Yale SCHOOL OF ENGINEERING & APPLIED SCIENCE

STRATEGIC VISION

At Yale's SEAS, we build excellence through inclusive collaboration, developing ideas from foundations of fundamental understanding into applications of deep impact. Our culture of innovation brings Yale's liberal arts tradition to the broadest benefit for humanity.

FOCUS ON INNOVATION, INCLUSION, AND EXCELLENCE

DEEPEN AND BROADEN STRATEGIC RESEARCH

BUILD STRUCTURES FOR PARTNERSHIP AND IMPACT

Executive Summary

Our strategy will focus on reimagining SEAS culture, deepening and broadening its research mission, and building the structures that are necessary for SEAS to have the greatest impact.

Focus on Innovation, Inclusion, and Excellence

SEAS' standing at the University should sit alongside that of Yale's great Professional Schools. Our identity will be framed through a signature emphasis on a tightly linked triad of innovation, inclusion, and excellence. SEAS will expand and deepen its innovation agenda, launching accelerator programs that will deepen our entrepreneurial spirit and our engagement with an emerging technology culture in New Haven. Industrial collaboration opportunities and new alliances will form and drive growth and hiring in SEAS. Our goals to diversify our community and build an inclusive environment will be well understood and data driven, and our inclusive culture will be viewed as generative of innovation and a driver of our excellence. New graduate programs in the service of Yale's priorities and at the interface of SEAS' other schools will be launched, and new high-impact signature courses will introduce all undergraduates to SEAS. We will establish new collaborative relationships and structures for joint appointments, leveraging the full strength of Yale toward our excellence. SEAS will seek new degree programs, joint research grants, and co-innovation opportunities with a broad range of faculty across Yale. SEAS' standing will reflect the greatness that is Yale's brand in the world.

Deepen and Broaden Strategic Research

New SEAS initiatives in AI, Materials Science, and Mathematical Modeling will cut across many disciplines and areas at the University, asking deep questions about foundational and societal aspects of AI systems, advancing discovery of novel materials that bring cutting-edge innovations across science and engineering, and integrating strength in fast algorithms and scientific computation to enable modeling and simulation in a virtuous cycle with data science. Initiatives in Robotics for Humanity and Biological Systems pursue more focused goals where SEAS can engage in well-integrated and collaborative research. All these initiatives engage the rest of the campus: science, medicine, environment, law, and humanities. Likewise, we will expand our engagement with the top-priority areas described in the science strategy: data science, quantum science, neuroscience, planetary solutions, and inflammation, driving forward success and leveraging progress toward SEAS' agenda of innovation. Through our role in the design of Yale's new Physical Sciences and Engineering Building, as well as a reimagining of the engineering campus on Lower Hillhouse in support of these initiatives, new infrastructure will transform the campus to drive forward our mission in research and teaching.

Build Structures for Partnership and Impact

By taking a strategic approach to allocation of “half-slots” from SEAS toward priority goals, we will incentivize engagement from departments in FAS and other Schools at Yale to partner with engineering, drawing our faculty and departments into deeper collaboration and building the number of faculty counted in SEAS for the furtherance of our education and research mission. A strategy that incentivizes risk-taking toward new federal, foundation, and industrial funding will bolster our culture of engaged leadership in technology development, entrepreneurship and innovation toward our scientific and other university priorities. More porous boundaries will allow new collaborative opportunities with industry, creating opportunities for SEAS ideas and innovations to grow in their external impact.

Yale has launched its mission to engage the world with a new era of innovation and impact.

SEAS is the engine.

INTRODUCTION

In June of 2018, the University Science Strategy Committee (USSC) released its report, summarizing the findings of a two-year effort to identify new ideas, directions, and targets for strategic investments to ensure that Yale remains a great research university, while addressing "the world's present and future challenges." It argues that Yale's "School of Engineering & Applied Science will play a vital role in implementing many of these ideas," but that for this to be possible, "SEAS must be fully integrated into the fabric of the University." For SEAS to have the envisioned impact as a School within Yale, SEAS' standing as a School must reflect Yale's standing in the world. Our strategy, outlined in this report, will be to set SEAS on a path to realizing the ideal of becoming a recognized center of excellence and a highly ranked school of engineering and applied science in support of and bolstered by Yale's strategic priorities.

Yale University sits poised to make historic investments across the sciences, with new institutes, centers, and facilities, all directed in the support of its science priorities. These priorities, articulated by the USSC report, identify certain areas for targeted investment, while also calling out the need for cross-cutting investments in graduate student support, diversity, instrumentation, and various operational priorities in support of science. On the question of Engineering, and on a strategy for Yale's School of Engineering & Applied Science, the USSC holds back from making concrete recommendations, emphasizing that the School should produce its own strategic plan, while noting that each of the five "top-priority areas" identified in the report offers an opportunity for engineering to play a crucial role as a catalyst or engine for strategic advancement.

In September of 2020, the Provost charged the SEAS Strategic Planning committee (Appendix A) with the task of crafting a new strategic plan for the School, instructing the committee to form bold aspirations, both engaged with and independent from the USSC Priorities. This strategic plan outlines such a vision for the future, one that focuses on how SEAS integrates into the University, while developing structures that allow for more nimble execution toward shared goals. SEAS should be structured to enable rapid innovation, to foster and incentivize strategic research, and to extend engagement and collaboration.

But our mission cannot succeed without attention to the core concerns of the School and its internal health. Enrollment in courses within SEAS is surging. As shown in Figure 1, interest in engineering and applied science grows with each incoming class.

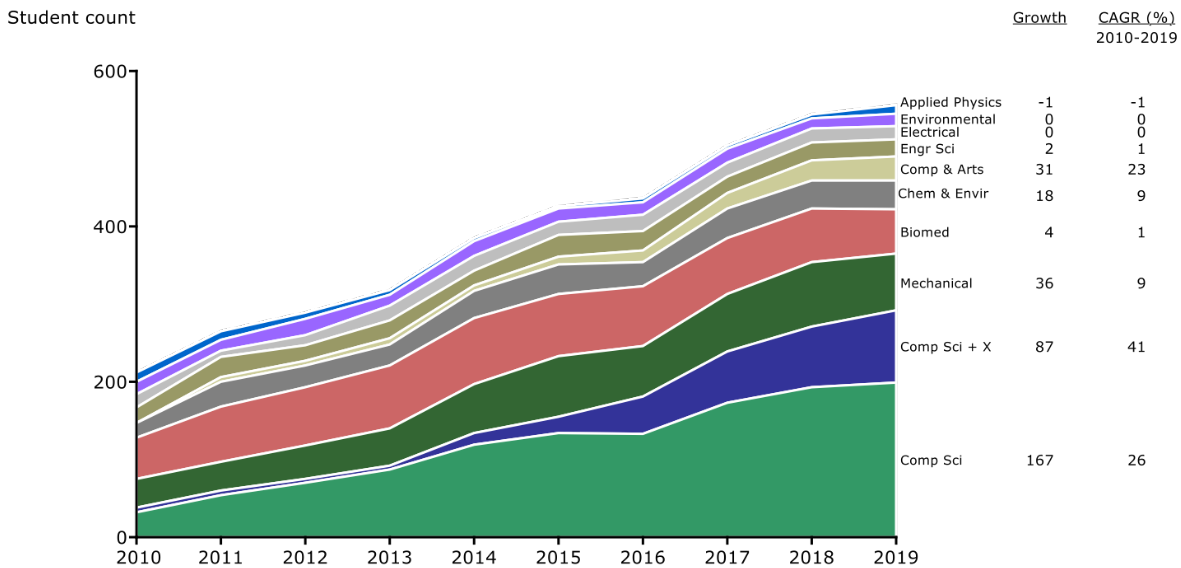

Figure 1: Enrolled Student Breakdown by Engineering Major, 2010-2019

Note: 'Comp Sci + X' includes combined majors of Comp Sci with Econ, Electrical Engineering, Math, or Psychology.

Source: IPEDS Enrolled Student Fall Snapshot

A new innovation revolution, driven by an emerging society increasingly dominated by technology, information, and automation, calls for a response from the great universities of the world, to train a generation of new leaders with the critical capacities to guide society through these grand challenges. To meet this challenge and to build Yale's excellence, SEAS faculty must engage with other schools at the University, with industrial partners, and with opportunities for innovation and entrepreneurship. Likewise, the pursuit of federal and other foundation funding should be framed as a primary goal, not just in support of research, but in furtherance of a new kind of external impact and engagement with the broader research community. We envision a SEAS that will serve as a university testbed for a new culture that rewards risk and is not afraid to learn lessons from failed experiments.

For Yale to thrive, SEAS must serve not only the University but its own mission to build excellence, relevance, and impact. Our ranking as a school should reflect the strength of the broader University. We outline specific strategies to improve the external view of the School, driven by strategic analysis and comparative data.

We submit that Yale's broad success in the sciences will be predicated on the strength of engineering in an increasingly technologically driven scientific enterprise, as well as its fidelity to Yale's mission in the liberal arts. Likewise, a broadly engaged and inclusive culture on campus serves the interests of SEAS and those of Yale, whether with the schools of environment, law, medicine, or public health.

Finally, we submit that Yale, through its investments to date, has an opportunity to leapfrog our competitors: our small size and emerging planning for new infrastructure give us a strategic moment to build a SEAS that is deeply engaged with the University at large, rather than one that is walled off from it. Yale's SEAS should be the School of Engineering & Applied Science that is most integrally engaged with its larger University mission. Each one of the priorities and goals outlined here advances this cause.

Our Process

We have engaged in a broad canvas of the school and its departments, consulting scientific and university leaders, deans of other schools at Yale, and members of the Provost's and other offices that provide consultation on research funding and infrastructure. Working with the Office of Institutional Research (OIR), we have collected significant comparative data with peer institutions that has informed our process. We have engaged deans of peer institutions in constructive conversations and identified areas where Yale's structure might be advantageous or disadvantageous to our larger goals. The committee has worked hard to represent the best interests of the School and how it can both benefit from and serve Yale's larger mission.

Implementation

This document outlines a strategic vision for SEAS. Once approved and accepted, we must move to focus on its implementation. The next phase of work will consist of operationalizing this vision with a tactical plan. The recommendations below will be considered by a strategic implementation committee, convened by the SEAS Dean, to consider how resources can be allocated to accomplish strategic goals. This committee will work with the Provost's office and the FAS Dean's office on questions that involve structural changes or central resource allocation and will serve as a cabinet for the SEAS Dean, advising on questions of how to marshal existing and incremental resources toward the recommendations that follow. The committee will work with the SEAS community to establish a timeline, establish budgetary needs, and identify key performance indicators to monitor progress as this Strategic Vision is implemented within and beyond SEAS.

ABOUT THIS DOCUMENT

This Vision will serve as a strategic set of recommendations for the School of Engineering & Applied Science to undertake as it plans for the next five to ten years alongside the implementation of the University Science Strategy and the launch of Yale's upcoming capital campaign. We have chosen to emphasize areas where investment can have the most dramatic impact, or where SEAS' engagement with and the larger University strategy is most critical.

We call attention to the rich and formidable history of the School, noting its emergence from the Sheffield Scientific School, and its evolution through many structural challenges and changes into its current state. Through these transformations, SEAS has managed many dramatic successes, and it continues to have numerous and significant strengths. This Strategic Vision is not intended to serve as an inventory or a current accounting of those many achievements or sources of excellence. Rather, it seeks to identify areas where focus, emphasis, and investment can have outsized impact on SEAS strengths on behalf of Yale, providing direction on how we can build on them to advance to the next period of the school's growth in ways that will have the most impact.

Finally, SEAS is composed of six departments, each with its own unique character, culture, and metrics for success. This strategy does not speak for departmental strategy as such, but it does offer departments the opportunity to engage with strategies for the School in their own planning. Crosscutting recommendations and efforts to increase impact should serve departments across the school. We also encourage departments to explore ways of strategically aligning their future goals with those outlined in this plan when developing long-term plans.

SEAS Priorities

Focus on Innovation, Inclusion, and Excellence

To recruit and retain the best and most impactful faculty to SEAS, we must work to improve the standing and ranking of the School of Engineering & Applied Science. We concede that such measures of excellence are by their nature capricious and to some extent based on perceptions, but their impact on our ability to thrive cannot be ignored. In particular, such measures play a direct and demonstrable role in our ability to recruit the top students and the best and most impactful faculty. As such, improving rankings is strategic for SEAS. Analysis of the process by which popular press arrives at such rankings yields a clear, differential strategy for making targeted improvements in the ranking of Yale's SEAS.

Reimagine Innovation

We acknowledge that our priorities, however pressing today, may not account for the great ideas our faculty will produce tomorrow. The School of Engineering & Applied Science needs a flexible structure for new faculty initiatives to grow and develop. We wish for SEAS to present a culture of *self-reinvention and flexibility*. We propose that SEAS implement an internal proposal process for new interdisciplinary center activities and create a structure for central support of such activities.

Recommendation:

In addition to the new SEAS priorities identified here as well as the USSC priorities, SEAS plans to invest in emerging, interdisciplinary intellectual domains that hold promise. To do so, we will call on the ingenuity and foresight of our faculty to propose new priorities through a competitive internal process. We propose to develop a research support structure within SEAS, from which winning priorities will receive catalytic seed funding and specialized support.

Excellence through Collaboration

SEAS can leverage the broad strength of the University to increase its impact. Interdisciplinary collaborations often lead to unexpected advances. Having these cross-campus partnerships in place allowed SEAS in 2020 to develop numerous ways of addressing COVID-related issues, including a method for predicting COVID outbreaks across the state of Connecticut by testing wastewater samples – an innovation that served an immediate benefit for public health, and in the long-term will be deployed to aid health crises in global regions lacking in resources.

Building *"improved mechanisms for interdisciplinary faculty appointments"* is among the USSC's recommended organizational structural changes to support science. Already, appointments in BME have shown the power of collaborating with the Medical School to build toward excellence. Likewise, joint appointments with the School of Management and the School of Environment represent points of strategic strength for excellence in SEAS and toward University priorities. Joint appointments with FAS Science and Social Science, such as those between Physics and Applied Physics, or Computer Science and Mathematics, or Statistics & Data Science would further strengthen SEAS while increasing its impact on University priorities.

Other collaborative endeavors already underway include the Computation and Society Initiative, launched out of Computer Science and Statistics & Data Science, which engages faculty from the FAS Science and Social Science divisions, SOM, the Jackson School for Global Affairs, the Yale School of Public Health (YSPH), and the Department of Economics. The proposed Yale Materials Institute detailed later in this plan will further the broad embrace of science across the FAS and West Campus.

Through joint appointments, SEAS will drive engagement with other Schools at the University, as well as with other FAS. This increase in size and breadth of expertise will enhance SEAS' position competitively. These new positions should bridge disciplines, expanding the impact and engagement of engineering on other disciplines at the University, and bring excellence from outside of SEAS to our departments and faculty. **A particular strategic emphasis will be the interdisciplinary synergy between areas of quantitative or computational strength and domains where modeling, optimization, machine learning, or AI is of outsized benefit.**

One of Yale's many strengths is the sheer amount of data production generated in research, and one of Yale's potential new areas of vigor could be developing systematic methods for data analysis and data consumption. A unified platform for sharing data needs - not just from SEAS, but also branching into select areas, such as public health, biostatistics, and medical imaging - could help facilitate a process to synthesize data and promptly arrive at meaningful conclusions.

Research in design and deployment of sensors and instrumentation sits as a crosscutting, common area of interest to a range of strategic goals (such as inflammation characterization, quantum signals, medical imaging, and planetary monitoring). SEAS should amplify its contribution of expertise and resources to campus-wide efforts related to these technologies. SEAS should also continue investigations with other Yale Professional Schools, in particular the School of Medicine and the School of Management, on ongoing developments toward innovative new initiatives and degree programs.

Other collaborative endeavors underway include a newly launched joint master's program with the Yale School of the Environment and Chemical & Environmental Engineering (CEE). We are actively engaged in planning similar joint degrees with SOM, and we are investigating programs with the Yale School of Medicine, Yale School of Public Health, and the School of Nursing.

To align collaborations with the recommended priorities of the USSC report, the committee encourages creating joint events, such as workshops, seminars, symposiums, and other structured intellectual and social gatherings. We envision researchers with varied and distinct research backgrounds across the University coming together and meeting potential collaborators to learn about the expertise needed to collaborate on projects.

Lastly, we propose the possibility of a pool of seed funds to support collaborative efforts between SEAS faculty and faculty from other Yale Professional Schools to help catalyze new efforts in these directions, putting SEAS in position as an engine of discovery and innovation in a range of schools across the campus.

Recommendation:

We recommend that a strategic allocation of SEAS half-slots be administered by a strategic implementation committee as a means to build strength and greater numbers in SEAS as an interconnected and broadly engaged School at the University. Facilitating joint appointments with nimble hiring procedures to streamline recruiting will be of critical importance to the success of this effort.

We recommend the exploration of developing new joint degree programs, particularly with the School of Management, the Medical School, and the School of Public Health.

Additionally, an innovation seed fund should be created to develop collaborative research projects at the interfaces of SEAS and other Schools. We recommend that a group consisting of SEAS faculty, students, and alumni explore this initiative. This group would highlight and detail the most promising and impactful collaborations in which the School can actively play a beneficial role and arrive at a working set of processes that can be successfully implemented.

Increase Research Funding

A clearly identified metric for improving rankings involves the amount of research funding that is raised by the School. While SEAS has done and continues to do reasonably well relative to peers in securing extramural funding for research, we lack current infrastructure to support at competitive levels the process of securing large-scale center grant funding for research enterprises that are hosted at Yale. We have studied models for this support at competitor institutions and found that many of our competitors have more extensive structures for anticipating and applying for major grants for centers and research institutes. With such funding opportunities very likely to increase dramatically in the coming years, we sit at a point of historic urgency for support of such activities.

Recommendation:
Because large center grant solicitations are often interdisciplinary and increasingly bridge subjects in science and engineering, we recommend a broadly configured and well-supported initiative to be developed in partnership with the Provost's Office and colleagues in the Office of the Vice Provost for Research. This effort, called for by the USSC, is further described in "Optimizing for Large Center Grants."

Elevating Faculty

Although it is a seemingly indisputable proposition that Schools of Engineering benefit from the placement of their faculty in externally honorific positions (with perhaps the ultimate being election to the National Academy of Engineering) it is likewise critical for external rankings. While Yale already has a number of excellent faculty in the NAE, we clearly lag behind our competitor schools in this respect. Some of our NAE faculty have risen up through the faculty ranks, but it will be challenging to make any near-term changes in this metric by such a process. Likewise, it is challenging to recruit faculty who are already members of the NAE. A broad canvas of external faculty doing excellent work in strategic areas who are also potential candidates for election to honorific societies could reveal opportunities for recruiting. Likewise, redoubling efforts at mentoring existing faculty toward research prominence and recognition of excellence will pay dividends in the long haul. This effort should follow a process that cuts across the school, and that takes into account opportunities where strategic investments are underway. Our best hope to attract such talent will lie in mentoring and recruiting to strength, and to our key areas of investment. Likewise, such faculty will advance these priorities once recruited.

Recommendation:
We recommend that SEAS create a structure for seeking external recognition of its faculty, by the appointment of a willing senior faculty member to undertake this task on behalf of SEAS. Through a concerted and sustained effort, faculty can be started early and brought through what can be a long process of mentoring toward increasing external recognition.

Focusing externally, we recommend SEAS raise targeted funds for a pool of slots within SEAS and a cross-school committee to identify and recruit Targets of Special Eminence. This pool will be identified as a particular goal for the campaign, and recruiting will focus on our identified areas of strategic emphasis.

Improve the Visibility and Vision for the School

A final key component to improving SEAS' position in the rankings has to do with the perception of the strength and vitality of our programs in the external community. Identifying and extolling our areas of notable strength and successfully communicating how SEAS will be integral to the University's larger strategy in the sciences and engineering will be messaging our excellence to the larger external community.

Recommendation:

We recommend that SEAS develop an aggressive branding and communication strategy that projects our strategic vision for the school of engineering and applied science. This includes identifying key strategic elements outlined below in a coherent branding strategy that can be communicated easily to key stakeholders.

Excellence through Diversity, Equity, and Inclusion

SEAS' impact is greatest when the perspectives of our engineers are broad and varied - across experience, demographic, background, and thought. The SEAS community embraces a celebration of difference, which creates an environment where curiosity, creativity, and collaboration can flourish. These differences contribute to our excellence - by helping us create better, more accessible, and more sustainable innovations, and by nourishing individual engineering leaders who can thrive and contribute in a multicultural world.

Increased recruiting of first-generation low-income (FGLI) students and other underrepresented groups is driving up interest in SEAS and its mission of impact through innovation and entrepreneurship. This interest, likewise, is driving up enrollments. As we grow our faculty and instructional ranks to meet this demand, we feel that SEAS must work doubly hard to recruit diverse faculty that are reflective of our society at large and of our student body if we are to build successfully toward programs that prepare our students to engage impactfully with our world beyond their years at Yale.

It is noteworthy that engineering is a particular field with great potential to improve our record of inclusion. Engineers are makers, tinkerers, creators. Many children are natural engineers but aren't exposed to the discipline in their formal education. Indeed, even though the fields are among the fastest growing, engineering and computer science are often missing from public school curricula. We believe that Yale SEAS has great potential to lead nationally with regard to diversity, equity, inclusion and belonging. To reach our full potential as a school that leverages *"the body of exceptional and increasingly diverse talent of tomorrow's students, postdocs, faculty, and staff," (USSC),* we have identified several areas for improvement, as outlined in four specific goals and several supporting tactics.

Increase Ready Access to Transparent Data

As noted in the USSC, *"all efforts should incorporate best practices and evidence-based strategies and should be designed to integrate ways of monitoring and assessing progress."* SEAS would like to establish clear goals for recruitment and retention of diverse students, faculty and staff. We are unable to measure success or hold ourselves accountable without ready access to baseline data that can be updated regularly.

Recommendation:

We see a need for dedicated support for data analytics within SEAS. This support should be allocated within or coordinated with the Office of Institutional Research, reporting regularly on demographic metrics, and responsive to departmental inquiries

Set Explicit Goals That Reflect Our Commitment to Diversity, Equity, and Inclusion

As part of a world-class university making historic investments in science and engineering, we recognize the unique opportunity SEAS has to create extraordinary graduates who combine technical prowess with appreciation for the complex ways in which humans interact with one another and the natural world. It is critical that our students and faculty reflect the rich diversity of the communities from which we hail and which we serve and that all members of our community feel included, valued, and appreciated.

Recommendation:

Form a SEAS committee, including representation from each SEAS department, the SEAS Data Analyst, Office of the General Counsel, and colleagues from Yale's centralized DEI efforts, to establish goals related to recruitment, retention and climate.

Support the existing Yale infrastructure for community engagement and DEI

Yale has invested in campus-wide offices that create, support, track, and oversee programs that advance Yale's partnership with the New Haven community. Notable Yale programs include Yale New Haven Teachers Institute and Pathways to Science. In addition, several offices actively seek to identify and recruit diverse students to Yale University, including STARS. There are also local non-profits in need of engineering expertise and partnership, such as MakeHaven. SEAS should strive to lower the barrier for faculty to engage in these programs and encourage all faculty to contribute.

Recommendation:

Within our to-be-established SEAS grants office, we recommend that SEAS build out a range of university-sanctioned broader impacts contacts that simplify faculty engagement and increase the overall SEAS involvement. We further recommend that SEAS create a central web-based repository where we can track faculty, staff, and student engagement with outreach. Such a portal would provide a venue for sharing existing activities and tracking success or lessons learned.

Follow SEAS DEIB Unit Plan

In parallel to the creation of this plan, a diverse group of SEAS community members has been writing a 5-year SEAS DEIB Unit Plan. This committee has reviewed and incorporated Diversity Equity and Inclusion Action Plans, charged by the SEAS Dean in summer 2020 and written by each department in fall 2020, and has been part of the campus unit planning process for DEIB. Our school commits to following these recommendations and tracking their progress.

Recommendation:

We recommend that SEAS create a diversity website, post its DEIB plan, and provide annual updates on progress.

Deepen and Broaden Strategic Research

It is notable that each of the top priority areas identified in the USSC report - data science, neuroscience, quantum science and engineering, planetary solutions, and inflammation - involve core scientific areas, but focus on applications of the scientific strengths of the university. We emphasize this point as one of connection with the mission of SEAS, while noting that in our context, the term *applied science* is something of a term of art, suggesting something that lies between core areas of engineering and the pure sciences. *We suggest that SEAS' role should therefore be primary in the university's science strategy.*

This vision takes as a primary goal the identification of a broad set of core ideas for research focus and depth. We begin by suggesting new SEAS top-priority areas that, while supportive of and strongly connected to existing science priorities, emerge naturally from SEAS as new critical areas of strategic focus for the University. Some of these new top priority areas are recommendations for new complementary initiatives to our current priorities, while others focus on areas in which SEAS is under-leveraged and need of investment. All stand to drive not only core research impact, but to address areas where growing interest from the community is driving demand. SEAS draws strength from our six constituent departments, each of which will be strengthened in turn from investment in these new research priorities. In a particular point of strategy, SEAS will devote half-slots to these priorities, with the aim of pairing such half-slots with disciplines outside SEAS, bolstering their strength and university-wide mission.

Artificial Intelligence

Intelligence – a word that has been hard to define – nevertheless is the basis of life as we know it. From the choice of laws and constants of nature that give this universe the ability to support life, to laws of evolution that have given rise to biological entities that exhibit an incredible array of intelligent behavior: recognizing, representing knowledge, learning, planning, adapting, reasoning, problem solving, creativity, and self-awareness. Thus, it is no surprise that understanding intelligence has been a central human endeavor. Intelligent behavior, whether by design (as in laws of physics or evolution) or learned (from experiences) or a combination, is usually an outcome of carefully chosen or designed dynamics or local steps. These local steps, in principle, can be captured in the mathematical language of algorithms. However, the realization of intelligence is itself contingent on the existence of matter or substrate that can execute abstract algorithms, and an environment that can provide experience of other agents.

In 1936, Alan Turing laid the mathematical foundations of computing by introducing a machine (now called the **Turing machine**) and hypothesizing that it is powerful enough to execute any algorithm. With the physical realization of the Turing machine – computers – around the mid-1900s, the question of whether we can use them to mimic intelligence in the natural world gained prominence and gave birth to the area of **Artificial Intelligence (AI).** The 65-year history of AI has seen many great ideas from within and outside of the discipline of computer science merge and make continual progress towards the central goal of creating intelligent machines that could outperform humans. Early major successes include Deep Blue beating Kasparov in 1997 and Watson becoming the Jeopardy! Champion in 2011. These achievements required complex scientific and engineering tasks and did not give the impression that AI could be developed in a cheap and scalable manner.

In the last decade, faster and cheaper computers, algorithmic improvements, and the availability of large amounts of data have led to major advances in using AI in engineering areas such as vision, natural language processing, and robotics. Besides revolutionizing various industries, these changes affect our day-to-day lives via tools such as facial recognition, voice assistants, and drones. AI-based methods are rapidly used in scientific discovery, such as the recently announced AlphaFold, a program designed to predict protein structures with incredible speed and precision. In other areas of life, AI is impacting everything from how we drive, interact with each other on social media, stay informed, conduct business, and learn.

With an environment where cross-disciplinary collaboration is encouraged and impactful, Yale is uniquely positioned to take AI into its next phase. Doing so means tackling questions that lie precisely at the intersection between fields - often disparate ones, both from a technical and a cultural perspective. For instance, the effect of AI on healthcare can be studied from the perspective of economics, medicine, computer vision, law, and the social sciences. Computer science needs to lead this effort, but truly understanding the impact of AI requires insights from all of these fields. Other fields critical to the initiative include psychology (for example, to understand how people react to information, and how information can be used manipulatively), and law to develop the legal and ethical principles related to the many ever-evolving issues in these fields.

While, to some, the idea of "artificial intelligence" presents an opportunity to radically improve the state of humanity, others worry about AI's propensity to fail and reinforce biases and the negative impact this might have on society. Driving this divide is a lack of consensus within the research community itself. For example, recent progress suggests that AI systems could have a major positive effect on healthcare, transportation, and finance. On the other hand, research in robustness, fairness, and privacy led by other disciplines raise deep concerns about AI systems' brittleness, lack of accountability, and strengthening of economic disparities.

To bring together our University community towards this goal, we propose a broad, campus-wide AI Initiative that will explore the broad question:

How will AI systems change our lives, and how do we make sure that this change is for the better?

The initiative, which would be centered in SEAS but collaborate broadly, would gather and incubate the breadth of expertise, ideas, and experience required to tackle answering this question head-on: from discovering novel foundational paradigms for AI (and for intelligence itself), toward making AI accessible to science and engineering, and to developing and regulating AI for the good of humans and society. The role of industry is paramount, and industry is increasingly engaged in strategizing to answer these questions itself, raising the deeper question of whether industry can self-regulate in the face of overwhelming profit motives.

The proposed effort will focus on the following:

Foundations of AI. Make significant progress on the foundations of artificial intelligence, along with a modern synthesis of data, models, algorithms, software, and hardware. Develop methods to bypass conventional assumptions on data, models that incorporate domain knowledge, algorithms, software and hardware that are cognizant of data and models, and that take inspiration from nature.

AI, Humans, and Society. Focus on the multi-faceted interactions between AI, humans, and society. On the one hand, work towards incorporating knowledge for fair, private, robust, and accountable algorithmic decision making and AI systems. On the other hand, explore how AI as a technology can transform our society and democracy, and how to ensure that this impact is a positive one.

Why an initiative?

It is evident that this mission requires a broad range of interdisciplinary expertise. However, just covering the space of required knowledge will not be sufficient—the success of such an endeavor hinges on tackling questions that lie precisely at the intersection between fields that are largely disparate, both from a technical and a cultural perspective. For instance, the effect of AI on healthcare can be studied from the perspective of policy, medicine, computer vision, and the social sciences—but to truly understand how AI will shape healthcare, we need to synthesize insights from all of these fields. Additionally, there is great demand for engagement with academic leaders in the aforementioned areas among various sectors of industry. As this initiative develops, we imagine a range of potential industrial engagements at varying levels of infrastructure needs – many models for such engagement between academia and industry have flourished at our peer institutions, but we seek a version that capitalizes on our unique strengths in SEAS and at Yale more broadly. Likewise, collaboration space (currently in short supply on lower Hillhouse until imminent moves of departments take place) will become more critical to the support of such engagements and educational activities. Ultimately, an administrative structure will be integral to our goals of establishing a place that can (a) bring together experts not only to "merely" work towards a common goal, but to do so in an interconnected, collaborative, and super-additive fashion; (b) effectively and equitably educate the local and global communities; and (c) empower its members to engage with and impact academia, industry, and society at large.

Recommendation:
We recommend an effort to build an initiative with a structure that

(i) significantly increases expertise toward the aforementioned goals;
(ii) nucleates this expertise to form a hub that connects the relevant academic domains across the University; and
(iii) creates mechanisms to consolidate and amplify industrial engagement.

Such an initiative would provide a SEAS-driven activity that would be transformational for the University. We recommend space be devoted for collaboration and outreach to potential industrial partners building on existing relationships. We recommend the slot resource and other pilot funding would come from the SEAS Dean's office, managed by the strategic implementation committee, and that aggressive efforts be made to bring in center-level funding to support these activities.

MATERIALS SCIENCE

From the introduction of metals in the Bronze Age to superconductors that enable MRI imaging and medical diagnosis, materials science sits as a fundamental area in need of targeted development. Among many other innovations that have benefitted everyday life, it is responsible for breakthroughs in broadening the range of edible foods, LEDs, building materials, new consumer products, MRI imaging and medical diagnosis. Its role in advancing quantum computing technology is critical, as was recently underscored in a study published in *Science*, positing that the field will require new materials to break through to the next level:

"To realize large-scale systems based on these technologies, we must achieve error rates much lower than have been demonstrated thus far in a scalable platform or devise a new platform entirely. These activities will require advances in materials science and engineering, new fabrication and synthesis techniques, and new measurement and materials analysis techniques."

At Yale, materials science currently sits in the MEMS department. Its work, however, is highly interdisciplinary and overlaps with efforts in Electrical Engineering, Applied Physics, Physics, Chemistry, Chemical Engineering, Biomedical Engineering, and Environmental Engineering. This delocalization is normal and also the norm in U.S. research universities. Its current efforts can be broadly categorized in the five following areas:

Energy and environmental materials: Catalysts, membranes, photovoltaics, thermoelectrics, and batteries are all active areas of materials research. Yale leaders include members of the Energy Sciences Institute (ESI), Chemistry, as well as in SEAS departments.

Biological materials: Study, control and engineering of biological matter allows for understanding and creation of new molecular systems and pathways that impact drug delivery, therapies, and tissue engineering.

Electronic materials: Control over and manipulation of electronic motion at nanometer dimensions underlies the power and ubiquity of electronic devices in everyday life. This area continues to be lavishly funded by U.S. federal agencies. Many campus leaders, primarily in Electrical Engineering and Applied Physics, can drive this effort forward.

Quantum materials: A proposed effort to build in quantum materials has emerged from the USSC, and we describe this direction in more detail below. Briefly, quantum materials represent materials where quantum phenomena underpin their unique properties and behaviors. Leaders from multiple departments in SEAS and FAS will drive this area forward, providing leadership for an initial pilot pillar.

Soft, polymeric, and disordered materials: Spanning organic and inorganic materials, these materials' interesting and important properties stem mainly from their structural disorder and/or fluctuations which, in turn, make them challenging to characterize and model. Yale leads in the burgeoning arena of bulk metallic glasses. Leaders from MEMS, Physics, and BME would drive this area forward, and connections with AI, machine learning and data science are ripe for development toward a materials discovery agenda.

Discussion:

We envision a degree-granting program with a Ph.D.-level coordinator with continuous funding for postdoctoral fellows and/or seed efforts, and resources for faculty hiring. We recommend building materials science as a SEAS-based, but widely integrated, initiative at Yale. Our ten-year vision includes an even more vibrant and collaborative MS effort at Yale. This includes multiple center grants focusing on or drawing on MS, and sufficient critical mass in MS faculty to enable bona fide undergraduate and graduate programs in materials, with the possibility of a stand-alone department with faculty in multiple sites across the campus. We strongly feel that these aims can and should be achieved in a manner that avoids a “siloing effect” wherein all “materials people” are funneled into a single department, and avoids the possible weakening of other existing departments such as AP or ME.

Given the current situation of MS and Yale, splitting the MS part out of MEMS in the near term makes little sense in terms of productivity. Instead, a coordinating body or agency is needed to achieve these goals across departmental boundaries. This body would be (or function as) a *Materials Institute*. This body would:

- Serve as a focal point for materials-related seminars and collaborative discussions
- Help organize multi-PI and center grant proposal writing
- Organize the MS course offerings and coordination needed to achieve degree granting programs in MS
- Oversee requests for resources, space, and faculty hiring related to MS
- Provide expertise and a knowledge base related to MS

Hence, we propose the formation of a **Yale Materials Institute (YMI)** with an initial research thrust on quantum materials as a model and pilot for the initiation of the other thrusts. Because considerable work has already gone into ramping up a focused effort in quantum materials, it is natural for this to be the first pilot to launch within the Institute. Choosing a particular initial focus should not inhibit the initiation of other research thrusts as resources become available. Rather, we aim to achieve a broad base of campus-wide support for YMI, with multiple active thrusts as expeditiously as possible. To have a broad representation and input for this initial pilot, a YMI advisory committee will be convened to develop a plan to launch the institute across the range of activities envisioned.

Recommendation:
We recommend a committee be formed to launch a Yale Materials Institute. The YMI will be a standalone materials effort, enfolding the previously envisioned Yale Quantum Materials institute, but sitting as part of a broader materials effort that includes electronic materials, energy and environmental materials, biomaterials and soft, polymer and disordered materials. We recommend that a quantum materials thrust be launched as an immediate-term pilot to test the structure and governance with a concrete goal. Further, we recommend that, given the considerable expertise and resources within SEAS and in adjacent fields, consideration be given to the possibility of creating a Materials Science graduate program and potentially a standalone department.

MATHEMATICAL MODELING AND SCIENTIFIC COMPUTATION

The first, and perhaps most universal priority in the USSC report called for Yale to develop vision and strength in *Integrative Data Science and its Mathematical Foundations.* The framing of this top priority area was data-centric, positing that data from a broad range of domain areas might be analyzed in a domain-agnostic manner, with novel methodologies and foundational understandings emerging through principled approaches. Indeed, with the scope and size of data in such overwhelming abundance across the university, it is no surprise that the need for deeper and better-grounded analysis of data emerged as a key concern. The priority in the USSC calls for an Institute to facilitate the development of these methodologies and envisions space at the top of the newly renovated Kline Tower to serve this role.

To drive scientific discovery, however, our base of scientific knowledge and understanding must play an equal role in the interplay of model and data. In physical sciences, the feedback loop between laws that govern physical systems and the data that are taken from instruments and experiments drives the developments of new theoretical models and new instrumentation to test these models. In biology, large scale dynamics of biological systems are extremely complex to model and susceptible to perturbation. This stochasticity, and the ability to model it successfully, requires deep scientific understanding of the phenomena, as well as a deep understanding of the mathematics that models the phenomena. In social science, an absence of explicit scientific laws only underscores the need for quantitative models as our social fabric becomes more technologically driven and engaged. Indeed, we need *models* to suggest modes of data collection and avenues for technological development of new instruments to collect data to validate and verify hypotheses. In engineering, the new technology that combines data awareness with learning and analysis drives new instrumentation design, which in turn inform and refine models.

Likewise, the laboratory of the future will involve significant need for simulation of complex phenomena, with the mathematical quantification and verification of such simulation tools sitting alongside models and data as an equally vital discovery paradigm. With this need, an effort in *Mathematical Modeling and Scientific Computation* would bridge computational science and applied mathematics with the sciences, applied sciences, and engineering in critical and strategic ways to advance research at Yale.

It is the combination of modeling expertise and the fundamental strength of our science and engineering fields at Yale that provide the possibility for investments in data science to have the greatest scientific impact. The need for sophisticated modeling of scientific phenomena runs across our priorities:

1. The call for modeling of climate dynamics has been heard across multiple proposals in the Planetary Solutions Priority, a theme that unites disciplines in engineering, science, and social science in a range of domains.
2. Modeling of the neural structure of the brain and its function is a grand challenge taken on by the Neuroscience Priority, as well as in the Wu Tsai Institute. Likewise, computational and applied mathematics is central to neural imaging challenges and the associated inverse problems raised.
3. Modeling of quantum phenomena, as well as quantum and other types of materials, is central to our efforts to advance understanding and discovery in quantum science, and modeling and discovery in materials unites structural modeling and data.
4. The behavior and interaction of inflammatory agents in the immune system is a complex problem studied with graphical models and is of central relevance in the current pandemic.
5. Developing sound, verifiable models for scientific phenomena is central to the development and deployment of instrumentation across the sciences and engineering. This theme is evinced clearly in the plan for the envisioned *Advanced Instrumentation Development Center*, where bringing AI and decision intelligence directly to instruments enhances the ability to collect high quality data efficiently.

To treat and address the two sides of this discovery dialectic, many universities have developed institutes or centers that focus on simulation and computational modeling (see the Oden Institute at UT Austin and the Center for Computational Science & Engineering at MIT). We note that it is also germane to consider what algorithmic challenges arise in the computational modeling required – such challenges frequently involve the development of computational methods that can arrive at numerical or closed form solutions to deeply complex problems in realistic timescales. This computability, and the study of the mathematics and complexity of such problems, lies at the interface of applied mathematics and computation and is an area in which Yale has deep traditional strength.

We note likewise that many collaborations across the campus between applied mathematics, engineering, and other scientific domains are already thriving, but are not coherently or consistently supported. We envision this as a platform for a deeper engagement around computational and applied mathematics between engineering and science. The opportunity to leverage our expertise in applied mathematics, AI, and computational modeling is an avenue for increasing the strength of SEAS that does not involve major infrastructure beyond the computational architecture needed, allowing us to 'leapfrog' our competition.

The role of mathematics

The applied math program at Yale, started about 20 years ago, grew out of the Operations Research department. It had three senior positions, including one shared between mathematics and engineering (without department affiliation), one shared between mathematics and computer science**,** and one within mathematics but dedicated to the applied math program. These positions were filled by eminent leaders in the discipline, although these "slots" have since been reallocated in various ways. This affiliation between mathematics and SEAS is thus a core part of the identity of the Applied Math Program at Yale, representing a strategic opportunity for the continued enhancement of both.

The strengths of the applied math group that are not covered by specific USSC priorities but that are critical to SEAS and to the broader science community are the development of mathematical analysis and computational tools and the collaboration in practically every quantitative activity on campus. These include, but are not limited to, immunology, pathology, electrical engineering, imaging devices, quantum and classical optics, public health, and genomics. In the origin story of the applied mathematics program and its connection to engineering lies a deep lineage of excellence and quality sitting at the interface of Yale's departments of mathematics, computer science, electrical engineering, mechanical engineering, and applied physics.

Joint appointments between applied mathematics and engineering disciplines as well as joint appointments between computer science and other science departments could build critical mass in applied mathematics from within and from without. This would have benefits to SEAS disciplines with quantitative or theoretical needs, while providing new connections to science and mathematics through joint hires. Likewise, resources directed toward graduate student and additional Gibbs Assistant Professors can provide linkages between applied and computational mathematics and domain sciences.

We envision a role for SEAS in enhancing and in building the applied and computational mathematics program at Yale: through these joint hires, our excellence in Applied Mathematics can leverage strength to build strength in SEAS and in Science. It would allow SEAS to build the prestige of its programs, and build training opportunities for undergraduates and graduate students in the computational and mathematical modeling challenges being brought to the fore by the science priorities and by our basic science, applied science, and core engineering departments as well. Likewise, we envision an increasing need for a core facility, perhaps administered through the **Yale Center for Research Computing**, dedicated to computational modeling that would be of critical benefit to the development in all of the above scientific areas.

Recommendation:

To build much needed and called for strength in computational and scientific modeling, data analysis, and model-integrated machine learning as well as deeper intellectual connections between mathematics and engineering domains, we recommend that half-slots from SEAS be dedicated to hires that crossover between SEAS disciplines and the mathematical sciences, broadly construed. Space for collaboration between SEAS faculty, postdocs and graduate students and applied mathematics should be located to function as a new center for mathematical modeling in science and engineering. We propose that in collaboration with the **Yale Institute for Network Science**, a committee be convened to frame further recommendations about structures required to support of research in modeling of complex systems, networks, science and society.

ROBOTICS FOR HUMANITY

When computers transitioned from large, expensive, and sensitive laboratory-based devices to pervasive, affordable, and robust personal devices, nearly every aspect of modern life changed. The way we conduct business, treat the sick, and even grow our food has been transformed. Today, robotics is poised to have an impact that is just as pervasive and revolutionary. In medicine, **robotic surgery is becoming the standard of care for certain procedures**, providing more precision and dexterity to shorten recovery times and improve outcomes. In particular, work in Yale's Department of Neurosurgery is deploying precision, minimally invasive, robotic surgical devices, with the aspiration of understanding how to link signals from the brain procedurally in real time.

In transportation, autonomous cars and trucks are being tested to provide safer, more efficient transit with less human effort. In manufacturing, collaborative robots are reinvigorating small- and medium-scale manufacturing and creating new, local jobs. The intellectual challenges in robotics are deep and will provide a wealth of research problems for decades, with computation at the core.

Other Ivy League universities have moved to become competitive in the field of robotics through specialization. For example, the University of Pennsylvania has become a leader in the field of robotics and control theory (which leverages their strengths in computer science, mechanical engineering, electrical engineering, and data science). Similarly, Cornell has specialized in robotics design, focusing on innovative methods for interfacing technology with people (which draws upon their existing strengths in human-computer interaction, mechanical design, and materials science). Moderate investments in these areas have attracted strong cohorts of students, immediate international attention, and significant outside funding.

We believe that **Yale could become the world-leader in connecting the technical aspects of robotics development with critical humanistic and societal problems related to healthcare, the environment, and education and employment.** We call this effort *"Robotics for Humanity."* With our existing core faculty in robotics, engineering, architecture, medicine, law, and psychology, Yale is uniquely positioned to demonstrate the ways in which robots impact society, and to drive robotics towards essential human challenges that will not be solved by pure engineering. Strong core robotics faculty in computer science and mechanical engineering already link to interdisciplinary collaborations both within the School of Engineering and with law, psychology, medicine, environmental science, architecture, management, and the humanities.

We believe that with a small number of incremental faculty, and a modest investment in space and resources, this institute would cement Yale as the leader in Robotics among Ivy and peer institutions, all while enhancing on-campus visibility and creating a "must visit" space for students and visitors. For space intensive work, we recommend exploring West Campus or other space resources not on the main campus to build out robotics efforts.

Societal Driver: Healthcare. Linking to the new Wu Tsai Institute for Neuroscience and the existing strength of the Yale School of Medicine, this new investment would position Yale as a leader at the intersection of robotics technologies and healthcare, in areas from surgery to mental healthcare. Exciting areas of collaboration will include: more robust and capable prosthetics that use **brain-machine interfaces** to connect directly to the nervous system; smart assistants and wearable sensors that help both individuals with specific needs (like diabetics or cardiac patients) maintain their treatment regimens, and everyday users to maintain an active, healthy lifestyle; technologies that help seniors age in place and maintain their independence; and increasingly capable surgical systems that extend the capabilities of human surgeons to perform procedures with super-human dexterity and at great distances.

Societal Driver: Environment. Leveraging connections with the School of the Environment, the School of Management, and the department of Ecology and Evolutionary Biology, our enhanced teams could help reshape the impact that we are having on our fragile ecosystems. Research would focus on areas that include: wildlife tracking using autonomous sensor networks and drones; autonomous vehicles for undersea exploration and the tracking of chemical spills; sustainable approaches to manufacturing, recycling, and waste management that combine the strengths of both human and machine workers; flexible and dexterous materials handling for precision agriculture; and widespread environmental monitoring using a combination of citizen science, autonomous data collection, and predictive modeling. The natural implications for **Yale's Planetary Solutions Project** would thus be widely varied and deeply impactful.

Societal Driver: Education and Employment. With contributions from faculty in the School of Management, the Law School, and the Education Studies program, we will shape how our workforce is trained to engage in the next-generation workplaces that combine AI-based robotics technologies with human labor. Our investigations will bridge research, policy, and education and include topics such as: how intelligent technologies will enable smarter, more seamless transitions between in-person and remote work; technologies that help foster inclusion and diversity in the workforce; mechanisms for reskilling workers to take part in the new economy; technologies to help support job skill development for neurodiverse workers; and policy development that supports the deployment of robotics technologies in new job sectors.

This proposal would also position Yale to train undergraduate and graduate students in a key area of domestic and global need. Similar to the training needs in computing topics more broadly, competency in robotics/mechatronics will be required of many of our graduates and will open doors to those who have been given those opportunities. Hiring more faculty will address a key deficit in our current curricular offerings at both the graduate and undergraduate levels. While we already attract top students in these areas, our faculty are currently constrained to teach lower-level introductory courses. While these courses are popular with students (many with 100 or 150+ enrollments for 400-level survey courses), we cannot offer advanced courses in these areas due to our small faculty size. Yale's proven ability to recruit top students interested in robotics due to our excellent, but small, faculty in the area, is currently mismatched with our lack of course offerings in this area.

The field of robotics and its interaction with AI and computation moves at the pace of industry, and innovation in this area will require greater flexibility of SEAS structures. In particular, we envision opportunities for faculty to be jointly appointed with industrial partners collaborating with SEAS and other schools on campus such as YSM. Our Industrial Partnership Strategy will call for such innovative approaches.

Recommendation:
We recommend an effort to develop an initiative in *Robotics for Humanity* that draws on the expertise from numerous fields to study robotics and its impact on multiple facets of society. We also recommend that SEAS work with the University to allocate space for robotics activity with this emphasis in mind, building on adjacencies to the CEID, the Computer Science Department, and the Innovation Corridor, but looking also to other space resources such as West Campus.

Biological Systems

Within the Yale University Science Strategy Committee Report, Yale faculty and administration converged on the importance of biology as a cross-cutting emphasis. The priority areas of *Neuroscience* and *Inflammation* were two areas identified as biological themes of focus. SEAS has a history of contributing to these areas of research, impacting the basic biological understanding of processes as well as the development of translational therapeutics for pathologies associated with neurological and immunology disorders.

As might be expected, faculty in the department of Biomedical Engineering have independently, and in collaboration with medical school faculty, developed material-based models of brain tissue, vascular structures, as well as partial and complete human organs to understand stages of development and deterioration of neurological and immune-affected human tissues. Likewise, great successes have been made by SEAS faculty in the biotech area in recent years. A few examples include breakthroughs in single-cell technology, skin cancer treatment, and cardiac tissue restoration - all of which have led to start-up companies, including one that has expanded to 250 employees.

SEAS is also positioned to play a key role in computational biology, in which algorithms and models are developed to understand biological systems and relationships. This entails collecting and analyzing extensive sets of data across a wide range of data types. For that reason, systems approaches to analysis of signal input and outcomes has become the norm in understanding organ development and predicting disease state. In addition, the use of machine learning in computational biology is an emerging area of importance.

The broad role of computation in biological systems forms the premise of the following areas:

> **Quantitative Biology (QBio)**, which uses advanced mathematical and physical approaches to solve biological problems, particularly those in molecular, cellular and developmental systems.
>
> **Physical and Engineering Biology (PEB)**, which takes quantitative approaches and methodologies to address biological questions. SEAS faculty led the Integrated Graduate Program in Physical and Engineering Biology.
>
> **Systems Biology**, which focuses on complex interactions in biological systems and characterizes the organizational principles that unite living systems. The Systems Biology Institute on West Campus, led by SEAS faculty, has focused on dynamic gene regulatory networks, which provide a springboard for the integration of mathematical theory and bioinformatics.
>
> **Biomechanics and Biophysics**, in which SEAS faculty focus on the control of motor behavior in humans and other animals, spanning mechanics, dynamics, robotics, biomedical engineering, as well as comparative and evolutionary biomechanics.

Each of these areas provides an important instance of SEAS involvement in biological research at Yale writ large. There is strong thematic overlap with AI, Robotics, Materials Science here, to which we recommend attention, but the particular emphasis on Mathematical Modeling and Scientific Computing stands to play an outsized role in strengthening Yale's efforts in Biological Systems. We recommend emphasis in:

- computational modeling of biological networks, including neuronal networks, inflammatory process feedback loops, and other complex biological systems,
- advanced computational signal processing,
- development of brain-computer interfaces for biological signal control of external devices,
- computation for large data acquisition, parsing, and analysis, and
- engineering of computational mechanisms in biological systems, as well as bio-inspired computational systems.

Recommendation:
SEAS has a vital coordinating and supportive role to play in driving the work in each of these areas forward including new transformative hires, funding opportunities, and innovation and entrepreneurial efforts. We recommend a task force to explore the areas in biology where SEAS can play a role in advancing the above areas.

ENGAGE WITH STRATEGIC SCIENCE PRIORITIES

The USSC identified five high-priority areas for strategic investment. While these do not encompass all of the strategic aspirations and goals of this plan, there are clear synergies and shared emphases for our strategic goals and those of the USSC. In this section, we focus on how these top priorities serve to motivate our efforts within SEAS.

INTEGRATIVE DATA SCIENCE AND ITS MATHEMATICAL FOUNDATIONS

As we detailed above, the urgency of the need for a strategy to confront the vast amount of data that is emerging in the research context in science and engineering is hard to overstate. Among our SEAS cross-cutting priorities, the need to build capacity in Mathematical Modeling and Scientific Computation articulates a strategy to develop strength and competency in an area that is indicated by but not subsumed by the priority area for Integrative Data Science and its Mathematical Foundations.

Fundamentally, this priority area argues for the need to integrate and work with data from a range of sources, in an integrated manner that draws out commonality between data across domains. Mathematical and Statistical methods development are primary goals, and the idea that these goals can be achieved in a domain-agnostic manner is a central element of the strategy. An Institute for Computation, Mathematics, and Data Science is envisioned at the top of the newly renovated Kline Tower, and this institute will host programs, visitors, and postdocs to investigate questions at the interface of domains and methods, inviting faculty from across campus and outside the University to participate in a robust slate of programmatic activities.

To be sure, SEAS has a deep role to play in the activities of this institute: computational methods and algorithms for data scientific challenges, from natural language processing to computer vision to genetics, will directly involve computer scientists, while work to optimize algorithms and design hardware for computational challenges arising in data analysis will involve faculty from electrical engineering. Certainly, faculty in these areas should be key stakeholder participants in the activities of the institute in the Kline Tower, helping to build bridges from the institute to SEAS.

We also envision a dialogue between our SEAS priority areas and the Kline Tower Institute.

- *Mathematical Modeling and Scientific Computation* should engage the institute around questions of refining models based on data science insights, designing new experiments based on these findings.
- AI systems train on large data, but also on sparse data, where results can be uncertain. An institute program on AI in the presences of sparse data could be an important collaboration with the *AI Initiative*.
- *Materials Science* increasingly finds itself engaged with methods from machine learning and big data analytics to drive forward materials discovery. This complex problem involves physical models and data analysis in parallel, and an Institute program in this area would facilitate communication.

It is difficult to imagine an area of engineering that is not taking significant data of sensors, instruments, and other experiments. We envision a 'data-enabled' SEAS, where these data are constantly being analyzed and used to revise experimental approaches, and where likewise the data analysis methods themselves are informed by experimental results.

Recommendation:

We recommend a pervasive and thourough approach to data collection and management from all corners of SEAS. Through the Institute for Computation, Mathematics, and Data Science in Kline Tower, SEAS faculty should help organize and participate in novel programs to bring data from SEAS fields into a context of data analytics and methods development fostered by the institute. SEAS should bridge its own priority areas with the work of the Kline Tower Institute and contribute to its development on campus. Finally, we advocate for SEAS to be broadly engaged with the question of engineering and collection of biomedical data on the medical campus.

Quantum Science and Engineering

There is a pivotal strategic role for SEAS to play in the furtherance of the University Science Priority in Quantum Science and Engineering. Already, and in particular with the return of Applied Physics to SEAS, a large cohort of faculty in SEAS play a clear strategic role in furthering Yale's research in quantum information, quantum computing, and quantum materials, and the related engineering and scientific disciplines, such as quantum algorithms, microelectronics, devices, and materials chemistry that support the effort.

With the envisioned Physical Science and Engineering Building (PSEB) well into the first phases of planning, it is all the more critical that our committee consider and recommend how SEAS should be configured and envisioned within this new structure, with its central position as a singular new building project articulated as a goal of the USSC report.

In the initial phases of planning, the building's occupants were imagined as drawing from SEAS faculty from the departments of Applied Physics, Mechanical Engineering & Materials Science, Electrical Engineering, Chemical & Environmental Engineering, and possibly some presence from Computer Science. This inclusive framing, however, leaves unanswered the question of how a core presence and identity from SEAS could be configured with an overall faculty headcount that is considerably smaller than the aggregate size of the departments named.

The focus on quantum science and engineering naturally leads to the inclusion of the Yale Quantum Institute and its faculty as natural players in the organization of the PSEB. Research in quantum and electronic materials is likewise central to the effort, which leads naturally to the inclusion of faculty from other parts of AP and from the materials science group in MEMS and CEE; faculty from the microelectronics, devices, and electronic materials-focused faculty from EE are likewise critical to this strategic goal.

The move of these faculty into the PSEB when it is completed will provide a formidable nexus of physical sciences and engineering faculty on the north end of campus. While it will move the center of gravity for engineering northward, the committee anticipates that a home base for the Yale Materials Institute will provide synergy and vitality around this top priority for University investment.

Recommendation:
Our recommendations here are multiple and vital.

SEAS Faculty in the PSEB. The quantum and electronic materials foci of the envisioned Yale Materials Institute should take their future home in the PSEB. Others from the microelectronics group in EE that connect with quantum information science efforts, as well as other potential computational faculty would be of primary importance for inclusion in the PSEB.

Fundraising and faculty hiring. The Quantum Science and Engineering priority will be slated for Development focus. It is important that this focus work to build SEAS support of the efforts in Quantum Information as well as Quantum Materials. We recommend, moreover, that incremental hiring support efforts in quantum algorithms, electronic materials, microelectronics and devices foci.

Graduate programming in quantum. The market for graduate training for future quantum scientists and engineers has become quite intense. Harvard's recently announced program has increased the sense of competition in this space. We recommend taking a fresh look at the viability of such a program at Yale and how it might be best structured.

Planning for PSEB. As activities are mounted to move forward with the Yale Materials Institute, it is appropriate that the organizing committee for the YMI report to the Dean of SEAS. Leadership of the YMI should be represented on the planning committee for the PSEB, and the committee proposes that the YQI have similar representation on the PSEB planning committee. Finally, the committee recommends that faculty in microelectronics and quantum algorithms consult with the chairs of the PSEB planning committee as well.

Neuroscience

The USSC priority area in neuroscience outlined a range of research topics, "*from molecules to mind*." With the recent transformative gift to Yale to form the Wu Tsai Institute, these focus areas have transformed into three pillars, *Neurodevelopment and Plasticity*, *Neurocognition and Behavior*, and *Neurocomputation and Machine Intelligence*. Each of these pillars provides opportunities for deep engagement with SEAS, and research in SEAS already aligns well with the foci of these research centers.

Our faculty in Biomedical Engineering have already engaged in planning for searching in the area of Neuroengineering, broadly construed. This envisioned search will complement strengths in BME in the areas of neuroimaging and image analysis, while extending strengths in a way that significantly enhances both the Wu-Tsai Neuroscience Institute and the planned Neurosurgery Center of the Yale-New Haven Hospital.

The intersection of neuroscience and engineering has been identified both nationally and internationally as an area that can lead to transformative changes for society. Using techniques from Engineering, we can improve our understanding of neuroscience and translate our understanding of neuroscience to create synthetic systems with new capabilities. We can see the potential of this area of research in such innovations as the artificial cochlea and retina, neural stimulation to treat Parkinson's disease, and robotic limbs controlled with brain-computer interfaces. Undertaking a challenge of this scale requires the expertise of many engineering disciplines in addition to the medical and biological sciences. In fact, reverse-engineering the brain has been identified as one of the grand challenges by the U.S. National Academy of Engineering.

The following highlights areas where SEAS has current investments, as well as possible areas for future investments at the intersection of neuroscience and engineering.

Neuroengineering: This broad research area uses engineering principles to understand and interact with the brain. Brain-machine interfaces and neural prostheses, closed-loop neural stimulation for treatment of disorders as well as motor control, and signal processing to uncover the information embedded in neural signals are all examples of important problems where SEAS should play a major role.

Neuropathology: SEAS should continue to complement the expertise in the Yale School of Medicine on drug-delivery systems and engineered materials for treatment.

Robotic surgery: Our top-tier neurosurgery department in the Medical School is actively building in robotic surgery, seeking collaboration with AI, neuroscience and robotics to build at the frontier of this technology.

Neuroimaging: Neuroscience, like many other areas of scientific exploration, benefits enormously from new experimental techniques that provide insight into both molecular and large-scale behavior. While neuroimaging is already represented in SEAS, it is important for Yale to be at the forefront of research in this area if it is to be a leader in neuroscientific discovery.

Neurocognition: The engineering approach to analysis and modeling will play an important role in translating the behavior of biomolecules and assemblies into the collective behavior of groups of assemblies, and ultimately the behavior of an organism and cognition.

Neurocomputation: Modern neural network models that have transformed artificial intelligence trace their origins to models of the behavior of biological neurons and synapses. We are still far away from the computational efficiency of biological systems, and a strong interaction between engineering and neuroscience is needed to achieve breakthroughs in both artificial intelligence and the understanding of neural systems.

Recommendation:

Given the critical role of engineering in the above areas of neuroscience study, SEAS will explore new ways to increase SEAS' involvement and funding in these areas of study. In addition to searching within SEAS for neuroengineering, neuroimaging, and neuro-inspired computing, SEAS will also work to partner with the newly created Wu-Tsai Institute, particularly in the areas of Neurocomputation and Machine Intelligence, and Neurocognition and Behavior. Further, SEAS should increase involvement with emerging medical technologies, such as robotic surgery.

Planetary Solutions

The USSC report and the Planetary Solutions Project present SEAS with opportunities for increased involvement at Yale in research and educational activities related to **environmental systems**. In particular, the environmental engineering faculty in the CEE Department can play an important role in the planetary solutions initiative, enabling the environmental engineering (EnvE) program to grow and expand to new areas of research. The EnvE program has currently 5.5 faculty, carrying out research on water, air, and sustainability. The program has been consistently ranked in the top 10 in the U.S. News & World Report Graduate Program Ranking and is notably the smallest program on the list. The Yale EnvE program can be a leader in developing technological solutions to water scarcity, water pollution, and air quality.

The Yale Planetary Solutions Project specifically calls for the integration of the natural and social sciences and engineering to solve global environmental problems, and follows three broad categories — **Mitigate**, **Adapt**, and **Engage** — intended to capture the breadth of the global environmental challenges, without limiting the range of research activities.

The EnvE program can play an immediate and critical role in Planetary Solutions' call to develop engineering solutions for carbon capture and conversion and transformative renewable energy technologies. It is a goal that entails areas of research that fit well within the EnvE program and would strengthen the program's current focus on *engineering solutions* to environmental problems. These new areas of research can range from the molecular scale to system level. Further, research in these areas will further strengthen the link between the EnvE and chemical engineering groups of the CEE Department.

Likewise, researchers in MEMS are also well-positioned to answer the Planetary Solutions project's call for more renewable energy solutions. Among other examples, significant advances have been made at SEAS in developing new materials to facilitate the water splitting process for converting hydrogen into a viable and renewable fuel source. In Applied Physics, researchers are incorporating recent developments in machine learning to discover materials with exceptional technological properties, for energy storage and generation, such as supercapacitors, batteries, thermoelectrics, solar cells, and solar thermochemical conversion. SEAS roboticists have collaborated with the School of the Environment to develop technologies for automating the recycling process, which would improve the quality of recycling output. This would help ease a bottleneck that's resulting in large stockpiles of waste – an issue that threatens the global recycling industry.

We are also exploring an international program/experience for undergraduate students to highlight the global impact of SEAS. With projects that cut across majors, students would engage in human-centered design and appropriate technology development in resource-limited settings. This could initially be a class with a spring break trip but could grow to a semester-long experience if possible. It may offer a chance to partner with the Jackson Institute and potentially the School of Management.

As part of its mission, Planetary Solutions aims to design adaptation strategies based on Earth-system, economic, and public health forecasting and understand and address impacts to human health. Toward that goal, SEAS faculty in BME have long been developing projects designed to reduce public health inequities around the globe. Such projects as a low-cost infant respirator have shown strong collaborations between Yale faculty and partners around the world. Going forward, building on these strengths is critical. Faculty hires focused on these areas of expertise would significantly advance many of the goals outlined in the USSC report and the Planetary Solutions Project. Similarly, forging future creative collaborations on projects designed for global impact will yield impactful results. There is also significant room to expand to other areas of research that are relevant to planetary solutions but traditionally not in the mainstream of engineering departments, through **joint appointments with the Yale School of Environment and the Yale School of Public Health** and other FAS Science departments such as **Chemistry** and **Earth & Planetary Sciences (EPS)**.

Importantly, Yale's Planetary Solutions Project will provide impetus for us to enhance the SEAS curriculum by offering a broad range of new undergraduate and graduate level courses related to climate change and energy. The envisioned jointly appointed faculty will offer courses in their respective areas, which will enrich the education and experience of our students. Lastly, the EnvE major can also be revised to offer concentration areas in engineering solutions to climate change and renewable energy. We anticipate that climate change mitigation will be a major focus area in the coming decade, and Yale should take this opportunity to prepare the future leaders in this field.

Recommendation:

With SEAS uniquely positioned to play an immediate, leading role, we recommend that effort be concentrated on future faculty hires that have deep research ties to the climate and environmental efforts highlighted in the USSC Report and Planetary Solutions Project. These areas should include hires that strengthen Environmental Engineering, but also hires that bridge Engineering and YSE, and the EPS department or partner with ESI on West Campus. We recommend the development of new courses related to environment, energy, and biodiversity, with a focus on engineering challenges and solutions.

Particular attention should be given to building up strength in computational modeling of climate dynamics, synergistically with our Mathematical Modeling and Scientific Computing focus area. Such hires will provide engineering links to the effort and strengthen collaborations across the university to unlock novel solutions, positioning SEAS well for pursuing large federal grants to establish national research centers at Yale.

INFLAMMATION

Our discussion with representatives from the inflammation priority underscored the need for deeper conversation on how SEAS can integrate with and advance the work in this vitally important field. Efforts in our Biomedical Engineering department to understand the mechanisms of intracellular communication as well as tools for drug development and delivery stand to play a critical role in this Priority Area when it takes further shape.

Of particular interest is the data and modeling challenge related to the notion of the *exposome*, namely the range of environmental exposures and factors that might produce health outcomes generally, and immune or inflammatory responses in particular. The goal of cross-referencing environmental factors with electronic health records and genetic data to understand these health outcomes causally represents an important and developing challenge that cuts across disciplines in SEAS and leverages our strength in public health. We see opportunities for our Environmental Engineering and BME faculty to engage with the data analytics strength across campus to move this area forward.

Recommendation:

The need for deeper interaction and conversation around the topic of inflammation and how innovation can take place in this top priority area prompts us to recommend that resources be directed toward convening, seminars and colloquia, as well as possible seed funds for collaborative grant proposals. Modeling of networks and complex systems as a SEAS initiative would be a focus in addition to the natural connection to BME through existing research, and with Environmental Engineering to develop tools and means for understanding connections between environmental factors and inflammatory response.

BUILD STRUCTURES FOR PARTNERSHIP AND IMPACT

The SEAS Strategic Planning Committee recognizes the strong motivation on the part of the faculty to direct research and programmatic activity toward the goal of transformational impact on science, society, and for the benefit of humanity. Excellence in the above priorities and transformational research in each will be a necessary condition for such impact and outcomes, but it is not sufficient. We describe structures and activities that will facilitate and enhance the impact of core research activities, and structures that will likewise enable the best research through engagement with opportunities for innovation entrepreneurship, as well as industrial partners and external funding opportunities.

We recommend that an allocation of half-slots be reserved for allocation to identified priorities as a means to build strength and greater numbers in SEAS, and to develop its status as an interconnected and broadly engaged School at the University. There are many opportunities to facilitate impactful joint appointments that drive excellence and collaboration. Doing so with nimble hiring procedures will be critical to the success of this effort. **In particular, we envision these half-slots for the Yale Materials Institute, Artificial Intelligence Initiative, and Robotics for Humanity. Similarly, we recommend that half slots from SEAS be dedicated to hires that crossover between SEAS disciplines and the mathematical sciences, with particular support directed toward mathematical modeling and scientific computing.**

INNOVATION AND ENTREPRENEURSHIP

The current commercialization landscape at Yale, as noted in the USSC report, has a **"strong focus on biomedical efforts, particularly pharmacology."** Technologies developed in SEAS labs are often non-pharmacological and have different IP considerations. The kind of legal and logistical support needed to maximize the number of SEAS technologies that go to market requires a new model.

Innovation and entrepreneurship are core attributes of engineering and applied science as they serve as the avenues for translational research. At Yale and its peers, a strong culture of innovation and entrepreneurship is an evident priority for our potential faculty and student recruits. Entrepreneurial hubs are created where there is an abundant supply of intellectual capital, human capital, and financial capital. The availability of these distinct forms of capital creates a regional culture for innovation that is both dynamic and sustained.

The Yale School of Engineering & Applied Science should accelerate its impact and development related to innovation and entrepreneurship by creating a culture that supports such activities and simultaneously reduces the barriers to translate research into commercial entities. Focusing on our strategic vision of Engineering and Applied Science for Humanity, we will develop a singular, Yale-focused, brand of innovation and entrepreneurship, and enhance the reputation of the School.

Recent independent investments in these areas have aided the ability of Yale's students to investigate, develop and pursue innovative and entrepreneurial activities. The President's coinage and promotion of the Innovation Corridor (composed of the Tsai Center for Innovative Thinking at Yale, the Center for Engineering Innovation and Design, and the Greenberg Engineering Teaching Concourse) is intended to enhance Yale's reputation as New Haven's center for technology and innovation. Collaborative efforts in the Innovation Corridor have already led to many exciting ventures, including a joint learning experience with Tsai CITY focused on innovation and product development in large corporations, leading to the creation of three student-developed patents. The Innovation Corridor was also home to a partnership between SEAS and the Yale School of Architecture to design The Dreamers School, a technology school for high school students – attended by both boys and girl – in Afghanistan. Additionally, the Innovation Corridor is actively engaged with the Projects 2 Products initiative, where students gain real-world experience by taking a promising student project to market. SEAS is encouraged by the initial success of the Innovation Corridor collaborations and encourages fostering the development of beneficial and creative collaborations between all Innovation Corridor entities.

The culture for innovation and entrepreneurship for Yale's undergraduate students should be extended to build and augment an analogous culture among SEAS graduate students and faculty, creating a school-wide culture for innovation and entrepreneurship.

As called for in the USSC's recommended changes to organizational structures that will support science, we seek "better support for commercialization and entrepreneurship." While faculty have access to elements needed for innovative and entrepreneurial activities, the restricted access to these resources limits the ability for a thriving culture to develop. The Office of Cooperative Research has been an important partner for SEAS faculty who pursue large-scale projects by providing them with excellent commercialization guidance. Understandably, though, OCR must favor aiding the most developed and highest impact projects, which limits its resources to a subset of SEAS faculty members. Others, such as young PIs who are at the earliest stages of ventures, often do not have access to OCR's resources.

Following the lead of Tsai CITY, a similar support system focused on faculty initiatives within the School of Engineering & Applied Science can spur an innovative and entrepreneurial culture, with contributions from both faculty and students. Potential programs spanning topics from entrepreneurship boot-camps to venture pursuits would be made available on a rolling basis, so that there could be support for the needs of any faculty at any point in the calendar. A faculty innovation center would provide assistance for applications related to technologies that align with SEAS research areas. When a project shows potential, the resources at other offices at Yale, such as the Office of Cooperative Research, could advance the ideas to commercialization. **Programs sponsored by OCR, such as the Innovation Summit and Blavatnik Fund for Innovation**, would also benefit from the increased activities that result from the developing SEAS culture for innovation and entrepreneurship. To establish a thriving culture, multiple levels of support for faculty innovation and entrepreneurship need to be explored. **Faculty leave policies should be studied and possibly amended to facilitate the creation of faculty-founded startups**. Developing industrial collaboration policies that favor the innovative approaches while addressing the concerns of each party would also benefit this initiative.

A thriving culture for innovation and entrepreneurship provides a unique chance for alumni to participate in innovation and entrepreneurial activities within the School of Engineering & Applied Science by serving as business mentors, networking contacts and potential financial investors in SEAS projects. The likelihood of success for SEAS-originated startups will increase with additional support, such as the creation of incubator and accelerator programs and facilities. This success will send important signals to our students as well – they will benefit from a range of opportunities to engage with faculty in their innovation activities, and an engaged student community will attract new faculty to pursue such projects.

Recommendation:

Because of the many layers of structure involved in launching new activities to promote entrepreneurship, we propose that a **SEAS Innovation and Entrepreneurship Task Force** comprising SEAS faculty, Yale administrators, and Yale alumni to identify the viability and potential impact of developing and deepening the culture for innovation and entrepreneurship within SEAS. With one year of work identifying concrete means to envision innovations, provide seed funding, and find space for new ventures, a plan of sufficient detail should be developed to allow full implementation of all elements.

Industrial Partnerships

Engineering schools that have a positive societal impact also have close and nimble relationships with industry. These relationships require unique administrative structures.

A study published by the National Academy of Engineering posits that collaborations with industry lead to the development of more immediate and applicable innovations. It encourages "adaptable" university-industry relations that benefit the specific needs of both partners:

"Industries and universities should continue to explore mechanisms and pathways for bringing the benefits of academic research to industry, keeping in mind that what works well in one industry may not work well in another. Both partners should experiment with new approaches."

Developing a flexible culture of collaboration with industry requires a multipronged approach, such as creating more programs within SEAS that form industry partnerships and allow industry projects to easily plug into the curriculum. We can form more fluid partnerships by designating a space on campus intended for the use of industrial partners to interact with the Yale community. Increasing industry's presence on or near campus will increase connections between industry with students and faculty.

With the right industry partners - those with whom SEAS can share resources, align with Yale's mission, and are invested in the partnership's success - students will gain real-world, first-hand experience, learn what drives and motivates a company to make research and development decisions, access to internships, and jobs. In turn, students offer a great deal of value to our industry partners, such as breadth of resources, new perspectives, and time to make real-world observations in the field.

Recommendation:

Develop a structure for industrial support in SEAS that allows for a **culture of innovation**. To build toward deeper and more synergistic connections with these opportunities in industry, SEAS will develop models for collaboration that allow greater flexibility with industrial partnership agreements, in the form of **unique contracts between industry and faculty**. To develop a culture of collaboration with industry, we will seek space to form more fluid partnerships with industry in the form of a **designated space on campus that welcomes industrial partners** to interact with the Yale community.

Specifically, SEAS would pilot various industrial funding opportunities for industry, **including postdocs, graduate fellowships, faculty appointments, professor of the practice appointments.** These funding arrangements should incentivize industrial involvement with SEAS. Appropriate staffing would be needed to manage these partnerships, and flexible space to host collaborative activities would be desirable.

Optimizing for Large Center Grants

The USSC Report recommends more organized support for large grant submissions that will support science and consideration of how to support and incentivize faculty who apply for and then obtain center-scale grants. While we perform reasonably well relative to peers in securing extramural funding for research, we are rarely the lead institution on large scale center-grant proposals. We recommend improving the infrastructure to compete for large-scale center grant funding for research enterprises hosted at Yale.

Large center grant solicitations are often interdisciplinary and increasingly bridge subjects in science and engineering. We propose to **pilot a centralized proposal support structure** within SEAS that would carry out multiple activities, such as conducting pre-proposal research, offering project management and grant writing support, and providing a process for faculty to be considered for relief from certain normal duties when pursuing large grant submissions. Yale is currently a partner institution to two NSF Engineering Research Centers: Center for Quantum Networks, which has funded $3.5M to date, and the Center for Nanotechnology Enabled Water Treatment Systems (NEWT) which funded $25.2M through 2020. There are a handful of institutions, including the respective leads on these centers, the University of Arizona and Rice University, but also Arizona State and others, which have distinguished themselves by establishing transparent and faculty-friendly offices for incentivizing and supporting large grant submissions. In partnership with the Office of the Vice Provost for Research, we have researched these models. With a modest investment, we feel confident Yale has the faculty talent and the institutional expertise to lead center grants.

We acknowledge that such activities would need to be evaluated for their cost effectiveness and general value for the University. We would propose multiple metrics to evaluate the performance of such grants for the sake of the university, including:

- Resources raised through cost recovery.
- Publications and new collaborations directly traceable to grant-related activities.
- New grant activity that results from these collaborations.
- New opportunities for commercialization that results from discoveries funded through these grants.

- Higher visibility and rankings for the School of Engineering & Applied Science.

The potential benefits of these activities are clear and present in terms of research activity. Yet faculty lack a sense of the incentives that exist for them to make the time allocation needed to pursue them successfully. It is important that a rationalized model be put forward that incentivizes appropriately the pursuit of center grants and large-scale federal funding opportunities.

Recommendation:
We recommend SEAS establish and staff a large center grant support office. This office would work in close partnership with the Research Development team in the Office of the Vice Provost for Research. This collective support should provide templates for existing funding opportunities, engage faculty in meeting with program managers, enable collaborative pilot grant opportunities, and provide consultative proposal preparation, all of which will generate a deeper and more engaged culture of external funding.

Faculty Development

The USSC notes that "[t]he Deans, particularly in FAS and YSM, should review their policies regarding faculty leave for research purposes in the sciences and compare their policies with those of peer institutions." Indeed, like law and business schools, our best faculty will always be targets for recruitment by industry (as well as national labs). This report recommends **greater flexibility within our leave policy** that will allow for all short-term faculty appointments with national labs. The particular circumstance of leaves at industrial labs or for the purposes of the conduct of research in industrial settings provide a particular case that is worthy of deeper comment. In computer science and related areas, it is frequently the case that tools available in industry greatly exceed those available in our academic setting. Our academic researchers frequently can benefit from opportunities to work with industrial partners to enrich their research.

The question remains: does Yale's academic and educational mission suffer from these absences? We imagine that this is a primary reason for such constraints. *We suggest that it is possible that faculty who wish to take extended leaves at national labs or in other industrial settings make themselves available for educational purposes online with methods now commonplace in our remote learning model. With this approach, the value of the remote experience for the faculty member can be shared with the students locally, and students might gain deeper appreciation for the intellectual or academic value of the experience in which the faculty member is engaged.* This "test-bed" model for exploration of a new mode of learning is vital for SEAS to compete with engineering schools at our peer institutions – we will hope it gives us additional advantages.

Recommendation:
We propose that SEAS study faculty leave policies among peer schools of engineering and applied science. The natural boundary between SEAS and the rest of the University provides an opportunity to pilot a new policy at a School focused on innovation and entrepreneurship. Such a pilot would be studied with well-defined guardrails, timelines and metrics for success.

Curriculum that Reinforces Strategy

SEAS' commitment to teaching and learning can be seen in investments in the Greenberg Engineering Teaching Concourse (GETC, the epicenter of SEAS' lab-based instruction) and the Center for Engineering Innovation and Design. The proximity and programming provided by the Tsai Center for Innovative Thinking at Yale (CITY) and the Schwartzman Center are additional opportunities for SEAS students to learn and develop. Existing SEAS learning partnerships, such as those established with the School of Medicine and School of the Environment also increase SEAS' effectiveness in developing students.

These strengths are set against rising challenges associated with student learning, such as the increased need for computing resources and innovation-associated spaces associated with computer science over the last decade to meet surging enrollments in undergraduate and graduate programs. As another example, the full-time undergraduate lab support in SEAS is limited to two individuals with experience in the mechanical and electrical engineering disciplines, requiring each to assist in out-of-specialty domains. As one last example, Environmental Engineering undergraduate students do not have a lab course unique to their discipline. Finally, while SEAS prides itself on providing an education having depth in the discipline, breadth in the social studies/humanities, and opportunities to solve problems of purpose, the School is limited in its ability to provide engineering and applied science breadth for non-SEAS students.

The curriculum and extra-curricular offerings provided by SEAS remain an opportunity for significant impact through modest investment. As one example, the Advanced Graduate Leadership Program has been in existence for more than ten years and provides SEAS PhD students with a unique chance to develop leadership skills and learn management techniques as a component of their Yale experience. The leadership development component of that program features a 26-month sequence to learn, experience and retain leadership competencies and emotional awareness skills while strengthening the participant's ability to practice leadership. The program is highlighted as a model of non-traditional learning that is a hallmark of the Yale SEAS experience. An undergrad parallel of unique SEAS learning opportunities is the portfolio of engineering professional and project organizations that are facilitated by SEAS and self-managed by SEAS students. These organizations provide students with valuable project management experiences that are highly valued by employers and graduate school researchers. Securing the status of such programs is imperative to SEAS' continued success in these areas.

Allowing GETC to make additional contributions to student learning would garner a significant return on additional investments. For example, augmenting the GETC full-time support team with a member having a technical background that aligns with unrepresented SEAS disciplines will improve the student learning experience (and increase Teaching Fellow opportunities) in these disciplines. The addition of Lecturers for lab-based instruction associated in biomedical, chemical and environmental engineering, computer science, and electrical engineering would duplicate this success in other SEAS programs. These investments have the potential to advance the value of GETC as a student learning hub while strengthening the community nature of the School. Similarly, we propose that the leadership development component of the Advanced Graduate Leadership Development Program be offered, in due time, to SEAS undergraduate students, thereby providing an additional (optional) mark of distinction to the participants' resumes in a unique way that only SEAS can.

Marquee courses. SEAS also has an opportunity to export the culture of engineering throughout Yale College by developing and offering "marquee courses" aimed at 100+ enrollments of SEAS and non-SEAS majors. The courses would be taught by SEAS faculty luminaries, addressing engaging multidisciplinary topics (such as computational thinking and its applications to social concerns; engineering contributions to planetary science; biomedical applications to enhance quality of life; and water purification to ensure regional prosperity). Analogs for these SEAS-sponsored "marquee courses" exist throughout Yale College and provide a template for SEAS faculty to adopt and adapt. Like existing high-enrollment multi-disciplinary courses, these "marquee courses" would be co-taught with a faculty member from outside of SEAS, highlighting each course's multidisciplinary nature. The number of "marquee courses" would be limited and would need additional non-ladder faculty support to cover the required and elective elements of each discipline's curriculum.

Other examples include expanding the internal internships program (discussed elsewhere in this Plan) that gives SEAS students on-campus experience with industrial sponsors). SEAS' "Projects2Products" program provides a path to advance student work into commercialization, a model that represents a new form of communal, hands-on learning, focused on manufacturing engineering and entrepreneurship skills in an open-source environment.

Recommendation:
While some of the presented proposals are available for immediate implementation, such as pursuing additional GETC support and department-aligned lab Lecturers, other concepts will benefit from discussion among interested faculty members from across SEAS. We recommend a student, staff, and faculty task force aligned with specific learning environment proposals, be created to develop and implement the operational elements of each proposal. The proposed actions can spur immediate individual action, such as the creation of a "marquee course" by an individual faculty member, which can then be strengthened and improved through community discussion, allowing the SEAS teaching community to learn from each other in our global efforts to enhance SEAS learning opportunities.

TOWARD THE FUTURE

This plan puts forth an ambitious direction for the upcoming years, leading to a stronger School of Engineering and Applied Science based on a culture of innovation, collaboration, and inclusion. It is a plan that will require the efforts and focus of the full SEAS community. Progress toward these goals will be continually monitored, discussed annually, and reported back to the School.

Yale has charted a new, bold path in science and engineering, one that calls upon the full strength and resources of the University to redefine and reimagine a bold and innovative future for Yale. SEAS will catalyze this change, building on strengths and fundamental understanding, and re-envisioning its own future as the innovation engine for Yale. Our strategic vision and its implementation will marshal our strengths and reserves to bring our liberal arts focus and tradition to the broadest benefit for humanity.

Appendix A

Strategic Planning Charge & Committee Members

COMMITTEE MEMBERS:

- **Jeffrey Brock – Chair**
  Dean of the School of Engineering & Applied Science; FAS Dean of Science; Zhao and Ji Professor of Mathematics
- **Menachem Elimelech**
  Roberto C. Goizueta Professor of Chemical & Environmental Engineering and the Environment
- **Anna Gilbert, outside member**
  John C. Malone Professor of Mathematics and Statistics & Data Science
- **Anjelica Gonzalez, ex officio**
  Associate Professor of Biomedical Engineering; Tsai CITY Faculty Director
- **Sohrab Ismail-Beigi**
  Professor of Applied Physics, Physics, & Mechanical Engineering & Materials Science
- **Rajit Manohar**
  John C. Malone Professor of Electrical Engineering and Computer Science
- **Sarah Miller, Staff**
  Assistant Dean for Science and Engineering
- **Laura Niklason**
  Professor of Anesthesiology & Biomedical Engineering
- **Corey O'Hern**
  Professor of Mechanical Engineering & Materials Science, Physics, Applied Physics & Graduate Program in Computational Biology & Bioinformatics
- **Vladimir Rokhlin**
  Arthur K. Watson Professor of Computer Science and Professor of Mathematics
- **Nisheeth Vishnoi**
  A. Bartlett Giamatti Professor of Computer Science
- **Vincent Wilczynski, Staff**
  Deputy Dean, SEAS and James S. Tyler Director of the Center for Engineering Innovation & Design

FROM PROVOST SCOTT STROBEL, 9/11/20

Charge for SEAS Strategic Planning

Yale's School of Engineering & Applied Science (SEAS) embodies the ideal of a strong school of engineering within a liberal arts culture. It has had an eminent history, granting the first engineering PhD in the United States, to Josiah Willard Gibbs in 1863. Today, it should be a portal and magnet for Yale's most creative students and scholars, its most undaunted innovators, and its most acute problem-solvers. The recent introduction of Computer Science and Applied Physics into the School, the founding and development of Yale's Innovation Corridor, and the recent vision for new institutes at Yale in neuroscience, data science, and quantum science have positioned SEAS to play a critical role in furthering Yale's strategic vision. All these developments and more have brought to the fore the need to define and articulate a bold new strategy for the School.

Indeed, the USSC Report recognized "the need for Yale to have strength and intellectual coverage in areas of engineering and applied science" and emphasized "that engineering and applied science will play a vital role in implementing an overall strategy for advancing STEM across Yale." The USSC Report explicitly invites SEAS to develop a strategic plan to further integrate engineering into the fabric of the university.

I ask you, now, to take up this invitation. With Dean Brock's appointment in 2019 and the recent arrival of Applied Physics into your school, the timing is right for you to embark upon an inclusive process to chart the bright future of the School of Engineering and Applied Science. Please consider a ten-year timeframe and examine the following questions:

A. How can the unique configuration of expertise in SEAS support excellence across Yale?
B. How can SEAS engage with and lift Yale's strategic priorities?
C. How is SEAS positioned to address the global societal challenges of 2020 and beyond?

D. How will SEAS enhance the diversity and excellence of our campus?
E. How can SEAS be a portal for Yale to industry, entrepreneurship, and innovation?
F. Is SEAS internally structured to maximize its impact, excellence, and support of Yale?
G. What space uses and adjacencies will maximize opportunities for collaboration and synergy?
H. What curricular opportunities and innovation should SEAS pursue?
I. How can SEAS contribute to the strength of Yale College?

As you embark on this process, you should envisage ambitious aspirations. However, these ambitions should present a range of scenarios that allow for advancement under a resource-constrained environment. Please produce a framing so that future decisions can be made with your current guidance.

I ask that the committee:

6. Establish three to five visionary goals for SEAS to realize over the next five to ten years.
7. Develop tactics to support each of these goals. Include ideas that could be incorporated at current resource levels as well as those that would be feasible with additional resources.
8. Make suggestions about organizational structures and behaviors that could support excellence in engineering and applied science at Yale.

I expect diverse disciplinary expertise on this committee, and I hope that, collectively, you will all prize the interests of SEAS in the long term. Thank you, in advance, for the ingenuity, commitment, and collaboration that this will necessitate.