competitive or non-competitive

Role of University/Private Sector Partnerships

- Kansas Regent's universities have substantial resources in advanced computational science
- KU, KSU and WSU all have extensive track records in collaborative computing research with the private sector—the universities have a strong commitment to promoting economic development
- Promoting research collaborations in computing between emerging companies and universities will be a cost effective investment

How Much Investment is Enough?

- Many states that we compete with have already made substantial investments in university/private sector high performance computing partnerships.
- Computing infrastructure is expensive and costly to operate (top 50 system):
  - Up to $5 million initial investment (assuming pre-existing data center space)
  - Up to $4 million per year operating expenses

Current Strategy for Determining Need

- Kansas' research universities assess current strengths and weaknesses in high performance computing
  - Infrastructure
  - Advanced computational expertise
- Collaborate with Kansas Department of Commerce to define private sector need for high performance computing
  - By critical sector (manufacturing, health, natural resources).
  - By areas of emphasis for each institution.
- Project actual need for State investment and anticipated return on investment

Acknowledgements

- Vision 2020 High Performance Computing Task Force members:

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Summary Report:
Vision 2020 High Performance Computing Committee

David Larson, Chair; January 11, 2012

Executive Summary

A committee composed of representatives of the Kansas Legislature and Department of Commerce, the State's research universities, as well as various private sector stakeholders was tasked with examining the need of developing high technology companies for access to high performance computing (HPC) resources. The committee unanimously agrees that the State should seek to structure future investments in HPC resources in a way that will leverage collaboration between the private sector and the computational science researchers in our Regents' institutions. The committee further recommends that the Kansas Department of Commerce and representatives of the University of Kansas, Kansas State University, and Wichita State University collaborate to assemble a comprehensive picture of the high performance computing capabilities of the Regent's universities and the need of emerging high technology industry for access to high performance computing solutions. The data produced by this study will ensure that future HPC investments by the State will be adequate to address the needs of the developing high technology private sector and that these investments will be sustainable and provide maxim benefit for HPC users.

A. The increasing use of high performance computing in high technology applications.

As a nation, we face many challenges in the new century: maintaining world economic leadership, conquering disease, developing new sources of energy, and providing adequate supplies of food and water to name but a few. Many of these challenges will find their solution in research now being conducted in universities and corporations, and through collaborations that span university and industry laboratories. At this pivotal point in our nation's history, it is important that we position Kansas to play a key role in the nation's future through a strong and growing ecology of high technology businesses and research universities and the resources to solve the toughest problems facing the country and the world.

Modeling, simulation and data-driven science and engineering are essential for the basic research and product development processes that serve most modern high tech industries.[i] Airplanes, cars, computers, pharmaceuticals and medical devices, as well as many objects, household products and appliances we use every day are designed, tested and have their manufacturing processes developed using high performance computing (HPC). In this "21st Century industrial revolution", HPC plays a pivotal role not only in product design and manufacture, but also in business services such as the exploration for new energy sources, evaluation of complex financial arrangements and instruments, and production and delivery of entertainment media (movies, games, music and television). The availability of HPC capacity and expertise are essential to build the competitiveness of any region aspiring to be a leader in technology and knowledge-intensive industries.

It is important that we position Kansas to play a key role in the nation's future through a strong and growing ecology of high technology businesses and research universities.

Computational capacity is also critical for businesses as they transform basic research into innovative products. It is noteworthy that much of this innovation is accomplished by *small- and medium-sized businesses* that are key drivers both of economic growth and of the creation of high-skill, high paying jobs. These small- and medium-sized businesses frequently encounter significant challenges gaining access to the HPC capabilities they require: This is particularly true of the programming and database design skills required to solve cutting edge design and simulation problems.

In addition to modeling and simulation, *data-driven discovery* is a new and powerful use of HPC that applies statistical techniques to very large amounts of data about a system to uncover new relationships that can be used to build testable models about how systems work. For example, as more and more experimental and clinical data are collected in human health research and practice, data-driven discovery can be used to develop new medical diagnostic tests and personalized therapies based on the particulars of individual genomes. Because this process is data-intensive rather than computing-intensive, systems needed for data-driven discovery emphasize storing, organizing and moving large amounts of data as well as raw computing power.

Six essential components need to come together to make HPC modeling, simulation and data-driven discovery an essential tool for economic growth: Computing power, high speed data storage, high speed networks between computing and storage components, simulation and data management software, computational science expertise, and system administration expertise. Though it is necessary to create a system that provides all of these functions to meet the needs of developing high technology industry, the primary ranking tool for a computer's computational power is a set of linear algebra problems representing the computations needed to solve a variety of mechanical and dynamics problems. This test suite, the High Performance LINPACK Benchmark,[ii] ranks a computer's ability to perform the specified tasks in floating point operations per second (FLOPS), and a list of the top five hundred fastest computers are reported twice a year in the Top500 list.[iii] **Table 1** below shows rank in the November 2011 Top500 list, number of cores (CPUs), LINPACK benchmark in TeraFLOPS ($1x10^{12}$ FLOPS), and approximate capital cost.

Table 1. Selected entries in the Top500 supercomputer list, November 2011.

Name and location	Top500 rank	Number of cores	LINPACK performance in TeraFLOPS	Approximate Capital Cost
K Computer RIKEN Advanced Institute for Computational Science Japan	1	705,024 (Fujitsu SPARC)	10510.00	$1.2B
Red Storm -Cray XT3/XT4 Sandia National Laboratories	50	38,208 (AMD)	204.20	$50M
SuperServer 2026GT-TRF Virginia Tech United States	96	8,320 (Intel)	120.40	$2M
HP ProLiant SL390s IT Service Provider United States	500	7,236 (Intel)	50.94	<$1M

The type of "arms race" mentality that accompanies many of these exercises in rating computing technology should not be a primary driver behind our analysis of the HPC computing needs of universities and the private sector in Kansas. Rather, by defining the common HPC computing problems faced by Kansas' researchers, technology innovators and entrepreneurs, we can develop a reasonable timeline and estimate of the need for future investment in all facets of a comprehensive HPC system.

B. The need for HPC computing resources

The application of high performance computing in modeling and simulation for industrial competitiveness is a national priority. The U.S. Council on Competitiveness, through numerous studies, workshops and pilot projects over the last six years, has demonstrated that HPC plays a role in attracting businesses and a highly talented workforce and thus is critical for economic development at the state and regional levels.

> HPC is essential for addressing some of the nation's grand challenges: energy independence, protection of critical infrastructure (e.g., power, telecommunications, financial and transportation systems), and scientific leadership. But the real impetus for innovation occurs at the crossroads between businesses, national labs and other research centers, universities and skilled workers throughout the country. Regions have become the critical nodes for innovation-based economic growth, and some U.S. regions are already exploiting HPC in their economic development plans. Much more of this is needed. ...Many U.S. regions and states do not yet understand that HPC is crucial for economic development, for attracting the best-and-brightest companies and individuals.[iv]

The same need for HPC capacity is true for building the vibrant university-based foundation of scientific and engineering research that is required for the growth of high tech businesses across all areas of science and technology.

The application of high performance computing in modeling and simulation for industrial competitiveness is a national priority.

The Council's studies recognized three key areas of need that are common to small and large businesses: 1) HPC facilities at a reasonable cost, 2) software relevant to a businesses' problems, and, most important, 3) relevant expertise to help businesses use the software and hardware tools to maximum effectiveness. The availability of these assets is linked to the following benefits for regional private sector competitiveness:

- Shorter design and build times and lower overall cost for highly integrated products such as airplanes and cars.
- Better integration of supply chain engineering with OEM product engineering through virtual product and process design and testing.
- Minimization of raw material and energy use, and waste in process design.
- Discovery and exploitation of natural resources, including oil, gas and mineral deposits.
- Development of novel materials and compounds for U.S. energy self-sufficiency through modeling and simulation.

- Discovery of novel pharmaceuticals and development of medical devices through simulation.
- Lower healthcare cost through personalized medicine and efficient treatment based on individual genomes.
- Cost saving diagnostic tests through the blending of medical imaging with mechanical and fluid simulation techniques to model body systems.

The sections that follow outline three areas – private sector competitiveness, workforce readiness, and science and engineering research competitiveness – in which the State's competitiveness would be enhanced by access to improved HPC capabilities and services.

Private Sector Competitiveness: High Performance Computing and the "Missing Middle" of Manufacturing. Manufacturing is divided into tiers; with the large, original equipment manufacturing companies (OEMs) standing at the top of the manufacturing chain in the U.S. OEMs are supplied by about 300,000 smaller firms. These smaller "missing middle" businesses provide the OEMs with parts, design and process expertise, and advanced manufacturing equipment and processes. Though they typically they have fewer than 500 employees, the smaller businesses account for far more employment in aggregate than the major "name brand" companies. The smaller firms also account for 60 percent of R&D expenditures, as compared to the 40 percent provided by the OEMs (down from a total of 72% in 1981).[v]

Although small and mid-sized manufactures are clearly capable of providing the R&D innovations, many lack key tools needed to remain competitive in this increasingly global competition. As manufacturing and knowledge economy focuses more on "born digital" design processes, smaller firms need tools for high performance modeling and simulation. These tools need to integrate the research, design, and testing processes into the global supply chain. HPC-based design, modeling and simulation tools allow these firms to engage in faster innovation at lower risk. With additional computing power these companies can take on new design challenges, improve the efficiency and lower the cost of existing processes and improve their overall competitiveness. Many small and medium businesses have already started down this road, motivated by their OEM customers' requirements or by a need for a competitive edge in their market.

The presence of an HPC capability with an economic development focus in the state will also enable and encourage the creation of new types of businesses and services.

Still, the capital cost of acquiring either in-house or cloud-based HPC services and the cost of incrementally building computing expertise as new problems require novel computing applications and solutions, often pose significant barriers to adoption of digital design and prototyping tools for small and medium sized businesses. Recognizing the crucial role of these manufacturing firms as a primary contributor to economic growth, the challenge becomes how to lower the barriers to adoption of modeling and simulation tools in digital manufacturing.

HPC resources are also a critical tool for stimulating competitiveness among small, medium and large businesses in areas related to pharmaceuticals, medical diagnostics, human and animal health, natural resource development and utilization, and energy management. The presence of an HPC capability with an economic development focus in the state will also enable and encourage the creation of new types of businesses and services such as on-line diagnostic screening services, disaster planning and real-time emergency response coordination, and better water, mineral, and agricultural resource management.

Workforce development for a 21st century Kansas economy. High-tech industry desperately needs undergraduate and graduate students who are trained in advanced computing. HPC is used as a key business tool in many sectors critical to Kansas' economic future: Advanced manufacturing, virtual product design and testing, process improvement, pharmaceutical research and development, medical device design and manufacture, health care, advanced agriculture, economics, financial trading, development and evaluation of financial instruments, and many others.

Students who have access to educational programs that can provide training with leading edge computational tools will be far better prepared and far more able to keep the companies that hire them on the competitive edge than students who are not prepared to use the best tools at industry's disposal. Having a higher education system that uses HPC to collaboratively address the research needs of the private sector and employs advanced computing across the curriculum will produce better trained work force that will make it possible to attract and retain businesses that are important to the current and future economy of the State.

High-tech industry desperately needs undergraduate and graduate students who are trained in advanced computing.

Impact on science and engineering research competitiveness in higher education. HPC, and computing in general, are an indispensable part of the research and development mission of State research universities. Two areas of computation in particular – theory (model) testing by simulation, and data-driven discovery – make it possible for research teams to explore huge parameter spaces and sift through huge amounts of data in order to make new discoveries. Employing these strategies, limited budgets for experimentation can be efficiently used on the most promising leads. In some areas, such as nanotechnology design and modeling the action of new drug candidates, high performance computing has become a mainstay of research activity. A recent detailed study about the impact of investments in high performance computing on university competitiveness for R&D funding based on measures employed by the National Science Foundation determined that investments in HPC, and increased returns in terms of new NSF funding, increased faculty research productivity and are strongly correlated to research competitiveness.[vi]

The potential to boost competitiveness in these areas that are critical for the continued development of the Kansas economy is a strong argument for creating a plan to enhance HPC resources within the State. There is little doubt that State support for the development of a world-class computing facility would result in:

- Core capabilities that would benefit the competitiveness of all high-tech businesses.
- Key services that facilitate the development of ideas into new companies.
- Services to allow clusters of businesses to form efficient vertical and horizontal R&D relationships.
- Scientific and technological discoveries made by engineers and scientists at the State's Regents'

universities of increasing quality and value for the future of the state.

However, the cost of creating a competitive position for the State in HPC capacity could be very high. Estimates for the initial acquisition of a top-tier (top 50) computing capacity can easily approach $10 million, with recurring annual operational and maintenance costs amounting to around $4 million.[vii] For this reason, plans to develop these resources must address both shorter- and longer-term goals. In the short-term, the State must make investments that maximize value and engage the broadest range of the State's stakeholders in HPC resources. The State must then adopt a tiered approach to long-term investment in HPC, applying new HPC resources where this will enhance the competitiveness of private sector and university users while building a framework that will support an inevitably increasing demand for HPC resources. This long-term planning will help the State understand whether a costly investment in a top tier computing resource will become essential over the next five years, or whether the needs of developing high technology businesses can be met with a more modest series of investments.

C. The value proposition for current State investment in HPC resources

Given the importance of HPC resources in fostering the development of high technology businesses, a committee was formed at the request of Reps. Tom Sloan, Vern Swanson, and Gail Finney and chaired by Mr. David Larson to "explore the feasibility of Kansas developing enhanced computing capabilities to aid Regents' institutions researchers, private sector researchers in Kansas and as a business development and recruitment tool for the Department of Commerce." The committee has spent the last 5 months examining how to bring together the appropriate stakeholders from the private sector, the research universities and State government to advise the State on future direction for investment in HPC resources. The initial questions posed to the committee and responses to those questions are included in Appendix 1.

The committee has reached the conclusion that an important short-term value proposition for State investment in HPC capacity is to foster an environment where the HPC knowledge and expertise within Kansas' universities could be even more readily accessible to Kansas businesses. State universities and representatives of the private sector already cooperate to solve real world HPC problems facing the aircraft, energy and natural resources, and human and animal health industries. Moreover, Kansas' universities are committed to enhancing these interactions in ways that will support the competitiveness of Kansas companies and spur economic growth. This process has the added advantage of introducing university researchers with new, challenging problems that will help them move into the forefront of innovation and competitiveness among U.S. research universities. An advantage of focusing on expanding collaborations among the universities and private sector partners on HPC-related problems is that initial phase of this investment is likely to focus more on the need for additional computational science expertise (human resources) in areas of critical need (aeronautics, energy, human and animal health, natural resources modeling, etc.) rather than on expensive infrastructure. As private sector and university demand for HPC resources increases and a clear need case for new permanent infrastructure can be made, the State will be well informed about how to target investments in computing and networking hardware.

The next step in achieving the goal of enhancing existing HPC-related collaborations between Kansas' research universities and the private sector is to conduct a study of current university/private sector activities and assets. A proposed process for accomplishing these goals is outlined in the plan below.

D. Objectives and recommendations: Next steps in building High Performance Computing capacity

This project will conduct a comprehensive 12-month study of strategies for enhancing collaborations between the private sector and State research universities on HPC-related issues. The study will culminate in data that will guide future State investment in HPC computing resources. Representatives of WSU, KSU and KU, and personnel from the Kansas Department of Commerce will collaborate on collecting this information.

Kansas' universities are committed to enhancing these interactions in ways that will support the competitiveness of Kansas companies and spur economic growth.

The Project Objectives below identify the key goals of this initiative, while the Recommended Actions define the strategies that will be used to achieve these goals.

Project Objectives

1) Assess current strengths and activity in university/private sector collaboration on problems involving high performance computing.
2) Assess likely future need for high performance computing to support private sector development in Kansas.

Recommended Actions

Each of the recommended actions outlined below are linked to the one of the five project objectives:

1. *Assess current activity in university/private sector collaboration.*
    - Develop a survey to gather information on university/private sector collaborations in high performance computing at WSU, KSU and KU.
    - Work with research leaders on the three campuses to determine an optimal strategy for collecting this data.
    - Collect survey data and provide an analysis of the results to an advisory committee on high performance computing.

2. *Assess likely future need for high performance computing among the private sector.*
    - Create a high performance computing advisory committee composed of representatives of the research universities, key representatives of the private sector (e.g. aerospace, energy, agriculture, human and animal health, and manufacturing) and the Kansas Department of Commerce to guide development of a plan.
    - Gather input from the private sector on potential need for high performance computing resources.
    - Gather information defining industry concerns about using common computing resources.

Many states that compete with Kansas for high technology industry have already committed to these types of investments.

Over the next 12 months, this study will work to assemble the data needed to support future State investment in HPC resources. This study will lay groundwork for State actions that will promote the growth of Kansas' R&D capacity and promote the competitiveness of State industry.

Table A. Examples of high performance computing projects in other states.

	New York High Performance Computing Consortium (HPC2)	Computational Center for Nanotechnology Innovations (CCNI)	Rocky Mountain Supercomputing Centers (RMSC)	Renaissance Computing Institute (RENCI)	Blue Collar Computing
Established	2008	2006	2009	2004	2004
Home Institution	NYSTAR/RPI	Rensselaer Polytechnic Institute	State of Montana	University of North Carolina - Chapel Hill, Duke University, North Carolina State University	Ohio Supercomputer Center (OSC)
Partners	CCNI, Brookhaven National Lab, Stony Brook University, NYSerNet, IBM	IBM, State of NY, RPI	IBM	East Carolina University, UNC Asheville, UNC Charlotte and UNC's Coastal Studies Institute	Ohio Board of Regents, Council on Competitiveness, University of Southern California's Information Sciences Institute
Governance	Executive Committee is comprised of faculty and scientists from all participating institutions and led by RPI.	CCNI is a center under Rensselaer Polytechnic Institute (RPI). RE: Governance structure. All three partners (NY State, RPI and IBM) representatives attend weekly meetings which operational, business development and planning issues are addressed.	501(c)(3) not-for-profit corporation with a Board of Directors (Government, Academic, Private Sector & Industry Directors)	The Provost and VP for research of all university partners serve on RENCI's advisory board.	Program under the Ohio Supercomputing Center with its own Director
Mission	HPC2 is a partnership between NYSERNet and supercomputing centers at RPI, Stony Brook, Brookhaven, and SUNY Buffalo. Our goal is to increase New York State's competitiveness and foster economic development by providing industry and academic	Designed both to help continue the impressive advances in shrinking device dimensions seen by electronics manufacturers, and to extend this model to a wide array of industries that could benefit from nanotechnology.	To enable next generation discoveries, advancements, and solutions for commercial, academic, and governmental stakeholders through the utilization of high performance computing applications and services.	Develops and deploys advanced technologies to enable research discoveries and practical innovations. They build software tools, create visualizations, and employ powerful data management systems, networks, and	Collaborative program to help industry gain easy and affordable access to advanced computing technologies

	institutions with high performance computing resources, including staff with expertise in modeling and simulation.			computing systems to address problems in health and medicine, weather impacts and disaster management, and energy innovation.	
Available to commercial partners	Yes	Yes	Yes	No	Yes
Pricing Model	Chargebacks for services.	Transitioning to user fees.	1. Pay per Use 2. Fixed capacity/term 3. Turn-key and Customized Solutions.	One-half of funding provided by the state legislature, and one-half by sponsored research. Other than certain customers (Army Corps of Engineers, National Weather Service) there are no outside customers, and RENCI does not provide services to companies or others on a cost recovery basis.	Fee for service.
Services provided	1. A variety of HPC platforms, file systems, high bandwidth network connections, and computational science support. 2. Assistance with account creation and serve as a help resource for clients.	The consortium provides hands on assistance, through their scientists and engineers to the broader New York State user community, both to ease access to supercomputing resources at the institutions and to guide users in the utilization of HPC.	RMSC is a leader in supercomputing platforms for Cloud Computing. Provides the computing capacity to develop and design new solutions to complex problems more quickly and effectively. Assist organizations of all sizes to tackle complex projects, collaborate with		BCC provides computational resources, hardware, training, software and expertise, to industrial clients. Advanced computational technologies provide companies with tools for the virtual development of new and improved products. Virtual

			other innovators, and achieve goals within real-world time and budget constraints.		modeling and simulation improves manufacturing processes and assists in decisions regarding alternative processing methods
Research Focus Areas	bioinformatics, biogenomics, structural analysis, computational fluid dynamics, textual analysis.	optics, energy, nanotechnology, biotechnology, telecommunications, material sciences, information technology, environmental sciences, and economic and social sciences	None defined	1) Environmental Sciences – weather and flood forecasting, hydrology, emergency preparedness, climate change, etc. 2) Life Sciences – CTSA (NIH Funded Clinical Translational Science Awards) work for Duke and UNC, and genomics work	Expertise in supercomputing applications, networking, data communications, utility computing node operation, cluster installation, and training. Experience in a wide spectrum of subject areas, including: mechanical engineering, chemistry, visualization, data storage, and bioinformatics.
Funding	Grants, user fees, university and state support ($60M capital + $3M yearly operational)	Each of the three partners contributed to the $100 million partnership.	State appropriations, $5M per year.	Funded by a line-item appropriation to the UNC System level budget. RENCI's employees are employees of the UNC.	Industry contracts, economic development incentives, grants (small amount)

Appendix 1: Original questions posed by representatives of the Legislature to the Vision 2020 High Performance Computing Committee.

I. Committee background and mission. A committee was formed at the request of Reps. Tom Sloan, Vern Swanson, and Gail Finney and chaired by Mr. David Larson to "explore the feasibility of Kansas developing enhanced computing capabilities to aid Regents' institutions researchers, private sector researchers in Kansas and as a business development and recruitment tool for the Department of Commerce." Specific questions to the committee and responses are given below. A full report follows this summary.

II. Composition of the committee per commissioning letter. The committee consists of the following representatives: David Larson, Director, Legislative Computer Services (Chair); Stan Ahlerich, Economic Advisors Council; Dan Andresen, Associate Professor, Department of Computer Science, Kansas State University; Don Colbert, Kansas Bioscience Authority; Jason Glasrud, Department of Commerce; Keith Harrington, Kansas Bioscience Authority; Joseph Heppert, Associate Vice Chancellor for Research, University of Kansas; Bob H. Lim, Chief Information Officer, University of Kansas; Donald F. (Rick) McMullen, Senior Research Scientist, University of Kansas; Ravi Pendse, Distinguished Professor, Chief Information Officer, Wichita State University; and Ken Stafford, Chief Information Officer, Kansas State University.

III. Desirability, feasibility, and probable benefits of the state supporting development and/or upgrade of existing capabilities such that the state may market a top 50 in the world computing capability. It is the conclusion of this committee that the State Department of Commerce and representatives of the University of Kansas, Wichita State University and the University of Kansas collaborate to conduct a survey of private sector need for high performance computing and an assessment of the current capabilities of the Regent's universities to support the high performance computing needs of Kansas' industry.

IV. If the state were to pursue such a computer capability, determine the feasibility of such capability being scalable such that annual upgrades can be made to maintain a global top 50 status. One possible outcome of this study could be a call for the State to create a globally competitive "top 50" high performance computing capacity to serve the needs of the private sector and university researchers. The study is likely to recommend that initial State investments in personnel and infrastructure focus on incrementally building levels of service to meet the increasing needs both of businesses and of the research mission of our institutions of higher education over the coming decade. As the Kansas economy and the research activity of the Regents' universities continue to expand and diversify, the high performance computing needs of these sectors will eventually require the creation of a truly globally competitive computing capability.

V. Determine the probable value to Regents' institution researchers and recruitment efforts, and the prospects for attracting in-and out-of-state private sector interests contracting to use such computing capacity. The benefits of investing in high performance computing, storage and networking in research intensive universities has been estimated to be between a 5:1 to 7:1 return on investment in the form of increased federal funding in science and engineering research. This, with the well-understood necessity of having world class computing and data management facilities to attract and retain top research talent, is a strong justification for improving the research computing capability of our universities.

VI. If the prospective value to the state of establishing such computer capabilities is positive determine whether upgrading one or more existing Regents' Institutions' computers are scalable, whether one or more existing computer systems can be linked to address capacity needs/opportunities, or whether a new computer would be more beneficial and cost-effective. These questions need to be addressed in a follow up study that would engage nationally recognized experts in high performance computing as consultants to tailor new computational science expertise and computing infrastructure to meet the needs of Kansas' private sector/university partnerships.

VII. If the prospective value to the State of establishing such computer capabilities is positive, determine

whether a cloud infrastructure or a more traditional computer design would best meet long-term state Interests; and, such other issues is the group may determine relevant to the state's long-range best interests. A comprehensive follow up study will allow participating stakeholders to better address this question.

End Notes

[i] The term *modeling* refers to the use of mathematical equations and statistically derived relationships to represent the properties of physical objects and the physics of dynamic processes. Computer models are typically databases of properties and sets of computer programs that implement a model's physics equations. Computer *simulation* is the use of computers to explore how a model behaves under specific conditions, as in the use of mathematical models of aerospace structures to explore the behavior of a specific wing/fuselage designs in high-speed transport. Each real-world test of an aeronautical component can be incredibly expensive (costs can easily reach into the tens or hundreds of thousands of dollars per test), whereas computer simulations of the same events cost only a few dollars.

[ii] http://www.netlib.org/benchmark/hpl/

[iii] http://www.top500.org/. Today's fastest reported Linpack Benchmark is from Japan's Riken K Fujitsu machine at 10.51 quadrillion FLOPS, abbreviated 10.51 PFLOPS. By way of comparison, an iPad2 personal tablet computes at 1.5 billion FLOPS (1.5 GFLOPS) or about ten million times slower (http://bits.blogs.nytimes.com/2011/05/09/the-ipad-in-your-handas-fast-as-a-supercomputer-of-yore).

[iv] K. A. Holbrook, D. E. Shaw, Eds. "Collaborate. Moving Beyond Islands of Innovation," Council on Competitiveness, Third Annual High Performance Computing Users Conference Report September 7, 2006, Washington, D.C.

[v] National Science Foundation, Science Resource Studies, Survey of Industrial Research Development. http://www.nsf.gov/statistics/srvyindustry/sird.cfm.

[vi] Apon, A., S. Ahalt et al. (2010) "High Performance Computing Instrumentation and Research Productivity in U.S. Universities", Journal of Information Technology Impact, Vol. 10, No. 2, pp. 87-98, 2010.

[vii] These projected costs consider the use of existing spaces for housing new HPC infrastructure and support personnel. Construction of new facilities could dramatically increase these estimates.