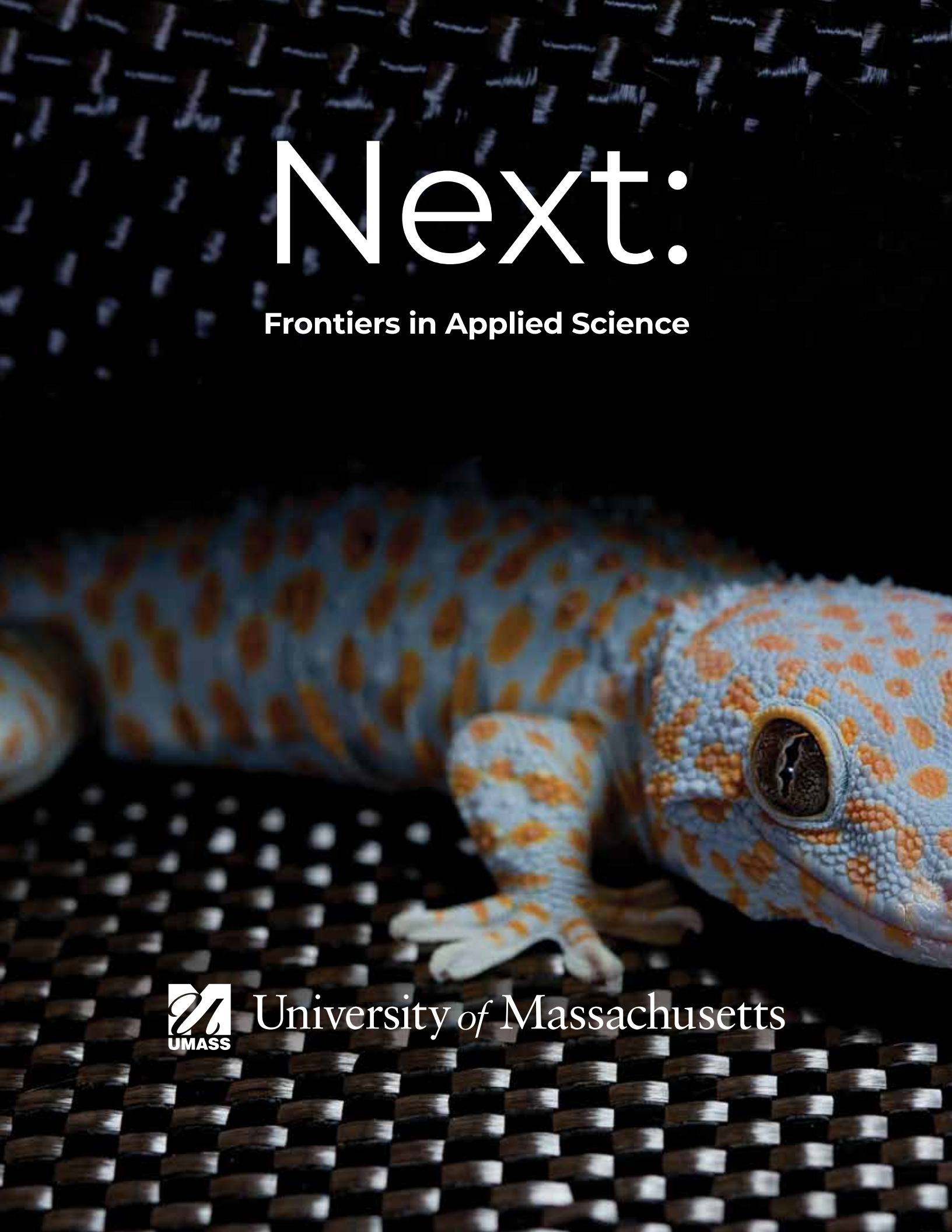


Next:

Frontiers in Applied Science

UMASS University of Massachusetts

A MESSAGE FROM THE PRESIDENT

Applied science research is a vital part of what the University of Massachusetts is all about. It's been programmed in our DNA since the very beginning.

When Congress mandated the establishment of land-grant colleges in each state in 1862—in a time of unprecedented national crisis—the purpose was to advance research and access to education in the practical sciences. When Massachusetts expanded its land-grant university into the current five-campus UMass system in 1991, the intent was to give the people of the Commonwealth a world-class public research program: a seat of cutting-edge research, education, and outreach aimed at advancing the common good.

It is amazing to see what the system has accomplished in the realm of research since that time. Over three decades, we have grown into one of the top three research powerhouses in Massachusetts—the country's hotbed of academia-driven innovation.

Now, the nation is battling another crisis: the coronavirus pandemic. Our "practical scientists" joined the fight against the virus in many ways, from running a $100 million NIH incubator for COVID diagnostic technologies to designing and donating plans for a fast-manufactured face shield. And we stand ready to help revitalize the Commonwealth during the COVID-19 recovery. By pursuing advances at the vital frontiers of applied science, we will lead the people and industries of Massachusetts forward.

Martin T. Meehan '78
President, University of Massachusetts

On the cover:
UMass Amherst researchers created Geckskin™— a reusable, fabric-backed super-adhesive that mimics the toe pads and ligaments of the gecko.

At the University of Massachusetts—the Commonwealth's public research university—internationally renowned researchers are at work in labs from Boston to the Berkshires. In the applied sciences, UMass is one of the largest research enterprises in the state, playing a crucial role in promoting economic growth and job creation in industries that are key to the Commonwealth's prosperity.

In addition to its tragic human cost, COVID-19 dealt a heavy blow to the Commonwealth's economy and workforce. With vaccinations promising the beginning of the end of the coronavirus crisis, UMass scientists and engineers are redoubling their focus on the question *What's next?*, building on today's breakthroughs and innovations to boldly move into the post-pandemic future.

Massachusetts boasts—and depends on—one of the country's most active innovation sectors. Boosting the industries that support our knowledge-based economy is a prerequisite for post-COVID prosperity. That is a mission to which UMass can and does contribute enormously. By devoting our research expertise and facilities to the cutting edge of applied science, we create new opportunities for application and commercialization for key industries in the state, helping to usher in the next phase of the Commonwealth's innovation evolution.

The five-campus system of the University of Massachusetts

UMass **Amherst**

UMass **Boston**

UMass **Dartmouth**

UMass **Lowell**

UMass **Medical**

The next frontiers in applied science

The universe of research at UMass is vast. In partnership with government and industry, our faculty have been instrumental in advancing basic and applied science discoveries that have transformed the lives of thousands.

Six domains of investigation in particular are central to our research mission and key to the Massachusetts economy. Within each of these strength areas, we have identified what we believe will be the vital challenges to tackle and opportunities to pursue over the next 5 to 10 years.

Applied Life Sciences

- Addressing genetic diseases, Alzheimer's disease, and aging through gene therapy
- Creating self-repairing, self-correcting, and self-regulating artificial systems
- Managing microbiomes to optimize health, address antibiotic resistance, and combat disease
- Preparing for future pandemics
- Programming the immune system to identify and eradicate cancer

Precision Health

- Creating genomics-informed disease prevention, diagnosis, and treatment plans
- Designing next-generation, useful, and usable digital health technologies
- Translating complex health data into actionable knowledge
- Using data and technology to improve health equity
- Training an innovative, data-driven, and technology-informed precision health workforce

Advanced Manufacturing

- Making manufacturing agile, responsive, instant, customized, and adaptive
- Creating sustainable manufacturing processes
- Scaling up industrial 3D printing
- Integrating biological and non-biological manufacturing
- Employing collaborative robots in manufacturing

Artificial Intelligence, Robotics, and Data Science

- Creating trustworthy AI systems
- Transforming the future of work at the human-technology frontier
- Boosting military robotics with AI
- Advancing autonomous systems, underwater and on land
- Harnessing the power of big data

Sustainability and Climate Resilience

- Empowering thriving coastal communities and the blue economy
- Transitioning to clean energy, with an eye to social justice
- Making transportation sustainable
- Creating resilient seafood supply chains

Aerospace, Defense, Undersea Technologies, and Remote Sensing

- Developing real-time, autonomous cyber operations
- Integrating humans, machines, teams, and systems
- Empowering pervasive awareness and monitoring
- Exploring challenging environments: in space, undersea, and on land
- Creating adaptable next-generation materials and manufacturing techniques

These are the research imperatives that will be crucial in the near-term future, to the people of our state and to our partners in government and industry. Discoveries and technologies in these domains offer high returns on new investment. Research on these fronts is underway at UMass, and we are already preparing students to fill the workforce demand that is projected as new ideas, born in our labs and transmitted to the next generation in our classrooms, become industrial realities.

These topics—and the promising areas of interplay between them—are our next frontiers in applied science research.

UMass Amherst polymer scientists have created wearable, flexible sensors that monitor soldier stress

Researchers at UMass Medical School are exploring connections between microbiome composition and dementia

Advancing the frontiers

Scientists and engineers on all five UMass campuses are conducting exciting research in—and across—these vital domains of applied science.

UMass Amherst engineers are exploring the use of data-intensive 3D laser scanning to assess roadway deterioration

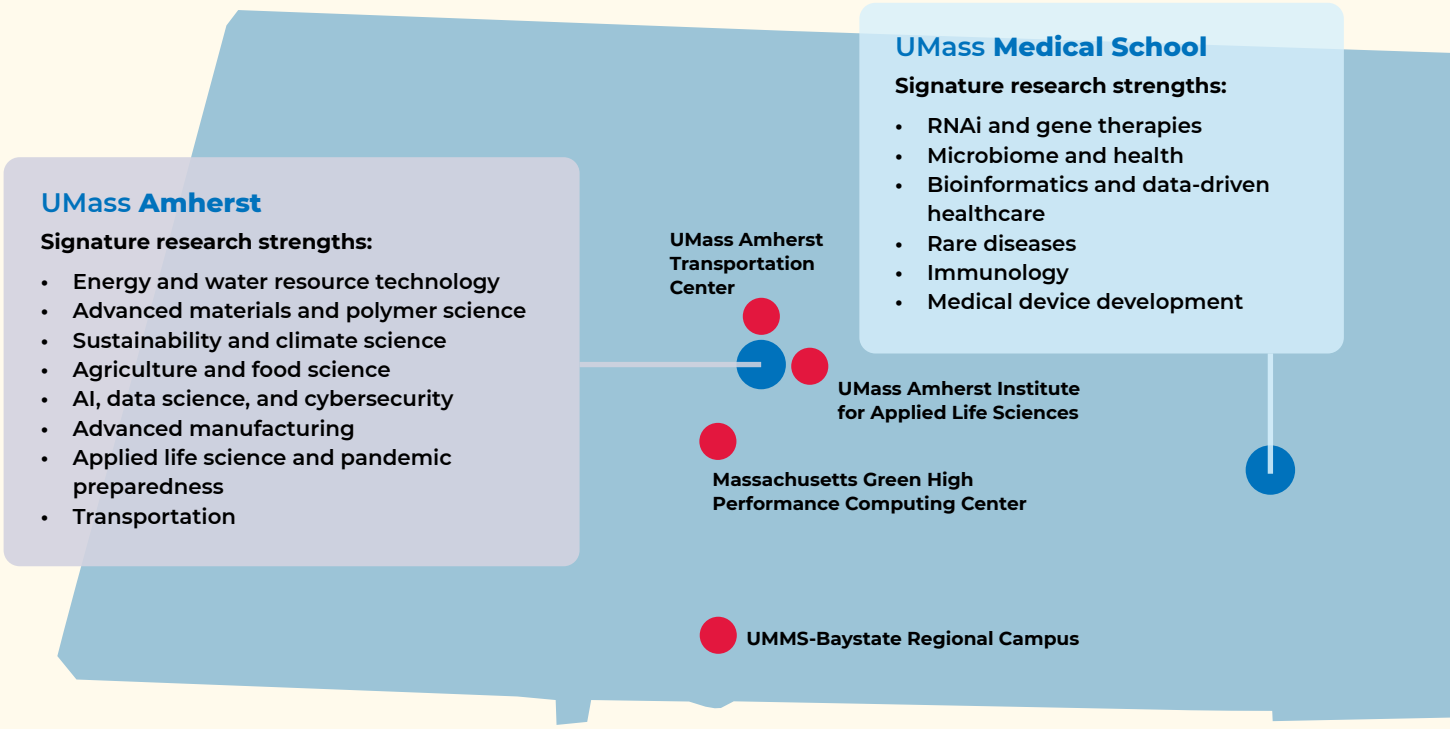
At UMass Lowell, plastics engineers are using high-speed extrusion to make plastic waste more recyclable

Engineers at UMass Dartmouth have developed a wireless, wearable biosensor system that detects and predicts life-threatening events in newborns

UMass Boston climate scientists are using satellite- and drone-based systems to monitor environmental change

Statewide strength on the leading edge

UMass is uniquely positioned to tackle these issues in the Commonwealth. Why? For one, the massive, statewide scope of our research enterprise.

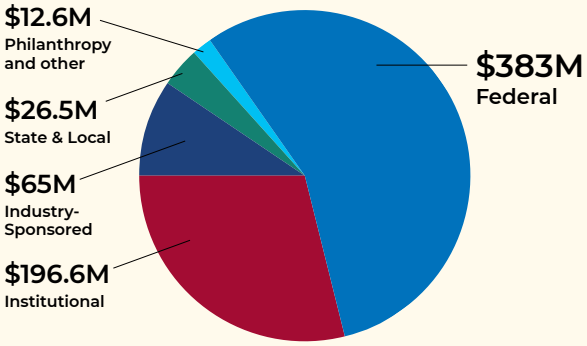


The system has thousands of faculty members conducting groundbreaking research across an immense range of basic and applied sciences, including a Nobel laureate, members of the National Academy of Sciences, and Fulbright and MacArthur fellows. UMass had 16 faculty members on *Clarivate Analytics*' 2018 "Highly Cited Researchers," a list of the top 1 percent of the world's research scientists.

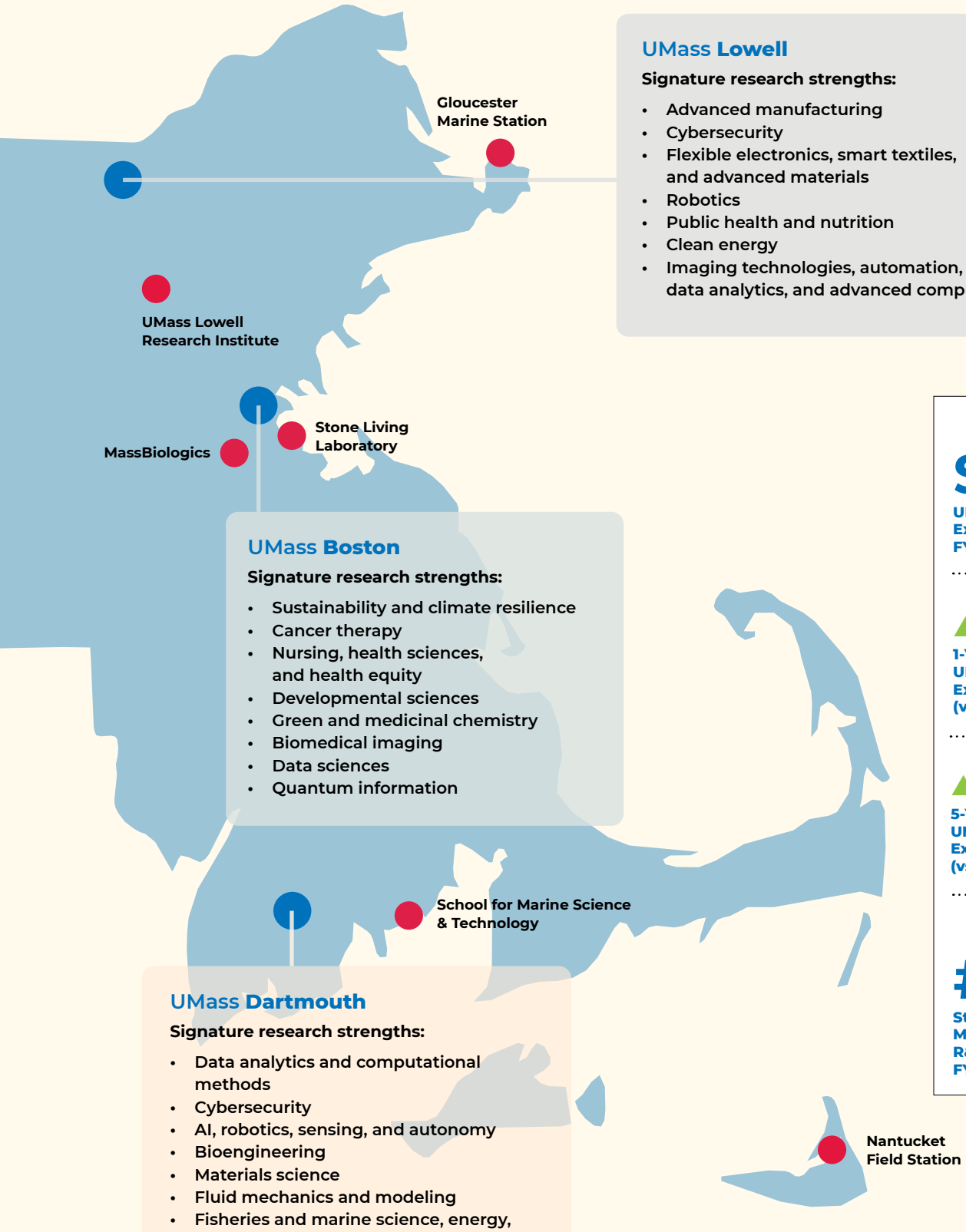
The UMass faculty provides critical research and development support to partners in business, government, and academia. The system conducts more than $680 million in research across the campuses every year, making it the third-largest research university in Massachusetts, and the fourth-largest in all of New England, behind only Harvard, MIT, and Yale. These expenditures represent 17 percent of all sponsored research conducted in Massachusetts.

Collectively, the system ranks 16th among US public institutions, 33rd in the US, and 63rd in the world on Reuter's 2019 list of the 100 most innovative universities. Each campus brings its own signature strengths to the enterprise, creating opportunities for intercampus cross-fertilization that make the system as a whole more than just the sum of its parts.

UMASS SOURCE OF FUNDING FY 2019



Source	1-Year % Change (vs. FY 2018)	5-Year % Change (vs. FY 2014)
Federal	▲ 2%	▲ 6%
State & Local	▲ 24%	▲ 16%
Industry Sponsored	▲ 8%	▲ 43%
Institutional	▲ 4%	▲ 19%
Philanthropy and other	▲ 70%	▲ 129%



UMass **Lowell**

Signature research strengths:

- Advanced manufacturing
- Cybersecurity
- Flexible electronics, smart textiles, and advanced materials
- Robotics
- Public health and nutrition
- Clean energy
- Imaging technologies, automation, data analytics, and advanced computing

UMass **Boston**

Signature research strengths:

- Sustainability and climate resilience
- Cancer therapy
- Nursing, health sciences, and health equity
- Developmental sciences
- Green and medicinal chemistry
- Biomedical imaging
- Data sciences
- Quantum information

UMass **Dartmouth**

Signature research strengths:

- Data analytics and computational methods
- Cybersecurity
- AI, robotics, sensing, and autonomy
- Bioengineering
- Materials science
- Fluid mechanics and modeling
- Fisheries and marine science, energy, and technology
- Community-engaged research

$684M
UMass Total R&D Expenditures FY 2019

▲ 5%
1-Year Change in UMass Total R&D Expenditures (vs FY 2018)

▲ 14%
5-Year Change in UMass Total R&D Expenditures (vs FY 2014)

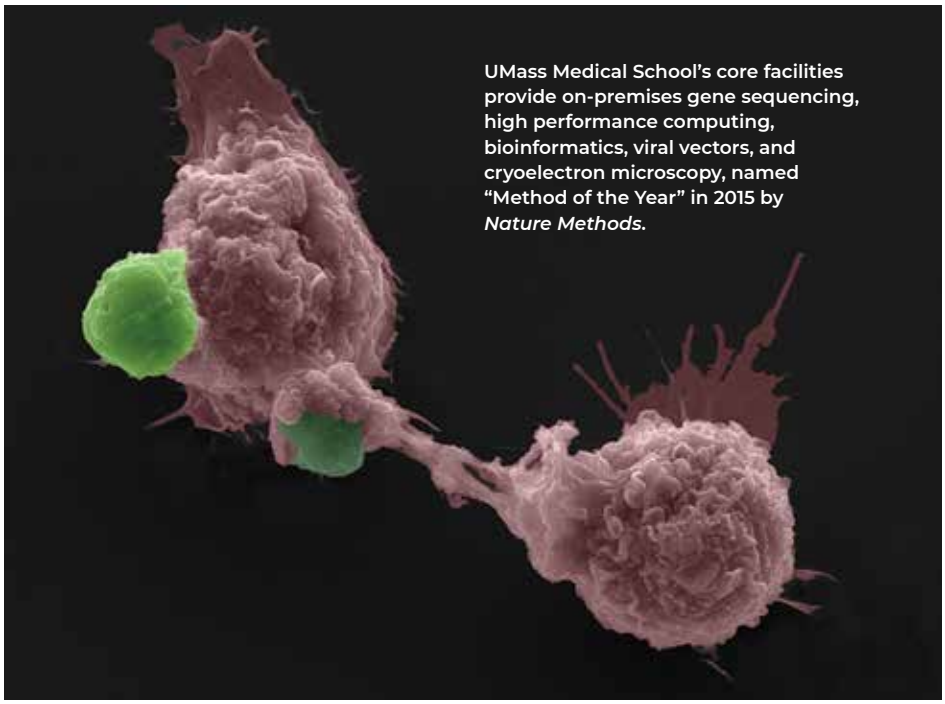
#3
State Ranking among MA Universities in R&D Expenditures FY 2019

For more information about research and development at UMass, visit www.umassp.edu/reports-and-initiatives/institutional-research.

Network of state-of-the-art infrastructure

UMass's statewide network of 90+ core equipment facilities makes world-class research resources available to scientists on all five campuses—and to government, industry, and academic collaborators across the state.

This shared science and technology infrastructure, housed across the system, features more than $100 million in cutting-edge equipment, overseen by facility directors expert in its use. The facilities exist to turbo-charge the research of UMass faculty, enhance student training for the innovation workforce, and spur collaborations with external partners. They also create major benefits for Massachusetts industry, providing opportunities for companies to use—on a fee-for-service basis—state-of-the-art technologies that would be prohibitively expensive to manage themselves.



UMass Medical School's core facilities provide on-premises gene sequencing, high performance computing, bioinformatics, viral vectors, and cryoelectron microscopy, named "Method of the Year" in 2015 by *Nature Methods.*

The core facilities network has tremendous power to advance scientific discovery and industry innovation, and the Commonwealth and federal government have made significant investments in increasing both its capabilities and access to them. In 2016, the Massachusetts Life Sciences Center contributed $95 million to support the launch of UMass Amherst's Institute for Applied Life Sciences, which houses more than 30 core research facilities for advancing translational programs towards novel drug targets, drug delivery technologies, personalized healthcare devices, nutraceuticals, and other technologies that enhance human health and well-being.

The Commonwealth also sponsors innovation vouchers that allow small- and medium-sized Massachusetts companies to access the core facilities at significantly discounted prices. Since June 2018, 593 vouchers totaling $3.36 million have been awarded to 235 companies, aiding research and development in 76 cities and towns across the state.

> **"A key challenge for a biotech startup is access to infrastructure and personnel, which can be difficult in the early phase of company building, since funds are limited. The UMass Medical School core facilities provide valuable means to solve this problem by providing cost-effective access to a wide range of services.... [We have] been able to tap into the small-molecule drug discovery, proteomics, and structure-based drug design core facilities....This has enabled our company to be capital-efficient while building out its platform, which will then enable us to better seek additional financing to build the company."**
>
> — Juswinder Singh, founder and Chief Scientific Officer, Ankaa Therapeutics

UMass Lowell's core facilities give more than 200 industry users per year access to micro- and nanoscale fabrication equipment, materials characterization, gene sequencing, controlled radiation environments, textile/flexible electronics testing and prototyping, and, most recently, a lyophilizer for freeze-drying biopharmaceuticals.

UMass Boston's Center for Personalized Cancer Therapy, a joint program with the Dana Farber/Harvard Cancer Center, used $10 million from the Massachusetts Life Science Center to launch a Genomics Core facility integral to the development of new cancer therapeutics and biomarkers.

UMass Dartmouth's Center for Scientific Computing & Visualization Research provides facilities enabling the development and use of computational algorithms to simulate complex physical problems.

> "Calorique had been dealing with the challenge of getting a uniform thickness of coating on a particularly thin film...for a defense project. Our visit to UMass Amherst and working in the equipment there educated us on how to make the fine controls to get to the right thickness. It had a huge immediate as well as long-term economic impact for us. We want to continue the partnership."
>
> — Yudhisthira Sahoo, R&D Director, Calorique LLC

Advancing health and prosperity

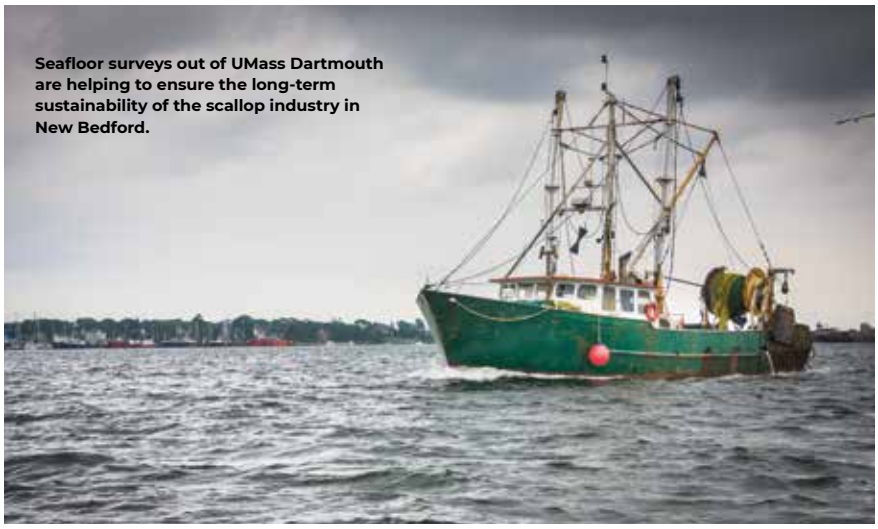
UMass Amherst's $150 million Institute for Applied Life Sciences partners with Massachusetts companies to combine academic innovation with an industry-like focus on commercially significant results. The Institute has three research thrusts: creating state-of-the-art wearable devices, at its Center for Personalized Health Monitoring; exploring new biomolecule delivery systems, at the Center for Bioactive Delivery; and discovering novel treatment approaches, at the Models to Medicine Center. IALS also offers government and industry access to advanced instruments and "collaboratories" where outside researchers can work alongside faculty from more than 200 research groups.

An engine for the innovation economy

Through its research programs, UMass drives economic development in all corners of the Commonwealth. Advancing our applied science frontiers promises to keep that engine running.

UMass is the single largest economic force in Massachusetts, with more than $6 billion in annual economic impact as an employer, a crucible of human capital, and a source of new knowledge in a wide range of fields. The system is committed to serving the needs of Massachusetts' innovation economy—which employs 40 percent of the state's residents—through its research.

How? For one, by generating insights that shape industry best practices. UMass Amherst biomedical engineers, for example, have created new methods for detecting ammonia that are inexpensive, waste-free, and among the most sensitive ever developed—an advance with implications in medicine, agriculture, and beyond.



Seafloor surveys out of UMass Dartmouth are helping to ensure the long-term sustainability of the scallop industry in New Bedford.

UMass also generates millions of dollars in intellectual property licensing revenue and is foundational to hundreds of start-up companies. UMass ranks 37th on the National Academy of Inventors/Intellectual Property Owner's Organization's list of the top 100 worldwide universities granted utility patents, with nearly 400 issued since 2014.

The medical school ranks fourth in the nation for faculty-derived discovery and product revenue, amounting to

Licensing metrics 2014–2020

87
EXCLUSIVE LICENSES COMPLETED

84
NON-EXCLUSIVE LICENSES COMPLETED

$325M
GROSS LICENSING REVENUE

24
NEW SPINOFF COMPANIES

System technology transfer 2014–2020

1222
INVENTION DISCLOSURES

1143
PATENT APPLICATIONS

397
PATENTS ISSUED

A global hub of high-performance computing

The Massachusetts Green High Performance Computing Center (MGHPCC), based in Holyoke, Mass., provides state-of-the-art infrastructure for computationally intensive research that is indispensable in the increasingly sensor and data-rich environments of modern science and engineering. Computers at the MGHPCC run millions of virtual experiments every month, supporting 1,400 researchers and almost 500 labs in Massachusetts and around the world. The MGHPCC operates as a joint venture among UMass, Boston University, Harvard, MIT, and Northeastern.

$146 million in 2018 alone. The system as a whole licensed $325 million dollars worth of intellectual property between 2014 and 2020 and spun off 24 new companies.

The system also operates a number of incubators to help Massachusetts businesses develop viable products and successfully launch. In FY19, the 100+ tech companies incubated in UMass Boston's on-campus Venture Development Center hit more than $1 billion in funding and 1,000 employees, including over 300 UMass Boston students. The Massachusetts Medical Device Development Center, a collaboration between UMass Lowell and the UMass Medical School, is a lifeline for the state's smaller medical device companies, offering inventors and executives easy, affordable, and coordinated access to world-class researchers and resources.

The six applied science frontiers fields we have identified promise to yield even more dividends in both discovery and economic impact over the next ten years.

They are already central to the Massachusetts economy:

- The Commonwealth ranks first in the nation in life sciences R&D investment.
- Department of Defense and Homeland Security grants and contracts generated $26.5 million of economic activity in the Commonwealth in 2019.
- Some 350 robotics companies operate in Massachusetts, and more than 470,000 residents work in fields related to sustainability and coastal resilience.
- Advanced manufacturing is a top-three economic and employment sector in the state, and the Massachusetts Department of Higher Education predicts it will remain economically important for the foreseeable future.
- Globally, the precision medicine market is projected to grow from $58 billion to $141 billion over the next six years.

The University's focus on basic science and its translation to life-altering therapeutics, revolutionary technologies and devices, and environmentally sound strategies for resilience and reclamation have already contributed billions to the prosperity of the Commonwealth's industries and communities. But the best is yet to come as we emerge from the pandemic and focus on the "next economy." Our six frontier fields will, we believe, be the backbone of that recovery.

The next-generation workforce

Workforce demand is projected to grow in the Commonwealth in all six of our frontier fields. Who will provide the qualified workers industry needs to thrive? Data show it's UMass.

Our faculty are directly responsible for shaping our state's talent pool. The Commonwealth's labor force of the future passes through their classrooms. Running parallel to UMass's research effort is the imperative to train the next generation of highly skilled professionals. They will join the research laboratories of private sector firms, non-profit organizations, and public sector agencies that are vital to the application of these discoveries and technologies.

As the state's premier public research university, UMass plays a special role in preparing students to contribute to the Commonwealth's prosperity. Roughly 75 percent of UMass's 75,000 students are residents of Massachusetts, and the majority of them remain in Massachusetts after graduation. Our responsibility is to safeguard the state from a "brain drain" by creating a talented, professional, workforce that is ready from day one to contribute to our knowledge economy.

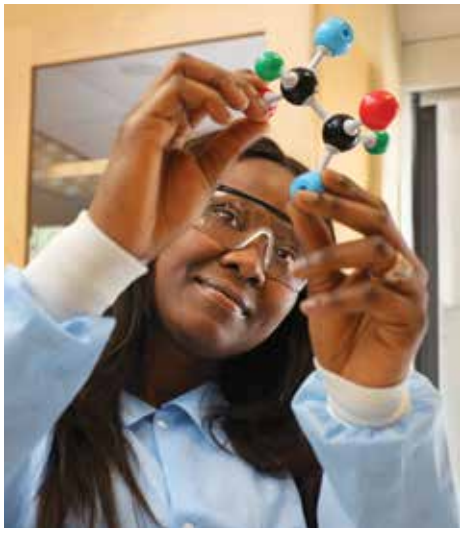
Over the next ten years, employment is expected to grow in all of our focus areas by between 5.3 and 8.2 percent—well in excess of projections for state and national employment growth in general. As the Commonwealth's top degree producer in all of these fields, UMass will play the leading role in filling this workforce need, and our students will be the primary beneficiaries of it.

We prepare them for success with a combination of top-tier teaching and opportunities for hands-on experiential learning, through programs like UMass Lowell's Professional Cooperative Education program and UMass Medical School's Interprofessional Center for Experiential Learning and Simulation.

UMass rank in degree completions among MA institutions in all six frontier areas

The diversity imperative

UMass is dedicated to ensuring that thousands of talented students of color, women, immigrants, and first-generation and low-income college students take their place at the cutting edge of scientific discovery and industrial innovation.



STEM jobs pay more than twice the salary of other jobs, on average, and are expected to grow at twice the rate of employment in general over the next decade. But these advantaged positions aren't equitably distributed: Women occupy only 26 percent of Massachusetts jobs in computer- and mathematics-intensive fields and 15 percent in architecture and engineering. The state's Hispanic/Latinx workers are underrepresented in all STEM occupations and African Americans in all fields but healthcare.

As a public university, UMass has a moral imperative to prepare all students for success in an increasingly STEM-oriented job market. In planning for the post-COVID recovery, we have a particular obligation to help Massachusetts residents—especially those disproportionately impacted by the pandemic—succeed in fields with robust job demand and high income.

Diversifying the sciences isn't just right; it's good business. The US faces a gap in qualified STEM workers, and the number of "traditional" college-

UMass Amherst social psychologist Nilanjana Dasgupta is leading UMass's efforts to increase STEM inclusion.

age students in the Northeast is shrinking. To maintain its innovation edge, the Commonwealth must bring a broader swath of young professionals into the sciences, engineering, and technology.

UMass has a critical role to play. We educate more students than any other university in the Commonwealth, and conduct more research than most. Our student body is already relatively diverse: UMass Boston is currently the third most diverse university in the nation, and all of our campuses have significant communities of color and high proportions of first-generation college students and students from low-income families.

By helping these students attain college degrees, UMass is an engine of social mobility for Massachusetts. And much of that success runs straight through our students' training in the applied sciences. As such, we are actively working to increase participation of underrepresented groups in STEM.

Leading the way is the UMass Amherst Institute of Diversity Sciences, whose founding director, social psychologist Nilanjana Dasgupta, has pioneered innovative work on the factors that ignite student interest, motivation, and persistence in STEM fields, and developed research-driven solutions to promote student success in STEM.

Supported by a National Science Foundation award, the Institute launched a Massachusetts-wide network called REBLS (Researchers, Educators, Business Leaders, and Students), a partnership among four UMass campuses and high schools, community colleges, tech and engineering industry partners, and informal learning organizations.

These multi-institutional stakeholders join forces to identify pain points that result in the attrition of diverse talent from tech and engineering pathways. Then they develop, implement, and rigorously evaluate solutions that help underrepresented students find, persist, and thrive in technology and engineering majors and careers.

UMass is also striving to increase faculty diversity. UMass Amherst, UMass Boston, and UMass Lowell have received $6.8 million in NSF ADVANCE grants supporting their work to develop evidence-based strategies for cultivating faculty equity in STEM.

These research-rich projects put the science into our efforts to promote STEM success and inclusion across our campus communities and promise to make the STEM workforce reflect the communities that compose our state.

Social science-driven approaches from the Institute of Diversity Sciences

- **Fostering peer mentoring within identity groups.** Mentoring relationships between first-year and senior college students in the same identity group increase mentees' persistence in STEM majors, success securing STEM internships, and aspirations to STEM careers.
- **Creating diverse STEM work groups.** Underrepresented students feel more motivated to pursue STEM careers when they work in teams with a critical mass of similar others.
- **Modeling within identity groups.** Drawing attention to role models from underrepresented groups who are successful in STEM attracts students to similar careers.
- **Connecting STEM to equity and social good.** Underrepresented students are more attracted to STEM careers when they see how science and engineering promote human welfare.
- **Creating professional development programs** that catapult students to STEM careers by teaching professional skills, providing industry mentoring, and creating communities of peers and role models.
- **Creating bridge programs** to college that strengthen the STEM foundation of students from under-resourced high schools and connect them with peers and professionals.

To learn more, visit www.umass.edu/diversitysciences

As Massachusetts' public research university, UMass is the Commonwealth's emissary on the frontiers of applied science. Our faculty are advancing forefronts of research that we believe will help create post-pandemic prosperity for the Commonwealth and its people.

The state and federal governments, along with our partners in industry, have invested in making UMass a research powerhouse that spans the state. As a result, UMass faculty are feeding industry and workforce in the Commonwealth, with a unique determination to bring all Massachusetts residents along on the road to COVID-19 recovery.

No problem is unsolvable. In pursuing these research frontiers, we are tackling society's most daunting problems and science's most exciting questions head on. We look forward to collaborating with our partners in government, industry, and academia to create tomorrow's opportunities.

> **"The University of Massachusetts system is a leader in applied sciences innovation both in terms of carrying out cutting-edge research and in training the next generation of talented young investigators. It also has a long tradition of generating innovative new ideas that can be translated into novel medicines and products by industry—across multiple sectors, including biotechnology, defense, advanced manufacturing, pharma, robotics, energy, remote sensing, and all aspects of computer/data science. As such it is a key driver of the innovation ecosystem in the Commonwealth and beyond. We know we can look to UMass for the research we need and the diverse talent that is so critical to the private sector. We salute their achievements in the applied sciences.**
>
> — Jeffrey M. Leiden, M.D., Ph.D.
> Chairman, Massachusetts Competitive Partnership
> Executive Chairman, Vertex Pharmaceuticals

FluSense, a compact device developed by UMass Amherst computer scientist and mobile sensor expert Tauhidur Rahman, uses artificial intelligence and thermal imaging to predict trends in infectious respiratory illnesses by detecting cough sounds and counting people in public spaces.

FluSense data gathered in medical waiting rooms like those scanned here strongly correlated with lab-based testing for flu-like illnesses. The new platform could expand the arsenal of health surveillance tools used to forecast seasonal flu and other viral respiratory outbreaks, such as COVID-19.

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