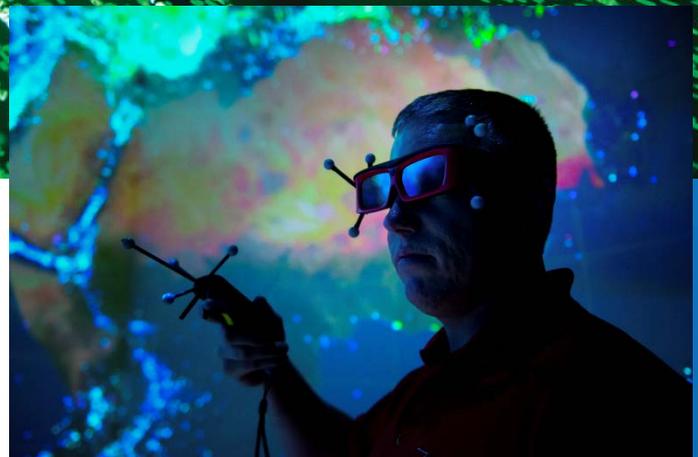
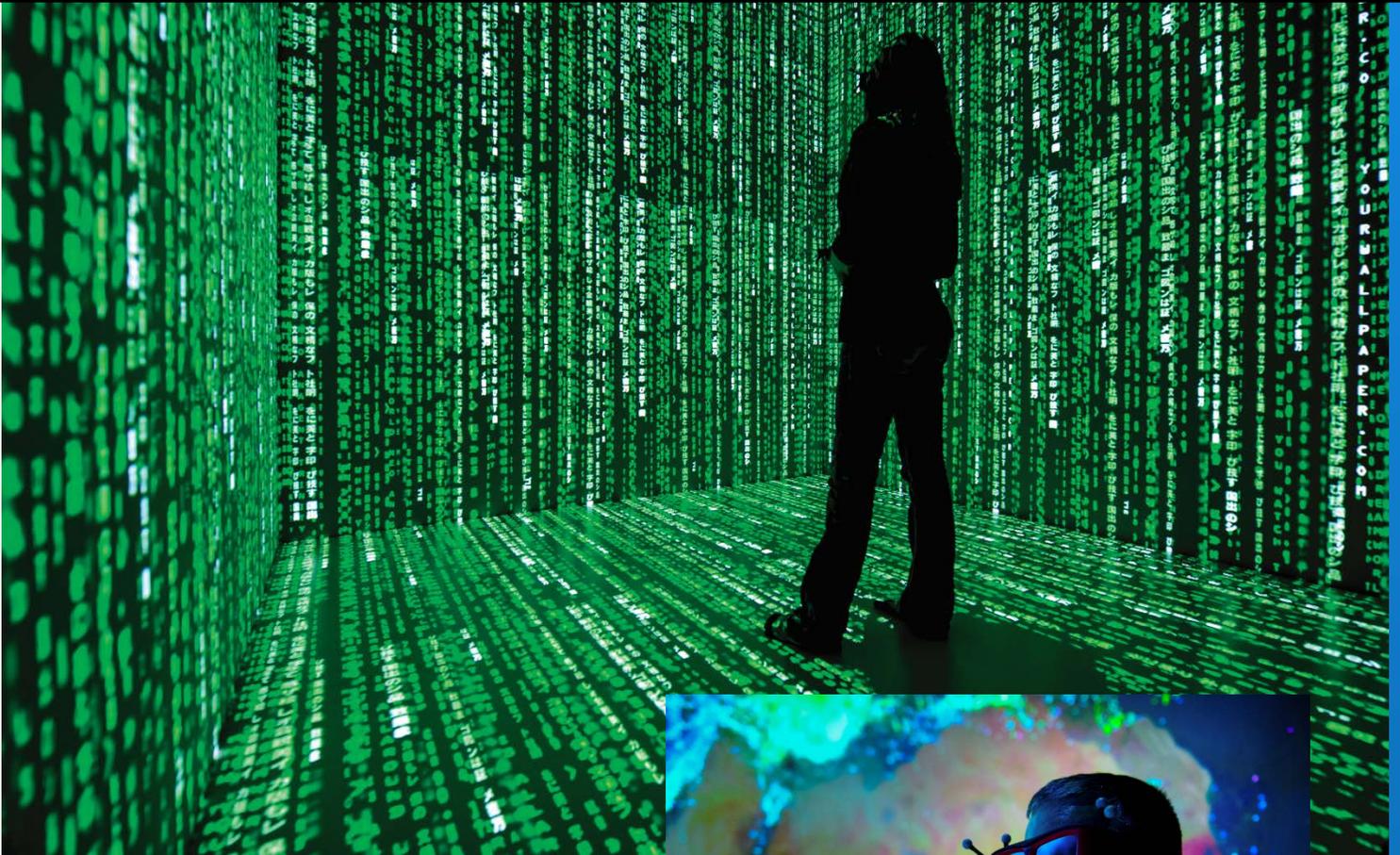


2016

Wyoming Science & Technology Plan



Office of the Governor

July 29, 2016

To the Wyoming EPSCoR Science and Technology Planning Group

I applaud your efforts to create a Wyoming Plan for EPSCoR Science and Technology. This plan allows for coordination and collaboration between a number of state interests and plans. Your focus on energy, water and computational science are core topics for Wyoming's economy now and in the future.

The EPSCoR plan recognizes high priority State of Wyoming initiatives, such as:

- Diversification of the Wyoming economy and support for technology as a key economic driver; and
- Support for the Tier-1 College of Engineering Initiative and the Wyoming Science Initiative. Both have the goal of the University of Wyoming earning a national leadership role in Science, Technology, Engineering and Mathematics research and instruction. We already see promising and exciting progress in these fields as a result of the initiative; and
- Opportunity for every Wyoming high school student to learn computer science.

The State of Wyoming has made significant investments in our Science and Technology infrastructure. These investments include:

- The NCAR Wyoming Supercomputing Center providing Wyoming researchers abundant resources through one of the world's most powerful supercomputers dedicated to the geosciences.
- The Wyoming Unified Network providing Wyoming students access to online resources from and around the world. Broadband capacity for K-12 school districts in Wyoming is top tier. Businesses around the state have access to tremendous networking capabilities and e-business.

I am pleased the plan recognizes Wyoming's K-12 schools, Community Colleges, economic development goals and economic strategies.

I look forward to the development of a reporting mechanism to provide information on the progress of each initiative. The plan is ambitious, yet achievable. I and Wyoming citizens will eagerly follow your progress.

Sincerely,



Matthew H. Mead
Governor

MHM:dp



Situation Analysis

“U.S. strength in science, technology, engineering, and mathematics (STEM) disciplines has formed the basis of innovations, technologies, and industries that have spurred the nation’s economic growth throughout the last 150 years.”

2016 National Academy of Sciences: Promising Practices for Strengthening the US Regional STEM Workforce Development Ecosystem.

July 2016

Introduction

Wyoming competes at the national and global levels in the Science and Technology (S&T) arena. This dynamic ecosystem is characterized by rapid and constant change, massive acceleration in the volume and type of data and information, the growth of informatics and analytics and the increasing complexities, uncertainties, and economic constraints therein. The 2016 S&T plan establishes a roadmap focusing on key features that have high probability of differentiating Wyoming and establishing a holistic approach that promotes agile, flexible, and adaptive execution across a broad array of innovation scenarios.

The 2016 S&T Plan amends and updates the previous (2010) plan and remains completely consistent with its mission. The Wyoming 2010 Science & Technology plan (see <http://www.uwyo.edu/epscor/files/documents/wy-science-and-technology-plan-2010%20.pdf>) proposes five strategies:

- focus R&D on strengths to establish critical advantage;
- support and expand WY R&D infrastructure at UW;
- build alliances among businesses, entrepreneurs, government, non-profit entities and academia;
- develop and retain an educated, technically-skilled and business savvy workforce; and,
- promote the S&T plan to increase public awareness and support for an innovation-driven economy.

These strategies remain highly relevant and have been supported by several major initiatives over the past five years.

In particular, these include the WY legislature funded Tier 1 **Engineering Initiative**:

https://www.uwyo.edu/acadaffairs/plans/uw_engineering_initiative_may_13.pdf

Science Initiative:

<http://www.uwyo.edu/science-initiative/>

NCAR-Wyoming Supercomputing Center

<http://www.uwyo.edu/nwsc/>

EPSCOR funded Wyoming Center for Environmental Hydrology and Geophysics

<http://www.uwyo.edu/epscor/wycehg/>

Wyoming’s Action Plan for Energy, Environment and Economy

<http://energy.wyo.gov/>

Wyoming admittance to the Center for Advanced Energy Studies

<https://caesenergy.org/>

In addition, the Wyoming State Department of Enterprise Services has built out the Wyoming Unified Network (WUN), providing very broad band connectivity to all Wyoming schools. It is the most complete network of its type in the nation.

Taken together these S&T investments have positioned Wyoming for significant advancement over the next 5 years.

In order to expand the scale and scope of the innovation pipeline, the 2016 Plan continues focus on energy, water resources, and high performance computing as areas of distinction. In each case, workforce needs are discussed. Imperatives for the 2016 S&T plan are designed to accomplish three main objectives:

- align the current energy production and export dependence business model with new approaches that will transition Wyoming toward a center for value added advanced materials and sustainable energy production and utilization;
- establish Wyoming as a national force in near sub-surface hydrology that is fundamental to all aspects of water resource management; and,
- expand high performance computational capacity that is foundational to innovation and deployment across the S&T arena.

Changes in Wyoming's economic landscape and outlook between 2010 and 2015

Since the last Wyoming Science & Technology plan in 2010-11, economic conditions in the state have changed significantly. Specifically, presently the state is experiencing a decline in energy related revenues. At the same time, however, Wyoming's technology sector is experiencing significant growth. What follows is an assessment of the economic factors which effect

Wyoming and which must be considered as the S&T plan is implemented.

Energy

In late 2010 the primary concern in the Wyoming and national economy was the slow economic recovery occurring after the "Great Recession" of 2008-2009 had ended. Along with this expected recovery, a general expectation of higher commodity prices, especially energy prices, was anticipated. This was predicted to be of great benefit to Wyoming with its large energy sector providing the base of its production economy. Still, in December of 2010, Wyoming and national unemployment rates remained elevated, with Wyoming reporting a 6.4% rate, having declined from a high of 7.2% recorded in January of that same year. The national unemployment rate was significantly higher, at 9.4%. This too had declined from a high of 10.0% recorded in October of 2009. Overall, economic conditions in Wyoming were sluggish due to low national demand for Wyoming commodities and limited growth in household incomes inside and outside the state, which depressed retail and tourism activity in Wyoming. Optimism that a national recovery would help Wyoming was widespread.

Moving forward to the end of 2015, national and state economic conditions improved markedly. In December 2015 the Wyoming unemployment rate stood at 4.3%, while the national rate stood at 5.0%. Nationally, the economy was approaching what economists refer to as near "full-employment," having experienced growth rates in national output of between 2 and 3% over the past five years in most quarters. In January of 2016, the national unemployment rate fell below 5% for the first time since 2007, recording a post-recession low of 4.9%. While post-recession growth historically has been stronger, national economic



performance over the past five years has been robust, especially when compared to other developed economies such as those in Europe.

Similar to the national economy, Wyoming's economic conditions improved steadily from 2010 through 2014. In early 2015, however, strength turned to weakness in the state and outcomes began to diverge from the national trend in the Cowboy State. In particular, Wyoming's unemployment rate, a general indicator of the strength of state economy, began to rise in March of 2015 after posting a post-recession low of 3.8% that February, and by January 2016 stood at 4.7%. While from 2011 to 2014 strong conditions had reduced Wyoming's unemployment rate and state incomes increased, a dramatic reversal of fortune over the calendar year 2015 resulted in Wyoming posting the largest increase in its unemployment rate of any state in the

country. The reason for this sudden reversal in economic fortune has been the sudden decline in energy commodity prices for oil, natural gas and to a lesser extent coal, and the ensuing production and revenue declines these price changes have caused. This also has created a sudden change from optimism to pessimism as Wyoming policy-makers looking forward.

Causes of energy price declines in Wyoming are varied with some beginning long before 2014. For example, in 2010 Wyoming looked back at the recent natural gas boom experienced in the early to mid-2000s, well before the Great Recession, and assumed that this sector would resume growth with a recovering national economy. In the early 2000s natural gas had revived the state's energy economy and had become the state's most important revenue source. Wyoming's Consensus Revenue Estimating Group (CREG) forecast in January 2011 presumed that by 2015 natural gas prices would be 15% higher than recorded in 2010, while state natural gas output would rise by 8% over that period.

This boom, however, never returned. Widespread use of hydraulic fracturing technologies, particularly in the northeast U.S. (including the Marcellus and Utica formations), while simultaneous increases in natural gas production also occurred in the southeast and southern mid-west U.S. The result was a sudden natural gas oversupply nationally, resulting in prices averaging below \$5/mcf, sometimes well below, for the entire 5-year period of 2011 to the end of 2015. Hydraulic fracturing has resulted in such an increase in natural gas production in the eastern United States that storage levels have broken records in consecutive years.

Since March of 2014 conditions in the natural gas market have been especially adverse for producers, with price declines of nearly 60% by February 2016. In that month prices stood at below \$2.00/mcf for the first time since 1999, during what has historically been one of the highest price months of the year as winter

demand causes a peak in prices. Comparing Wyoming natural gas output at the end of 2015 to levels in 2010, production has declined by more than 22%, and with it a significant source of state revenue.

Not all energy related news was negative since 2010 for Wyoming. Though gas declines have continued, revenue also increased from unexpected sources. Specifically, oil production enabled in large part by improvements in enhanced oil recovery techniques including hydraulic fracturing and directional drilling technologies and aided by

growth that had been observed for over two decades. Prices were anticipated to exhibit modest growth.

But the effect of cheap and abundant and importantly reliable natural gas coupled with the independent problem of retirement of an aging fleet of coal-fired power plants and new regulation has caused change in the coal markets. Coal and nuclear used to provide base load to the nation power delivery system. Now with abundant, and reliable natural gas it is becoming a baseload fuel of choice for power companies, further displacing coal from the market.

Table 1: Wyoming Economic Indicator Comparison 2010 vs. 2015

| | 2010 | 2015 | May 2016 |
|--|----------------|-----------------|-------------------|
| Unemployment rate (Dec.) ² | 6.4% | 4.3% | 5.5% |
| Unemployment change month-month ² | -0.2% | +0.2% | |
| Personal Income per capita ² | \$48,178(2009) | \$54,584 (2014) | \$55,303 |
| Coal (Powder River Basin) | | | |
| Production (short tons) ¹ | 426.5 | 370 | 120 ³ |
| Price (\$/short ton) ¹ | \$12.04 | \$13.50 | \$13.50 |
| Oil | | | |
| Production (millions bbl) ¹ | 51.5 | 85 | 6.53 ² |
| Price (Wyoming Sweet) ² | \$74.09 | \$32.29 | \$34.90 (Apr) |
| Price (Wyoming Sour) ² | \$65.92 | \$20.65 | \$26.17 (Apr) |
| Natural Gas | | | |
| Production (Tcf) ¹ | 2.54 | 1.969 | 0.68 ² |
| Price (\$/mcf – Opal Hub, WY) ² | \$4.03 | \$2.16 | \$1.71 (Apr) |

Sources:

¹ Consensus Revenue Estimating Group (CREG) Reports January 2011 and 2016; ²Y-charts.com; ³EIA.gov

new unconventional oil extraction methods caused output to increase by 65% between 2010 and 2015. This compared to 2010 CREG forecasts that anticipated a decline over that period of 7%. Further, oil prices over that period were also stronger than anticipated in 2010, at least through 2014, resulting in the realized total value of production in 2014 being 62% higher than projected in 2010. In 2014, oil severance taxes eclipsed those from coal for the first time in over two decades, to become the second most important energy commodity in the state after natural gas.

Compared to oil and natural gas, predictions made by CREG for coal in 2010 were actually relatively accurate, at least from the perspective of production value. In 2010 it was anticipated that coal would continue its steady production

Therefore, actual outcomes were somewhat different as production began to decline slowly. Still, realized coal prices over the period exceeded 2010 predictions with the result being that the value of coal production in the state in 2014 was only 11% below the 2010 prediction. Coal will remain an important fuel for the nation's power production, but will probably continue to see a decline in demand as natural gas supply remains strong and more aging coal-fired plants are taken off line and replaced with natural gas for renewables.

Overall, from 2010 through 2014, while realized changes in specific energy commodity markets important to Wyoming were generally not predicted, the positive outlook predicted across energy markets was mostly realized. Total value of energy commodities produced rose by 10%

between 2010 and 2014, increasing state revenues and employment. Oil, gas and coal employment remained strong throughout the period in Wyoming as did total drilling rig counts and other measures of energy sector production. Wyoming's average per capita personal income levels, in part driven by the healthy energy sector, rose from \$48,178 in 2009 to \$54,584 in 2014, and as previously noted, unemployment rates continued to decline throughout this period.

Unanticipated changes in world oil markets, however, radically changed the Wyoming outlook in 2015. World oil prices, having hovered in the \$100/bbl range for much of the period from 2011-2014, crashed in late 2014 to levels below \$50/bbl by the end of the year. After recovering to approximately \$60/bbl in mid-2015, prices again fell and by January of 2016 stood below \$30/bbl. The first three months of 2016, oil traded in a narrow \$30-\$40/bbl range. The fall in oil has resulted in about 5,000 job losses in Wyoming, and this is the primary cause of the sudden increase in the Wyoming unemployment rate over 2015. Oil price declines are anticipated to result in Wyoming production falling over time and CREG estimates now forecast Wyoming oil production in 2020 to be nearly 25% below the level recorded in 2015. Over this same period oil prices, while predicted to recover somewhat, are anticipated to remain below \$60/bbl for the rest of the decade, resulting in oil revenues 30%-40% lower than observed in the first half of the decade through 2020. Finally, there is very little Wyoming can do to bolster oil prices since this commodity, perhaps more than any other energy market is under control of powerful geopolitical forces acting on it worldwide.

Overall, the Wyoming economic outlook has changed significantly since the 2010 Wyoming Science & Technology plan. In that year expectations were of a national and statewide economic recovery, and stronger economic growth over the coming five years. In early 2016, while the national economy remains quite strong, Wyoming anticipates very weak, if not recessionary

conditions for the next few years. Low energy price and production outcomes, proportionate reductions in overall economic activity, and government austerity to offset attendant tax revenue shortfalls will all contribute to continuing depressed economic conditions in the state.

Growth in Technology-Related Business

The Laramie-Cheyenne Corridor

A stated goal of Wyoming's Governor Mead is to make technology the 4th largest business sector in the state. While Wyoming's energy economy was experiencing declining prices, the innovation and entrepreneurial economy continued to add steam. Much of this increase was noted in southeastern Wyoming and more specifically in the Laramie-Cheyenne corridor. Through considerable leadership by Cheyenne's LEADS, the local economic development entity and the University of Wyoming, significant innovation based business was added in both locales.

LEADS effectively demonstrated its North Range Business Park is a great location for technology based business. This location has abundant electrical power (through Cheyenne Light, Fuel and Power), redundant optical fiber from various sources, a large amount of land holding and installed infrastructure. Furthermore, for those entities interested in data and computing centers, both Cheyenne and Laramie have a cool, dry climate that helps reduce operational costs.

LEADS provided the land and infrastructure necessary to bring the

National Center for Atmospheric Research supercomputing resources from Boulder, Colorado to the Front Range Business Park. Now known as the NCAR-Wyoming Supercomputing Center (NWSC), this facility houses one of the nation's largest computer systems for science discovery. NWSC and its computing infrastructure effectively demonstrated that Cheyenne is an excellent location for data and computationally based business. For example, this facility is one of the top two or three and perhaps the most efficient computer system in the world. Boasting a power utilization efficiency (PUE) close to 1.0 -- meaning that in this facility, for every megawatt of power used for facilities operations a very similar power usage is realized on the computing system itself; many data and computing facilities use two or three times more power for facility operation than for computing systems operation thus reporting a PUE > than 2 and oftentimes higher -- NCAR-Wyoming Supercomputing Center more than anything else demonstrates how efficient data centers can be in southeastern Wyoming's climate. The amenities provided by the North Range Business Park and the decision by NCAR to place their supercomputer at this site was an important signal nationwide that southeastern Wyoming should be considered for data and computational center placement.



As a result, Microsoft Corporation made a decision to place a large-scale data center at the North Range Business Park. Microsoft has now completed multiple buildings at the site and more are planned, making it a major location for their data and computing services.

Cheyenne is home for EchoStar Corporation's broadcast center. This company is a major provider of satellite and video delivery solutions and Cheyenne is home for their up-link and down-link satellite services. Cheyenne's geographical location, basically in the latitudinal middle of the U.S., is very important in satellite communications. EchoStar taking advantage of this fact and the abundant power and redundant optical fiber installed their technologically rich the broadcast center.

Greenhouse Data, LLC is another important technology player in Cheyenne. This large-scale data center, also takes advantage of redundant optic fiber, while delivering cloud hosting, high-performance colocation, managed IT services and disaster recovery solutions to its customers. And there are other technology related businesses in Cheyenne.

Lastly, Cheyenne is the northern terminus of a series of Front Range cities stretching from Pueblo, Colorado in the south, to Cheyenne. This large population center includes Colorado Springs, metropolitan Denver including Boulder, and Ft. Collins. It is one of the nation's larger technology centers and includes significant technology related businesses, important higher education facilities including one of the largest medical centers in this part of the United States and many large federal installations with significant technology such as NCAR, NOAA/NIST, and NREL to name a few. Resident in the Front Range technology region are many of the nation's largest technology companies, such as IBM, Intel, Hewlett-Packard, Ball Aerospace, to name a few. There are 97,200 students in the major universities along the Front Range with a total research income greater than \$1 billion annually providing a very large source of funds to produce technological advance.

Laramie, with the University of Wyoming, is the other part of the Laramie-Cheyenne Corridor. Considerable growth in the technology business sector has

occurred here as well. In 1994, there were approximately 8-10 technology-related businesses in Laramie. Due to a concerted effort by the University of Wyoming this number has now grown to approximately 60. Of these about 85% have a connection to the University. Importantly, graduates from the University of Wyoming

provide a significant workforce to these companies as well as a base of new entrepreneurs interested in starting a business.

This growth is rooted in a three-pronged plan developed and put into action in 1994 to spur such growth. First the University became host to a set of business assistance programs including the Small Business Development Center (SBDC) and the embedded Market Research Center and a Procurement and Technical Assistance Center, a Manufacturing Extension Partnership (MEP) program known as Manufacturing-Works (MW), the Research Product Center (where IP protection and licensing occurs) and a statewide Small Business Innovation Research (SBIR) program.

From 1994 to 1998, the University of Wyoming provided all funding for the Small Business Development Centers, the MEP at that time, and the infant Wyoming SBIR initiative (funded through an NSF EPSCoR grant). Through action of the state legislature, the Wyoming Business Council was created and as part of this action, funding going to the university to run these programs was shifted to the WBC. Since 1998, the Wyoming Business Council and the University of Wyoming have participated in perhaps the most profound partnership for economic development found anywhere, due to the uniqueness of having a single state entity created for economic development purposes and a single research university. Through the years, these programs (now known as the Business Resource Network – the joint business assistance programs supported and run by the two entities) have become more successful in being able to provide more and more support to small

business of all kinds statewide. Since their inception, these programs have helped inject more than \$500 million of capital into the state's businesses which in turn have created or retained more than 17,000 jobs. These are very significant numbers and they clearly demonstrate that the partnership works, is relevant to Wyoming, and that small business is an important economic force in Wyoming.

Of course the second element of the plan was to grow the research enterprise as large as possible. Rearranging the University of Wyoming's Research Office budget allowed for maximum funding that could be made available for three purposes each having a significant effect on growing UW's research enterprise, namely creating new faculty start-up funding, matching significant grants and equipment purchases. As a result, growth in external funding to the university grew from about \$25 million in 1994, to an amount approaching \$100 million in 2016. In addition to all the public good done with these external awards, a goal was to create a healthy stream of intellectual property emanating from the research to be used in helping to create an innovation economy around the University.

Capturing innovation stemming from faculty research was the second prong of the plan. In 1994 the University had very few patented technologies, even though the emancipating effect of the Bayh-Dole act had been in effect since 1980 – almost 15 years. Working with faculty, the University's patent portfolio now has 100's of protected technologies. This represents the University's well-spring of technologies from which innovation companies can arise. Just as important as protecting the technologies are marketing and licensing to established business or to spin-out companies. Today nearly 30 spin-out companies and start-up companies have been created and many developing significant business presence in Laramie.

A major element in the strategy to capture University of Wyoming

technologies was creation of the Wyoming Technology Business Center in 2006. It has become instrumental in the development of technology related start-up companies and improving the entrepreneurial ecosystem throughout Wyoming. Within the context of Wyoming being profoundly rural, there is not an indigenous reservoir of experienced business executives/entrepreneurs or experienced technology segment business service providers that could be used as mentors or advisors who might be utilized to council startups and spinouts.

The WTBC is working to fill the above-mentioned gap (shared with many other rural regions in the U.S.) using highly skilled professionals to counsel new business through the various stages of their growth. Importantly this service is now being provided to two other incubator locations in Wyoming, Casper and Sheridan along with distributed service to other Wyoming locales.

Eight companies have graduated from the Wyoming Technology Business Center, UW's technology business incubator, of those we have specific information about the economic impact of six (the other two are too recent at this writing):

- there are 112 FTE employees;
- average annual salary of \$65,000;
- almost \$16 million in total revenue; and,
- occupying almost 40,000 sq. ft. of leased, or build space.

Laramie is home for approximately 65 technology-related companies. Many of these are the direct result of UW licensing activities. Others were recipients of services provided by the Wyoming Technology Business Center, and finally several exist because of University activity. Taken together a robust and growing sector of the Laramie economy is occurring. They clearly represent that technology companies reside near research universities for a variety of reasons, key among these are a steady flow of workforce in the form of graduating students with skills

demanded by these companies. However, the University provides other services to these companies as well such as assistance with SBIR awards, other forms of technology-business counselling and access to sophisticated equipment and faculty expertise to assist in solving problems or creating new lines of products.

Laramie is gaining the attributes found in other technology hubs related to universities. For example, many of the technology companies



are occupying buildings in the old downtown. This is common in other technology centers associated with research universities, for example Boulder, CO, Austin, TX and Clemson, SC, resulting in a resurgence in downtown areas with other new businesses like coffee shops, restaurants, etc. catering to a relatively unorthodox workforce (bike riding, late arriving – late leaving, etc.) developing. Laramie government is reacting to this growth as well with ordinances supporting the diverse workforce required by technology business.

Technology is gaining a toe-hold in other parts of Wyoming as well. Jackson is home to several technology-related businesses. This community has a strong support system for building technology based-business with business competitions and anonymous angel investing groups. Sheridan and Casper each have a small but growing technology sector. Innovators throughout Wyoming are served by a strong business support network provided by a partnership between the University

of Wyoming and the Wyoming Business Council – the Business Resource Network.

The WUN has attracted the attention of large players in the technology sector. Microsoft has committed to building a \$750,000 data center adjacent to the WUN. Salesforce is targeting the delivery of cloud services through Wyoming's massive capacity. Google has heralded Wyoming's partnership in leveraging the best in application and data services.

Major Developments in Wyoming's Science and Technology Infrastructure

Major growth in Wyoming's science and technology infrastructure has occurred throughout the past five years. This represents in total investment by the State of Wyoming in science and technology approaching \$320 million. Each investment will have a significant role in placing Wyoming on a new and far more substantial footing than in the past.

The Wyoming Unified Network

UW is one of the founding members of the Front Range GigaPOP (FRGP) – a major point of access onto the nation’s research networks. Connected through the Bi-State Optical Network (BiSON) UW enjoys 100 gigabits per second (Gbps) bandwidth connectivity to other Colorado universities and institutes including NCAR and to the FRGP. An additional fiber track capable of 10 Gbps directly connects UW and the NCAR Wyoming Supercomputing Center (NWSC) and provides greater redundancy to the BiSON Loop and FRGP.

Over the past 5 years, led by Wyoming’s Governor Mead and with the support of the Wyoming State Legislature, a 100 gigabit, redundant, statewide network backbone known as the Wyoming Unified Network (WUN) was designed, engineered, and completed. This \$16 million project leveraged innovation in numerous areas including technology, the supply chain, procurement, business and service models and operational strategy.

The WUN connects to the FRGP from two directions over the BiSON ring, placing Wyoming directly on Internet and Internet2. Wyoming peers with Microsoft and Google in Denver, Colorado.

In addition, the WUN can connect directly to Wyoming located data centers, creating a closed economy with contractor preference for delivering cloud solutions directly to any education or government facility in the State. This ability places statewide commercial data centers “On Net” presenting an unparalleled opportunity for innovation in Wyoming’s technology ecosystem.

Key components of the WUN include:

- A 100Gbps IPv6 backbone connecting school districts and State offices via Ethernet.

- School districts connections to Internet2 and 40-fold increases in capacity.
- Direct connections to the backbone for Wyoming data centers that provide protected services to State agencies and school districts.
- Many Wyoming cities gained either 10 Gbps or 100 Gbps access from multiple vendors thanks to Wyoming partnerships with private industry.

This backbone currently exceeds the White House’s ConnectED educational broadband targets for 2018, and places Wyoming, along with Hawaii, as the most connected. The Wyoming State Legislature plans on sustaining the WUN at the level of \$12 million per year.

Computational Science

Currently, UW’s computational resources place it amongst the very highest in an American university in terms of available computational resources and networking. These resources are crucial to innovation in scientific advances and the information management to position the state at the forefront of the 21st century knowledge economy. Major strides in computational science include:

- Maximization by UW scientists and students of UW’s share (which currently is 75 million core hours per year) of the computational resources at the NCAR Wyoming Supercomputing Center. See Figure 1.
- The growth, and extensive and broad usage of UW’s computing cluster (Mount Moran), high performance storage system (Bighorn) and support group house in the Advanced Research Computing Center.
- The installation and high-utilization of Loren, a GPU-based supercomputing system at UW optimized to study the flow in porous media at the pore scale.
- The design and installation of the Wyoming PetaLibrary, a large scale storage system providing UW researchers with scalable, flexible, long-term digital and archival storage with guaranteed protection, integrity and interoperability with UW and national cyber-infrastructure resources.
- 100 Gigabit network connections to the Front Range GigaPOP (a major entry point into the nation’s research networks) that allows UW faculty and students to access an array of major computational resources in those, including those including those maintained by NSF and DOE.
- New partnerships such as the joint UW-NVIDIA GPU Research Center, and UW’s partnership with the Center for Advanced Energy Studies at the Idaho National Lab.

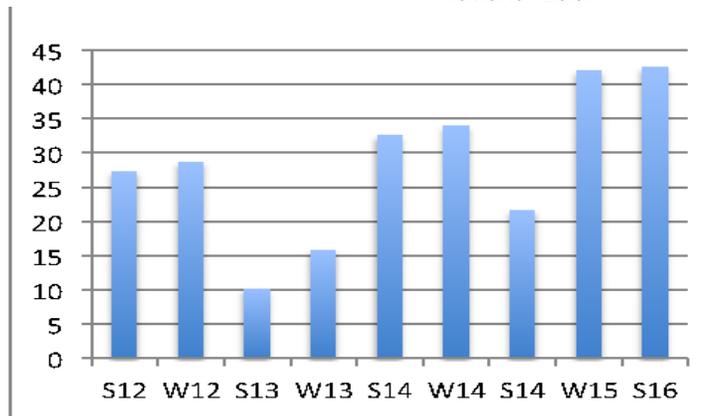


Figure 1: Growth of UW Allocations at the NWSC in millions of core hours. Allocations are awarded every summer (S) and every winter (W), and UW’s share is 75 million core hours.

Investments in cyber-infrastructure have and will continue to allow Wyoming researchers to address grand challenges in water, energy, transportation, and environment that are facing Wyoming and the Nation and compete effectively at the national level. Recent major research projects utilizing Wyoming's computational capabilities include but are not limited to the following:

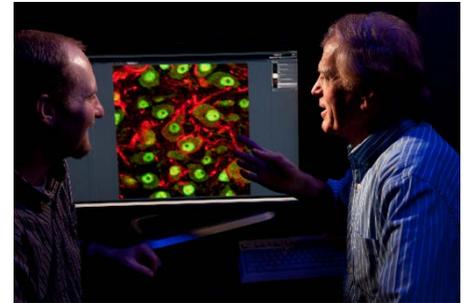
- The NSF funded Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG) project combined new technologies, interdisciplinary research and computation to provide better understanding about water pathways and develop tools that have led to improved water resource management.
- The NSF funded CI-WATER project produced ADHydro, one of the most robust, high resolution, water modeling systems in the world. This tool includes all processes relevant to water (e.g. evaporation and transpiration, human factors and more) and enables water professionals to benefit from high-performance computing (HPC) capabilities without having to develop HPC expertise. At present, the National Water Center and the National Weather Service are exploiting the capabilities of ADHydro to make it the framework for their high performance computing relative to surface waters including flood and drought prediction, river management and for modeling of the effect of severe storms on surface waters.
- The Hess Digital Rock Physics Laboratory at UW hosts a suite of some of the world's most advanced high-resolution 3-D X-ray microscopy instruments which are devoted to increase the understanding of underground oil and natural gas reservoirs. This research leverages the computational power of Loren, UW's GPU-centric supercomputer.

- The Department of Energy funded "Atmosphere to Grid: Addressing Barriers to Energy Conversion and Delivery" a project that brings together researchers from six departments to look at barriers for penetration of renewables into the electrical grid. Expected impacts include improved placement of wind farms and individual turbines in areas of complex terrain and transient weather; increased efficiency of wind farm generation; a better understanding of how high use of wind power will impact the reliability of the power grid; and development of economic models for diverse and variable energy generation and transmission scenarios allowing managers to understand where and when to send wind generated electricity to maximize efficiency and profits. These examples illustrate how leveraging computing capability (e.g. more and faster processors, ample storage capacity and network interconnectedness) accelerates scientific discovery for Wyoming researchers.
- NVIDIA Corporation has named UW as a NVIDIA University and is providing NVIDIA technology for UW faculty and students to work with. UW is rapidly becoming a location where graphic processors units (GPU's) such as those manufactured by NVIDIA are used to develop unique solutions to high-performance computational problems.

It is very apparent that since the last plan went into effect major initiatives supporting science and technology have occurred. The major projects listed above are the most apparent, but they do not in themselves constitute a comprehensive list of achievements. Below lists some of these major achievements.

High performance computing (HPC) is a central component of Wyoming's capacity to compete at the national level and enhance a stable, sustained ST based economic environment. It allows Wyoming researchers to

address grand challenges in water, energy, transportation, and the environment that are facing Wyoming and the Nation and to compete effectively at the national level. And, it leverages Wyoming's past investments in faculty with computational expertise, the State's investments in data centers, it's K-20 educational system, and the NCAR-Wyoming Supercomputer. Importantly, computational thinking is absolutely critical for a 21st century workforce.



Computational science has grown to become the third pillar of the scientific enterprise, together with traditional methods of physical experimentation and theoretical investigation. The ever increasing power of high performance computers enabling rapid calculations, drives ever-increasing accuracy of simulations of natural phenomena, manages and analyzes enormous data sets, and creates insightful visualizations.

In turn, Wyoming researchers have leveraged these resources to make

major breakthroughs on grand challenges that are critical to Wyoming and the nation. UW's Academic Plans and Initiatives have, and continue to target computational science as a major focus area. As a result, over 30 faculty members, in a variety of disciplines, whose research is highly computational in nature have been hired.

The NCAR-Wyoming Supercomputing Center (NWSC) is a petascale (15 quadrillion (1,000 trillion calculations) per second), supercomputing center designed to maximize data-intensive science. NWSC opened in October 2012. The Wyoming legislature's \$40M investment in the NWSC provides UW's researchers with a 20% allocation of the NWSC resource for each year through 2032. Yellowstone's successor, Cheyenne, is a 5.3 petaflop system due to come online in January 2017. It has approximately 3.8-times the computing capacity of the present system.

UW's 10-year-old \$34M Information Technology facility houses a state-of-the-art student computing lab and a \$6M, 6,000 ft² data center with Tier II+ redundancy. Further, UW has recently developed a comprehensive cyberinfrastructure plan outlining strategic, sustained investments (of approximately \$750,000 year) in the networking, hardware, and personnel to support computationally enabled research. The system includes Mt. Moran (an approximately 180 TFLOPS high performance cluster for modeling, data analysis and data-mover nodes, and a shared pool of 800 Terabytes of network attached high performance disks). Currently hosting over 200 users, the system runs around 90% capacity on average. A successor to Mt. Moran will be installed in early 2017.

A petascale GP-GPU based cluster, Loren, devoted to interfacial and pore-scale flow analysis was installed in the Spring, 2015. Additional computational resources include the School of Energy Resources CAVE and Wyoming Geographical Science Center. SER houses a state-of-the-art visualization center to enable

data-intensive science, and engineering research by transforming massive data sets into representations and patterns with which people can work. The center provides UW researchers and Wyoming companies with a broad range of visualization technologies ranging from the desktop visualization to an immersive 10' x 10' x 10' cave for 3D, interactive visualizations.

The Wyoming Geographic Information Science Center (WyGISC) is an interdisciplinary research institute housed at UW focused on the development of geospatial information and technologies and their applications in science, education, government and business. WyGISC provides leadership to the Wyoming geospatial community, advocating for coordinated development of a statewide spatial data infrastructure and supporting standards and policies for data development, sharing and stewardship. In addition, a cadre of IT specialists designed to enable faculty and student research includes specialists in application development and optimization, data-analysis, research network engineering, HPC system management, user support and a high-performance storage.

Science Initiative

Over the past three years, the University of Wyoming, working with an external committee appointed by the Governor, developed a plan to enhance several science disciplines at the University of Wyoming. As a result, the Wyoming legislature appropriated approximately \$100 million for the construction of a new science building on campus to house two departments, Botany and Molecular Biology, and support the newly formed Center for Integrative Biology. As these two departments belong to two different colleges (Botany – Arts and Sciences; Molecular Biology – Agriculture and Natural Science), their occupation of a single new building will promote

interdisciplinary collaboration among two of UW's strongest research programs. The new building also will promote interdisciplinary collaboration among life scientists, chemists, physicists and geologists by housing the newly formed Center for Advanced Scientific Imaging that will provide a variety of imaging technologies and their support personnel. Further supporting the imaging, is a link-up between UW astronomers with the Apache Point observatory. Within the building will be office and research laboratory facilities for faculty and their students both graduate and undergraduate, a research greenhouse and other amenities supporting discovery and innovation.



The new building will contain large active learning classrooms for the core sciences to support UW's transitioning active-learning in the sciences.

A permanent increase to the University's state funding of \$1.15 million annually to support a variety of science initiative programs including seed funding for faculty research, an active-learning mentorship program for faculty and graduate students, funding undergraduate student research in a sponsoring laboratory was included in the new legislation.

Engineering Initiative

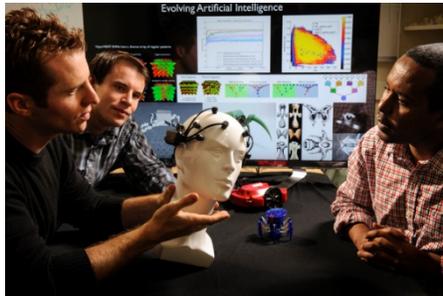
After the Wyoming Legislature called for "an approach to lead the University towards Tier 1 academic and research institution in areas of excellence appropriate for Wyoming" the Governor created and charged a taskforce to develop "a well-articulated, understandable strategy that will enable us to fulfill the challenge of becoming Tier 1." Further the Governor "cited significant investments already made at the University in the areas of energy, engineering, computational capacity, science, technology and mathematics as providing a solid foundation for moving forward, the Task Force "interpreted" the Governor's notion as an "integration that" includes programs as well as physical facilities."

The Taskforce plan included eight specific points:

- defining areas of distinction;
- improving integration across colleges and facilities;
- improving and enhancing undergraduate curriculum;
- improve the number and quality of facilities;
- improve the inflow of quality of students; and,
- improve connections with industry and alumni.

Over the past two years, UW has designed a new engineering facility, funded largely with funds from the State of Wyoming, and construction of this building will start in the Fall of 2016. Private funds also are being raised for construction as well. Currently the building is almost \$102

million. It will hold specific space for faculty offices, teaching space, research laboratories and importantly a space to promote entrepreneurship amongst the students and faculty to name a few that will strongly support engineering disciplines and aid in preparing a modern engineering workforce.



Several Research Centers of Excellence have been created based on faculty input and coupled to areas important to the State of Wyoming. These include:

- Improved Oil and Gas Recovery;
- Oil and Gas Flow in Unconventional Reservoirs;
- Wind Energy and Power Engineering;
- Advanced Combustion;
- Deep Learning/Artificial Intelligence; and
- Water.

Currently the college is developing a center to examine uses of produced water and continues to support

strongly groundwater and surface hydrology.

Other state funding is used to support teaching and infrastructural improvement to promote modern teaching in engineering and applied science disciplines.

Center for Advanced Energy Studies (CAES) and the Idaho National Laboratory

Wyoming recently celebrated its first year as a member of the Center for Advanced Energy Studies (CAES). CAES is an excellent model for regional collaborative innovation to drive competitive advantage at the national level. CAES is a public/private partnership including the state of Idaho and Wyoming through their academic research institutions including Boise State University (BSU), Idaho State University (ISU), the University of Idaho (UI), the University of Wyoming (UW) and the federal government through the Department of Energy and its Idaho National Laboratory (INL), which is managed by the private entity the Battelle Energy Alliance (BEA; in itself a major S&T entity in the nation being, among other things the managing entity for several of the Department of Energy's laboratories).

It is designed to engage, aggregate and leverage capacity among partners and public/private sector collaborators to enhance competitiveness and achieve consequential impacts in the transition to new energy technologies. By growing research partnerships via a university-government-private sector network, CAES facilitates large scale and scope research development and deployment, and efficiently engages in workforce reinvigoration.

With an emphasis on the value proposition of R&D, this novel platform for collaboration leverages unique strengths to accelerate the

innovation pipeline to benefit students, industry, and collaborating partners. Already, the University of Wyoming and INL through CAES has won a major award investigating strategic elements, including rare Earth elements and in oil and gas production water. The FORGE project investigating use of new geothermal technologies strongly leverages UW's capacity in subsurface hydrology. Furthermore, the University of Wyoming will have an important role in the upcoming analysis of Nuclear Energy in the US being conducted through the Office of Nuclear Energy which was brought to us through CAES.

Enzi-STEM Science Laboratory Building

In January of 2016, the Enzi STEM Science Laboratory Instruction Building opened providing state-of-the-art teaching laboratories for UW's freshmen and sophomore level STEM courses. This 107,000 sq. ft., \$50 million building houses 32 laboratories and other teaching space for general chemistry, organic chemistry, introductory physics, life science, mathematics and computer science courses. Designed for modern laboratory and classroom instruction, using active learning when possible this building will help UW faculty to challenge and extend the STEM literacy of students through integrated theory, experimentation and computation.

Enzi-STEM along with the Berry Biodiversity Center, are anchors for university efforts promoting the development of a scientifically literate citizenry and more specifically workforce by engaging STEM with the experiences necessary for a 21st century career in a STEM discipline. At the same time, non-STEM students will gain an appreciation of the process of science and discovery through university-required laboratory courses. Enzi-STEM is a showcase for the University and it already is being used in recruiting new students to UW and STEM fields. Finally, the large and impressive central atrium, a

gathering place for students also will serve as a place where the public can be brought together for lectures and demonstrations of STEM topics important for the 21st century.



Wyoming Science Standards

From May 2015-February 2016 the Wyoming Department of Education led the development of statewide science content and performance standards <https://edu.wyoming.gov/educators/standards/science/>. Public comment on the standards will be taken through August 12, 2016, with the goal of having standards adopted by the end of 2016.

The standards were developed on the premise that quality science education enables students to learn science by being actively involved with scientific and engineering practices as they progress from kindergarten through 12th grade. They encourage students to be inquisitive, to actively explore their environment, and become productive, scientifically literate citizens, and provide the necessary foundation for local school district decisions about curriculum, assessments, and instruction. Implementation of the new standards will better prepare Wyoming high school graduates for the rigors of college or careers. Additionally, the standards will provide Wyoming employers with a workforce pool with a strong science and engineering base — both in specific content areas and in critical thinking and inquiry-based problem solving.

The Wyoming Science Content and Performance Standards support that:

- all students can engage in sophisticated science and engineering practices.
- students must have the opportunity to conduct investigations, solve problems, and engage in discussions.
- students learn through relevant context and use modeling to explain observed phenomena.

NSF-EPSCoR Research Infrastructure Initiative Track I

Wyoming's most recent NSF EPSCoR Track I RII sought to place Wyoming among the Nation's leaders in understanding shallow, subsurface and mountain front hydrology. While this award still has a year left prior to completion several important milestones deserve mention.

During the first four years of this award, UW acquired a large and important suite of equipment necessary to become a leader in

shallow, subsurface hydrology, the hydrological observatory (including drilled test wells). The entity created to house the scientific components of the NSF EPSCoR Track I RII proposal was the **Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG)**.



The NSF EPSCoR investments in WyCEHG have produced tangible and highly visible improvements in the predictive understanding of the pathways and rates by which water moves through mountain watersheds. The St. Clair et al. (2015) paper published in *Science*, entitled “Geophysical imaging reveals

topographic stress control of bedrock weathering.” proposed a novel mechanism for regolith (that part of the Earth’s crust from the surface to bedrock) development that invokes the effect of topographic and tectonic stresses on fracture opening – thus providing a connection between how water moves in the subsurface, plate-tectonic-scale forces and evolution of the regolith upon which a vast majority of Earth’s life exists.

Watershed managers can now use the global tectonic stress map to determine the first order interaction between the surface and groundwater. As this finding takes hold, it will help in understanding how water flows in the subsurface. A large-scale integrated hydrological model has been constructed and tested that incorporates subsurface geophysical data to improve runoff predictions. The model (Parflow) runs in parallel on NWSC’s Yellowstone Supercomputer using up to ~2000 cores. Based on geological, geophysical, and hydrological data collected at WyCEHG’s main research sites, the project discovered that properties of subsurface flow channels, subsurface hydraulic conductivity, hydrostratigraphy (i.e., geometry of surficial deposit, fractured bedrock, and less fractured bedrock), land cover, and accuracy of the land surface elevation are all important to the prediction of the timing and magnitude of stream discharge.

The project also developed new approaches to estimating snow-water equivalent using ground penetrating radar (GPR). This work resulted in a publication in *Geophysics* (Holbrook et al., 2016) entitled, “Estimating snow water equivalent over long mountain transects using snowmobile-mounted ground-penetrating radar.” This research shows how snowmobile-mounted GPR can provide rapid and extensive measurements of snow-water equivalent (SWE; the number used by to estimate the amount of water that is present in an accumulated snowpack) in mountain watersheds. This technology has great potential as a spin-out technology into the private sector. The work involved a collaboration between geophysicists

and hydrologists that is emblematic of WyCEHG’s philosophy. The snow GPR work provides another example of how WyCEHG results are being transferred to stakeholders in Wyoming.

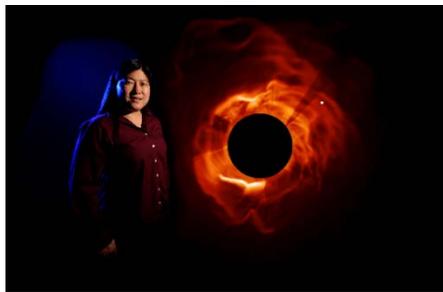
The Wyoming State Engineer’s Office, which is responsible for snow surveys that are crucial to estimating spring and summer runoff in Wyoming, has adopted our technique in the field for a validation phase. Their team, after training by WyCEHG staff, is using WyCEHG equipment during their monthly snow surveys. After validation, they hope to use WyCEHG-developed GPR methods to expand their knowledge of winter snow pack in Wyoming.

WyCEHG is fulfilling its intended goals of transforming our knowledge of flow of water in the subsurface, not only in Wyoming, but worldwide, and is providing specific new technologies and information to Wyoming’s water managers as they work to estimate annual flows important to Wyoming and to downstream states through our water compact agreements as a headwaters state.

Taking from the discussion presented above, it is very apparent that since the last plan went into effect major initiatives supporting science and technology have occurred in Wyoming. The major projects listed above are the most apparent and placed in table form below.

| Major Investments Made by the State of Wyoming from 2007-Present | |
|--|---|
| Engineering Initiative | \$102 million; and \$3.5 million continuing* |
| Science Initiative | \$100 million; and \$1.15 million continuing* |
| NCAR-Wyoming Supercomputing Center | \$20 million construction \$1.0 million continuing* |
| Enzi-STEM Science Facility | \$50 million construction |
| High Bay Research Facility | \$48 million construction |
| Energy Innovation Center | \$25.4 million construction |

The table on the previous page is impressive, but it is only a part of the infrastructure building that has occurred as a result of the present S&T plan. UW has received several Major Research Instrumentation Awards from the NSF supporting S&T infrastructure, and externally funded awards which also used the plan.



Experimental Program to Stimulate Competitive Research (EPSCoR)

This Science and Technology plan is a requirement of, and strongly supports Wyoming’s EPSCoR as this program uses specific federal funding to build science and technology infrastructure – including a workforce – in Wyoming. The plan is adhered to while writing grant proposals to federal agencies with EPSCoR programs including NSF and DOE.

The plan’s purpose is to align state S&T goals with those of the federal government.



| Major Experimental Program to Stimulate Competitive Research (EPSCoR) award funding received during the period of the last Wyoming science and technology plan period | |
|--|--------------|
| NSF EPSCoR Track I RII | \$24,000,000 |
| NSF EPSCoR Track II | \$2,564,000 |
| DOE EPSCoR Implementation Solar | \$6,300,000 |
| DOE EPSCoR Implementation Wind | \$4,200,000 |

Science and Technology Plan

This Wyoming Science and Technology Plan outlines directions, capabilities and vision for the educational, research, and economic development efforts of the state that will frame future decisions about directions for Wyoming and for public higher education.

This plan is an element in the development of Wyoming's participation in the Experimental Program to Stimulate Competitive Research (EPSCoR) and other federally-supported research stimulation programs. As such, it provides the foundation for focusing primarily EPSCoR-associated research and education efforts statewide.

The strategies summarized in this plan will better leverage the state's research and development resources, promote innovation, create jobs, and diversify the state's economic basis in an increasingly global economy.

Details of the Planning Process

Visioning meetings were held with a variety of entities representing Wyoming government, education and industry, 23 in all, as part of the planning process. The Innovation Index and a draft plan was distributed to these entities as background material, but more importantly during these visioning meetings items were gleaned to be used in shaping the strategies, outcomes and outputs of this S&T plan.

| Entities Participating in Meeting (listed alphabetically) |
|--|
| Campbell County Economic Development Corporation |
| Cheyenne LEADS |
| Laramie Economic Development Corporation |
| Manufacturing-Works! |
| National Center for Atmospheric Research |
| Research Products Center |
| United States Geological Survey |
| University of Wyoming |
| Western Research Institute |
| Wyoming Association of Conservation Districts |
| Wyoming Business Council |
| Wyoming Community College Commission |

| |
|--|
| Wyoming Department of Environmental Quality |
| Wyoming Entrepreneur |
| Wyoming EPSCoR |
| Wyoming Game and Fish Department |
| Wyoming Governor's Office |
| Wyoming SBIR/STTR Initiative |
| Wyoming Small Business Development Centers |
| Wyoming State Climatologist |
| Wyoming State Engineer's Office |
| Wyoming Technology Business Center |
| Wyoming Water Development Commission |

Specific meetings were held with members Governor Mead's policy staff were arranged by Ms. Mary Kay Hill, Policy Director to Governor Mead and a member of the Wyoming EPSCoR Committee to review the amendments to the Wyoming Science and Technology Plan. Others who viewed the plan were Mr. Flint Waters, Wyoming Chief Information Officer, Ms. Jillian Balow, Wyoming State Superintendent of Public Instruction, Mr. Shawn Reese, Chief Executive Officer, Wyoming Business Council, Ms. Mary Kay Hill, Senior Policy Advisor to Wyoming Governor Matt Mead. Finally, the plan was reviewed and accepted by the Wyoming EPSCoR Committee.

This plan is intended to provide a framework for state government, economic development organizations, and business and academic leaders to make informed decisions that produce a more vibrant and dynamic state economy.

The plan consists of five strategies:

1. focus research and development in areas that take advantage of Wyoming's strengths;
2. support and expand the state's research and development infrastructure at the University of Wyoming in key R&D areas;
3. leverage strategic alliances and research collaborations among community colleges, business, entrepreneurs, government and non-profit entities.
4. develop and retain an educated, technically-skilled and technology business savvy workforce with special attention to alliances with Wyoming Community Colleges; and,
5. increase public awareness and support for innovation, research and how an innovation-driven economy works and become more important in Wyoming.

An annual report card for this plan will be provided to all stakeholders involved in implementing the plan.

Strategy One: Focus Wyoming's research and development in areas in which Wyoming has strength and in which additional strategic investment will provide the critical advantage.

A. Advocate for and support focused state research and development investments in Wyoming's targeted areas:

1. Energy development, use and transmission

Output:

- i. Working with UW's School of Energy Resources and the Integrated Test Facility, promote the engineering of carbon found in coal to high-value products.
- ii. Through research on microbial life, enhance the reclamation of mined land, pipeline corridors, oil and gas development sites and other areas of disturbance promoting more effective and rapid reclamation.
- iii. Gain more understanding about the existing western power grid, its markets and impacts from base-load generation and also renewable power generation so that modern control technology can be developed for Wyoming's export of electrical generation.
- iv. Support enhanced oil recovery technologies from the pore scale to new reservoir techniques.
- v. Support modeling of wind-generation facilities (here called wind plants) from the level of turbine design to the integrated design of wind plants with consideration of efficiency of plant design, terrain and atmospheric boundary layer management.

2. Water use and management

Output:

- i. Develop research programs aimed at improving predictive capability for precipitation and water availability in specific river systems in Wyoming such as the Platte-Yellowstone-Missouri-Mississippi, the Green-Colorado and the Snake-Columbia, all with headwaters in Wyoming.
- ii. Provide predictive capability of late season flow in river systems dominated by glacial melt and snowpack.
- iii. Improve predictive capability for water utilization by agricultural, reclaimed, and natural ecosystems by incorporating microbial life into mechanistic models.
- iv. Quantify and predict the impact of water flow in the subsurface on streamflow, which positions UW as the nation's leader in flow from the surface to the depths of oil and gas reservoirs.
- v. Support the development of a produced water center at the University of Wyoming.

3. Information technology and computational capacity

Output:

- i. Develop computationally intensive yet parsimonious models of biosphere-atmosphere interaction that help improve predictive capability for water availability by incorporating novel physical and biological mechanisms such as turbulent transport of mass and energy in complex terrain and microbial life controls on plant water uptake.
- ii. Use ongoing research programs, such as weather modification research to improve predictive understanding of the snow to streamflow connection.
- iii. Develop sophisticated models describing fluid and gas flow behavior at the pore to field scale.
- iv. Multi-physics, multi-scale models for optimizing design of wind plants that incorporate terrain and weather
- v. Engineering and economic feasibility studies on ways to optimize transmission on existing power lines and to support strengthening and building a more robust western power grid.
- vi. Develop infrastructure (e.g. the Wyoming PetaLibrary) and expertise (students and faculty) in data management data science to support transformative research.
- vii. Support usage of the WUN's capabilities to support education, governmental and business development through access to data analytics and computing resources.

B. Promote synergies between these focus areas

1. Catalysis and advanced biological, chemical and thermal cycles, including hybrid cycles
2. Material science and engineering for advanced energy and water systems
3. Environmental sciences and emission control sciences and technologies
4. Computational modeling and simulation (M&S)
Output:
 - i. The University of Wyoming Office of Research and Economic Development will provide to interested entities listings of potential science and technology funding opportunities in these four areas through databases.
 - ii. Students are educated and graduate with not only leading-edge, state-of-the-art knowledge for target areas to support industry growth but also an ability to think critically and computationally to anticipate future technologically-enabled job opportunities.
 - iii. Increase in new innovative technology inventions and patents.
 - iv. Commercially viable technological solutions for Wyoming and our Nation.
 - v. Routinely inform the Governor's Office staff of accomplishments in all areas of the S&T plan and other items relevant to the state.
 - vi. Routinely inform the Wyoming Business Council of accomplishments with which they may be able to provide support for economic development purposes.

Strategy Two: Support and expand the state's research and development infrastructure at the University of Wyoming.

- A. Provide continued support for R&D infrastructure programs such as Wyoming EPSCoR, the Wyoming Unified Network, the NCAR-Wyoming Supercomputing Center, the School of Energy Resources and the Ruckelshaus Institute for Environment and Natural Resources and the College of Engineering and Applied Science.

Output:

- i. *Retain leading faculty and hire new faculty in areas critical to the major focus areas of this Science and Technology plan.*
- ii. *Support community colleges throughout Wyoming as they develop programs in water, energy and computational technologies and prepare Wyoming's Associate Degree holders for transfer to the University of Wyoming.*
- iii. *Refresh the computational and storage systems at UW to continue to provide a mid-sized high-performance computing and storage system to serve as the core of the UW computing facility.*
- iv. *Maintain UW's world-class networking capabilities through internal funds and external grants, and networking partnerships such as the FRGP, BiSON, and the WUN.*

- B. Support these infrastructure programs by providing
- Outstanding and maintained physical facilities
 - Modern equipment
 - Support infrastructure
 - Critical mass of highly qualified research scientists, engineers, graduate students, and technicians

Output:

- i. *Strategically enhance the technical staff in and associated with UW's Advanced Research Computing Center to support computational, and data-intensive research in Wyoming.*
- ii. *Through the Science and Engineering Initiatives, hire technical staff to support and enhance competitiveness of the researchers using the university's shared suite of advanced scientific and data analytics equipment.*

- C. Share these strengths and assets with existing Wyoming community colleges, schools, and businesses to garner their participation and thus extend use of this R&D infrastructure throughout the state

Output:

- i. *Expand and make more visible programs that provide Wyoming community colleges and schools access to R&D infrastructure;*
- ii. *Provide a stream of graduates trained in utilizing the latest technologies in key areas (e.g. GIS & remote sensing, geohydrology, surface hydrology; carbon engineering,*

application of advanced enhanced oil recovery methodologies, data analytics).

- iii. *Work with the state Division of Enterprise Technology Services to promote use of IT-related technologies in Wyoming communities, community colleges and schools.*

Strategy Three: Build strategic alliances and research collaborations among business, entrepreneurs, government, non-profit entities and academia.

Through partnerships with business, support to education, new investments in technologies and practices for the development of new ideas and inventions, help produce informed citizens and employees.

- A. Develop public and private funding, including SBIR/STTR, angel and venture capital for early stage, research-intensive business development and commercialization of research.

Output:

- i. *Working with UW's Research Products Center, provide the Wyoming Business Council access to research results to develop transfer of new technology to the private sector.*

- B. Build a critical mass of entrepreneurial management and science to technology transfer assistance. Promote strategic alliances between these organizations.

- Wyoming Business Council
- Western Research Institute
- Regional state economic development groups
- Small Business Development Centers (SBDC)
- Manufacturing-Works (M-W)
- Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR)
- Wyoming Technology Business Center (WTBC)
- Research Products Center (RPC)
- Wyoming Tourism
- State resource management agencies
- Center for Advanced Energy Studies

Output:

- i. *In the first year of plan implementation, hold a meeting where all entities with an interest in developing and assisting entrepreneurial business, create a plan with specific actionable items focused on enhancing the technology business sector in Wyoming. In subsequent years each entity will report on activities and developments specifically supporting technology business development. An important output is that each entity knows the full toolkit of support programs and the critical contact point for each.*

- ii. *Identify and carefully examine other such plans, for example the Canadian Innovation Centre program, where compatible ideas are gleaned and put into action for Wyoming.*
 - iii. *Provide information at the annual Senator Michael B. Enzi Inventor's Workshop about the activity of each entity listed above and how they work with each other to support technology related businesses in Wyoming.*
 - iv. *Provide the Wyoming Business Council a list of University generated technology that is open for licensing to the private sector.*
- C. Increase training opportunities for university employees, students, Wyoming businesses, and citizens in entrepreneurship and research commercialization in order to increase the ability of Wyoming citizens to contribute to Wyoming's innovation efforts.
 - D. Provide ongoing SBIR training programs and proposal writing and grants management workshops to increase Wyoming's success in obtaining federal grants.
 - E. Provide an annual conference on new scientific advances to share new knowledge with technology development entities and business.
 - F. Partner with the Wyoming Business Council in providing information to local economic developers regarding all aspect of development and use through the School for Energy Resources Outreach program.
 - G. Partner with the Wyoming Business Council in development of materials for trade shows and other presentation regarding Wyoming's energy resources.
 - H. Partner with the Wyoming Technology Business Center in support of their entrepreneur-2-entrepreneur (e2e) program to provide case studies, networking opportunities and a cultural environment supporting development of innovation-based business.

Output:

- i. *Accelerated transfer of scientific discoveries into technology developments.*
- ii. *Shortened technology maturation timelines.*
- iii. *More rapid growth of Wyoming's technology business sector.*
- iv. *Become a sponsor of e2e and support attendance by nascent entrepreneurs.*
- v. *The Wyoming Technology Business Center, will work with academic colleges at the University of Wyoming to provide education and training to students (both undergraduate and graduate) about establishing and managing entrepreneurial business.*
- vi. *Hold an innovation challenge for students from the academic colleges, especially Engineering & Applied Science, Arts & Sciences and Agriculture & Natural Resources, where business concepts are developed, evaluated, judged and qualified to be investor ready for establishment and fit for residency in one of the three incubators managed by the Wyoming Technology Business Center.*
- viii. *Develop the "Innovation Diploma" program supporting student-based entrepreneurship.*

- I. Partner with the State of Wyoming Enterprise Services to develop programs to provide schools, agencies, and companies with the expertise to leverage the WUN.
- J. Partner with the State of Wyoming Enterprise Services to develop a work-force stream and internships to help address the State of Wyoming Data Analytics needs.
- K. Partner with the Wyoming Department of Education to create, implement and innovatively assess (e.g. perhaps includes a project-based component) Wyoming-specific, age-appropriate, curricular activities related to Energy, Water and Computing.
- L. Invite community college faculty to growth opportunities provided to UW faculty

Output

- i. *Provide GrantWriters training to all interested community college faculty.*
- ii. *Institute focus session at articulation conferences between CC and University faculty where research topics are discussed that lead to interaction in broader impact development for NSF grant proposals.*
- iii. *Track and report to the Wyoming Community College Commission all interactions between CC faculty and students and the University of Wyoming.*

Strategy Four: Develop and retain an educated, technically-skilled and technology business savvy workforce.

Advanced, targeted education and skills training are key to science and technology development. Opportunities for graduate students to attend the University of Wyoming and to work with a mentor on research projects will produce students dedicated to solving problems important to Wyoming and the nation.

- A. Prepare highly skilled, knowledgeable bachelors, masters-level (including teachers and PhD graduates with strong mathematics, science and computational capabilities through a new Computational and Data Science Center.
- B. Continue to develop and sustain interdisciplinary PhD programs in Ecology, Computational Science, Water Resources.
- C. Develop a "Innovation Diploma" for graduate students to encourage knowledge and technology transfer and greater societal applications for the student's research.
- D. Expand visiting professorships and professors of practice usage engineering, business environmental, data analytics, computation and other programs.

Output:

- i. *Develop a specific set of courses that can be taken at Wyoming Community Colleges which will transfer to the University that support*

degree programs or degree enhancements in computational science.

- ii. Articulate Education Outreach and Training programs between NCAR and the University of Wyoming using the special assistant as the point of contact.*
 - iii. Establish a critical mass of trained technical and business professionals to support new S&T business growth.*
 - iv. Increase in skilled workforce to support Wyoming S&T business growth.*
 - v. With the University of Wyoming, the State's community colleges, the Wyoming Department of Education, the Division of Technology Services, the Wyoming Business Council, national partners and business, work to develop a computer science, data science and data analytics curriculum that enhances career opportunities for Wyoming students and feeds a technically competent workforce supporting technology-business growth and growth in the technology business sector.*
- E. With the Wyoming Department of Education, Wyoming Community Colleges, and state industries develop scalable career pathways for students in the areas of Energy, Water and Computing.

Strategy Five: Promote this Science and Technology Plan to increase public awareness and support for an innovation-driven economy.

Solutions to the state's most serious challenges will be based upon science, research and data. These needs and opportunities must be communicated to the public, from school-age students, to legislators, policy-makers and government officials, and to all interested residents. Wyoming residents should be informed and understand the significance of energy and water issues as they relate to their quality of life and economic opportunity. A well-informed public can support difficult decisions and the need for development of new laws and policies that policymakers and administrators may have to make. Also, growth of a technology business sector as outlined by Wyoming's governor will need significant support as communities begin understanding the needs of such business. Small computing devices are becoming ubiquitous in today's society, for example, activity monitors, watches taking the place of handhelds, modern car keys, smart appliances – all these are embedded in the term "the Internet of things," which is now part of modern life. Sixty percent of careers that today's first graders may be working in are not yet in existence.

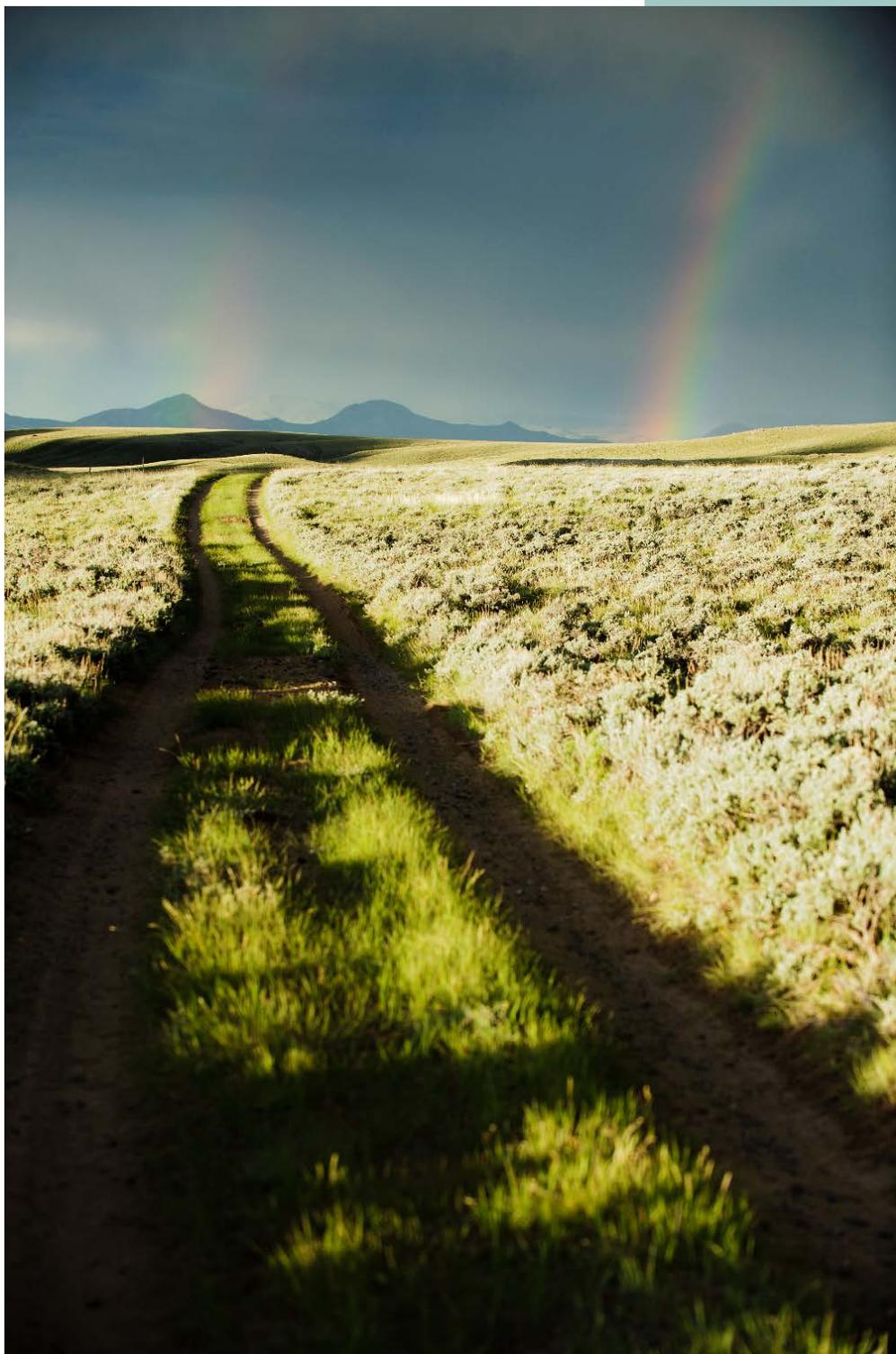
- A. Provide accurate and reliable information, data and analysis of Wyoming's innovation-based economy in order to promote public understanding and support.

Output:

- i. Continue to produce and update the Wyoming Innovation Index or something similar every two years.*
 - ii. Provide outreach opportunities to Wyoming communities on issues of energy, water, and microbial life computational sciences and technology-related business.*
 - iii. For each of the targeted R&D focus areas develop a digital repository which is readily accessible to researchers, state agencies, and the general public through the WUN, and which contains useful data sets, software applications, and embedded data analytics tools, and vetted open source curricular materials.*
- B. Inform legislators through frequent concise reports
- C. Establish high school science and technology institutes at UW to encourage more young Wyoming residents to pursue scientific or technical careers or at least have an appreciation of the importance of science and technology for their own benefit as well as the state's.

Output:

- i. Expand the EPSCoR Summer Research Apprenticeship Program.*
- ii. Support ongoing and new programs with the aim of increasing diversity in STEM disciplines.*
- iii. Develop special Education Outreach and Training programs with NCAR on computation and modeling.*
- iv. Help SER expand their Energy Academies for Wyoming K-12 students.*
- v. Work with the UW Department of Mathematics, Computer Science Electrical and Computer Engineering and the ARCC to expand REU opportunities in the computational sciences.*
- vi. Continue development programs teaching computational thinking, coding, engineering design, and innovation to Wyoming middle and high school students through the use of cheap simple and powerful technologies driving the development of the "Internet of things."*
- vii. Organize annual professional development programs to better equip Wyoming middle and high school teachers to guide computational thinking and counselors to guide Wyoming students into STEM courses, disciplines and careers.*
- viii. With the Wyoming Department of Education run pilot courses and outreach activities that utilize the WUN, virtual reality software and other technologies to deliver geographically and time-shifted educational experiences between UW faculty and middle-school and high school students located throughout Wyoming.*



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