THE WHITE HOUSE
OFFICE OF SCIENCE AND TECHNOLOGY POLICY

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FACT SHEET: Announcing the National Microbiome Initiative

WASHINGTON, DC – Today, the White House Office of Science and Technology Policy (OSTP), in collaboration with Federal agencies and private-sector stakeholders, is announcing a new National Microbiome Initiative (NMI) to foster the integrated study of microbiomes across different ecosystems, and is hosting an event to bring together stakeholders vital to advancing the NMI.

Microbiomes are the communities of microorganisms that live on or in people, plants, soil, oceans, and the atmosphere. Microbiomes maintain healthy function of these diverse ecosystems, influencing human health, climate change, food security, and other factors. Dysfunctional microbiomes are associated with issues including human chronic diseases such as obesity, diabetes, and asthma; local ecological disruptions such as the hypoxic zone in the Gulf of Mexico; and reductions in agricultural productivity. Numerous industrial processes such as biofuel production and food processing depend on healthy microbial communities. Although new technologies have enabled exciting discoveries about the importance of microbiomes, scientists still lack the knowledge and tools to manage microbiomes in a manner that prevents dysfunction or restores healthy function.

The NMI aims to advance understanding of microbiome behavior and enable protection and restoration of healthy microbiome function. In a year-long fact-finding process, scientists from Federal agencies, academia, and the private sector converged on three recommended areas of focus for microbiome science, which are now the goals of the NMI:

(1) **Supporting interdisciplinary research** to answer fundamental questions about microbiomes in diverse ecosystems.
(2) **Developing platform technologies** that will generate insights and help share knowledge of microbiomes in diverse ecosystems and enhance access to microbiome data.
(3) **Expanding the microbiome workforce** through citizen science, public engagement, and educational opportunities.

The NMI builds on strong and ongoing Federal investments in microbiome research, and will launch with a combined Federal agency investment of more than **$121 million**

in Fiscal Year (FY) 2016 and 2017 funding for cross-ecosystem microbiome studies. This includes:

- The **Department of Energy** proposes $10 million in new funding in FY 2017 to support collaborative, interdisciplinary research on the microbiome.
- The **National Aeronautics and Space Administration (NASA)** proposes $12.5 million in new funding over multiple years to expand microbiome research across Earth's ecosystems and in space.
- The **National Institutes of Health** will invest an extra $20 million into microbiome research in grants in FY 2016 and FY 2017 with a particular emphasis on multi-ecosystem comparison studies and investigation into design of new tools to explore and understand microbiomes.
- The **National Science Foundation** proposes $16 million in FY 2017 for microbiome research that spans the spectrum of ecosystems, species, and biological scales.
- The **U.S. Department of Agriculture** proposes more than $15.9 million for FY 2017 to expand computational capacities for microbiome research and human microbiome research through the Agricultural Research Service, and approximately $8 million for FY 2017 to support investigations through the National Institute of Food and Agriculture of the microbiomes of plants, livestock animals, fish, soil, air, and water as they influence food-production systems.

In addition, following OSTP's national call to action issued in January, more than 100 external institutions are today announcing new efforts to support microbiome science. These include:

- The **Bill and Melinda Gates Foundation** will invest $100 million over 4 years to investigate and develop tools to study human and agricultural microbiomes.
- **JDRF** will invest $10 million over 5 years to address microbiome research related to type 1 diabetes.
- The **University of California, San Diego**, is investing $12 million in The Center for Microbiome Innovation to enable technology developers to connect with end users.
- **One Codex** is launching a public portal for microbiome data, allowing greater access to this data for researchers, clinicians, and other health professionals.
- **The BioCollective, LLC**, along with the **Health Ministries Network**, are investing $250,000 towards building a microbiome data and sample bank, and the engagement of underrepresented groups in microbiome research.
- The **University of Michigan**, with support from the Howard Hughes Medical Institute and Procter and Gamble, will invest $3.5 million in the Michigan Microbiome Project to provide new research experiences for undergraduate students.

Federal Involvement in Microbiome Research to Date

The Federal Government has been investing in microbiome for many years. More than a dozen Federal departments and agencies support microbiome research today, and the magnitude of investment has recently grown: a 2015 report released by the National Science and Technology Council (NSTC) noted that annual Federal investment into microbiome research tripled over FY 2012–2014, with more than $922 million invested during this 3-year period. This figure includes multi-agency collaborations and independently funded work. Notable Federal investments and accomplishments in microbiome research to date include:

- In 2007, the **Department of Energy (DOE)** and the **National Institutes of Health (NIH)** together launched the open-source bioinformatics pipeline MG-RAST (Metagenomics Rapid Annotations using Subsystems Technology), an open-source web application server that provides quantitative information on microbial populations. MG-RAST now has over 12,000 registered users and nearly a quarter million data sets.

- The **Department of Justice (DOJ), National Institute of Justice (NIJ)** invested $3.2 million in FY 2015 in microbiome related research. NIJ is the leading agency in funding forensic science research and has focused its microbiome portfolio on: the necrobiome as an indicator of time-since-death in the investigation of human remains, the soil microbiome for analysis of trace soil evidence, and the trace microbiome as an orthogonal method to human DNA analysis for associating people with evidence and environments.

- In FY 2016, the **Department of Veterans Affairs (VA), Office of Research and Development (ORD)** is investing $4.2 million in microbiome research efforts. This research spans a spectrum of diseases and medical conditions, including investigating the role of the microbiome in alcoholic liver disease and cirrhosis, characterizing components of the nasal microbiome that could prevent transmission of methicillin-resistant Staphylococcus Aureus (MRSA) in VA hospitals, and determining the role of the microbiome in preventing or reducing infection at the implant sites of Veterans receiving certain prosthetic lower limb implants. These research efforts aim to enhance the well-being and health of American Veterans, as well as contribute to the broader research fields surrounding microbiome related disciplines, studies, and treatments.

- In FY 2007, **NIH** initiated the 10-year Human Microbiome Project (HMP) to develop foundational research resources to catalyze the field of microbiome science. Roughly 50,000 files of sequence and other genomic data from HMP is now publicly available

through repositories such as GenBank, Sequence Read Archive (SRA), and the Genotype and Phenotype database (dbGaP), and this past year, approximately 75,000 users from 178 countries accessed HMP data. A total of $215 million has been invested in the HMP since its inception, with $50 million of that total invested over FY 2012-2014.

- Over FY 2012-2014, **NIH** invested $491 million into research that explores the involvement of the human microbiome in conditions as diverse as diabetes, obesity, cardiovascular disease, autism, asthma, cancer, preterm birth, brain development, and behavior. This funding was distributed across 19 of the 27 NIH Institutes and Centers, and was expended mostly through grants to individual university investigators and for intramural research support.

- The **National Institutes of Standards and Technology (NIST)**, in collaboration with NIH, has organized the Standards for Microbiome Measurements workshop for later this year. The workshop will bring together stakeholders from other Federal agencies, academia, and industry to identify priorities for and plan the creation of reference materials, protocols, and measurement tools that will accelerate development of microbiome-based clinical treatments and marketable products.

- In FY 2016, the **National Oceanic and Atmospheric Administration (NOAA) Oceanic & Atmospheric Research (OAR)** line office begins an initiative to support microbiome research efforts at a level of $1.8 million. The multi-pronged effort includes close collaboration with NOAA's National Marine Fisheries Service (NMFS) line office, the J. Craig Venter Institute (JCVI), the Monterey Bay Aquarium Research Institution, and academic partners, including the Scripps Institute of Oceanography and the University of Miami. NOAA's projects include microbiome metagenomic and metatransciptomic work to support ecosystem understanding and fisheries assessment, microbiome assessment via in-situ and mobile technologies, and metagenomics research to garner intelligence on higher trophic levels via ocean microbiome assessment.

- The **National Science Foundation (NSF)** and the **Department of Agriculture (USDA)** supported the Joint Microbial Genome Sequencing Program for 10 years, starting in FY 2000. The program provided genetic sequences of hundreds of ecologically relevant and agriculturally important bacteria, viruses, fungi, and oomycetes (water molds). **NIH**, **NSF** and the **USDA National Institute of Food and Agriculture (NIFA)** are currently supporting the Joint Ecology of Infectious Diseases Program. Both programs encourage timely and broad data sharing through the use of public repositories.

- The **Smithsonian Marine Station (SMS)** has invested in two microbiome projects in FY 2016, which include $50,000 to work with collaborators across the United States

to understand the roles that microorganisms play in healthy coral reef ecosystems. Additionally, the Smithsonian Marine Station has invested $120,000 on understanding healthy and diseased coral microbiomes.

- **USDA Agriculture Research Service (ARS)** invested $11.9 million in FY 2015 in microbiome research. The investments included animal-microbiome research that encompassed alternatives to antibiotics to enhance feed efficiency; plant-microbiome research to learn how crop productivity and quality can be influenced; soil-microbiome research that optimizes the nutrient cycle and prevents soil degradation and enhances sustainability; and human-microbiome research, which focuses on the gut microbiome in immune-system development and its effect on disease resistance, health, and well-being.

In addition, the newly chartered **NSTC Microbiome Interagency Working Group (MIWG)**, will develop a Federal Strategic Plan for microbiome research. The Plan will outline an approach for addressing research needs and gaps identified in the November 2015 Report of the Fast-Track Action Committee on Mapping the Microbiome, and recommend ways to improve coordination of microbiome research among Federal agencies.

The NMI will build on these past and ongoing activities by supporting more interagency cooperation and interdisciplinary and cross-ecosystem research to enable the next breakthrough discoveries in microbiome science.

Federal Investments in Support of the National Microbiome Initiative

The NMI will launch with more than **$121 million** of strategic investments from Federal agencies into interdisciplinary, multi-ecosystem microbiome research and tools development. This investment is based on funds appropriated in FY 2016 and proposed in the President's FY 2017 Budget.

- The **DOE Office of Science** proposes $10 million in new funding in FY 2017 to support collaborative, interdisciplinary research on the microbiome. Research will focus on both experimental systems and new computational tools to generate predictive models of microbiomes. Priorities for funding will include partnerships among DOE national labs, academia, and field research facilities (such as those supported by USDA) and projects in mission-relevant environments such as biomass-focused agricultural systems and terrestrial ecosystems vulnerable to climate change.

- The **National Aeronautics and Space Administration (NASA)** proposes $12.5 million in new funding over multiple years to expand microbiome research across

Earth's ecosystems and in space. This includes $2.5 million for the Human Exploration Research Analog (HERA) study, scheduled to begin in January 2017. NASA is also investing $10 million in FY 2016 funding in the Ocean Worlds program, to support development life-detection technologies to search for microbiomes on other planetary bodies in our solar system.

- In addition to its normal review and support of microbiome-related applications, **NIH** will invest an extra $20 million in grants in FY 2016 and FY 2017 with a particular emphasis on multi-ecosystem comparison studies and investigation into design of new tools to explore and understand microbiomes. The microbiome sequence and other genomic data produced in these projects will be deposited in publicly available NIH repositories or other appropriate public repositories.

- In FY 2017, **NIST** is devoting $1 million to improve the reliability and reproducibility of microbiome measurements, and engineer and model microbial ecosystems *in vitro*. This investment will support development of microbiome standards and reference materials, and of *in vitro* tools that allow complex microbial communities to be reproducibly engineered, measured, and modeled. Such resources will facilitate the translation of microbiome discoveries into useful applications in precision medicine, agriculture, and the environment.

- The **NSF Biological Sciences Directorate (BIO)** proposes $16 million in FY 2017 for microbiome research that spans the spectrum of ecosystems, species, and biological scales. This funding will be directed at interactions between microbes in the microbiomes (the inter-microbiome relationships), and also among the microbiomes of biological hosts. These studies will advance discovery of fundamental principles and research tools that transcend habitats.

- The **NSF-NIFA Plant Biotic Interactions Program (PBI)** includes $8.5 million in FY 2017 funding from NSF, and $6 million in FY 2016 funding from NIFA, for a joint agency funding of $14.5 million for proposals reviewed in FY 2016. PBI supports research on processes that mediate beneficial and antagonistic interactions between plants and their viral, bacterial, oomycete, fungal, plant, and invertebrate symbionts, pathogens, and pests. This joint NSF-NIFA program supports projects focused in current and emerging model and non-model systems and agriculturally relevant plants.

- **USDA-ARS** continues to invest substantially in animal, plant, soil, and human microbiome research efforts, with an estimated total investment of $16.9 million by the end of FY 2016. USDA-ARS has proposed over $15.9 million for FY 2017 to expand computational capacities for microbiome research and human microbiome research. This includes the development of SCINet, a new high-speed, high-capacity research network to support computationally intensive analyses of plant, animal,

and soil microbiome DNA sequence data at USDA-ARS. In addition, **ARS** and **DOE** scientists are working together to develop KBase, an open platform for comparative genome analysis-for agriculturally relevant plants and microbes. And on the human side, ARS will use a computer-controlled artificial intestine to study the effects of foods and their isolated constituents on the microbiomes and the metabolites produced by the bacteria.

- **USDA-NIFA** has proposed to invest approximately $8 million in new funding in the FY 2017 budget to support investigations of the microbiomes of plants, livestock animals, fish, soil, air, and water as they influence food production systems. The agency will also support studies on the role of the microbiome in the occurrence and management of antimicrobial resistance from farm to table, and the impact of climate on the microbiomes in agricultural production systems.

- Earlier this year, **USDA-NIFA** and **NSF BIO** established a joint funding opportunity, with $3 million from each agency (for a total of $6 million) to support the development of transformative plant and animal phenomics and microbiome technologies.

- The **Smithsonian Institution** has proposed $300,000 in new funding in FY 2017 to develop a program that will enhance its microbial research on ecosystems across the planet. The program will investigate how microbes shape ecosystem functions, services, and restoration across habitats in the United States and around the world.

New Efforts in Response to the Administration's Call to Action

Earlier this year, the White House Office of Science and Technology Policy (OSTP) issued a national call to action on microbiome science. Stakeholders in all sectors have responded with new commitments—which are being announced today—to develop a comprehensive understanding of microbiomes across all ecosystems. Combined, these efforts include more than **$400 million** in financial and in-kind contributions that support the overarching goals of the NMI of supporting interdisciplinary research; developing platform technologies; and expanding the workforce.

Supporting Interdisciplinary Research

There is no part of the human experience untouched by microorganisms. Microbiome science has the potential to revolutionize healthcare, agriculture, biomanufacturing, environmental management, and even building design and construction. Today, institutions across the country are making commitments to advance interdisciplinary microbiome research through new collaborative research endeavors, new research and

therapeutic centers, grant opportunities that elucidate basic knowledge of microbiomes, and more:

- *The Ann Romney Center for Neurological Disease at Brigham & Women's Hospital will establish a Microbiota-Gut-Brain Center of Excellence*. This multidisciplinary center will provide resources and educational training for conducting studies on the influence of microbiomes on a variety of neurological and related immune diseases—including multiple sclerosis, Alzheimer's disease, brain tumors, amyotrophic lateral sclerosis, and Parkinson's disease—and to develop new therapeutics and diagnostic tools. The center will support more than 25 medical researchers and trainees.

- *The Bill and Melinda Gates Foundation will invest $100 million over the next 4 years in human nutrition and crop protection*. This investment will support clinical studies assessing the effects of the human microbiome on childhood malnutrition and stunting, along with trials aimed at reversing or improving microbiome-mediated gut injury associated with and contributing to malnutrition. These studies aim to translate knowledge generated in animal models about the importance of the microbiome in determining host nutritional and immune status. This investment will also support projects examining how components of the soil microbiome can be used to mitigate critical pests and diseases that affect crops grown in sub-Saharan Africa.

- *Evelo Biosciences is dedicating $1 million to award up to 10 academic research grants for joint studies exploring the human microbiome and cancer*. This new funding opportunity will support collaborative, multidisciplinary approaches aimed at illuminating how the human microbiome influences cancer susceptibility and progression. Evelo will work with researchers to identify and develop novel, microbiome-based cancer therapeutics.

- *The Forsyth Institute will dedicate up to $100,000 per year on an ongoing basis to fund grants for novel microbiome pilot projects*. This multi-year investment will fund exploratory or proof-of-principle studies that test new paradigms and for which few other funding sources are available. The grants will support projects at the Forsyth Institute's newly formed Host Microbiome Center with the potential to move the field of microbiome science forward and to translate microbiome research into new preventative regimens or therapies that improve human health.

- *The Gastrointestinal Research Foundation of Chicago, the Bay and Paul Foundations, and the Helmsley Charitable Trust will invest $1.5 million in gut-microbiome research*. This joint commitment will support a team of interdisciplinary investigators from six institutions to engage in "top-down," patient-centered microbiome research, exploring the role of the gut microbiome in the development of complex immune

disorders such as inflammatory bowel diseases (IBD) and metabolic disease (obesity).

- *The Gordon and Betty Moore Foundation will provide $31 million over the next 4 years to support fundamental ocean-microbiome research*. This investment will help scientists develop a deeper understanding of microbial ecosystems in the sea and their role in supporting the ocean's food webs and biogeochemical cycles. For example, the Moore Foundation will fund a new project with the Station Biologique de Roscoff, the University of British Columbia, and others to support a new universal taxonomic framework, called "UniEuk," for classifying eukaryotic microbes. In addition, a joint venture between the Moore Foundation and the Canadian Institute for Advanced Research will support four competitively sourced workshops that will explore the complexity of microbial life in the oceans and its importance in marine microbial ecology and evolution. These efforts will advance the overarching goal of the Moore Foundation's Marine Microbiology Initiative, which is to understand the scientific principles that govern how microbes interact with one other and that influence how microbial communities transform nutrient pools in the sea.

- *JDRF will invest $10 million over 5 years to support type 1 diabetes (T1D) research*. This year, JDRF will release a T1D Request for Applications to investigate the functional mechanisms underlying changes in the microbiome that lead to T1D susceptibility and/or progression. Better understanding of these mechanisms could enable the development of developing therapies that prevent or delay symptomatic T1D. In late 2016 or early 2017, JDRF will run a trial of a probiotic approach for preventing T1D. The trial may include a prebiotic, synbiotic, or an engineered bacterial product.
- *The Kimberly-Clark Corporation will invest $5 million over 5 years in microbiome research to enhance the health and wellness of people of all ages*. This investment will support fundamental research into the role of the microbiome in women's health as the basis for future applications. Key areas of interest include how the microbiome changes with age and menopausal status and the impact of probiotics on urogenital health. The investment will also support research into the adult skin microbiome and the effect of occlusion (blood-vessel blockage) on this microbiome.

- *Mead Johnson Nutrition (MJN), in partnership with MassGeneral Hospital for Children (MGHfC), will invest an additional $285,000 to further study the microbiome development in infants and children*. This partnership will work to develop a system based on human cells to better understand how dietary factors impact the gut microbiome, fund new educational opportunities at the graduate and post-doctoral level that focus on gut microbiome research, and host a symposium on the gut microbiome at a major pediatric-nutrition conference in 2016. The partnership will also pursue open access publication of documents generated from this research, and MJN will supply in-kind contributions of scientists' time to provide gut-microbiome and

industry career lectures at MGHfC. These new joint activities will advance understanding of the developing microbiome in childhood.

- *The College of Agriculture & Life Sciences at North Carolina State University will host "Stewards of the Future: Microbiomes - The Next Frontier*." This public event, scheduled for October 2016 in Raleigh, NC, is designed to raise awareness and understanding about microbiomes and their importance in agriculture, health, and the environment; to foster interdisciplinary research collaborations; and to inform policymakers and the general public about emerging developments in microbiome science.

- *The University of Chicago is investing $1.3 million to launch The Microbiome Center, in collaboration with the Marine Biological Laboratory (MBL) and the U.S. Department of Energy's Argonne National Laboratory*. This joint effort will support faculty and scientists working across fields of study to understand the identity and function of microbes across ecosystems including the human body, oceans, marine systems, plants, soil, and the built environment. By leveraging world-class expertise and facilities, and expanding research and learning opportunities, scientists will have the opportunity to challenge new frontiers. The Center will support a dynamic research community, enable rapid translation to private and clinical sectors, and train a new generation of scientists able to take on fundamental questions about the microbiome.

- *The University of Texas Medical Branch (UTMB), Texas A&M University (TAMU), and industrial partners are investing $400,000 in studies into controlling industrial and environmental microbiomes.* This new funding from the UTMB at Galveston's Sealy Center for Structural Biology & Molecular Biophysics, TAMU at Galveston's Marine Engineering Department, and industrial sponsors EnhanceCo and Industrial Metagenomics will support studies that use high-throughput sequencing to identify protective or less-damaging microbial compositions in industrial systems. Study findings may lead to novel, environmentally friendly microbiome transplants and other probiotic treatments designed to minimize the negative effects of the microbial presence in industrial systems, including heat exchangers, water-treatment and distribution facilities, and systems used in the petroleum industry.

- *The founding members of the Plant Soil Microbial Community Consortium (PSMCC) will invest $100,000 to study disease resistance conferred by the maize and rice microbiomes*. Three major agriculture companies are announcing their participation in the PSMCC, part of North Carolina State University's Center for Integrated Fungal Research. The industry-supported PSMCC will integrate many different aspects of soil microbiome research—including environmental and climate initiatives, disease, agriculture, evolution, mathematical modeling, genomics and bioinformatics—and will translate knowledge from fundamental research to stakeholders, the general public, and the scientific community.

- *The Simons Foundation Life Sciences Division will invest $6.5 million to support multidisciplinary research in ocean and forest microbiomes*. As part of this investment, the Simons Foundation is announcing an award of $1.5 million to the University of Washington for a multidisciplinary, multi-institutional team to investigate ocean transition zones, where strong biochemical gradients support diverse and productive microbial communities. These gradients provide opportunities to understand ecosystem connectivity as well as the mechanisms that govern microbiome behavior across diverse ecosystems. In addition, the Simons Foundation is announcing a grant of $5 million over 10 years to The Smithsonian Tropical Research Institute to study the role of microbiomes in shaping the ecology and evolution of tropical forest ecosystems. The research will address fundamental questions related to the role of microbes at various scales, ranging from individual plant-microbe interactions and their effects on plant physiology to plant diversity in forests and ecosystem-level processes.

- *UAS Labs LLC is investing $100,000 to advance understanding of interactions among bacteria in probiotics, other commensal bacteria, and the human host*. This investment will support a comprehensive evaluation of the human gut microbiome—a new component in UAS Labs LLC's probiotic studies. This evaluation aims to advance understanding of the microbial community in healthy and unhealthy people in order to link changes in microbiome composition with changes in functional activity and health markers following probiotic intervention.

- *The University of California Center for Pediatric Microbiome Research is announcing a new interdisciplinary microbiome initiative*. Within the next year the Center will launch an initiative across the University of California system to: (1) understand the factors that influence microbiome dynamics and health outcomes in early life; (2) leverage this knowledge to develop preventative therapies; and (3) influence policy to promote development of healthy microbiomes across pediatric populations. This initiative will bring together an interdisciplinary group of clinical and basic science investigators with expertise in pediatric gastroenterology, neurology, metagenomics, metabolomics, immunology, ecology, genomics, bioinformatics, and biostatistics.

- *The University of North Carolina (UNC) Chapel Hill and North Carolina State University (NCSU) are announcing $40,000 for seed grants to foster translational microbiome research*. UNC-Chapel Hill's Center for Gastrointestinal Biology & Disease and NCSU's Comparative Medicine Institute are partnering to fund a series of seed grants designed to foster interdisciplinary collaborations between clinical and non-clinical faculty conducting translational research on human and animal microbiomes.

- *The University of Pittsburgh (PITT) Center for Medicine and the Microbiome will invest $5 million to support a joint venture to enhance basic and clinical microbiome research*. PITT's

Department of Medicine and School of Dental Medicine, the University of Pittsburgh Medical Center (UPMC), UPMC Enterprises, and uBiome are investing $5 million in PITT's newly established Center for Medicine and the Microbiome to foster basic, translational, and clinical research to understand the role of the microbiome in health and disease and to apply this knowledge to develop novel diagnostic and therapeutic strategies. The new investment will also support ventures such as the Pittsburgh Biome Project, which will engage the local community in large-scale microbiome research related to health and disease.

- *USANA Health Sciences will invest $250,000 in research to investigate microbiome markers with health relevance*. Such markers could include the variation of a single bacterial species, a unique combination of different species, or a biological pathway in microbiota. This work could lead to prediction of changes in health status and personalized measures of health maintenance.

- *The Valhalla Charitable Foundation will invest $11.8 million to launch an international study to investigate how the gut microbiome influences multiple sclerosis (MS)*. The International Multiple Sclerosis Microbiome Study (iMSMS) consortium, which examines how the gut microbiome influences MS, is announcing a new international research partnership to study the role of the gut microbiome in MS and pave the way for new therapeutic approaches to control this and other common autoimmune diseases. The study will involve 2,000 patients and investigators in the fields of MS and microbiome research across the United States, Europe, and South America.

Developing Platform Technologies

Platform technologies include tools, techniques, and instruments that enable novel approaches for scientific investigations across a broad range of disciplines. For instance, the advent of high-throughput DNA sequencing revolutionized microbiology in a way not seen since the invention of the microscope by enabling detection and description of thousands of previously unknown species. Now, new platform technologies are needed to enable further breakthroughs in microbiome science—to determine the roles of various microorganisms in microbiomes of interest, understand how microbiomes can be managed, and store and analyze relevant data. Today, institutions across the country are committing to invest in tools, technologies, references, and other resources that will help answer fundamental questions about microbiomes that span ecosystems:

- *Bigelow Laboratory for Ocean Sciences, with support from private donors and state funds, is investing $1 million to support research to improve single-cell genomics (SCG) technology*. SCG enables routine analyses of uncultured microbial groups and provides references for interpreting of integrated microbiome data sets. Bigelow Laboratory's Single Cell Genomic Center is working to develop SCG technologies that improve

genome recovery from individual cells and viral particles and that integrate single-cell genotype and phenotype analyses.

- *C3 Jian (C3J) will invest $75 million over the next 3 to 4 years to develop and commercialize safe and effective pathogen-specific antimicrobials that correct microbial imbalances in many human diseases*. Responding to the national call to action, C3J, a clinical-stage biotechnology company, will advance the basic understanding of gut and oral microbiomes by investing in "Specifically Targeted Antimicrobial Peptides" (STAMPs) technology, a microbiome platform licensed from the University of California, Los Angeles (UCLA). The company is using the innovative platform to conduct research and development into microbial imbalances, known as dysbioses, associated with chronic diseases affecting millions of Americans, including obesity and diabetes. These STAMPs have the potential to reduce, even eliminate, the use of broad-spectrum antibiotics and associated antibiotic resistance, which poses a significant public health threat. The investment also includes C3J's commitment to late-stage clinical development efforts to advance their lead microbiome program towards U.S. FDA approval for the prevention of dental caries (cavities/tooth decay) in children, adolescents, and adults. Dental caries is recognized as the most common chronic childhood disease in the United States, five times more common than asthma, and nearly 100 percent of adults have dental caries worldwide.

- *The California NanoSystems Institute (CNSI) at the University of California, Los Angeles will launch a new Center for Nano-Microbiome Convergence*. This new research facility will feature technical infrastructure for nanofabrication, direct electron detection, and superresolution microscopy, and other tools for observing and manipulating at the nanoscale. By providing seed funding, research space, technology centers, administrative support for team science, and the capabilities of an on-site start-up incubator, the center will empower CNSI's material scientists, physicians, biologists, engineers, chemists, physicists, mathematicians, environmental scientists, and public health experts to develop a new generation of tools and technologies for understanding and engineering the microbiomes that shape life on our planet.

- *The Jackson Laboratory (JAX) will invest $35 million to create an interdisciplinary Center for Microbiome Science*. The Jackson Laboratory for Genomic Medicine (JAX-GM) in Farmington, Connecticut aims to provide improved technologies and methods for deeper, more informative microbial surveys and advanced technologies for mechanistic studies of the microbiome, such as single-cell genomics and the use of mice as sophisticated models for microbiome research. The Center will also advance phenotyping and data-analysis techniques for integrated analysis and study of host-microbe interactions and provide community resources (e.g., databases, strain collections, educational resources) to accelerate microbiome research beyond JAX. The hope is to foster interdisciplinary microbiome science by facilitating research partnerships in non-health areas such as agricultural and environmental

microbiome studies, and by recruiting outstanding computational biologists and computer scientists for algorithm development, coding, and data management.

- *The Kavli Foundation is committing $1 million to an ideation challenge supporting the development of next generation scientific tools for investigating life on a microbial scale*. These funds will enable scientists to advance technologies for imaging, sensing, and manipulating microbes *in situ* and in real time, bolstering the experimental foundation for accelerating discovery in microbiome research. The Kavli Foundation will also support interdisciplinary gatherings that explore the intersection of microbiome research with a wide range of other scientific fields, including neuroscience, astrophysics, engineering, and computation.

- *Lawrence Berkeley National Lab (LBNL) is investing in a "Microbes-to-Biomes" Initiative*. The Initiative will support teams of scientists working collaboratively to develop a new class of approaches to monitor, simulate, and manipulate microbe-through-biome interactions and feedbacks. The initial focus will be on building a mechanistic and predictive understanding of the soil-microbe-plant biome through controlled laboratory "ecosystems," which will be virtually linked with critical ecosystem field observatories. Ultimately, the Initiative aims to bridge the gap from microbe-scale to biome-scale science in order to help predict how ecosystems will respond to global change, and to harness beneficial microbiomes in natural and managed environments for a range of applications, including terrestrial carbon sequestration, sustainable growth of bioenergy and food crops, and environmental remediation.

- *The Mayo Clinic Center for Individualized Medicine will open a new $1.4 million Microbiome Clinic offering new clinical services, diagnostics, and education for patients*. The new clinic will focus on improving patient care through diagnostics, therapeutics, and education based on microbiome science. These diagnostics will include whole-genome sequencing, antibiotic-resistance profiling, metagenomic profiling, targeted environmental testing and 16S rRNA-gene based tests to individualize treatment of undiagnosed infections and conditions, as well as to perform hospital surveillance. Therapeutics will include the Mayo Clinic's established fecal microbiota transplant program, as well as new therapies emerging from clinical trials. Education will focus on helping patients navigate the complex options that promote health and wellness, including diet, nutritional supplements, and probiotic foods.

- *Metabiomics will invest $23.5 million to develop a non-invasive test for earlier and more accurate detection of colon polyps and colorectal cancer (CRC) based on human microbiome biomarkers*. In partnership with gastroenterologists in the Washington, D.C., metro area, as well as George Mason University and the University of Colorado, Metabiomics will develop a technology platform that integrates advances in microbial ecology, next-generation DNA sequencing, and computational systems biology to enable the detection of colon polyps and CRC by sequencing the

microbial DNA in stool samples. The primary goal of the new platform is to help diagnosticians catch colon cancer or polyps early, as the removal of colon polyps can interrupt carcinogenesis and save lives. The new platform will also support a pipeline of molecular diagnostics for Crohn's disease, colitis, irritable bowel syndrome, chronic liver disease, and other gastrointestinal and autoimmune diseases.

- *A new collaboration is launching the Novartis-Foundry Sequence-to-Molecule Pipeline with an investment of $8.1 million over the next 4 years*. The University of California, San Francisco, The Broad Institute, the Massachusetts Institute of Technology, Harvard University, and Novartis have formed a collaboration to build a sequence-to-molecule pipeline to mine microbiome data for pharmaceutical discovery. Leveraging interdisciplinary advances in bioinformatics, synthetic biology, natural products chemistry, and high-throughput discovery assays, the collaboration will work to predict chemical structures of the tens of thousands of molecules that microbiomes have the capacity to produce, determine how these molecules influence physiology and behavior, and translate this work into development to new classes of pharmaceuticals.

- *One Codex is committing to launch a public portal for microbiome data, starting with partnerships with two academic microbiome consortia*. In partnership with the Metagenomics and Metadesign of the Subways and Urban Biomes (MetaSUB) consortium, the Extreme Microbiome Project (XMP), and the Metagenomics Research Group (MGRG) of the Association of Biomolecular Resource Facilities (ABRF), One Codex will provide integrated software for the analysis of genomic sequences from microbiomes. Through this new effort, One Codex hopes to enable microbiologists, clinical researchers, and public-health professionals to incorporate microbiome data into their ongoing and new research programs to improve understanding of complex microbial communities.

- *Replete Biotics, LLC will invest $35,000 to develop a novel medical device to facilitate the standardized collection, processing, and preservation of target microbiome environments*. This device will use a disposable closed system to homogenize feces for improved testing accuracy while protecting the largely anaerobic bacteria in target fecal biomes. The device is anticipated to be useful for sample testing, fecal microbiota banking, and evaluation of microbiota response to select stimuli.

- *The University of California, San Diego and its corporate partners will invest $12 million in The Center for Microbiome Innovation (CMI) to develop new microbiome technologies and tools for end users*. The CMI engages more than 150 faculty researchers from a wide range of disciplines in efforts to create standards for microbiome data (e.g., Microbiome Quality Control and the Genomic Standards Consortium), large-scale, crowdsourced microbiome research projects (e.g., Earth Microbiome Project,

American Gut, Global Natural Products (GNPS)), and to foster collaboration across a network that spans thousands of investigators at other institutions. The CMI also engages corporate partners—including Illumina, GE, J&J, Qiagen, Monsanto, Biota, Sirenas, GALT, and ChuckAlek—and industry associations to help connect microbiome-technology developers and end users in fields ranging from pharmaceuticals to agriculture.

- *The University of Minnesota and the State of Minnesota are committing over $5 million to developing better methods for dissecting microbiomes and applying microbiome knowledge in medicine, industry, and agriculture*. This investment includes substantial seed funding for development of the "Minnesota Microbiome Data Engine," which will enable more precise measurement and analysis of microbiome data. This investment also includes funding to enable application of those methods to study the role of the human microbiome in obesity, diabetes, and infectious disease, as well as in industrial and agricultural applications. The University of Minnesota has also committed to funding development of a new microbiome course for undergraduate and graduate students, in which students analyze their own gut microbiome using deep shotgun metagenomic sequencing.

- *The University of Oklahoma (OU), the National Cancer Institute (NCI), and Leidos will grant open access to data collected by citizen scientists for drug-discovery research*. OU's Citizen Science Soil Collection Program engages the general public in collecting soil samples. Researchers at OU are teaming up with NCI's Natural Products Branch, Developmental Therapeutics Program, Division of Cancer Treatment and Diagnosis to make this data freely available to support drug discovery. Over the next 5 years, OU will make available 20,000 fungal isolates derived from citizen-science-collected soil samples to the NCI to build natural products libraries with the potential to provide scientists with new therapeutic leads against cancer and other human disease targets.

- *Vedanta Biosciences will invest $40 million over the next 2 years in advancing translational microbiome science*. This will include the development and scale-up of technologies for the development of drugs based on live bacteria (live biotherapeutic products, or "LBPs"), including a large collection of commensal bacteria sourced from human donors; *in vitro* and *in vivo* assays to screen bacteria based on pharmacological properties; methods to assemble bacteria in consortia; process development; and manufacturing techniques to produce Good Manufacturing Practices-grade LBPs. Vedanta will also invest in clinical trials of multiple candidate LBPs in several autoimmune diseases, such as colitis and Crohn's, and in infectious diseases.

- *Seven institutions have come together to launch the Microbiome Coalition (TMBC)*. Through TMBC, the founding entities—AO Biome, Abbott Nutrition, CosmosID, Diversigen, the Mayo Clinic, Second Genome, and Whole Biome—aim to promote

greater public understanding of the role of the microbiome in human health and wellness; advance microbiome education, investment and infrastructure; and facilitate collaborative discussions and relationships among the companies, academic laboratories, and government funding, regulatory, and scientific agencies that will play a key role in translating findings in microbiome research to applications in diagnostics, therapeutics, adjunct therapies, and direct-to-consumer products.

Expanding the Microbiome Workforce

The staggering diversity of microbiomes makes it challenging for scientists to describe the range of microbiomes' membership and function. To gather more data than is possible through traditional research projects and make it accessible to researchers, scientists need to develop academic courses and engage a broader community in citizen-science projects to expand the capacity for collecting and studying samples of microbiomes. Today, institutions across the country are making commitments to expand the microbiome workforce through investments in new faculty, fellowship opportunities, educational resources and programs, and opportunities for citizen scientists to participate in microbiome research:

- *The American Gastroenterological Association (AGA) is investing $100,000 to support early-career investigators, and will host its first health-care professionals meeting*. Over the next year, AGA will continue its investment in microbiome research with an emphasis on supporting early-career investigators, and will work with the AGA Center for Gut Microbiome Research and Education to host its first meeting for health-care professionals on practical clinical applications of the microbiome. The AGA Council is also announcing the creation of a new Microbiome & Microbial Diseases in the Gastrointestinal Tract section to enhance connections and collaborations within the community of gastroenterology scientists and physicians interested in the gut microbiome.

- *The American Gut Project (AGP) will expand its partnerships across cities and sectors to improve the understanding of the microbiome*. This expansion includes new partnerships in cities including the San Diego Fermenters Club, the Santa Barbara Earth Day Festival and Fermentation Festival, and the Pittsburgh Fermentation Festival to support "fermentation clubs" that analyze the effects of the consumption of fermented food on the human microbiome; with Northeastern University, to study connections between the gut microbiome and Lyme disease; with the University of San Diego, to study connections between the human microbiome and athletic performance; and with Rady Children's Hospital, to analyze stool microbiomes of 1,000 children from birth to toddlerhood. These partnerships will include metabolomics to provide insight into microbiome function.

- *Arizona State University (ASU) will invest $9 million to launch the Center for Fundamental and Applied Microbiomics (CFAM), and to hire five new faculty*. CFAM will bring together trans-disciplinary expertise in microbiomics at ASU and new recruits within the ASU Biodesign Institute to conduct new research in this area. To launch CFAM, ASU will expand existing faculty membership with five new faculty positions in Microbiology, Engineering, Health Sciences, and Bioinformatics, and endow CFAM with common core facilities, laboratory spaces, equipment, and staff.

- *The Biocollective, LLC, in collaboration with the Health Ministries Network (HMN) will invest in excess of $250,000 to build a microbiome sample bank for whole, preserved, characterized, and divided samples that come directly from donor-members*. The sample bank will use a revenue-sharing model that will bring revenue and research discoveries to the donors. The Biocollective will fund the costs associated with the collection kits, sample and data storage, with a starting target of 1,000 samples; specifically from participants with Sickle Cell (500 having the Sickle Cell Disease, and 500 having Sickle Cell Trait). The Biocollective will also work with the HMN and the Minority Coalition for Precision Medicine (MCPM), both divisions of the Future Marketing Group, LLC (FMG), to expand participation to underrepresented groups with the hope that communities in need will benefit from new discoveries and revenue associated with providing annotated gut microbiome samples to researchers.

- *Boston University (BU) will hire 8 to 10 faculty focused on interdisciplinary microbiome fields, and intends to make 2 new doctoral tracks available to up to 15 PhD students annually*. BU's new microbiome initiative will kick off with a Fall 2016 conference entitled "Microbes at Multiple Scales: From Genes to the Biosphere." The BU initiative will focus on multilevel theory and modeling of microbial systems, environmental and human health impacts, and using synthetic biology and synthetic ecology approaches. The University's new doctoral tracks will produce interdisciplinary microbiome scholars with the ability to combine quantitative ecology, systems biology, bioinformatics, physics, and quantitative biology. BU will also leverage portions of its Center for Integrated Life Sciences & Engineering and the Massachusetts Green High Performance Computing Center for interdisciplinary microbiome research, enabling collaborations on big data and infectious disease topics relevant to microbiome research.

- *Colorado State University will hire three new faculty focused in systems approaches to understanding microbiome-host-environment interactions*. These faculty will advance systems approaches to studying and modeling the capacity of organisms in a microbiome to adapt to changes in the host organism or environment, and the impact of that adaptation on interactions with the host organism or environment.

- *Dannon is partnering with AGA to provide a new $20,000 Gut Microbiome Health Award, and will double fellowship support for microbiome research to $50,000*. Through the new AGA-Dannon Gut Microbiome in Health Award, Dannon will award a research grant to an investigator selected by the AGA who has contributed significant advances in gut microbiome health. The recipient of the award will be announced in fall 2016. Dannon is also creating the Gut Microbiome, Yogurt & Probiotics Dannon Fellowship Grant, which will double Dannon's fellowship support for microbiome research by increasing its investment from one to two grants each year.

- *The University of Hawaii's Pacific Biosciences Research Center (PBRC) will invest $1 million in hiring two new faculty to explore complex microbial ecosystems*. These new faculty will explore microbiomes in extreme environments such as deep-sea hydrothermal vents, and will examine the relationships of viruses to their hosts.

- *The Howard Hughes Medical Institute (HHMI)'s Tangled Bank Studios will release a media project on the microbiome to introduce students to microbiome science*. The project will consist of a publicly accessible film or films and web-based resources, with resources targeted in particular to high school and college classrooms.

- *Indigo V Expeditions will work with citizen scientists to investigate the role of the marine microbiome in plastic cycling*. Indigo V Expeditions will engage its network of citizen oceanographers to collect microplastics from more than 400 ocean stations, and will partner with Oxford Nanopore Technologies to analyze more than 1,200 marine microbiome samples annually. These efforts will advance understanding of marine microbiome productivity, species identification, and roles played in the breakdown of plastic particles. Results will be made available to the public, policy makers, and concerned citizens.

- *The Janssen Human Microbiome Institute (JHMI) is developing a network of entrepreneurs and scientists passionate about accelerating microbiome research*. Over the next year, the JHMI, part of the Janssen Pharmaceutical Companies of Johnson & Johnson, will make strategic investments to build a portfolio of novel microbiome-based therapeutics, diagnostics, and solutions, while at the same time contribute to scientific and policy discussions focused on advancing the field of microbiome science. The JHMI network will connect entrepreneurs and scientists with resources dedicated to microbiome science, and with extensive access to discovery, development, regulatory, and commercial expertise within JHMI and Johnson & Johnson.

- *The Marine Biological Laboratory (MBL) will bring together scientists from across the country to form a new consortium for the comparative study of microbiomes across diverse environments*. Beginning this summer, and through the following year, scientists from multiple fields that intersect in the area of microbiome research will be invited

to become MBL Fellows and engage in collaborative research spanning genomics, microbiology, physiology, neurobiology, and ecology, using reductionist and systems-level approaches in the laboratory and in the field. In addition, expanding programs in the MBL Division of Education will bridge existing summer Discovery Courses to integrate microbiome studies with physiology, embryology, neurology, and parasitology, and will promote development of new courses that span many aspects of microbiome and marine research to train the next generation of microbiome scientists.

- *Oregon State University (OSU) is committing $100,000 to developing a transdisciplinary virtual center for microbiome research and education*. OSU's new Transdisciplinary Initiative for Microbiome Research will be a virtual center for research and education focused on understanding how microbiomes and their environments interact. The Center will bring together researchers from diverse disciplines through workshops and seminars in order to support collaboration on research projects, training and mentorship for junior scientists, increased participation of underrepresented groups in microbiome science, and public outreach and education.

- *The Pennsylvania State University (PSU) is launching a new microbiome research cluster for "Food and Agriculture Microbiomes," and will initially hire three new faculty to explore various ecosystems*. The cluster, which will engage faculty from PSU's College of Agricultural Sciences and Huck Institutes of the Life Sciences, will encourage microbiome research to support development of biological tools for improving human health and enhancing plant and animal health and productivity. In launching the cluster, PSU will hire new faculty for positions in Plant Pathology and Environmental Microbiology (Phytobiomes and Microbial Ecology) and Food Science (Microbial Ecology).

- *The Personal Genetics Education Project (pgEd) at Harvard Medical School will release a series of new educational resources on microorganisms across all environments*. These resources, which will be completed and released by fall 2017, will focus on the microorganisms that inhabit the human body, the soil, the oceans, the Arctic, and other environments, making this rapidly developing area of science accessible to a broad public audience. The resources will be freely available online and will include a lesson plan for teachers, kits for librarians, and web-based resources for the public. The content developed will be integrated into the broader platform of pgEd programs to educate communities through schools, libraries, religious institutions, museums, the entertainment industry, and social media.

- *Rutgers University is committing $3.7 million to future endowed chairs and four new faculty who will enhance research on the human microbiome*. The Rutgers School of Environmental and Biological Sciences and the New Jersey Institute for Food,

Nutrition and Health are committing $3.7 million to recruit leaders in human microbiome research to the endowed positions of the Eveleigh-Fenton Chair in Applied Microbiology and the Henry Rutgers Professorship at Rutgers University. Rutgers will also recruit four junior faculty over this and the next academic year in the area of digestive health.

- *Small World Initiative will expand its education and research program to identify new antibiotics from the soil microbiome to over 150 undergraduate and high school institutions by mid-2017*. Over 5,000 students a year will participate in this authentic research-based course exploring the biological and chemical diversity of soil. Through an investment from the University of Connecticut, this program will be complemented with an interdisciplinary research and education program, led by the Department of Molecular and Cell Biology and the Institute for Systems Genomics, which expands these explorations to new environments, incorporates graduate education, and utilizes several molecular approaches to determine microbiome diversity and function.

- *uBiome is providing a $1 million grant to researchers and citizen scientists for microbiome sampling and related analysis*. The goal of this funding is to fast-track studies with the greatest potential to affect human health and well-being. Grant recipients will have access to their own dashboard and be able to download raw data for analysis and publication.

- *The University of California, Berkeley, through its entrepreneurship and LAUNCH accelerator, will invest $5,000 in a student-run certification project for microbiome-based probiotics*. The project will also feature a publicly accessible educational website, which will distill and translate scientific research on the microbiome into actionable steps for those who need it the most, such as new parents and patients suffering from Celiac disease, Crohn's disease, diabetes, and asthma.

- *The University of Michigan (U of M), with support from HHMI and Proctor & Gamble, is investing $3.5 million in the Michigan Microbiome Project*. This new endeavor will provide a research experience for undergraduate students and drive discoveries of methods to manipulate the structure and function of the human gut microbiome through dietary interventions. Findings from the project will be used in an effort to improve clinical outcomes in U of M's Weight Management Program and the Bone Marrow Transplant Program.

- *The University of North Carolina (UNC)-Chapel Hill is investing $4.9 million to create a new interdisciplinary hub for microbiome research, establish seven new faculty and staff positions, and support a number of new research projects*. UNC-Chapel Hill's new MμNC hub will foster collaboration among the more than 60 UNC-Chapel Hill faculty and staff engaged in plant, human, nutritional, and environmental microbiome and

bioinformatics research. The hub will sponsor on-campus seminars and partner with Research Triangle Park institutions to host intellectual exchange events for microbiome scientists in the area. The hub will also pilot a data-science training program to groom graduating life-science students as graduate scholars who can provide bioinformatics support to UNC-Chapel Hill microbiome researchers. To support the hub, UNC-Chapel Hill will add five new tenure-track faculty positions in various microbiome disciplines, and will hire two bioinformatics engagement officers to supporting UNC-Chapel Hill's microbiome scientists. The establishment of the hub and the seven new faculty positions together represent a $3.4 million commitment. UNC-Chapel Hill is also investing $790,000 in a new computational cluster (LongLeaf) to accommodate the expanded computational and information processing needs of UNC's diverse microbiome disciplines; $743,125 to expand its environmental microbiome lab space, add new equipment, and double the square footage of its existing Microbiome Core Facility; and $50,000 to support a marine microbiome research expedition in the Galapagos Archipelago and investing.

- *With the support of the Alfred P. Sloan Foundation, the University of Oregon (U of O) will invest $75,000 to promote microbiome research, education, and outreach*. This effort will be carried out by the U of O's Biology and Built Environment (BioBE) Center. Research activities will include investigation, hosted by the Santa Fe Institute, into mathematical modeling of microbiomes. Education activities include introducing microbiome-science principles in courses offered by the U of O's Department of Architecture, and in a workshop hosted by the U of O that will connect microbiome scientists with the building industry. Outreach activities include a Microbiome Wikipedia edit-a-thon, the creation of a dust-microbiome animation, co-presenting research with the non-profit Enhabit at the Home Performance Coalition, and contributing to the AIA Design and Health Research Consortium.

- *The Program for Human Microbiome Research at the Medical University of South Carolina (MUSC) is devoting $45,000 annually to build two new microbiome curriculums*. The courses, which will be offered in spring 2017, will engage students in quantitative, biomedical, and dental sciences to advance microbiome science by developing interdisciplinary collaborations across the MUSC campus and regionally.