



MISSOURI S&T RESEARCH ROADMAP



Missouri University of Science and Technology

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Missouri University of Science and Technology Research Roadmap

INTRODUCTION

In late 2019 campus leadership decided that it was important for S&T to take a new look at its research in preparation for the next 7-10 years. The last research review had been conducted in 2013-14, resulting in the designation of “Best in Class” or “Signature Areas.” In the subsequent years many things have changed: our faculty, or facilities, the goals of the university, the goals of the funding agencies and industry, and our strategic directions.

We called the process the “Research Roadmap” to indicate that the goal was to create a vision of the future rather than focusing only on a snapshot of the present. Our process was guided in part by the 2018 Strategic Plan. Part of our strategic vision is that “Missouri S&T will be the leading public technological research university for discovery, creativity and innovation. We will cultivate curiosity, creativity and confidence in our graduates. We will be the institution of choice for partners around the world seeking a highly qualified, talented and entrepreneurial workforce; innovative research; relevant educational program.”

Also, Missouri S&T’s strategic research vision is that “We aspire to be among the list of *R1: Highest Research Activity* universities. Doubling our annual research expenditures by 2025 is an audacious but achievable goal that will contribute to this higher classification.”¹

This report summarizes the Research Roadmap development process, which involved the effort of hundreds of S&T faculty members.

HOW TO CREATE A RESEARCH ROADMAP

We started the process on February 13, 2020, by sending a survey to all our faculty asking for feedback on what they perceived as bottlenecks in interdisciplinary research, research with industry, barriers to scholarly productivity, etc.² Fifty-three of our faculty responded, and their answers became the focus of a retreat we scheduled for March 19, 2020.³

Before we could hold the retreat we were hit by the pandemic, which made it impossible to bring more than 35 of our faculty together in one place to discuss research. Thus, we cancelled our retreat originally scheduled for March 19.

As the impact of the pandemic became clearer to all of us, thoughts of the retreat receded while our faculty and staff pivoted to teaching and working remotely. In May we restarted the

¹ Our 2018 Strategic Plan is [here](#).

² The survey questions are included as Appendix I.

³ A summary of the survey results is included as Appendix II. The agenda for the March workshop is included as Appendix III.

Research Roadmap process, and reorganized the in-person workshop through Zoom, calling it VIZORR, “Virtual Zoom Research Retreat⁴.” VIZORR, which took place on May 15, focused on a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of our research enterprise, starting from the present and looking into the future. We focused especially on examining the ways we would overcome the barriers identified in the survey: interdisciplinary research, working with industry, positioning S&T to succeed in research in the next decade, increasing scholarship, and meeting our strategic goals to double research expenditures and move towards R1 status. The many great ideas in the SWOT report have been summarized in Appendix VI. Another major result of the VIZORR workshop was the initial identification of research areas that are our current strengths and our future directions.

Our next step was to broaden the participation in the Research Roadmap to as many of our faculty as possible. Deans, Chairs, Center Directors, the Provost, etc., recommended over 85 additional faculty members to be invited to participate in the next step of the Research Roadmap. The next meeting, which was held virtually on July 23, 2020, with broad participation, was recorded and made available on-line. The meeting was seeded by the results of previous retreat and the survey, and also by the Chancellor’s vision of Missouri S&T’s “research pillars”⁵. Excellent conversation was conducted live through Zoom and also via Zoom chat, and the participants agreed on the next steps: breaking into groups, inviting more faculty, and developing a list of the S&T research areas of current strengths and future focus. We also agreed that our research areas should not be considered “pillars,” which may show strong support of a research structure, but also indicate separation between them. Instead, after many discussions, our research areas were deemed “research constellations” to show the connections not only within an area, but also between areas.

Eventually our faculty defined eight *research constellations* and elected leads for them who would organize meetings, collect thoughts and ideas, and be the points of contact between the VCRDGS and the faculty working on the Research Roadmap. The areas with their co-leads are:

- Bio-X:** Co-Leads Akin Elvan, Yue-Wern Huang, and Hu Yang
- Data Science:** Co-Leads Melanie Mormile and V.A. Samaranayake
- Infrastructure:** Co-Leads Genda Chen and Kamal Khayat
- Intelligent Systems:** Co-Leads Steve Corns and Don Wunsch
- Manufacturing:** Co-leads Doug Bristow, Angela Lueking, and Ron O’Malley
- Materials:** Co-Leads Bill Fahrenholtz and Jenny Liu
- Resources: Natural, Energy, Water, for Society:** Co-Leads Kwame Awuah-Offei and Steve Gao
- Training, STEM Education, and Workforce Development:** Co-Leads Beth Kania-Gosche and Melanie Mormile

⁴ The VIZORR agenda is included as Appendix IV.

⁵ The presentation to the kick off the meeting which focused on the outcomes of the SWOT analysis is included as Appendix V.

These areas were selected based on the existing research foundation at S&T, the projected directions of disciplines, and the potential to create a true *research ecosystem*, which will include the creation of new knowledge, the sharing of scholarly results, the training of graduate and undergraduate students, and the successful transition of discoveries to the market through patenting, licensing, and spin offs.

The research constellations produced extensive reports describing the research, the S&T faculty participating in it, current and future research opportunities, and how each research constellation supports a broad S&T research ecosystem.

The following tables show participation in the Research Roadmap process by departments and faculty:

TOTAL DEPARTMENTS PARTICIPATING

Bio X	Data Science	Infrastructure	Intelligent Systems	Materials	ReNEWS	Workforce
13	10	10	12	16	14	11

TOTAL FACULTY PARTICIPATING

Bio X	Data Science	Infrastructure	Intelligent Systems	Materials	ReNEWS	Workforce
27	34	41	37	77	52	15

The Research Constellations shared faculty and department participation. The table below shows departments shared between the seven constellations. Some of these connections were expected, as, for example, between Infrastructure and Materials. Others, such as the strong connections between Intelligent Systems and almost all other constellations, were unexpected.

DEPARTMENT CONNECTIONS

	Data Science	Infrastructure	Intelligent Systems	Materials	ReNEWS	Workforce
Bio X	6	8	7	10	9	5
Data Science		4	7	7	4	5
Infrastructure			7	10	7	1
Intelligent Systems				11	7	5
Materials					10	5
ReNEWS						3

The following table shows individual faculty who felt that their research belonged in two constellations. Again, some results are expected. Others, though, show the need to bring more of our faculty together in research areas. For example, while Bio X and Data Science are

represented in six departments, none of the faculty in these departments are on both constellations. Similarly, Infrastructure and Bio X are represented in 8 departments, but they share only two faculty members. It will be important as a next step to build more collaborations between faculty in some constellations.

FACULTY CONNECTIONS

	Data Science	Infrastructure	Intelligent Systems	Materials	ReNEWS	Workforce
Bio X	0	2	4	15	4	3
Data Science		1	8	8	5	3
Infrastructure			14	23	10	0
Intelligent Systems				12	6	2
Materials					22	5
ReNEWS						2

CONCLUSION

I was humbled by the level of participation and quality and quantity of work and input by our faculty in the Research Roadmap process. The process involved dozens of meetings, hundreds of comments and conversations, and thousands of hours spent. The volunteer effort put in by our faculty proves their love of S&T, their focus on research, and their hunger to see S&T research and scholarship continue to grow and improve.

In the rest of this document we summarize the vision of seven of the eight research constellations. The complete reports of the seven research constellations are available [here](#).

BIO-X RESEARCH CONSTELLATION SUMMARY

The Bio-X constellation aims at serving as an academic platform for the entire Missouri S&T community to facilitate interdisciplinary and trans-disciplinary research in life science. The constituents include engineering, natural sciences, economics, the humanities, and the social sciences. Translation of basic research outcomes to innovation and entrepreneurship is the essence of this constellation.

Examples of current Missouri S&T inter- or trans-disciplinary strengths in the Bio-X research area include, but are not limited to, biomaterials (tissue regeneration for bone and wounds), bioprinting, traumatic brain injuries (TBI), sleep biology, COVID-19 pandemic related topics, drug delivery/biosensing, ecology/environmental science, eye research (disease treatment), biomarkers for disease diagnosis, chemistry for pharmaceuticals and agrochemicals, machine learning and cardiovascular diseases, imaging and diseases, metabolism and health, music and neurodegenerative diseases, sensors related to MRI or diabetes, Artificial Intelligence (AI) for enhancing research instrument algorithms, bioinformatics/medical informatics, and disease data modeling (mathematical and computational modeling).

Missouri S&T has the potential to excel in emerging Bio-X areas of promise such as health informatics, biosystem automation, bioprinting and tissue engineering, drug delivery and discovery, mental health and pandemic (music, painting, performing arts, misinformation, etc.), health intelligence and eco-canary species, ecological/environmental/evolutionary.

The Bio-X research area is intrinsically connected to Missouri S&T research centers, consortia, and other research constellations identified elsewhere within this document. Many Bio-X researchers are affiliated with the Materials Research Center and the Center for Biomedical Research, both of which have cutting-edge analytical capabilities that play a pivotal role in PIs competitively acquiring external financial resources for research. Bio-X also has strong synergies with the Center for Science, Technology, and Society, the Center for Research in Energy and the Environment, and the Intelligent Systems Center. Closely related research constellations include the ReNEWS: Natural Energy and Water for Society and Data Science constellations. Furthermore, the Bio-X research constellation can play an important role in the successful establishment of the Kummer School of Innovation, Entrepreneurship, and Economic Development. The Bio-X constellation vision aligns with Mr. and Mrs. Kummer's passion and vision in the context of biotech innovation, entrepreneurship, and economic development.

Through the Bio-X research constellation, Missouri S&T's wide spectrum of expertise and strengths in science and engineering can be leveraged create a unique environment for biotech/pharmaceutical research. We have an opportunity to strategically carve out a special niche to enter the biotech arena. Missouri S&T can take two potential approaches to biotech innovation and biotech entrepreneurship. The first approach is to work with strategic partners in Missouri or neighboring states to pursue high-end biomedical products, such as biologics and small molecule drugs. This takes time and is high risk, but very rewarding when successful. Our past success in Theraspheres and Mirragen was achieved by the innovation of materials in-

house and then collaboration with the University of Missouri-Columbia and Phelps Health. The second approach is to invent “picks and shovels.” The full Bio-X report provides several case studies that we can reflect upon as we develop subsequent plans and implementation actions.

Missouri S&T possesses all of the necessary expertise to grow its research in the Bio-X areas. However, certain mechanisms need to be in place for biotech innovation and entrepreneurship to take place at S&T. The first component is to have a team of identifiers (or facilitators) to 1) identify current needs and the future trends in biotech and medicine, and 2) identify potential products that already exist at S&T for marketing purposes as well as further facilitate collaboration among disciplines. The second component is to hire business professionals to support the development of entrepreneurship. The third component is to create an incentive-based model to encourage participation in biotech entrepreneurship.

Current needs that Missouri S&T must address in order for the Bio-X research constellation to grow include more biologists and biomedical engineers to enable collaboration, an interdisciplinary Ph.D. degree program to consolidate scattered strengths and train students for collaboration across disciplines, better imaging capacity to conduct animal studies, structured partnerships with institutes in Missouri and neighboring states, and a formal infrastructure for supporting biotech entrepreneurship.

Missouri S&T can address these needs by mapping areas of expertise to better leverage existing human capital, developing platforms for brainstorming research and development ideas, the development of a research proposal mentoring program, increased interactions with funding agency program directors, and development of partnerships with other institutes and universities.

The following existing campus resources can be leveraged to enable the Bio-X research constellation: Ph.D. degree programs in chemical and biochemical engineering and in materials science and engineering, a Bachelor of Science program and a Master’s degree program in Biological Sciences, a Biomedical Engineering minor, the Center for Biomedical Research (CBR), the Material Research Center (MRC), an Imaging Facility (confocal microscope; managed by CBR), an Animal Research Facility (brand new vivarium in April 2021), an Histology Laboratory (housed in biological sciences dept.), the nearby Delbert Day Cancer Institute (DDCI) at partner Phelps Health, the Ozark Biomedical Initiative (OBI) conducted with Phelps Health, and the Missouri S&T Field Station.

The Bio-X research constellation will target selected health-related funding opportunities issued by agencies including, but not limited to, the National Institutes of Health, Department of Defense, American Heart Association, Susan G. Komen Foundation, Health Effect Institute, National Institute for Occupational Safety and Health, Department of Energy, National Aeronautics and Space Administration, Environmental Protection Agency, National Science Foundation, Food and Drug Administration, Midwest Biomedical Accelerator Consortium, and industry (pharmaceutical companies; biotech companies, etc.).

Selected environment-related funding opportunities eligible for the Bio-X constellation include those offered by the US Fish and Wildlife Service; the US Geological Survey; the Environmental Protection Agency; the Department of Agriculture; National Science Foundation (NSF); state and regional agencies such as the Missouri Department of Natural Resources, Missouri Department of Conservation, Missouri Water Resources Research Center, and the St. Louis Zoo; and industrial entities such as mining conglomerate Doe Run.

Information hubs to be leveraged in development of Bio-X research constellation include the National Center for Biotechnology Information, Comprehensive Cancer Centers of U.S. medical schools, The European Bioinformatics Institute, the RCSB Protein Data Bank, and the Antimicrobial Peptide Database.

DATA SCIENCE RESEARCH CONSTELLATION SUMMARY

The vision of the Data Science research constellation is to create an interconnected network of researchers engaged in both foundational and applied areas of data science and to promote innovative research that transcends disciplinary boundaries, thereby creating an agile community of Missouri S&T researchers to successfully respond to opportunities and challenges not only in the data science arena, but also in scientific, engineering, and business endeavors that benefit from it.

Data Science is not a discipline that fits into any existing department on the Missouri S&T campus, but rather is work done in the Computing, Mathematics & Statistics, and Domain Knowledge fields. This is also the case at most universities across the Nation. Each member of the data science research constellation belongs to one of these fields, but may be doing work across multiple disciplines.

Multiple groups on campus are conducting research on fundamental areas of data science, on data science applications, as well as on its ethical implications and impact on society,. The goals and action items proposed in the full Data Science Constellation report are aimed at bringing these groups together to facilitate convergence between their technologies and create a more vibrant data science research community to the benefit of all researchers, emulating what has been done at three leading institutions and, thus, positioning Missouri S&T as a leader in data science.

The Data Science research constellation's major goals include

- establishing a collaborative research network that enables its members to engage in the exchange and synthesis of ideas and methods, thereby creating an incubator for transformational research
- bringing together researchers in application and foundational areas of data science
- creating a network of researchers who can respond quickly and effectively to large-scale funding opportunities and challenges
- within the framework of the big umbrella of data science, creating subgroups that work on synergistic areas such as foundational research in data science, high-performance computing, data and society, financial and business analytics, intelligence systems, etc.
- establishing and strengthening connections to research centers, signature research areas, and the newly proposed Kummer Institute
- creating resources and opportunities for both undergraduate and graduate students to engage in data science research that will prepare them for the modern workplace and for future research careers
- establishing cross-disciplinary data science emphasis areas in undergraduate and graduate degree programs, including those at the Kummer School of Entrepreneurship, which will integrate data science research with the university's core mission of education

Short-term actions that will facilitate these goals include

- establishing a website listing data scientists in our group with their expertise and research projects to enable members to find collaborators for existing projects and writing grant proposals

- establishing a seminar series for short presentations of members' work to enable members to get to know about each other's expertise as well as research projects and learn about new research techniques and methods
- creating opportunities for informal one-on-one as well as group discussion in a social setting to facilitate an environment for networking and exchange of ideas
- exploring opportunities for large-scale funded projects to enable our researchers' quick response to federal agency proposal calls
- exploring funding opportunities for undergraduate research
- engaging graduate and undergraduate students in data science research by, for example, organizing workshops, short training sessions, certificate programs, and similar programs
- establishing a colloquium series where national and international leaders in both foundational and application areas of data science are invited to give talks
- connecting with industry partners to seek out potential funding opportunities well as internship opportunities for students; such connections can lead to work on novel research problems and long-term partnerships

Long-Term Action Items to facilitate the Data Science research constellation include

- establishing a Center (or Institute) for Data Science Research
- establishing a Data Science Commons (a convening space) and other resources to enable cross-exchange of expertise and encourage the emergence of new research ideas and collaborations
- establishing collaborative partnerships with other Data Science Centers in the U.S. and abroad
- establishing scholar exchanges with select institutions

A considerable number of potential funding opportunities relate directly to data science research. In addition, data science techniques are becoming increasingly important in engineering and scientific research and, thus, a data science component has become a common requirement for grant opportunities in these areas. The funding opportunities for basic research in data science are mainly focused within the National Science Foundation initiatives (e.g. Harnessing the Data Revolution), but opportunities for application areas of data science extend across all national funding agencies. These range from the joint NSF-National Institutes for Health initiative: Smart Health and Biomedical Research in the Era of Artificial Intelligence and Advanced Data Science to Navy Research Lab's Broad Agency Announcements related to Big Data and high performance computing. In addition, data intensive research initiatives are not limited to what is considered data science in a narrow sense. For example, NSF's Division of Mathematical Sciences is partnering with the NIH's National Institute of General Medical Sciences (NIGMS) to promote research at the interface of the biological, biomedical, and mathematical sciences to exploit the extraordinary growth of available data. Details regarding Data Science constellation funding opportunities from these and other funding agencies such as the Department of Defense and Department of Energy are included in the full Data Science constellation report.

Missouri S&T has a core group of researchers working in both foundational and application areas of data science, with research innovations and funding successes associated with their work. We have identified the following areas of improvement that must be addressed in order to strategically develop the Data Science constellation.

- In order to be highly competitive when seeking multi-million dollar grants for establishing data science centers/institutes and similar projects, strengthening the core group of data scientists with strategic hires is desirable.
- As evidenced from schools that have established data science research centers, their success as research incubators is linked to having a physical presence where participants from multiple disciplines can gather and interact. Such a physical space needs to be established.
- Successful research goes hand-in-hand with having a vibrant graduate program and thus, interdisciplinary graduate programs in data science should be established.
- Resources will also be needed to bring in nationally known data scientists as visitors, both on a short- and long-term basis.

INFRASTRUCTURE RESEARCH CONSTELLATION SUMMARY

Infrastructure is the combination of fundamental systems that support a community, region, or country including the services and facilities necessary for its economy to function.

Infrastructure systems comprise physical structures, as well as cyber and fiscal processes that manage and control everything from water and sewer systems, to air, road and rail networks, to national power and natural gas grids, to economic and fiscal systems. This research roadmap aims to develop Missouri S&T's regional, national and international leadership and partnership in infrastructure research and technology transfer by creating, conveying, and applying knowledge that serves our communities, neighboring states, and nation, and helps solve the world's great challenges associated with aging infrastructure. We will focus our efforts to improve the safety, sustainability, and resilience of our nation's critical infrastructures under normal operations and extreme events (both human-made and natural).

Infrastructure is well-represented at Missouri S&T, where research initiatives are mainly coordinated through three university research centers: the Center for Infrastructural Engineering Studies, the Center for Intelligent Infrastructure, and the Center for Research in Energy and Environment. The centers are grounded in interdisciplinary and trans-disciplinary research collaborations, team building activities, proposal development activities as well as experimental and computational facilities to undertake research. Missouri S&T's expertise and capabilities in infrastructure are largely grouped into three clusters: (1) Infrastructure Materials and Engineering, (2) Smart Engineering Infrastructure, and (3) Energy Infrastructure.

The research enterprise in the field of infrastructure at Missouri S&T is directly related to critical needs at the local, state, and national levels that seek to develop safe, sustainable, and cost-effective solutions to construct, maintain, inspect, and rehabilitate the various categories of the infrastructure that are elaborated in the appended full Infrastructure constellation report. Research is focused on fulfilling the needs for maintaining our nation's infrastructure, where the problem is particularly acute in urban areas given the growing population as well as the increasing occurrence of natural disasters that stress society's support systems. The proposed strategic planning is focused on inter-disciplinary research to deliver new technologies with increased intellectual merit in areas with high broader impact; the outcomes of the proposed strategic planning position S&T as a national leader in multi-disciplinary research areas, to include the development of technologies to enhance the use of recycled and by-product materials in durable, economical, and more sustainable infrastructure.

Missouri S&T is strategically positioned to address key national priorities in the field of infrastructure engineering in the areas of restoring and improving urban infrastructure; extending the durability, service life, resilience, and safety of aging infrastructure; reducing greenhouse gases; and developing sustainable cities.

By promoting industry-university collaborative research, development, patented technology, commercialization, and workforce training and education in the area of design and use of sustainable materials and engineering, resilient design and construction, smart engineering

infrastructure, and green energy infrastructure, the Infrastructure research constellation will stimulate inter- and trans-disciplinary research opportunities in the greater discipline and will position Missouri S&T to seek major external funding opportunities. Some of the unique technologies that will be developed and implemented in this initiative are listed below.

- Novel and smart construction materials capable of meeting stringent sustainability performance specifications
- Highly durable infrastructure materials to double service life and secure a five-fold increase in structural toughness
- State-of-the art, resilient structural design and construction of the infrastructure to resist extreme loads including both natural and manmade events such as earthquakes, fires, explosions, floods, hurricanes, and tornados.
- Advanced sensing and computing, real-time structural health monitoring system with cloud-based database and machine learning capabilities for critical infrastructure performance evaluation and maintenance decisions
- Robot-assisted autonomous inspection and maintenance of infrastructure with embedded, surface, and remote sensing, real-time data-enabled damage/deterioration evaluation, artificial intelligence-supported decision-making, in-situ renewable energy harvesting, cyber-physical-social (CPS) system interdependence, and value-driven design and value engineering.
- Integrated automated, intelligent, data-driven design-build-management enterprise of cyber-connected bridges, buildings, power microgrids, pipelines, roads, transportation, and wind turbines that will be developed in a semi-controlled environment and powered by geothermal, solar, and wind energy

Categories of funding mechanisms to support will the Infrastructure constellation will include federal, state, and local funding such as from the National Science Foundation, US Department of Transportation, State Departments of Transportation, National Institute of Standards and Technology, The City of Rolla Utility Services and Construction, small- and medium-sized business, private donations, research foundations, and corporate initiatives including industrial consortia and in-kind support.

This research constellation will support the Kummer Institute through alignment with the Institute's research centers. The Kummer Institute for Entrepreneurship and Economic Development will facilitate the integration of new research infrastructure, strategic recruitment of faculty to reinforce multi-disciplinary aspects of the Infrastructure research constellation, and create opportunities for spin-off companies associated with the research efforts.

The efforts of the Infrastructure research constellation will impact our country's

- Economic Prosperity, enabling individual government management sectors to develop high-fidelity scenario analyses for better cost-benefit ratios when expanding their business opportunities in infrastructure, and more cohesive interactions among various business sectors at a city level;
- Living Environment – ability to understand the effect of infrastructure construction on surrounding environments and the role of infrastructure management in minimizing adverse impacts on the environment;
- Social Dynamics – ability to quantify the disaggregated effects of infrastructure construction and management on various cultures and communities as pertaining to ethics and equity; and

- Societal Resilience – greater preparedness and credible performance assessment of a digital infrastructure city in the context of emergency response and functional recovery in the wake of a natural disaster, pandemic threat, or terrorist attack.

INTELLIGENT SYSTEMS RESEARCH CONSTELLATION SUMMARY

The Intelligent Systems constellation will be the academic platform at Missouri S&T for fundamental and applied Artificial Intelligence (AI) research as applied to engineered systems, human interaction, and creative works (e.g., Artificial Creativity). It will provide a communication and collaboration environment for constituent researchers across campus, including science, engineering, business, humanities, and social sciences.

In the most general sense, Intelligent Systems are human-created systems that receive input from their environment and respond to that stimulus to achieve a beneficial response. They include 'smart' devices, autonomous systems, and the myriad of other modern scientific tools and engineered systems people rely on to improve their lives and increase human capabilities. In addition to applications of AI, the research on the foundations of artificial intelligence, artificial creativity, and the social impacts of AI. The faculty in the Intelligent Systems constellation are affiliated with many regional and national research centers.

Faculty affiliated with the Intelligent Systems constellation have established research programs currently underway in the areas of smart living, smart manufacturing, smart infrastructure, healthcare, advanced/smart sensors, energy storage and conversion, global Internet, economics, autonomous systems, and artificial creativity. The Intelligent Systems constellation features synergies with all other Missouri S&T research constellations.

Research opportunities and potential areas of growth for the Intelligent Systems constellation are varied. A concerted effort within the federal government to move artificial intelligence research forward can be mapped directly into one or more current research efforts underway by members of this constellation, as described in the appended full Intelligent Systems constellation report. Agencies providing these opportunities include the Defense Advanced Research Projects Agency, the National Science Foundation, and the Department of Energy. The appended report suggests additional industrial partners with whom we already have relationships that might be eligible partners for Intelligent Systems-related I/UCRCs.

Missouri S&T labs and centers associated with the Intelligent Systems research constellation include the following

- Intelligent Systems Center
- Laboratory for Information Technology Evaluation
- Virtual and Augmented Systems Engineering Laboratory
- Shared Psychological Science Laboratory
- Physical Human-Robot Interaction Laboratory

MATERIALS CONSTELLATION SUMMARY

Materials science uses the principles of chemistry, physics, and engineering to address societal needs and practical problems. Major technology areas including electronics, nanotechnology, biotechnology, medicine, civil infrastructure, energy, metal production, aerospace, and others rely on innovations in materials research. As an indication of the potential impact of materials research, more than half of the Grand Challenges for Engineering defined by the National Academy of Engineering are directly tied to advances in materials.

Materials research is ubiquitous across the Missouri S&T campus with some aspect of research on materials occurring in a majority of the departments on campus. Since the founding of our campus as the Missouri School of Mines and Metallurgy in 1870, materials research and education have been an integral part of the institution. By its nature, materials research is highly interdisciplinary and involves a combination of experimental, theoretical, and computational approaches.

The long history of materials research at Missouri S&T has led to several strengths including our infrastructure for materials research and demonstrated success in entrepreneurial efforts that utilize materials research. Most of the campus' income from royalties on licensed patents is generated by materials-based patents. Materials research is pervasive at Missouri S&T, with collaborations and research efforts spanning across departments and colleges.

Materials research is a key area for future growth due to its multidisciplinary and cross-cutting nature. New opportunities constantly emerge for materials research based on the constant push for increased efficiency, longer operating life, higher operating temperatures, and new technologies, all of which require new and improved materials. The materials research constellation addresses a number of grand challenges, such as those defined by the National Academy of Engineering or similar forward-looking groups, which requires large multidisciplinary teams. The appended full Materials constellation report delineates several suggested for growth of materials research including continued aggressive pursuit of single-investigator grants; alignment with priority areas of the Kummer Institute to create research synergy; exploration of emerging materials research areas; utilization of national user facilities; establishment of new consortia involving industry, government laboratories, and/or other universities; increased external collaborations; and pursuit of large grant opportunities. Targets for such significant funding opportunities include a Department of Transportation university transportation center, Department of Energy energy frontier research center, National Science Foundation materials research science and engineering center and engineering research center, and Department of Defense multidisciplinary university research initiative grant.

The grand challenges for Materials constellation research require broad, cross-disciplinary knowledge coupled with deep understanding in specific areas to address needs. Important considerations include

- Facilitating communication among faculty on campus to build collaborations and teams

- Hiring new faculty in key areas to complement existing faculty expertise and fill critical gaps in expertise
- Coordinating “cluster” hires across departments for strategic research areas
- Developing a program to increase numbers of research faculty in key areas
- Marketing existing research expertise and successes locally and nationally

The Materials research constellation requires state-of-the-art analytical equipment and specialized laboratory facilities. Future growth of this research constellation necessitates expansion of laboratory space and capabilities. Some needs include dedicated centralized laboratory space for research clusters; new, dedicated research space; increased professional staff support for major research instrumentation and computational facilities; coordinate and support for acquiring key analytical equipment; acquisition of new analytical equipment to complement and expand existing capabilities.

RENEWS RESEARCH CONSTELLATION SUMMARY

Both renewable and non-renewable natural resources play an essential role in the economic development and national security of the United States and many other countries in the world. As the premier technological research university of the State of Missouri, Missouri S&T is home to numerous research groups with research themes related to various aspects of natural resources, such as their accurate exploration, economical and environmentally friendly extraction, safe storage, and sustainable management. Improving the communication and collaboration among all the research groups has the potential to dramatically improve S&T's capability to respond to funding opportunities, and conduct cutting-edge interdisciplinary research projects that raise S&T's visibility and reputation.

The Resources: Natural, Energy, Water, for Society (ReNEWS) research constellation will focus on the exploration, extraction, and management of the following natural resources: water, oil & gas, minerals, geothermal and other renewable energy, and space resources (minerals and volatiles) in asteroids, the Moon, and other space objects. In addition to traditional key natural resources such as water and fossil fuels, this constellation includes some emerging areas addressing future national needs for our society with numerous funding opportunities, including critical minerals, space resources, geothermal energy, and application of artificial intelligence in various fields. This constellation's distinct expertise enables the creation of novel interdisciplinary programs to train tomorrow's entrepreneurs and innovators in responsible resource development, equipping them with specialized competencies derived from the engineering disciplines, the natural and social sciences, and public and business administration. The ReNEWS constellation can build on a vast set of expertise currently present amongst researchers at S&T (both in academic departments and existing research centers).

ReNEWS constellation research can be categorized into four areas: critical minerals, space resources, subsurface energy, and water resources. Additionally, the cross-cutting themes of societal impacts, science communications, high performance computing, and data science will serve as connectors for all of the constellation's work.

In order to for the ReNEWS area to be competitive, Missouri S&T needs a critical mass of faculty with key expertise within these focus areas and connecting them to facilitate a focused and comprehensive effort. Some of the expertise needs to be in-house, while other areas can be addressed by collaborating with researchers from other institutions. Tackling the critical minerals research challenges requires research expertise from disciplines such as geosciences and mining, metallurgical, environmental, and geological engineering. Additionally, expertise in data science, high performance computing, mineral and resource economics, policy analysis, other social sciences, and communication are required for a comprehensive approach. Missouri S&T has expertise in most of these disciplines with a 150- year history in minerals education and research starting with the Missouri School of Mines, and over 100 years of experience in Geology and Geophysics and Petroleum Engineering. S&T's reputation as a global leader in minerals, our relationships with global mining companies, and relationships with several government agencies and national laboratories place us in a unique position to tackle this

challenge. Globally, only a handful of institutions can match the breadth and depth of expertise of Missouri S&T in critical minerals.

Missouri S&T can address the growing field of space resources with its unique combined legacies in mining engineering, aerospace engineering, chemical engineering, materials science and engineering, and civil engineering, as well as history, technical communication, and political science. Missouri S&T is poised to become a nationally-recognized leader in addressing the grand societal challenges associated with water resources. Our existing research strengths in this area can be subdivided into the areas of surface water and groundwater hydrology, water infrastructure engineering, water quality and aquatic ecosystems, and water remediation. These skills position us to address most water sustainability and security challenges. The water resources focus area also pairs nicely with our campus' educational objectives, including existing online graduate certificates in Surface Water Resources and Subsurface Water Resources, as well as a pending new interdisciplinary graduate program in Water Science and Engineering.

A critical mass of faculty members in GGPE, Mining, and Chemical Engineering have a long track record of research in subsurface research. Moreover, this can be integrated with faculty members in mechanical engineering and civil and environmental engineering to provide transformative research in areas such as the characterization of fluid flow and the control of subsurface fractures. Faculty members in material science, chemistry, chemical engineering and civil engineering can also develop novel materials to solve subsurface drilling and well performance problems related to subsurface energy production and carbon storage. Faculty working on geophysics and sensors can also develop breakthrough tools to map subsurface features. Therefore, this subarea will provide an excellent opportunity for collaboration by a large and diverse group of researchers inside and peripheral to this core area. The ultimate goal is for each subarea to of the ReNEWS constellation to work towards attracting engineering research center-type funding to cement Missouri S&T as a national leader within these areas.

While S&T has existing expertise and resources to give it a competitive advantage, important gaps in our capabilities still remain in critical minerals, resource economics, space mission operations and unconventional oil & gas recovery improvement and wellbore integrity.

The critical minerals subarea could benefit from a state-of-the-art critical minerals laboratory that houses equipment for mineral processing and extractive metallurgy. The water resources and resilience area needs core leadership in the area of hydrologic data acquisition, integration across multiple platforms, and projective modeling through climate scenarios in water resources engineering and hydrology. Addition of demonstrated expertise and research interest in modeling of watershed hydrologic processes and water quality, eco- hydrology related to resource extraction and processing is also sought. Added expertise is also needed in use interdisciplinary use of informatics and AI-Machine Learning in hydrology, water quality, and flood hydrology. The subsurface energy area needs supporting instruments to extend its research capabilities.

TRAINING, EDUCATION, AND WORKFORCE DEVELOPMENT RESEARCH CONSTELLATION SUMMARY

The Training, Education, and Workforce Development research constellation represents the necessary collaboration among industry, K-12 schools, and postsecondary education to narrow the skills gap through workforce development, training, and education. These skills include technical knowledge but also essential skills including teamwork, innovation, leadership, and communication. This constellation focuses on not only training for the current workforce but also the pipeline of students in pk-12 schools who are the future for higher education and industry. This constellation, which will develop and study innovative partnerships and programs, including possible new academic programs, interfaces with all of the other research constellations by researching the impact of training, teacher professional development, K-12 student outreach programs, and workforce development initiatives and policy. The emphasis of this constellation is not that these activities are occurring, but how to determine whether they are accomplishing the stated outcomes with meaningful impact.

To respond to the needs of industry, government, and other organizations, effective recruitment, teaching, and training methods must be studied for creation of the necessary STEM-capable workforce. This constellation will provide opportunities to enhance the training of graduate students in existing programs by collaborating on projects focused on workforce development and STEM education. The interdisciplinary research produced by members of this constellation will be collaboratively developed using principles of team science; all members will be involved in teams at the outset of project development, and every voice will be valued. Using research, this constellation will also provide recommendations for university, local, state, and national policies on workforce development and STEM education. This constellation will produce research that enhances access to STEM for all people, not just dominant groups, resulting in a more diverse, creative, entrepreneurial, and skilled workforce.

The Training, Education, and Workforce Development constellation will support Missouri S&T's efforts to reach R1 status, which will require the campus to increase the number of research & development expenses in non-science & engineering fields. This constellation will support interdisciplinary research and development of academic programs in both STEM and non-STEM fields, or even new degrees that are a combination of both such as engineering education. Future Initiatives and Programs (outputs) will include, but not be limited to, increased funding in non-STEM research expenditures, a STEM Education/Workforce Development Center, a mobile lab for workforce development/education demonstrations in rural communities, diversified doctoral and masters programs, an engineering education graduate certificate and possibly graduate degree, a workforce development graduate certificate.

Resources needed to support the Training, Education, and Workforce Development constellation include

- Faculty with pedagogical content knowledge in STEM fields, e.g. engineering education, earth science education, biology education, chemistry education, math education, etc.
- Workforce development staff with expertise in this area

- OSP resources dedicated to non-STEM funding opportunities
- Seed funding for non-STEM research projects focused on funding opportunity ROI
- Assistantships to fund students in masters programs to help with this work.
- A center dedicated to STEM Education and Workforce Development
- Resources devoted to summer camps, high school competitions, and other programs that bring youth onto campus for potential research opportunities
- Expanded use of testing center for workforce development with community members, needs partnerships with nearby industry
- Tuition model for dual credit/dual enrollment courses with high school students to funnel them into STEM professions

Potential barriers to development of the Training, Education, and Workforce Development constellation, which are detailed in the appended report, include issues such as a lack of sustainable medium-range (3-5 years) funding to allow for full implementation of initiatives and programs to take effect; a lack of alternative routes to course delivery and admission that are efficient and customer-friendly; the perspective that Missouri S&T is only STEM-focused and perceived lack of support, particularly for nontraditional students and STEM-minority students.

Potential research directions for the Training, Education, and Workforce Development constellation include

- Social-psychological theory and research for improving recruitment/retention and reducing achievement gaps in STEM (and in higher education more broadly)
- Small business/rural organization development connecting relevant undergrad and grad programs to facilitate small business needs in the area through the Missouri Small Business Development Network
- Research about teaching STEM in higher education, Scholarship of Teaching of Learning (SoTL) projects for student engagement, retention, etc.
- Study of K-12 students' interaction with STEM activities while on campus for events, field trips, or in school settings, and study of knowledge gained and retained over time from such activities.
- Follow up regarding existing summer camps for high school and middle school students, which offer ample opportunities for studying STEM education
- Curricular and instructional revision of "bottleneck" courses, comparison of outcomes

The Training, Education, and Workforce Development constellation will leverage potential resources and funding opportunities from entities such as the Department of Education, Spencer Foundation, Union Pacific, the National Science Foundation, and the American Library Association. Legislation, such as H.R. 4979, the Rural STEM Education Act in the Senate at the time of this writing, offer other potential for funding. This constellation will contribute to the knowledge base in the field and expand the funding opportunities available to researchers from individual disciplines. Many funding opportunities in these areas are currently available, as referenced in the appended full Training, Education, and Workforce Development constellation report, but one example is the U.S. Department of Education's investment of \$540 million in grants for STEM education in 2019.

The Training, Education, and Workforce Development Research Constellation will enhance the economic growth of communities by researching the efficacy of existing strategies, structures, and policies while collaborating with organizations, industry, and schools. These collaborations and community engagement will result in innovative approaches that appeal to foundations, state and national agencies, and industry for large scale funding opportunities that are new or previously unavailable to S&T.

RESEARCH ROADMAP APPENDICES

APPENDIX A

Faculty Survey of Needs for Success in Scholarly Pursuits February 13, 2020

The Vice Chancellor of Research, Costas Tsatsoulis, is asking for your input about the culture of research at S&T. This information will be used to further refine the direction of support for research activities from the Research Office. Please complete this survey **by March 1, 2020**.

[Create Qualtrics survey – anonymous:]

1. In your opinion, what are the barriers to interdisciplinary research?
2. How do you propose that these barriers to interdisciplinary research might be removed?
3. In your opinion, what are the barriers to collaborations with industry?
4. How do you propose that these barriers to collaborations with industry might be removed?
5. In your opinion, what are the barriers to collaborations with other universities?
6. How do you propose that these barriers to collaboration with other universities might be removed?
7. In your opinion, what are the barriers to entrepreneurial pursuits: patent submission, licensing technologies, spinning off companies, etc.?
8. How do you propose that these barriers to entrepreneurial pursuits might be removed?
9. Describe what additional support you need to be more productive in scholarly pursuits, and identify if the support should be from S&T, from Centers, from the System, etc.
10. Please provide any additional thoughts you have about how scholarship at S&T could be enhanced.

Demographics

Please indicate your:

College: CASB CEC

Rank: Assistant Prof, Associate Prof, Professor; Assistant Res Prof, Assoc Res Prof, Res Prof.

Thank you for taking the time to complete this important survey concerning scholarship at S&T.

APPENDIX B

Q#	Questions	1	2	3	4
1	In your opinion, what are the barriers to interdisciplinary research?	Define interdisciplinary. Collaborators vs. service? Create awareness of other disciplines.	workload/time High risk, need time for category 1 and 6	Faculty (number, quality motivation/comfortable).	Support (space, funding, equipment, mentoring)
2	How do you propose that these barriers to interdisciplinary research might be removed?	cultural shift, understand scholarship from different disciplines; more reach to and understanding of CSTS, HSS, etc. Treat Co-PIs as equals. Policies to value interdisciplinary work.	Advisory Board (e.g., Curators' Distinguished Profs)	Resources/incentives	Awards, publicized to FS
3	In your opinion, what are the barriers to collaborations with industry?	location (limited options, not enough exposure, S&T champions).	proprietary info (secret; IP)	Processes (how to, accessible lawyers).	publication outlets (practitioner focus vs. academic journals)
4	How do you propose that these barriers to collaborations with industry might be removed?	University helps build collaborations (liaisons, instructions for MOUs online, marketing, exposure)	Bring industries to campus (e.g., symposium)	Keith Strassner-type office (legal support/counsel).	reward faculty who do
5	In your opinion, what are the barriers to collaborations with other universities?	Limited travel money	Technology support (e.g., Zoom)	S&T reputation as engineering; less visible; rankings	making connections/contacts
6	How do you propose that these barriers to collaboration with other universities might be removed?	system-wide research symposia/summits; speakers; mutual visits	more meet and greets	P&T role	
7	In your opinion, what are the barriers to entrepreneurial pursuits: patent submission, licensing technologies, spinning off companies, etc.?	Rolla Chamber of Commerce not helpful	lack funding	workload/time	incentive/faculty benefit (annual review)
8	How do you propose that these barriers to entrepreneurial pursuits might be removed?	administrators involved in STL, KC, Springfield, Columbia incubators	focus on women and minorities	pitch competitions / "Shark Tank" [used to have "Miner Tank"]	Build teams
9	Describe what additional support you need to be more productive in scholarly pursuits, and identify if the support should be from S&T, from Centers, from the System, etc.	Time/teaching release (e.g., staff advisors for scheduling)	Grad students support (e.g., visas, tuition)	Facilities and maintenance (websites?)	Staff (more researchers, NTT, staff support)
10	Please provide any additional thoughts you have about how scholarship at S&T could be enhanced.	Support	Recruitment (e.g., faculty, grad students)	Maintenance	culture (recognize differences)

Categories					
5	6	7	8	9	10
Grad students (quality, availability - in class).	Building Teams (understand disciplines, build synergies, meet & greets, vulnerabilities)	Department (organizational) structure	Center Roles (truly interdisciplinary?)		
Research center support for all researchers, promote interdisciplinary work.	More staff (replace full-time with adjuncts)	gathering location	Gathering events to build trust; weekly, bi-weekly symposia (dept.); networking (e.g., We Dig Research).	Mentoring	
Reward those who do					
Staffing/faculty (internships in industry for faculty)	Department and Center Roles				
incentives	marketing (success stories)				
Resources (money, grant writers, illustrators, databases)	Centers' roles (promote collaboration)	reward successes.			
Centers - training grants					

Research Retreat

WHEN: March 19, 2020
9:00 am – 7:00 pm

WHERE: Westphalia, MO

TIME	PRESENTATIONS / ACTIVITIES:	
8:30-9:00	Continental breakfast	
9:00-9:05	Welcome	VCR Costas Tsatsoulis
9:05-10:00	Developing a Research Ecosystem at S&T	Chancellor Deghani
10:00-10:30	A quantitative analysis of research, scholarship, and graduate studies at S&T – Where we are now; how far are we from our strategic goals	VCR Costas Tsatsoulis
10:30-10:45	Break	
10:45-12:00	Facilitated session – Research directions and goals for developing S&T’s research ecosystem: research, scholarship, innovation, tech transfer. Unique strengths, emerging opportunities, resources needed to overcome obstacles, role of Centers, potential changes in funding landscape, faculty lines, graduate student recruiting, new degree programs, etc.	All participants
12:00-1:30	Lunch – assigned seating – Each table addresses major themes collected by the faculty survey in the areas of: interdisciplinary research; collaborations with industry; entrepreneurial pursuits.	All participants
1:30-2:30	Presentation of group ideas from lunch	All participants
2:30-2:45	Break	
2:45-4:00	Facilitated session – Further development of research directions and goals for developing S&T’s research ecosystem	All participants
4:00-4:15	Break	
4:15-5:00	Summary of action items	All participants

5:00

Message by the VCR

VCR Costas Tsatsoulis

5:00-7:00

Social hour and dinner

Virtual Zoom Research Retreat

As the forefront of science and technology continues to evolve, we need to realign our research vision to meet the dynamic nature of scholarship and funding opportunities that can elevate S&T's academic stature. While we excel in many areas at national and international levels, we also face challenges and competitions in many emergent areas of research. We need your input and participation in preparing for our next phase of strategic planning beyond the existing best-in-class signature areas. Your inclusion in this thought process is critical as you are the leaders of your fields. This allows S&T to strategically allocate resources, to overcome obstacles, and become successful.

In this virtual workshop, we plan to identify areas of science and technology that we can pursue based upon our current strengths. Importantly, we would like to facilitate interdisciplinary research to create synergistic productivity. During the workshop you will be asked to perform SWOT analysis of our research. Appropriate documents with S&T research data and technology transfer performance will be made available before the workshop.

WHEN:	May 15, 2020	
TIME	PRESENTATIONS / ACTIVITIES: PARTICIPANTS/PRESENTERS	
1:00-1:30	Developing a Research Ecosystem at S&T	All/Chancellor Deghani
1:30-2:00	A quantitative analysis of research, scholarship, and technology transfer at S&T – Where we are now; how far are we from our strategic goals	All/VCR Costas Tsatsoulis
2:00-3:00	Break into 6 Zoom meeting rooms of 6 participants each. Topic: SWOT analysis of research directions and goals for developing S&T's research ecosystem: research, scholarship, innovation, tech transfer.	All in groups of 6
3:00-3:15	BREAK	
3:15-4:00	Topic: How do we get there? What are the new areas we need to develop? What resources are needed to develop them? What is the role of Centers, new faculty lines, graduate student recruiting, new degree programs, etc.	All in groups of 6
4:00-4:15	BREAK	
		All /Breakout session leaders

4:15-5:00 The leaders of the 6 breakout sessions present the ideas of
their groups.

The outcomes of this first retreat will be summarized and discussed in a second 4-hour VIZORR that will include some of the original participants as well as new ones.

APPENDIX E

VIZORR SWOT Analysis Summary

Strengths

- Niche expertise in key technical areas to support the research theme
- Existing centers to build around and draw from
- Unique facilities and education programs that complement research area
- Unique opportunities for collaboration between different disciplines
 - Wide variety of specialties
 - One of the largest portfolio of engineering disciplines- but need Bio-X
- Reputation for world-class researchers engaging with undergrads
- Intelligent faculty in a lot of different research areas—lots of potential for collaboration
- Smaller school
- Broad coverage of disciplines and high density of diverse expertise on a small campus.
- Reputation for quality of education and experiential learning
- Several established research centers with long forged relationships with industry and federal agencies
- Collegial, dedicated faculty; strong departmental and research center leadership
- Strong industrial research connections, including some industrial consortia
- Intimate environment that promotes student development
- Facilities and space are good with dedicated staff supporting
 - S&T is not lab space limited
- User facilities add considerable value to the research mission of S&T
- Excellent national and international reputation in certain research areas
- Obvious interdisciplinary research activities, at least within the colleges
- Scholarship and scholarly impact strong in certain research areas
- Excellent partnership with a rural health system (Phelps Health)
- Strong senior faculty who are able to recruit and mentor junior faculty
- Have Signature Areas designed to address research grand challenges
- UM President and S&T Chancellor have a strong research background and vision
- Faculty at S&T do excellent research with limited resources
- S&T has great collaborative culture amongst research active faculty
- We dig research is a great venue to learn about research capabilities across campus – more of these opportunities are deemed necessary

Weaknesses

- Typically our campus starts strong and then does not follow through
- Lack of new faculty hiring to support new areas
- Research infrastructure and need for tools for science
- Unclear role of centers: facilities vs. spearheading collaboration
- We don't do a good job marketing ourselves—websites, Quad charts, etc
- Retention of outstanding faculty
- Compared to other research Universities, not an enormous amount of proposal preparation resources such as grant writers and grant opportunity hunters
- Some programs and departments have few senior faculty members who have been successful in winning major grants and who can mentor junior faculty in that field
- Percentage of research active faculty is low
- Research \$/T-TT faculty across S&T is low

- S&T lacks a research-oriented culture across all departments
- Not pursuing large funding opportunities + missing opportunities from DOD, NIH, industry..
 - Not enough faculty have the experience to contribute in these roles
- Missing interdisciplinary research activities across college boundaries
- Lack of professional grant writers in OSP
- S&T's rankings (departments and university) are too low
- Faculty recruiting, development and retainment is poor. Needs a more strategic approach. Recruitment for specific research expertise was suggested. Also post tenure professional development plan is lacking and was suggested. Faculty need incentives for faculty development.

Opportunities

- Draw on existing resources, cross campus expertise and existing centers
- Learn from past experience such as signature area investment
- Benefit from increased cross-campus collaboration
- Expanding programs in biosciences and engineering
- Get funding from other sources than federal agencies—what about private entities
- Connect to companies who come to recruit
- Collaboration with local and state agencies/institutions
- STEM fields can better interact with non-STEM fields. Non-STEM can offer creative and innovative ways to bolster broader impacts in STEM related proposals. Even a small fraction of funding from a STEM related grant can have an enormous impact on the expenditures in a non-STEM program or department
- Developing PhD programs in departments that do not already have them
- Need to transition more of our own BS students to MS & PhD programs at S&T
- Add interdisciplinary programs, as needed, based on emerging areas
- Team up core faculty on campus to go after larger funding opportunities
- Minus COVID-19, there have been strong Federal, and industrial, funding opportunities
 - How to take advantage of the COVID-19 research needs?
- Create or bolster what is missing or largely missing at S&T?
 - Not enough multi-disciplinary 'Biotech' R&D activities
 - Biological Sciences needs a PhD program
 - Emerging areas again...biomedical engineering, bioX...
 - Not enough multi-disciplinary 'Data Science' R&D activities
 - Strengthen CS research activities with other departments/programs
- Use marketing to elevate visibility of S&T research, scholarship, and entrepreneurship
- Not enough international collaborations (e.g., research, dual-PhDs, etc.)
- Proximity to Fort Leonard Wood not being taken advantage of w.r.t. to Army funding
- Need to strengthen partnership with Phelps Health and build more relationships
- S&T needs to strengthen its Congressional lobbying efforts
- To foster research competitiveness amongst faculty, have campus wide annual research proposal competition (multi PI and/or single PI; centers can review/judge). This could be similar to "We dig research", like "We reward research". Benefits: sharpen writing skills, expose faculty to breadth of research expertise, encourage more faculty to do research.
- Technology transfer has lots of potential to improve success; momentum to generate spin-off companies is lacking and can be improved; increase opportunities with SBIR funding; install professional system in place that takes this step out of faculties' hands – have professionals do

that. Could be called “Center for innovation” run by business professionals that can advise faculty.

Threats

- Change in leadership/direction before the investments gain momentum
 - Moving strategies
- Lack of qualified graduate students applying to Missouri S&T
- Depending so much on federal agencies
- budgetary constraints—enrollment and state budget
- General decline in international graduate students. Visa processing times

What do we do next?

- Improving the research culture:
 - Expanding the pool of active research faculty
 - Must do a better job promoting collaborations between colleges
 - More than supporting roles for CASB
 - E.g., engagement with the Collaboratory
 - Campus-wide research seminars
 - Emphasizing the importance of research/emphasis on research, in all hires, promotions, recognitions
 - Promoting the successes of our colleagues
 - Finding administrators with histories of research success and who then understand the research culture
 - Expanding graduate fellowship programs to recruit or reward outstanding candidates
 - Hiring decisions based on research needs, not teaching needs
 - Developing and promoting the graduate education infrastructure, beyond individual research projects
 - Increasing the value of graduate education
 - Endowments that promote research and attract (or reward) successful researchers
- NIH is a difficult nut to crack
 - Teams/clusters need to be a critical size- we must develop critical collaborations
 - Identify/develop niche opportunities; e.g., TBI
 - What’s the strategy to leverage these programs into sustainable capabilities?
 - Biological sciences must develop biomedical expertise
 - Interdisciplinary PhD in Biomedical Sciences and Engineering
- Infrastructure: how do we acquire the cutting-edge facilities that attract faculty, students, funding opportunities
 - Strategic/coordinated MRI process
 - Strategic “wish-list” at the campus level, to be reviewed whenever funds or opportunities become available
- Niche expertise: go after opportunities based on unique strengths and diverse programs at S&T
 - TBI: explosives and bio-chem markers, and electronic sensors, and neural network analyses, and materials
 - Strategic minerals: mining and geochem and metallurgy and policy
 - Marketing: who knows that we are good in these areas?

- Business manager: invest in someone whose mission is to find new partners, new projects, new funding opportunities for one of our centers or one of our research areas
 - TBI- is this how we could grow this campus expertise into another pillar for SARDI?
 - EMC, CAMT, PSMRC could all benefit
- Start by changing our identification as a small engineering school and expanding our definition to include more programs that complement the S&T part.
- Retain students—undergrads (they need to know there's more than just engineering);
Undergraduate research opportunities
- Retain faculty—recognize them all as having value
- Role of centers—
 - Mentorship
 - transparency, help with budgets
 - learning about what each center does—we dig research
- Marketing to external actors
- Look at how are resources invested—reinvest in faculty
- Perhaps we can get the "we dig research" effort to include faculty from other universities and program managers from funding agencies to discuss their research and potential research interests, that way we can continue to get our name out there and diversify our collaborators...
- Need to stop changing strategies every few years. Need to develop a unified vision and strategy and stick to it
- The role of centers
 - Current centers need to proactively identify and attack big problems
 - Need to bring faculty together from disparate disciplines into larger teams that can tackle big grants
- New programs, centers and research areas
 - STEM Education. An area that all disciplines can contribute to and matches with our reputation for teaching excellence
 - Try to identify what interdisciplinary expertise exists on campus that is not well matched with by a current center
- Find a way to “reactivate” faculty that have taken a break from research
 - Revising department workload policies
 - Policies should emphasize high impact publications, production of PhD students and advising postdocs
- Graduate recruiting
 - Better advertise the unique research opportunities in interdisciplinary fields
 - Shake off the reputation for being a “traditional engineering” school and replace it with a reputation for a school that produces innovators and leaders

How do we get there?

- Recruit research-excellence faculty (getting the right people on boat), with emphasis on multidisciplinary faculty
- Retain research-excellence faculty
- Resources – development of excellent faculty requires abundant resources
 - Financial (seed funding, fixed price policy, F&A return, etc.)
 - formal mentorship to junior faculty
- Leadership support – Strengthen leadership support for faculty, especially junior faculty.
 - Engage the Univ. of Missouri system and also the state and federal governments
 - Improve the stability in the leadership direction

- Strengthen the sharing of research expertise and skill sets among young faculty members
- Continued strong support for areas of existing strength, especially the signature areas, and exploring new directions
- Strengthen the quality of our graduate students

What are the new areas we need to develop?

- Data science
- BioX
- Renewable energy
- Industry 4.0 technologies
- Cyberspace security
- Artificial intelligence
- Infrastructure resiliency
- Environmental nanotechnology

What resources are needed to develop them?

- Financial resource needed to recruit the highest-quality faculty
- Provide help for recruitment of high-quality graduate students and post-docs
- Hire grant writer & graphic illustrator to help prepare large-scale proposals
- Research marketing to improve S&T ranking
- Funding support for Class-C center in emerging areas of national importance
- Allowing for hiring of high-caliber mid-career faculty for emerging areas

What is the role of Centers, new faculty lines, graduate student recruiting, new degree programs, etc.?

- The role of Centers is mainly to nurture new faculty and to coordinate center members as well as to collaborate with other Centers toward seeking funding opportunities, especially for large-scale research projects and research centers
- New faculty lines are needed in the areas of importance mentioned above
- A more effective approach is needed for recruitment of quality graduate students
- Development of new degree and certificate programs is needed in emerging interdisciplinary areas
- Ph.D. degrees should be offered for some existing academic programs such as Biological Sciences
- Continuous innovation and consolidation of research infrastructures is needed
- LIMITED RESOURCES is greatest challenge:
 - How to maximize and leverage? How to do this without affecting the academic freedom of all faculty?
 - Recruiting good students requires “free money”.
 - Branching out and sharing individual resources is risky because no incentives exist to do so.
 - Long term planning is crippled by short term budget cuts. In research this prevents any stimulus and growth.
- Centers: What is their role beyond internal S&T collaborations? How can they be promoted externally to increase industry involvement? Involve Development office to ring doorbells and do marketing of research.

Research Roadmap Kickoff Meeting



MISSOURI
S&T

Our Visions

MISSOURI S&T VISION:

- Missouri S&T will be the **leading** public technological **research** university for discovery, creativity and innovation. We will cultivate curiosity, creativity and confidence in our graduates. We will be the institution of choice for partners around the world seeking a highly qualified, talented and entrepreneurial workforce; **innovative research**; relevant educational program.

MISSOURI S&T RESEARCH VISION

- We aspire to be among the list of **R1: Highest Research Activity** universities. **Doubling** our annual research **expenditures** by 2025 is an audacious but achievable goal that will contribute to this higher classification.

Need for Research Roadmap

- **CURRENT STRENGTHS and EMPHASES:**
 - Last time a research strategic plan was created was 2013-14: *Signature Areas*
 - > Advanced Manufacturing
 - > Advanced Materials for Sustainable Infrastructure
 - > Enabling Materials for Extreme Environments
 - > Smart Living
 - Where should we be 10 years from now?
- **TOP-DOWN:**
 - Chancellor has identified 4-6 research “pillars”
- **BOTTOM-UP:**
 - Research Retreat in May did an excellent SWOT analysis
 - In the following I summarize responses (full responses also provided to control for bias)

S&T ARMY RESEARCH AND DEVELOPMENT INSTITUTE (SARDI)

Concept Proposal
April 20, 2020



MISSOURI
S&T



The Four Research Pillars

Combining S&T's legacy of strength in science and engineering, we analyzed our past and current research areas, focused on Army needs, and determined our strengths for future defense partnerships. The institute will leverage our university's highly regarded areas of national expertise and prominence in Additive Manufacturing, Materials and Explosives Engineering, Smart Systems (AI, sensors, autonomy, cybersecurity, information assurance), and Infrastructure for Mobility, Resilience and Sustainability.



Additive Manufacturing

As one of the world's leading technological research universities, Missouri S&T is nationally recognized for its research and scholarship and serves as a center of excellence for the development and transition of innovative advanced manufacturing technologies and research efforts in next-generation additive manufacturing. Our expertise includes energetic materials and transparent armor to manufacturing with 2D/1D nanomaterials for multi-functional sensors, devices and coatings.



Materials and Explosives Engineering

Missouri S&T has expertise in mastering extreme environments with unique materials and innovative approaches for modeling and design in diverse fields, including ballistic impact and high-radiation environments with materials engineering and science. This research bridges fundamental and applied research on shape-memory metamaterials shells for impact protection of structures to explosives engineering research on novel impulse instrumentation for buried explosive charges.



Smart Systems (AI, sensors, autonomy, cybersecurity, information assurance)

S&T merges advanced computation and big data with signature strength areas in the latest research on artificial intelligence techniques and robotic and autonomous solutions — from securing information forwarding through fragmentation for collaborative missions in a battlefield environment to smart cyber-physical warfare.



Infrastructure for Mobility, Resilience and Sustainability

S&T researchers are developing novel approaches to advance resilient infrastructure through innovative technologies that are critical for rehabilitation and restoration of critical military and national defense assets. Research includes the development of blast-resistant concrete that provides protection on our home front and abroad and highly efficient, sustainable construction designs that minimize the use and transport of natural resources and waste generation.

STRENGTHS

- Unique opportunities for collaboration between different disciplines
 - Wide variety of specialties
 - One of the largest portfolio of engineering disciplines- but need Bio-X
- Intelligent faculty in a lot of different research areas—lots of potential for collaboration
- Obvious interdisciplinary research activities, at least within the colleges
- Excellent partnership with a rural health system (Phelps Health)
- S&T has great collaborative culture amongst research active faculty

WEAKNESSES

- Typically our campus starts strong and then does not follow through
- Lack of new faculty hiring to support new areas
- Not pursuing large funding opportunities + missing opportunities from DOD, NIH, industry.
- Missing interdisciplinary research activities across college boundaries
- Faculty recruiting, development and retainment is poor. Needs a more strategic approach. Recruitment for specific research expertise was suggested.

OPPORTUNITIES

- Benefit from increased cross-campus collaboration
- Expanding programs in biosciences and engineering
- STEM fields can better interact with non-STEM fields.
- Team up core faculty on campus to go after larger funding opportunities
- Proximity to Fort Leonard Wood not being taken advantage of w.r.t. to Army funding
- Need to strengthen partnership with Phelps Health and build more relationships

WHAT DO WE DO NEXT?

- Improving the research culture:
 - Expanding the pool of active research faculty from 15% to something greater
 - Must do a better job promoting collaborations between colleges
- NIH is a difficult nut to crack
 - Teams/clusters need to be a critical size- we must develop critical collaborations
 - Identify/develop niche opportunities; e.g., TBI
- Niche expertise: go after opportunities based on unique strengths and diverse programs at S&T
 - TBI: explosives and bio-chem markers, and electronic sensors, and neural network analyses, and materials
 - Strategic minerals: mining and geochem and metallurgy and policy
 - TBI- is this how we could grow this campus expertise into another pillar for SARDI?

WHAT ARE THE NEW AREAS WE NEED TO DEVELOP?

- BioX
- Renewable energy
- Industry 4.0 technologies
- Cyberspace security
- Artificial intelligence
- Infrastructure resiliency
- Environmental nanotechnology

IN SUMMARY

- Collaborations
- More DoD, NIH, Industry
- A **CASE** for S&T research
 - CHAMPION
 - ALIGN
 - SUPPORT
 - ENGAGE
- Continue to **champion** our strengths
- **Align** our strengths to new directions, agencies, and programs
- **Support** our strengths and our new directions
- **Engage** all our faculty, our industry partners, and our academic partners

Advanced Manufacturing Systems

Bio-X



Information Assurance



Materials and Explosives Engineering



Rapid Systems Prototyping



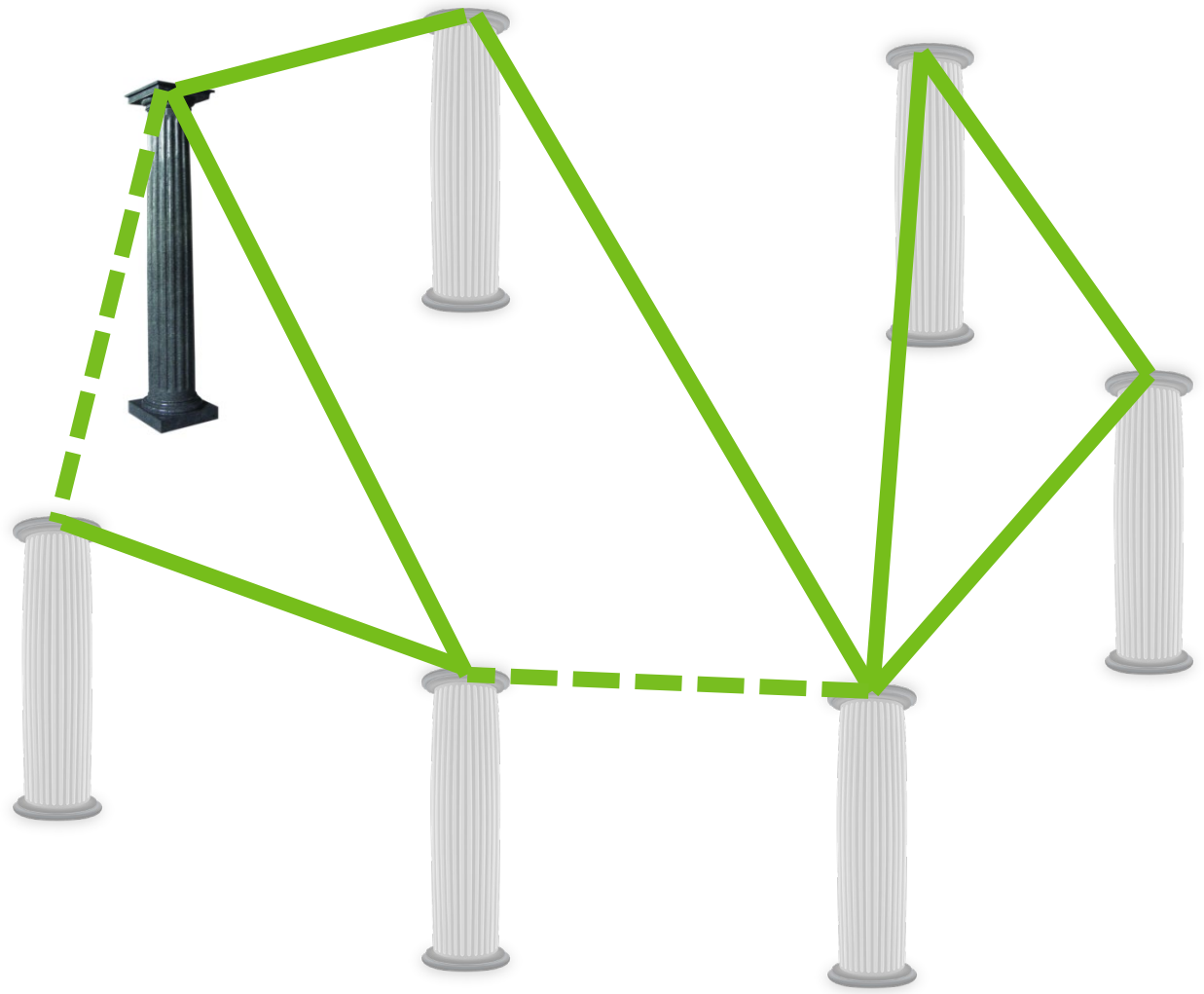
Infrastructure and Environmental Systems for Mobility,
Resilience & Sustainability

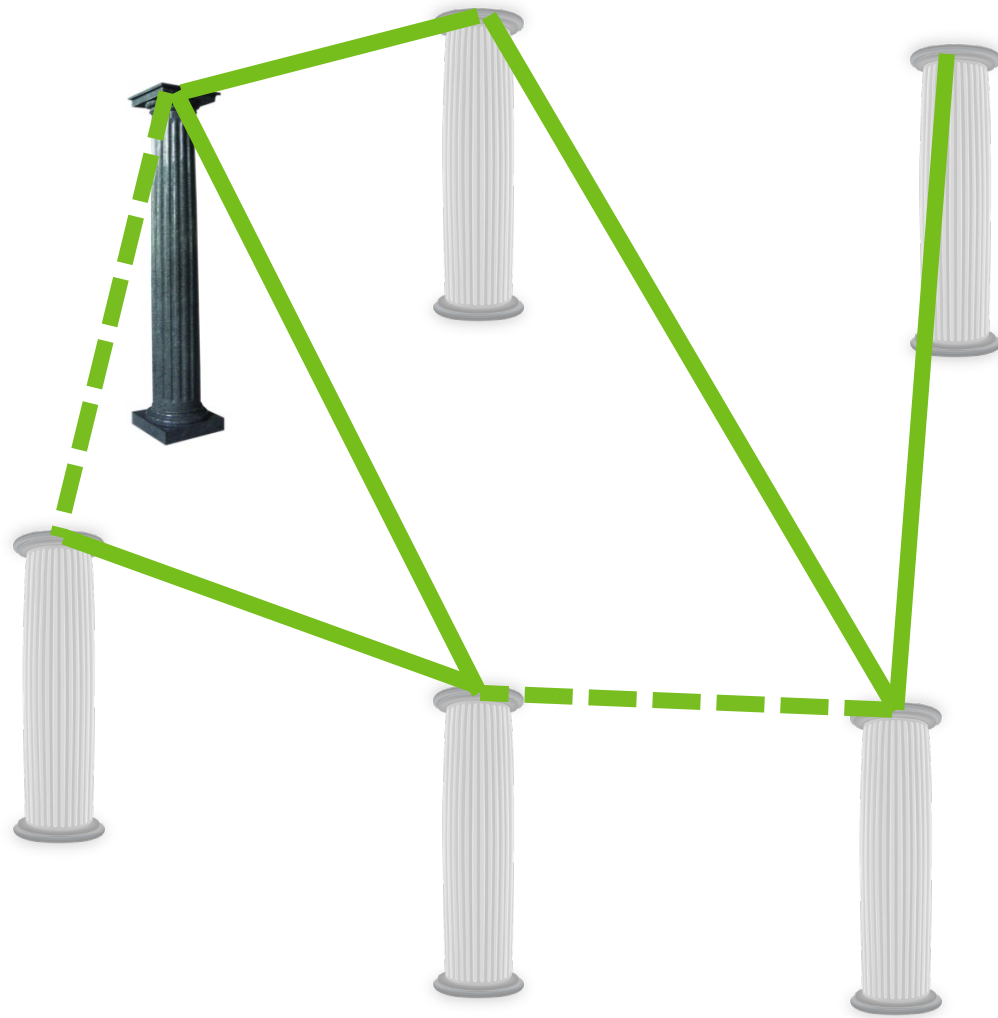


Smart (Intelligent/autonomous) Systems









A Role for You

- Examine the pillars
 - Do they represent the current strengths of S&T?
 - > Faculty have left
 - > Faculty have been hired
 - > Investments have been made in equipment, facilities, people
 - Expand, combine, change, add, delete pillars
- What is the status of Bio-X on campus?
 - Identify bio-related research activities at any state, from just starting to mature
- What should be our strategic directions?
 - Strengthen pillars
 - Strengthen Bio-X
 - Build binders/connectors
 - Or something completely different

What's at Stake

- Future of the Signature Areas
 - Parallel, independent review is being planned
- Future hires
 - Hire for research areas vs. departments
 - Pillars vs. Connectors vs. ?
- Future role of Centers
 - Pillars vs. Connectors vs. ?
- Future graduate degrees
 - Support of research areas and faculty hires
 - Targeted recruiting of graduate students
- Future research partnerships
 - DoD, DoD Medical, Army, NIH, Industry, Foundations, Federal Labs, Universities, etc.
- Future distribution of limited resources
 - Existing vs. new research directions
 - Postdocs vs. NTT research faculty vs. T/TT faculty

