Priority Research Directions | Cornell Engineering 2030

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The Big Idea

With a remarkable ability to create synergy between fields of study, a dedicated striving to be an exemplary research institution, and a public engagement mission focused on tangibly improving lives, the College of Engineering (COE) has established five *Core Areas of Excellence:*

- *Advanced Materials*
- *Bioengineering and Human Health*
- *Climate and Energy Systems*
- *Cyber-Physical and Autonomous Systems*
- *Computer and Data Engineering and Informatics*

The Cornell Engineering 2030 plan will position COE as a center of excellence for incubating influential ideas in engineering education, technology translation, and research. By recruiting new talent, leveraging new and existing collaborations, and reimagining research possibilities — particularly at the intersections of these Core Areas of excellence — the college intends to focus on advancing research in ten specific **Priority Research Directions**, which were identified during a rigorous, college-wide strategic planning process.

Priority Research Directions

- **Quantum Information Science and Technology**
- **Advanced Molecular Engineering**
- **Translational Biotechnology and Precision Medicine**
- **Space Technology and Systems**
- **Data-Driven Decisions, Artificial Learning, and Machine Learning**
- **Robotics and Autonomous Systems**
- **Climate, Energy, and Environmental Systems**

Outcomes

These strategically selected Priority Research Directions are strongly aligned with grand societal challenges identified by the National Academy of Engineering and the National Science Foundation. By creating new knowledge, educating future-ready students, and driving technology innovations in these domains, Cornell Engineering will extend its global influence and increase its contributions in areas that have emerged as national priorities.

COE has many advantages when it comes to breaking significant new ground in these ten areas. For example, the college's collaborations across Cornell University — including with Cornell Tech and Weill Cornell Medicine in New York City — create unique opportunities for pioneering new education and research initiatives.

INTRODUCTION

At the end of the 20th century, the College of Engineering (COE) the COE examined the breadth and depth of its rigorous scientific research and chose four areas for targeted investment: advanced materials, bioengineering, computer and data science, and energy and the environment. In the ensuing decades, COE has built a community of core scholars supported by state-of-the-art infrastructure, and the resulting research programs became the institutional backbone for exploring the emerging challenges of the 21st Century. Now, the college needs to renew its efforts and set new goals for large-scale research investment.

Building on the college's current core areas of excellence, and aligned with urgent priorities identified by the National Academy of Engineering and the National Science Foundation, the COE has identified ten priority research directions to pursue over and beyond the next decade. These priority directions will fuel faculty recruitment across all levels and enable the COE to pursue additional investment in research infrastructure. Robust faculty programs will also allow Cornell to attract top graduate students who play a critical role in furthering this research.

The priority research directions build upon – and in many cases, exist at the intersection of – the college's current core areas of excellence, and they are strongly aligned with urgent priorities identified by the National Academy of Engineering and the National Science Foundation.

QUANTUM INFORMATION SCIENCE AND TECHNOLOGY

- *How can we revolutionize society's use of technology and communication through quantum science?*

Across the world, universities and businesses are racing to produce the next generation of research and applications in the field of quantum-scale information science and technology (QIST). Quantum cuts across every single engineering discipline and has broad-based societal and economic impacts — from the basic interactions of nature to developing cutting-edge technologies.

There are many untapped and exciting possibilities that can come from quantum research. Understanding how atoms interact and organize themselves, or being able to visualize protein behavior, for example, are just two ways in which innovation in quantum engineering could transform essential parts of science, medicine and defense.

Driven by COE, Cornell University is uniquely poised to spur advancement in QIST fields. The strength of existing research programs and the collaborative potential of the Provost's Radical Collaboration initiative provide the perfect base for investing in more people, facilities and infrastructure.

The college already has world-leading research programs in the fields of quantum communication, quantum sensing, quantum materials, quantum internet, and quantum computers and simulators. By taking those programs' success and capitalizing on federal priorities, such as the 2020 National Quantum Initiative Act, and by responding to the high student interest to gain access and experience in QIST fields, COE will be well suited to attract additional faculty expertise and philanthropic support.

In addition to the goal of becoming a breakthrough leader in the quantum field, this work has the potential to secure global communication, develop a quantum internet, build cutting-edge tools, simulators and sensors, and fill the existing workforce gap in quantum engineering.

Recommendations

1. **Recruit talented faculty with expertise in strategic QIST fields**

COE already has strong roots in several areas of quantum research — including quantum-scale materials, atomic-scale characterization, optical physics, spintronics, information science and computer architecture. Using these core programs as a platform, COE should seek to hire faculty with strategic and complementary expertise that can help take this work to the next level.

Individual labs already produce world-leading quantum research, and Cornell stands ready to catalyze these efforts thanks to a strong culture of cross-college partnerships. Through existing programs, such as the Provost's Radical Collaboration initiative, the COE can advocate for hires with quantum-relevant experience in the realms of data science and nanoscale science and microsystems engineering (NEXT Nano) — which have already been identified as strategic areas for investment at the university level.

The best way to expand the capacity for COE's overall performance in QIST is to start by triaging the potential of theoretical and experimental researchers. In particular, the college could advance quickly in the field by recruiting 3-4 faculty whose research is based on the systems side of QIST — examining quantum information and quantum communication — as well as faculty dedicated to the following areas:

- Experimentalists
    - Focused on materials and QIST devices
- Theorists
    - Interested in condensed matter and quantum information
    - Invested in working closely with experimentalists

This hiring approach will provide COE and the university with the most efficient and promising returns on investment, especially given the potential to make joint-appointments with other colleges and the capacity for co-locating lab space.

New faculty and their cutting-edge research programs also start a new cycle in which the college can attract more highly talented personnel, advocate for philanthropic support and pursue highly coveted funding opportunities.

2. **Invest in facilities needed to perform higher quality quantum research**

COE's legacy of success already includes multiple state-of-the-art facilities and programs that house interdisciplinary research and share some overlap with QIST fields:

- Cornell NanoScale Science and Technology Facility (CNF)
    - Provides efficient access to nanotechnology infrastructure and expertise
    - Enables rapid advancements in nanoscale science, engineering and technology

- Cornell Center for Materials Research (CCMR)
    - Promotes interdisciplinary collaborations that tackle fundamental issues in materials science and engineering
    - Funded by the National Science Foundation and New York state
- Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials (PARADIM)
    - Helps design new materials with unique properties
    - Works to develop the next generation of electronic devices
- The Cornell High Energy Synchrotron Source (CHESS)
    - Home of high-intensity, X-ray source and synchrotron radiation facilities for conducting research across physics, chemistry, biology, environmental and materials sciences — including quantum characterization
    - Funded by the National Science Foundation

Both CNF and CCMR provide excellent models for beginning to create the dedicated facilities and infrastructure needed for QIST research. The college should accumulate a library of specialized equipment — available for sharing across multiple labs — so that it becomes easier to generate and collect the data needed for crossing the current boundaries of knowledge.

Quantum materials is an area in which Cornell particularly excels, and the COE should also invest in top-of-the-line electronics, laser tools and cryogenics that will allow researchers to further push the limits of discovery. New infrastructure should support both the development of quantum materials and materials used for quantum applications.

3. Establish a national quantum research center

To truly raise the bar for QIST research, COE needs to establish the Institute for Quantum Information at Cornell (QuIC). This institute would allow the college to develop world-class QIST research infrastructure and to increasingly recruit leading scholars with both interdisciplinary and field-specific expertise.

Such efforts will expand faculty expertise in the quantum sphere and invite more opportunities for institutional, entrepreneurial and philanthropic partnership.

As a dedicated home for QIST research, the QuIC would foster new, high-risk and interdisciplinary collaborations to expand the current boundaries of quantum engineering. This institute would be highly attractive to students — creating unique learning opportunities that empower them to help shape the future of the field.

Currently, quantum science is receiving national attention from Congress, the U.S. Department of Energy, the National Science Foundation and other federal organizations. By jumping on this explosion

of interest, the establishment of a quantum center at Cornell would allow the institution to seek higher value opportunities for external investment and support.

This level of visibility and commitment to real-world impact will drive cross-college quantum engineering innovation and keep the COE at the forefront of an ever-changing field.

ADVANCED MOLECULAR ENGINEERING

- *How can Cornell Engineering use molecular engineering to design better materials?*

The field of molecular engineering is continually pushing the boundaries of knowledge. This research examines the unique chemical and physical properties of the molecules and atoms that make up existing materials. Scientists then use those smaller elements to build new materials and systems to match unmet needs in other fields and industries.

This work has the potential to revolutionize energy capture and storage, to deliver better medicines, vaccines and therapies, and to change how humans interact with the environment through soil remediation, carbon sequestration and water desalination.

Nationwide, there is a huge interest in molecular engineering applications, and targeted programs have been established at the U.S. Department of Energy, Department of Defense and the National Science Foundation. The collaborative and cross-disciplinary nature of molecular engineering, design, and manufacturing supports the presidential priority of One Cornell, and it aligns with other research investment opportunities, such as the Provost's Radical Collaboration initiative.

COE aims to become a national leader for molecular engineering through strategic hiring, infrastructure investment and the establishment of a high-performance computing center. Through targeted collaboration that integrates efforts across the full molecular design, engineering and manufacturing cycle, COE will become a key player in developing solutions for the grand societal challenges of the 21st Century.

Recommendations

1. **Recruit faculty with expertise in strategic areas of the design cycle**

The broader field of molecular engineering is highly cross-disciplinary. Before new products can be designed and marketed, there are three key areas of research that need to come together: materials synthesis and processing, materials characterization, and theory, computer modeling and simulation.

COE seeks to perform cluster hires across these three domains so that Cornell retains the expertise and infrastructure needed to make a complete conception-to-commercialization pipeline. The college already has many researchers working in each domain, and a more strategic approach to project development will build on the institutional legacy of catalyzing interdisciplinary groups to solve real-world problems.

For the first two areas of the design cycle — materials synthesis and processing, and materials characterization — COE is already in a key position to attract top researchers, due to its world-class facilities and characterization tools. New faculty trained in these important areas will be able to leverage this infrastructure and jump-start their Cornell careers as soon as they arrive.

Through strategic recruitment, the college plans to hire new professors of practice and design. These faculty would be able to build on research advancements and be well-equipped to assemble new materials into products ready for the market and other translational use.

The college can leverage the Provost's Radical Collaboration initiative to find relevant expertise that also builds on existing excellence in the areas of data science, and nanoscale science and microsystems engineering.

2. Further investments in high quality infrastructure

In the past 10 years, significant advancements in technology have transformed the way scientists can examine and work with soft matter far from equilibrium. What makes this research challenging is the ever-changing and minute nature of these materials, especially in a wide range of environments.

The college's world-class electron microscopes already enable faculty to perform experiments and achieve results that rival the work of other academic institutions. Other existing state-of-the-art infrastructure allows faculty to push the limits of discovery, including:

- Cornell NanoScale Science and Technology Facility
- Cornell High Energy Synchrotron Sources
- Cornell Center for Materials Research
- Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials
- Cornell Institute of Biotechnology
- AFRL-Cornell Center for Epitaxial Solutions

However, the college needs to maintain support for this infrastructure to stay at the top of an ever-advancing field. High-resolution imaging and molecular characterization instruments need to have the capacity to examine molecular systems in finer detail, on shorter time scales, in different environments and over longer, dynamic periods. COE also needs bigger and better computers to model complex systems and work with large datasets.

The college will also benefit from creating an integrated product design and manufacturing institute. This would allow faculty and professors of practice to control every stage of the design cycle right on campus. Such an institute would also provide great benefits for student education — providing seniors and Master of Engineering students with a high-quality space for completing capstone projects.

3. Advance high-performance computing center on the Ithaca campus

To take molecular design and manufacturing to the next level, COE needs to establish a high-performance computing center based on the Ithaca campus, and use this as a catalyst to double the number of faculty working across the intersection of molecular engineering, computer theory and simulation. Artificial intelligence and machine learning also play a critical role in these collaborations.

This center will attract top faculty from around the world and accelerate research programs. It would also help solidify cross-college collaborations between Cornell Tech, the Cornell Ann S. Bowers College of Computing and Information Science, and other relevant units.

High performance computing is an essential tool for working with large datasets and performing complex modeling of molecular systems. It allows researchers to account for a higher number of dependencies and variables in dynamic systems, which would be timely and costly to study in traditional trial-and-error experiments. Computing also gives researchers a much higher degree of precision, yielding critical details that affect other parts of the design cycle.

Through dedicated programs at this high-performance computing center, COE will be able to pair domain scientists with data scientists to truly achieve novel insights and results.

TRANSLATIONAL BIOTECHNOLOGY AND PRECISION MEDICINE

- *How can Cornell Engineering use biotechnology to propel discovery and improve health?*

Engineers have traditionally focused on developing better tools to advance biological inquiry, but now they are also increasingly contributing toward scientific research itself. Thanks to advancements in technology, the current field of biology is experiencing rapid, revolutionary change in a race to solve fundamental questions in health, medicine and life.

At COE, biotechnology sits at the sweet spot between engineering, physical sciences and life sciences, where it can leverage cutting-edge research collaborations and fuel the presidential vision for One Cornell.

The goal is to build upon COE's legacy of engineering the tools of scientific discovery and advance its cross-disciplinary approach to working with science applications — particularly as they relate to other areas of Cornell excellence, such as medicine, health, food, agriculture and the environment.

The college's long history of innovation in working with biological systems and developing solutions for diseases, such as cancer, will also allow the college to expand key clinical relationships. It aims to maintain national leadership in key biomedical disciplines, invest in research partnerships and expand its world-class facilities.

These efforts have the potential to transform current approaches to human and animal health, as well as to provide greater insight on how living organisms function and shape interactions on both microscopic and macroscopic scales.

Recommendations

1. **Develop stronger programmatic connections**

The COE currently has more than 70 faculty working on areas of translational biotechnology and precision medicine, including imaging, nanobiotechnology, tissue engineering, biomaterials and disease expertise. It also has a strong reputation for engineering excellence as it relates to applied systems in agriculture, food and health — in human, animal and microbial systems.

This legacy comes from many strong individual connections with other scientists across Cornell, and to truly advance this work, COE needs to invest in program-based research. Doing so will build scientific depth, translational relevancy and overall longevity into these individual efforts.

Here, strategic faculty hires can boost existing synergies, and expanding four key research areas would provide a quick return on investment:

- Disease
    - Immunoengineering, a rapidly growing area within COE
    - Cancer, providing a strategic bridge to Weill Cornell Medicine (WCM)
- Computation and modeling
    - Yielding connections to big data and artificial intelligence
- Systems and synthetic biology
- Brain-computer interface

In addition to a history of excellence, COE already has world-class facilities to support this work, both in Ithaca and with its partners in New York City. The Provost's Radical Collaboration initiative provides university-level interest in pursuing this approach, especially as it relates to targeted advancement in genome biology, infection biology, data science, and nanoscale science and microsystems engineering.

These new research partnerships should capitalize the potential synergies that come from working across engineering and both the physical and life sciences. Further analysis will yield which additional programs should be supported between the COE, WCM, the College of Veterinary Medicine (CVM), the College of Agriculture and Life Sciences, the College of Human Ecology and the College of Arts and Sciences.

By turning individual contributions into programmatic investments, the college will be able to attract and retain top faculty that can help expand and advance technological tools, science applications and clinical translations.

2. Advance partnerships for increased clinical translation

Engineering and technology play a huge role in the medical field. From using quantitative tools to improve the knowledge of biological systems, to translating findings for better medicines and clinical care, the COE is in the perfect position to accelerate research and meet the changing needs of societal demographics and human healthcare — including those fueled by the COVID-19 pandemic.

COE faculty have already led several successful multi-investigator efforts focused on health:

- Cornell Physical Sciences Oncology Center on the Physics of Cancer Metabolism — funded by the National Cancer Institute in the National Institutes of Health
- Memorial Sloan Kettering-Cornell Center for Translation of Cancer Nanomedicine
- NeuroNex Hub — funded by the National Science Foundation
- T32 Immunoengineering Training grant — funded by the National Cancer Institute in the National Institutes of Health

Across nearly every department, the college has maintained disciplinary success in both biology and medical applications. These efforts benefit greatly from preclinical models that the COE has developed with CVM in Ithaca, but they ultimately depend on strong clinical ties with WCM, as well as WCM's connections to other affiliates, including the Hospital for Special Surgery.

As the COE moves forward, it can use these partnerships as models for how to expand in other areas of disease. This also offers the opportunity to invest in new relationships where a formalized structure could support both research and educational programs.

For example, a joint COE-WCM institute would provide comprehensive infrastructure covering undergraduate immersion, professional programs, disease centers, healthcare delivery and relationships to industry. This could even be expanded to include Cornell Tech and its Jacobs Technion-Cornell Institute, which provide education in immersive health and health technology.

Developing programmatic connections to WCM must remain a COE priority, and it will ultimately benefit college's ability to enhance education, promote discovery, foster research and develop technology to improve human health.

3. **Expand Ithaca-based infrastructure for clinical translation and commercialization**

COE already has excellent on-campus facilities to work with materials, imaging and omics, and its success in biotechnology and translational medicine is in part due to world-class facilities:

- Cornell NanoScale Science and Technology Facility
- Cornell Center for Materials Research
- Cornell High Energy Synchrotron Source
- Cornell Institute of Biotechnology

It is imperative that the college stays on the leading edge of infrastructure advancements to continue driving research, applications and commercialization.

To enhance clinical connections with WCM, the Ithaca campus needs to establish complementary infrastructure for clinical translation. This should include additional imaging tools, as well as manufacturing facilities certified by the U.S. Food and Drug Administration. It would also support much-needed development with industry relationships.

These investments would make it easier to pursue ties with industry, entrepreneurship and venture funding. It would also open the door for establishing more national centers of excellence on the Ithaca campus.

Finally, more high-quality infrastructure will allow the COE to strengthen its research and application efforts with regard to other priority research directions, since the tools of biotechnology lend themselves to everything from earth and outer space to robotics and materials science.

SPACE TECHNOLOGY AND SYSTEMS

- ***What role can Cornell Engineering play in the New Space industry?***

In the last 10 years, the way humanity explores and exploits space has changed dramatically. The commercialization of space travel has allowed successful, innovative entrepreneurs to compete with the advances of government programs and agencies. Moreover, humanity is on the cusp of establishing a permanent and sustainable lunar settlement, which will become a paving ground for sending humans to Mars.

COE is well positioned to build on Cornell's legacy of spacecraft innovation, exploration, systems engineering and entrepreneurship to lead in this time of New Space. In collaboration with the Department of Astronomy (ASTRO) in the College of Arts and Sciences, COE will leverage fundamental advances in autonomy, materials, space systems, robotics, additive manufacturing and propulsion science to push the boundaries of knowledge.

The college aims to create an Institute for Space Technology, Innovation and Entrepreneurship, which will serve as a one-of-a-kind, world-class facility to bring together leaders from industry, academia, government and the military to provide top research and educational opportunities.

This work will yield technical innovations that provide tremendous societal and economic benefits to meet the emerging needs of space travel. It will also train a new generation of program leaders, engineers and entrepreneurs who can continue to transform the astronautics and space industry, and it will foster a learning environment that increases diversity in the field.

Recommendations

1. **Launch a specialized center for Cornell space engineering**

Across Cornell, the university has a legacy of creating leaders in space science and communication, encompassing everything from exoplanetary discovery to rocket propulsion. Additionally, for more than 25 years after World War II, COE operated the Cornell Aeronautical Laboratory near Buffalo, New York. This facility gave rise to the first crash-test dummy, automotive seatbelt, and various radar systems.

As the aerospace and astronautics industries race forward, now is the best time for the college to reclaim a national leadership position and open the door to a new era of innovation. While the breadth of Cornell's space expertise is strong, to continue COE's history of excellence in spacecraft innovation, exploration and systems engineering, the college needs to become a unique expert in commercial space travel.

The mission is to gravitate efforts around a new center called the Institute for Space Technology, Innovation and Entrepreneurship (SpaceTech) and focus on lunar or cislunar exploration — encompassing everything within the volume of the Moon's orbit. This endowed institute will give faculty and students new opportunities to collaborate with space companies, government agencies, start-ups and other leaders in space engineering.

Building on the success of existing research activities and in partnership with ASTRO, SpaceTech will allow the COE to recruit top experts in key fields:

- Estimation and global navigation satellite systems
- Cislunar position, navigation, timing and communications
- In-situ resource utilization
- In-space assembly and manufacturing
- Space vehicle autonomy and robotics
- Planetary surface systems

To expand its education-to-enterprise approach, the college can also seek to establish joint research programs with the S.C. Johnson College of Business in the areas of commercial space, new space, space entrepreneurship and space policy.

The success of the Cornell Center for Astrophysics and Planetary Science — which currently plays a role in two-thirds of existing space missions — can serve as a model for this kind of cross-disciplinary institute.

Thanks to the falling cost of launch and use of space assets, this realm of the space industry is becoming increasingly accessible to universities for near-term experimentation. This will give SpaceTech the ability to pursue a broad range of scientific and technical activities, and investment in the new institute should include an instructional lab for spacecraft engineering.

2. Foster closer ties with industry

Succeeding in the era of New Space requires a new type of engineer, a new way of looking at space missions and a novel approach to how universities can contribute. Entrepreneurship is now central to developments within the space industry, including the recent national priority under the Department of Defense to develop the U.S. Space Force.

The New Space industry has also exposed the potential for previously inconceivable commercial opportunities, and adding the COE's efforts to Cornell's well-developed entrepreneurial ecosystem will further enhance the translation of the college's technologies to the marketplace.

The college should start by increasing industry engagement to build connections between faculty and commercial partners and to understand the potential for solving emerging needs. It successfully hosted a Cornell Space Tech Industry Day in April 2021 with seven non-Cornell partners — discussing trends in small satellites, New Space, autonomous vehicles, using planetary resources, enabling a sustainable human presence in space and an examination of technologies informed by new exoplanet discoveries.

By spurring industry connections, the goal is to boost the COE's engagement with more areas of New Space development and to play a bigger role in engineering designs, product development and company leadership.

3. Train the next generation of leaders in space engineering

One of the core strengths of the COE's education is to give students interested in aeronautics, astronautics and space engineering very unique opportunities for real-world engagement. Since 2006, they have played a role in approximately one spaceflight program per year. To date, more than 500 undergraduate and graduate students have also been involved in all aspects of concept development, design, integration, testing and mission operations.

The goal is to provide high-quality educational experiences that then empower graduates to become key innovators, entrepreneurs and leaders in the New Space industry. On campus, students already have access to state-of-the-art facilities. With the establishment of the new SpaceTech institute, they would also be able to work on novel projects in the proposed spacecraft engineering lab.

A complementary part of COE's educational mission is to increase the amount of diversity in the aerospace and space industries. To work in this direction, the college has plans to establish a chapter of

Women of Aeronautics and Astronautics, which is part of an international committee that promotes diversity and excellence in aerospace. COE would also like to form a similar group on campus. Cornell's commitment to fostering diversity, equity and inclusion provides a strong background for bridging this work into specific disciplines.

Finally, the COE will increase the quantity and quality of both distance education and on-campus immersive programming. With respect to the former, the Sibley School of Mechanical and Aerospace Engineering (MAE) and the Department of Systems Engineering are developing a spacecraft engineering track of the Master of Engineering program, and a fully remote program may be ready to launch as early as Fall 2022.

To increase external engagement via immersive programming, MAE and ASTRO have also launched a Space Science and Technology School, which held its first session in Summer 2021. This program offers a unique, hands-on educational experience which will lead to more collaborations, potential faculty recruitment and reputational advancement.

DATA-DRIVEN DECISIONS, ARTIFICIAL INTELLIGENCE, AND MACHINE LEARNING

- ***How can Cornell Engineering drive innovation in artificial intelligence, machine learning, and data-driven decision-making?***

Artificial intelligence (AI) is a sub-field of computer science focused on improving how machines can mimic human behavior. These machines need supreme capabilities in perception, learning, reasoning, language and actuation to perform in ways that rival human intelligence. For example, a self-driving car should not only be able to swerve to avoid a pothole, but also able to decide to go through it in order to avoid hitting pedestrians or other vehicles. Machine learning (ML), data-driven decision-making, and using fairness in decision-making are also important subsets of AI research and engineering.

COE strives to become a national leader in these fields — leveraging cross-cutting, interdisciplinary partnerships to solve real-world challenges and provide a premier education to students of all levels. By positioning the college at the heart of Cornell's ongoing work in AI/ML and data science, it will become an essential hub for attracting world experts, industry and government support, and bridging the efforts of other university initiatives.

The college plans to establish a Data Science in Engineering Center that connects across all Ithaca-based colleges, as well as Weill Cornell Medicine (WCM) and Cornell Tech in New York City. This level of cross-disciplinary collaboration and leadership is necessary to advance scientific discovery, engineering design and application translation.

The National Institutes of Health and the U.S. Department of Defense, for example, have already launched billion-dollar initiatives to advance the potential of AI solutions. By adding Cornell to the list of key players in this domain, the college will have the opportunity to be known for solving critical and complex problems — such as reverse engineering the brain, restoring and improving urban infrastructure, securing cyberspace and engineering better medicines.

Recommendations

1. **Serve as a Cornell hub for AI/ML activities**

One of the university's lasting legacies is its success in forming cross-disciplinary research and education partnerships. This includes programs such as the Provost's Radical Collaboration initiative, which spans eight strategic disciplines, as well as the Cornell Institute for Digital Agriculture.

The Radical Collaboration task force in data science helped launch the Center for Data Science for Enterprise and Society (CDSES) in fall 2019, and it is currently directed by COE faculty in the School of Operations Research and Information Engineering (ORIE). The center unites Ithaca-based faculty to tackle critical questions related to data generated by human activity — including computational and social science, digital agriculture, urban infrastructure, privacy, security, fairness, and the interplay of economics and computer science.

Overall, a wide range of high-quality COE research programs in nearly every school and department have benefited greatly by working with applied scientists in WCM, the College of Veterinary Medicine and the College of Agriculture and Life Sciences.

Now, the college needs to become a critical leader in AI/ML and data-driven decision-making across all Cornell campuses. The mission is to establish a Data Science in Engineering Center that drives ground-breaking research, technology and translation by bringing together the diverse groups of experts needed to solve complex problems and affect real-world change.

It is essential that this new center work closely with WCM and Cornell Tech, as well as help strengthen ties to industry at the college level. This comprehensive structure will give the COE the opportunity to advance solutions with both urban and rural applications.

Strategic, interdisciplinary hires should be made to fill the center's leadership team and support staff. By leveraging the external face of the center and the internal collaborations, the center will catalyze important projects that leverage existing faculty knowledge and welcome additional industry interest.

The university already has unique strengths in many cross-cutting areas that are necessary to truly understand and support breakthroughs in AI/ML and data science — from leadership in optimization, to the study and construction of algorithms, to hardware development and other AI/ML accelerators.

The center's intellectual scope would focus on the discovery of new methodologies in data science and engineering. Additionally, it would pursue engineering applications that relate to healthcare, robotics, imaging, autonomous vehicles and the discovery of both materials and biomaterials.

In addition to functioning as a research hub, the new center should have educational components at the undergraduate and Master of Engineering levels that compliments the existing doctorate program at CDSES. This unique combination has the potential to put Cornell in a world leadership position, with the COE as the primary driver.

2. **Enhance AI curriculum for students and increase diversity**

Another key goal in advancing the college's efforts in AI/ML, data science and data-driven decision-making is to improve students' access and exposure to such work. Student demand for such a program is already high, and the interest from alumni is increasing as well.

The college has already launched a working group to help develop a university-wide major in AI, and these efforts should be expanded to also create an AI minor. It is important to work with faculty from all colleges in developing a flexible curriculum that supports a range of interests within AI, while also providing students with the fundamental background in the five key pillars: perception, learning, reasoning, actuation and language.

This course-based framework should also give students opportunities to learn about real-world projects that are developing AI for social good and the ethics of using AI tools to create positive change. It is critical that students receive this level of comprehensive and complex education to understand how this work translates outside of separate academic disciplines.

After the AI major and minor programs are successfully established, the college should make a concerted effort to enhance diversity in both the undergraduate and graduate populations through external learning opportunities. COE could create high school immersion programs and connect with historically Black colleges and universities to create summer programs and fuel other pipelines into AI at Cornell.

3. **Strengthen college connections with industry**

In its efforts to advance AI/ML, data science and data-driven decision-making work, the COE should seek to increase connections with industry.

The proposed Data Science in Engineering Center would serve as a natural point to form industry partnerships, and the OR Advances through Collaboration (ORACL) program — run through ORIE — could serve as a model of success in this regard.

ORACL offers a membership-based program to companies that gives them influence and early access to COE research projects — giving them an advantage against competitors. Member companies can also work with faculty to help design novel programs to address upcoming challenges in operations research. This mutually-beneficial relationship helps shrink gaps between research and applications, and it provides better tools and programs more quickly.

ROBOTICS AND AUTONOMOUS SYSTEMS

- ***How can Cornell Engineering shape the future of society through robotics and autonomy?***

The science of autonomy, enabled by robotics systems, is shaping how humans drive cars, fly planes, pilot spacecraft, design and manufacture products, and much more. Moving into the future, these changes will transform nearly every industry, from healthcare to hospitality.

Cornell University has already established a world-class Robotics at Cornell initiative that integrates cross-campus partners such as Cornell Tech and the College of Human Ecology with key faculty in COE — including the Departments of Information Science, Electrical and Chemical Engineering, Computer

Science, Systems Engineering, Earth and Atmospheric Sciences, and the Sibley School of Mechanical and Aerospace Engineering.

The college's mission is to remain at the forefront of the fields of robotics and autonomy by expanding existing branding and marketing efforts, and investing in essential testing facilities. It will also look to enhance undergraduate and graduate education, as well as recruit leading experts to help build robotics programming and increase industry partnerships — especially in areas that drive collaboration with other unique units at the university, such as the School of Hotel Administration, the College of Architecture, Art and Planning, the College of Arts and Sciences, and the College of Agriculture and Life Sciences.

By investing in these four areas, the COE will become a national leader in the field — known for its development of technologies that enable equitable social good, and its educational programming that fosters unique student experiences and fuels a diverse workforce.

Recommendations

1. **Developing consistent, creative marketing to promote Robotics at Cornell**

COE, in collaboration with other units at Cornell, has developed an innovative program called Robotics at Cornell to help advance the university's work in robotics and autonomy. The program involves 18 faculty leaders and labs, addressing issues of perception, control, learning, planning and human-robot interaction. They work with a wide variety of robots — giving students unique opportunities for hands-on, experiential learning.

Currently, select faculty are well-known among sub-circles for their specific work in robotics. By tying their projects to a college-centric initiative and by increasing outreach, both the individuals and the COE will be able to expand their reputation in the field and with the greater public.

Now, the program needs a robust and targeted marketing strategy to promote its work to a broader audience. This dedicated branding and marketing will attract industry support, philanthropic interest and top faculty and students from across the country.

To achieve these goals, the college needs to hire full-time staff to create key messaging and manage strategic marketing campaigns. This person will work with the group to establish a clear, strong identity that promotes a unified vision, which will then be used to boost individual achievements, lab milestones, events and student recruitment materials. Via media engagement, it can also serve as a platform to show how faculty expertise applies to broader applications of robotics in society.

This campaign offers huge potential for impact, and existing content would help fuel the campaign until original assets can be developed. Compelling videos, news articles, unique images, social media, newsletters and ongoing events can all serve as beneficial communication materials.

A strong, compelling, outward-facing story can build progressive momentum among every type of potential industry partner, donor, educator and student — highlighting unique strengths in robotics and bringing the college and university to the forefront of an accelerating field.

2. **Develop more robust testing facilities**

COE already has several high-quality robotics labs that have been recently renovated to facilitate more advanced innovation. While they are not fully co-located, these 14 labs span adjacent areas, which fosters additional opportunities for collaboration and knowledge-sharing.

Advancing COE robotics program requires investing in more wide-ranging spaces for testing devices — including those that fly, drive, swim and run. Such spaces need amenities like high ceilings, long fields and multiple surveillance cameras to fully assess progress and experiment with how robots perform in diverse environments. This involves modeling how robots respond to different physical conditions, how they interact with people, other robots and environments, and how they process other uncertainties.

It is essential that the college adapts existing facilities to accommodates for a variety of robotics needs, and it should seek to develop new spaces when possible. These expansions or renovations should consider other research needs, such as the potential to work directly with industry partners in COE spaces.

3. **Recruit additional faculty to expand robotics expertise**

The college's work in robotics and autonomy encompasses several departments — including Computer Science, Earth and Atmospheric Sciences, Systems Engineering, Electrical and Chemical Engineering, and the Sibley School of Mechanical and Aerospace Engineering.

These faculty also drive collaborations with other groups in Cornell Tech, the Cornell Ann S. Bowers College of Computing and Information Science, the College of Arts and Sciences, and the Department of Design and Environmental Analysis in the College of Human Ecology — among others.

Additionally, the Provost's Radical Collaboration initiative has fostered more cross-college partnerships that show how robotics and autonomy can help advance work in many other fields, such as digital agriculture, sustainability, data science, and nanoscale science and microsystems engineering.

To leverage these interdisciplinary connections and make the COE competitive with larger programs in the nation, the college needs to strategically hire faculty and professors of practice in key areas of overlap. Some examples include:

- Healthcare robotics
    - Ranging from facilitating assisted living to designing better biomechanical implants
    - Connecting with biomedical engineering programs at Weill Cornell Medicine and the Hospital for Special Surgery
- Agricultural robotics
    - Building on the Cornell Institute for Digital Agriculture
    - Enhancing New York state and national impact through the College of Agriculture and Life Sciences and Cornell Cooperative Extension
- Autonomous air, sea, and spacecraft
    - Improving work in artificial intelligence and controls
    - Offering closer partnership with the College of Arts and Sciences

This broad investment in robotics expertise could help attract corporate partners and expand students' potential learning opportunities.

4. **Expand robotics curriculum for students at all levels**

Across the university, students are highly interested in learning about how robotics and autonomy relate to their other fields of interest. A popular undergraduate minor in robotics has already been established, as well as a Ph.D. program that includes faculty from five COE units.

To offer a more comprehensive educational program, COE should collaborate with cross-college partners to establish a robotics major that is open to all undergraduate students. A critical first step is to introduce more robotics-centric courses at the first-year and second-year levels, and to develop additional resources that enable hands-on experiential learning opportunities.

Undergraduates would also benefit greatly from a cohesive, interactive environment that allows them to learn from faculty and graduate students working on a broad range of diverse robotics projects. This could be created by establishing an open lab space or by starting a series of community-based events that provides such exposure.

These targeted efforts would also serve to increase diversity, equity and inclusion within the field and within the college. It also introduces organic opportunities to educate students about ethical issues in designing robots for social good and how to overcome existing disparities.

CLIMATE, ENERGY, AND ENVIRONMENTAL SYSTEMS

- ***How can Cornell Engineering help combat climate change and develop sustainable energy?***

The ultimate resilience of humans, natural systems and man-made ones depends on what people do next to develop new energy sources, respond to worsening natural hazards, increase environmental sustainability and actively combat climate change by removing carbon dioxide (CO_2) from the atmosphere. Humans' ability to adapt and thrive relies on a deep scientific understanding of these issues and the development of innovative, globally-scalable solutions.

COE is ready to confront these 21st Century grand challenges. It stands in a unique position to drive discovery and lead local, national and global efforts to protect people, the climate and environment. By advancing scientific knowledge and engineering technology, the COE can partner with other colleges to realize effective, efficient solutions — upholding the presidential priority for excellence across One Cornell.

Engaging with these issues requires a targeted approach so that the college can build on existing strengths and quickly gain momentum. Three critical areas where the COE can lead Cornell's efforts are: earth source heat, water systems and CO_2 removal.

Nationally, federal agencies are setting aside billions of dollars to help fuel this work, and there is strong potential to partner with members of industry as well. The goal is to make the college and the university top academic leaders for providing integrated solutions to climate issues that sit at the nexus of energy, water and food.

Engineers excel at innovations in speed, scale and impact, and they have a huge role to play in correcting the arc of the Industrial Revolution. By operating across the realm from fundamental materials to field-scale demonstrations, the COE can speed the national energy transition and attract vital partners for building bigger, multi-institutional collaborations.

Through strategic hires — including those with leadership potential — and additional investment in programs and infrastructure, the COE can galvanize and congregate efforts to combat climate change, develop sustainable energy and become a carbon-neutral campus by 2035.

Recommendations

1. **Invest in Ithaca's emerging geothermal energy system**

One of the existing programs for further COE support is the Earth Source Heat project, which will demonstrate the potential of using geothermal energy to provide a local sustainable heating resource.

The goal is to extract hot water from the Earth's crust, circulate it through natural heat reservoirs in subsurface rock and then use a heat exchanger to transfer that geothermal energy to Cornell's heating system — where it can use existing pipelines to reach campus facilities. Instrumental to the success of this program are partners in Cornell Facilities and Campus Services.

In 2020, the university received a 3-year, $7.2 million grant from the U.S. Department of Energy to establish Cornell as the national test site for this technology. The exploration phase of the project is scheduled to begin in fall 2021 by drilling a 10,000-foot deep borehole on campus. Dubbed the Cornell University Borehole Observatory (CUBO), it will allow researchers to collect critical data on the physical and geological characteristics of the underlying rock — an essential step before scientists can consider circulating fluids or extracting heat.

If feasible and ultimately successful, the Earth Source Heat project could prevent up to 82,000 tons of CO2 from being emitted every year — accounting for 38% of Cornell's emissions and 8% of Tompkins County's. It would also become a model for creating similar geothermal systems across the Eastern U.S., where the geology is similar to that of upstate New York.

The college needs to drive in this cross-campus effort by investing in the high-caliber instruments and borehole technology needed to perform such complex measurements.

Additionally, the college needs to recruit senior faculty hires in the Robert Frederick Smith School of Chemical and Biomolecular Engineering and the Department of Earth and Atmospheric Sciences to expand the existing base of COE experts. These hires can leverage the Provost's Radical Collaboration initiative in sustainability or data science, and potentially share joint appointments with other colleges.

Not only is CUBO a unique site for scientific discovery, it can provide one-of-a-kind experiential learning opportunities for students. The COE should seek to hire a professor of practice to manage the long-term operation of the borehole system and build educational opportunities around it.

2. **Create an integrative program to examine water systems in the Eastern U.S.**

The college already has more than a dozen faculty working with water systems — from agricultural use, to extreme weather events and modeling climate systems.

Now, the COE needs to establish an initiative that provides an integrative focus on how water quantity, quality and predictability is affected by climate change, urbanization and ecosystem sustainability. This targeted program should also seek to explore how better water management can help achieve the United Nations' Sustainable Development Goals.

The college is uniquely positioned to develop a novel program to study water in the Eastern U.S., which differs significantly from other national efforts that focus primarily on the West. Climate change has destabilized precipitation in the East such that it is currently difficult to prepare for shocks to the system, such as unexpected droughts, extreme rainfall, erratic freeze-and-thaw cycles and other seasonal changes.

Expertise spanning science, engineering and agriculture provides unique strengths for establishing an integrated program, and the COE should collaborate with the College of Agriculture and Life Sciences (CALS) to devise a collaborative framework with more concrete areas for focus and investment.

This work has great potential to receive funding from national organizations, and could be scaled up into a new Cornell center, potentially with connections to the Cornell Atkinson Center for Sustainability.

To further this priority area for research impact, the college should strategically recruit new faculty in the departments of Earth and Atmospheric Sciences, Biological and Environmental Engineering, Chemical and Electrical Engineering, and Chemical and Biomolecular Engineering. These roles could also be supported by the Provost's Radical Collaboration initiative and involve joint-hires with CALS.

3. **Cultivate cross-campus research for carbon dioxide removal**

Record-breaking highs in the concentration of atmospheric CO_2 and average global temperatures have shown that human-induced climate change has reached a critical point. It is no longer enough to simply reduce greenhouse gas emissions. Researchers must come up with ways to actively remove CO_2 from the atmosphere too.

Cornell stands in a unique position to lead in this regard due to the potential for strong, innovative partnerships between the COE, CALS, Cornell Atkinson and other key units. This work builds on existing ties from the Provost's Radical Collaboration initiative, but it warrants a separate, concentrated effort to explore carbon dioxide removal (CDR) technologies and practices.

COE has the scientific knowledge and engineering expertise to build novel technology and processing systems to work at the interface of land-air exchanges, where CDR takes place. These efforts are further enhanced by the applied research expertise in CALS and the outreach efforts in Cornell Cooperative Extension that connect to every county in New York.

Across the state, Cornell operates 14,000 acres of farms, forests and other field stations — giving the university tremendous potential to design and test a wide range of experiments.

The emerging, university-wide 2030 Project initiative is already establishing some of the framework for this interdisciplinary work to happen. Its goals are to catalyze impactful scholarship in climate change, to co-create solutions with all sectors of society and to make Cornell a leader in how universities can provide holistic solutions to climate challenges.

Within the 2030 Project and in other relevant projects, the COE must become a leader — working with applied scientists to better understand the needs of living systems and then developing the CDR technologies to enhance them. For example, sequestering atmospheric carbon on farms and ranches can be used as a fertilizer for plant growth and even boost crop productivity.

Additionally, the 2030 Project could offer the potential for the COE to help establish a technology innovation hub in Ithaca to recruit a variety of prominent external partners.

All these efforts should be leveraged to attract national grants, industry collaborations and philanthropic funding, and they can also be used to recruit new faculty and strategically hire in interdisciplinary areas that support both COE and CALS.