OSTP Report on the Industries of the Future Act

Introduction

Section 9412 of the National Defense Authorization Act for Fiscal Year 2021, titled "Industries of the Future Act of 2020",[1] directs that the Director of the Office of Science and Technology Policy (OSTP) submit to Congress a report on Federal research and development investments, infrastructure, and workforce development investments that enable continued United States leadership in industries of the future (IoTF).

OSTP delivered to Congress an interim progress report on May 5, 2021.[2] The interim report presented some of the requested baseline funding information under the previous Administration, provided a strategy for delivering a full report, and demonstrated this Administration's commitment to prioritizing investments in key technologies relevant to industries of the future. Following on the interim report, this report includes more complete responses to the six requested report elements specified in the legislation:

- *A definition of the term ''industries of the future'' that includes emerging technologies.*
- *An assessment of the current baseline of investments in civilian research and development investments of the Federal Government in the industries of the future.*
- *A plan to double such baseline investments in artificial intelligence and quantum information science by fiscal year 2022.*
- *A plan to increase investments baseline investments to $10,000,000,000 per year by fiscal year 2025.*
- *A plan to leverage current baseline and future Federal investments to elicit complimentary investments by non-Federal entities, including providing incentives for significant complementary investments by such entities and facilitating Public-Private partnerships.*
- *Proposals for the Federal Government, including any necessary draft legislation, to implement the aforementioned plans.*

Working Definition for "Industries of the Future"

There is no standard definition of "Industries of the Future" for the Federal government, nor for the broader innovation community. To the extent "Industries of the Future" is discussed as a concept, it has been defined most commonly as a list of emerging technologies rather than some *a priori* description of the character of the industries that these technologies enable.

In reviewing recent examples of emerging technologies lists, and lists of Industries of the Future, the types of technologies/industries typically classified as "future industries" include (in alphabetical order):

- advanced computing
- advanced materials, manufacturing, and robotics
- advanced, next-generation communications technologies
- artificial intelligence

[1] https://www.congress.gov/116/bills/hr6395/BILLS-116hr6395enr.pdf
[2] https://www.whitehouse.gov/wp-content/uploads/2022/02/OSTP_Interim_RTC_NDAA_Sec_9412_RD_IOTF.pdf

- battery technology
- biotechnology
- cybersecurity
- green products/clean technology
- plant genetics/agricultural technologies
- privacy-enhancing technologies
- quantum information science/quantum computing
- nanotechnology
- semiconductors/microelectronics technologies

From this list, it is clear that IoTF are not static. They change over time and reflect the potential of the future. They are topics that still have a firm footing in basic research and development (R&D), yet show the potential to create economic value in the years ahead. They are often marked by a revolution in a technology as opposed to a natural evolution. This drastic change means they are accompanied by periods of uncertainty, with the most transformative applications still to be discovered. It is this hope for something new, something not yet realized, that drives excitement in the research, innovation, and policymaking communities. Sustained investments are required until economic drivers are established; this often necessitate public seeding of funds as risk may outweigh near-term gains as a specific industrial sector emerges.

For the purposes of this report, OSTP proposes the following working definition of Industries of the Future:

- Advanced industrial sectors that support innovative, inclusive, equitable, and sustainable growth; have profound connection with technology R&D and STEM[3] workforce; require R&D investments to support growth that will lead to transformative impact; and will significantly benefit future economic prosperity and national security.

This definition can be translated into specific industrial sectors, although the specific sectors will change over time and will also vary based on analysts' judgments of whether specific sectors meet the stated criteria. Based on the definition, this report finds that all of the industrial sectors in the list above have characteristics of Industries of the Future.

Current Investments in Federal R&D Relevant to Industries of the Future

Table 1, below, shows Federal investments in R&D relevant to select Industries of the Future for which crosscutting agency inventories are available. In addition to Federal investments in Artificial Intelligence (AI) and Quantum Information Science (QIS) provided in the May 2021 interim report and now updated, this report provides investments for the Networking and Information Technology R&D (NITRD) program, which in addition to AI also supports R&D investments relevant to several of the IoTF sectors above, particularly: advanced computing; advanced materials, manufacturing, and robotics; advanced, next-generation communications technologies; cybersecurity; privacy-enhancing technologies; and, semiconductors/microelectronics. Table 1 breaks out only AI R&D within the NITRD crosscut because AI was explicitly called out in the legislation and because all the other program component areas are shown in public budget supplements. Table 1 also includes investments for the National Nanotechnology Initiative (NNI) of nanoscale science and engineering R&D, which again supports several

[3] Science, Technology, Engineering, and Mathematics (STEM)

of the IoTF sectors above, particularly: advanced computing; advanced materials, manufacturing, and robotics; advanced, next-generation communications technologies; biotechnology; and, semiconductors/microelectronics, and battery technologies.

Since most of the research activity captured within these interagency crosscuts is basic and applied research, these investments are by their very nature not targeted at specific technological outcomes, let alone specific industries. Also, these crosscuts capture relevant activity without regard for counting an activity more than once between one crosscut and another. For example, a microelectronics research project funded by the National Science Foundation could be fully counted within both NITRD and NNI. The Administration considers the multiple avenues for research outcomes across multiple PCAs and agencies to be a positive aspect of the Nation's federal R&D funding model. Therefore, the total across the inventory in Table 1 includes some overlap between categories.

Because comprehensive inventories of R&D supporting other Industries of the Future are not available, Table 1 likely undercounts the Federal investment in IoTF R&D. As just one example, there is no comprehensive Federal inventory of biotechnology R&D, although the National Institutes of Health (NIH), the Department of Energy (DOE), the National Science Foundation (NSF), the U.S. Department of Agriculture (USDA) and other research-funding agencies invest billions of dollars annually in life and agricultural sciences R&D relevant to supporting industrial sectors in synthetic biology, plant genetics, agricultural technologies, and other biotechnology areas.

Table 1: Federal R&D Investments Supporting Select Industries of the Future
(dollars in millions)

	2019 Actual	**2020 Actual**	**2021 Estimated**	**2022** Budget
Networking and Information Technology R&D (incl. AI R&D)	**6,472**	**7,153**	**7,233**	**7,777**
AI R&D (non-defense)[4]	*1,115*	*1,437*	*1,539*	*1,670*
Quantum Information Science[5]	**449**	**672**	**793**	**877**
National Nanotechnology Initiative	**1,858**	**3,465**	**5,076**	**1,975**
TOTAL	**8,779**	**11,290**	**13,102**	**10,629**

Source: Compiled from annual reporting from the National Quantum Coordination Office, Networking and Information Technology R&D national coordination office, National Artificial Intelligence Initiative Office, and National Nanotechnology Coordination Office.[6] Includes supplemental funding (FY 20 and 21).

[4] AI R&D is a subset of the NITRD total. AI R&D budget figures are from nondefense agencies. Consistent with the NITRD Program Component Area definition of AI, AI R&D budget figures include both core AI investments, as well as AI crosscut funding that reflects use-inspired AI R&D included in other NITRD budget categories. AI R&D budget figures are from nondefense agencies.
[5] These figures include NQI and base funding. "NQI" identifies National Quantum Initiative funding allocated for NQIA (NQI Act)-authorized activities; "base" identifies baseline QIS R&D activities separate from NQI Act activities.
[6] Annual reports from which these data are compiled are located at nitrd.gov, ai.gov, quantum.gov, and nano.gov.gov

Increasing Investments in QIS and Nondefense AI R&D

The total NITRD-AI and QIS investment in the FY 2022 Budget (see Table 1) represents a 63 percent increase over FY 2019 funding, the baseline year used for this report. This substantial requested increase is well above the norm for most R&D investments over this period. Such a qualitatively significant increase is in keeping with the high priority afforded Federal investment in these emerging technologies by the Biden-Harris Administration.

Increasing Investments in IoTF

This report indicates that the Biden-Harris Administration has put forward proposals to dramatically increase Federal investments toward realizing Industries of the Future for the benefit of the American people, especially American workers. Investments to support industries of the future exceed $10 billion annually even from the select investments in Table 1. Through the annual budget and appropriations process, the Administration looks forward to working with Congress, year by year, to build on past investments to secure the investments needed for America to lead the world in the future. OSTP will continue to report on many of these investments in established budget supplements to the FY 2023 and future budgets.

As noted in the interim report, the Biden Administration strongly supports increased funding for emerging technologies toward the Industries of the Future. In March 2022, Congress enacted final FY 2022 appropriations to provide funding for a key Administration proposal to establish a new NSF Directorate for technology, innovation, and partnerships to help translate research into practical applications. The Directorate will work with programs across NSF and with other existing Federal and non-Federal entities to expedite technology development in emerging areas that are crucial for U.S. technological leadership, including in the Industries of the Future of advanced communications, artificial intelligence, biotechnology, cybersecurity, high performance computing, quantum information systems, and robotics.

Leveraging Federal Investments in IoTF

Industries of the Future, as with all industrial sectors, rely on the public and private sectors to translate research findings to commercial products, services, and innovations. It is thus important for Federal investments to work together with complementary non-Federal entities and their investments. The Federal government is utilizing many tools and incentives for complementary investments by non-Federal entities, especially the promotion of public-private partnerships (PPP). This section describes some of these Federal leveraging activities for select IoTF.

Advanced Manufacturing[7]

"Manufacturing USA" is a key Federal initiative that brings together industry, academia and federal partners within a network of advanced manufacturing institutes to increase U.S. manufacturing competitiveness and promote a robust and sustainable national manufacturing R&D infrastructure. These public-private partnerships help to secure U.S. global leadership in advanced manufacturing through large scale collaboration on technology, supply chain, and workforce development. The Federal leads are the U.S. Departments of Commerce (DOC), Defense (DoD), and Energy, and partner agencies include the

[7] For more information, please see the 2021 Manufacturing USA Annual Report available at manufacturing.gov.

National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Departments of Agriculture, Education, Health and Human Services, and Labor.

Among the institutes' members, 62 percent are manufacturing firms and 72 percent of those are small manufacturers – critical components of the U.S. supply chain. Despite pandemic restrictions in FY 2020, more than 70,000 workers, students and educators were trained in advanced manufacturing through workforce efforts of the institutes and their partners. When organizations of all types and sizes work together on manufacturing innovation, it reduces risk, improves business, and ensures that our nation's scientific discoveries are turned into new products right here in the U.S.

Networking and Information Technology

Networking and information technology (IT) are pivotal to leading the world in industries of the future. Many of the sectors listed previously are directly within the networking and IT sector, others rely heavily on networking and IT to benefit our economic prosperity and national security.

The following four examples of current Federal efforts provide the foundational and applications-driven research, investments in Nation's R&D infrastructure, and public-private and international R&D partnerships needed to successfully maintain our leadership in IoTF.

Advanced Computing: Using Cloud Computing to Advance Biomedical Research: STRIDES[8]

With the STRIDES Initiative, NIH and its institutions are accelerating biomedical research by reducing barriers in utilizing commercial cloud services. This initiative harnesses the power of the cloud to accelerate biomedical discovery for NIH and NIH-funded researchers.

The Intersection of Advanced Computing, Artificial Intelligence, and Big Data: Enabling Precision Medicine[9]

The NIH All of Us Research Program is bringing together researchers, health care providers, technology experts, community partners, and the public to develop the basis for individualized health care.

Advanced Computing: Using All Available Resources for COVID-19 Research[10]

High-performance computing resources and funding from federal, academic, and industry sectors provide researchers from across the globe with the necessary computational capacity to help fight the COVID-19 virus.

Large Scale and Wireless Networking: RINGS: Resilient and Intelligent NextG Systems program[11]

The NSF, the DoD Office of the Undersecretary of Defense for Research and Engineering, the National Institute of Standards and Technology, and nine leading companies, are partnering to accelerate research on next-generation networking and computing systems.

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[8] https://cloud.nih.gov/

[9] https://allofus.nih.gov/

[10] https://covid19-hpc-consortium.org/

[11] https://www.whitehouse.gov/ostp/news-updates/2021/04/27/the-biden-administration-invests-in-research-to-develop-advanced-communications-technologies/

Artificial Intelligence

Over the last several decades, concurrent investments across government, universities, and industry have been mutually reinforcing and have led to an innovative, vibrant AI sector. Many of today's AI systems have been enabled by the American government-university-industry R&D ecosystem.

With the 2019 update to the *National AI R&D Strategic Plan*, increased importance is being placed on the benefits of public-private partnerships. These benefits include strategically leveraging resources, including facilities, datasets, and expertise, to advance science and engineering innovations; accelerating the transition of these innovations to practice; and enhancing education and training for next-generation researchers, technicians, and leaders.

Advances in AI R&D that promote Industries of the Future can benefit from public-private partnerships. Partnerships promote open, precompetitive, fundamental AI R&D; enhance access to research resources such as datasets, models, and advanced computational capabilities; and foster researcher exchanges and/or joint appointments between government, universities, and industry to share AI R&D expertise. Partnerships can also promulgate the inherently interdisciplinary nature of AI R&D, which requires convergence between computer and information science, cognitive science and psychology, economics and game theory, engineering and control theory, ethics, linguistics, mathematics and statistics, and philosophy to drive the development and evaluation of future AI-driven Industries of the Future that are fair, transparent, and accountable, as well as safe and secure.

Federal agencies are actively pursuing public-private partnerships to achieve these goals. For example, 18 National AI Research Institutes have been launched across the United States since 2020, all of which include industry partners. Many other agency programs are supporting collaborations between the Federal government and industry to leverage the fast rise of privately funded AI R&D to accelerate innovation in support of IoTF.

Quantum Information Science

The National Quantum Initiative (NQI) Act was established to accelerate quantum research and development for the economic and national security of the United States. The NQI, and subsequent language in National Defense Authorization Acts, provided several mechanisms to achieve this goal.

The Quantum Leap Challenges Institutes (QLCI) program (Solicitation NSF 19-559) supports large-scale interdisciplinary research projects that advance the frontiers of QIS and engineering. QLCI institutes foster multidisciplinary approaches to scientific, technological, educational, and workforce development goals for quantum computation, quantum communication, quantum simulation, and quantum sensing. There are more than 17 universities, 10 companies, 5 National Laboratories, and 1 Federal R&D agency involved in the QLCI.

The National QIS Research Centers fully leverage the DOE facilities across the National laboratory complex, incorporate industry facilities, use international facilities and build new capabilities such as quantum foundries. The aim of the Centers, coupled with DOE's core research portfolio, is to create and to steward the ecosystem needed to foster and facilitate advancement of QIS, with major anticipated national impact on national security, economic competitiveness, and America's continued leadership in science. In addition, each Center seamlessly integrates the science and technology innovation chain to accelerate progress in QIS research and development, to facilitate technology transfer, and to build the

quantum workforce of the future. In total, there are more than 38 universities, 15 companies, 12 National laboratories and 2 federal R&D agencies involved in the National QIS Research Centers.

NIST helped establish the Quantum Economic Development Consortium (QED-C)[12]. The QED-C creates whitepapers on areas where technology advancement would have broad utility. These focus areas can be supported through QED-C funding, individual companies' investment, as well as potential matching funding from federal agencies. The QED-C also provides a venue for industry, academia, and federal partners to discuss topics relevant to growing a thriving quantum ecosystem.

In 2020, the National Science Foundation and the National Quantum Coordination Office launched the Q-12 Education Partnership[13] to bring together industry partners, along with non-profit professional societies and educators to provide accessible quantum education resources, highlight quantum careers, support teacher development, and develop a framework for teaching quantum at the middle school and high school level. The Partnership activities are supported in part by an NSF grant, along with support from its members.

Through open-campus initiatives both the Air Force Research Laboratory (AFRL) and Army Research Laboratory (ARL) leverage public private partnerships to enable research. The AFRL open innovation campus, at the Innovare Advancement Center, specifically includes QIS[14] and has hosted a 1M Quantum Accelerator[15] program. In a similar vein, ARL includes QIS in its Open Campus initiative.[16]

Nanotechnology

A substantial portion of the above NNI investments are either directly or indirectly in support of basic and applied research that will enhance U.S. leadership in industries of the future such as artificial intelligence, quantum information science, and advanced manufacturing (including rapid vaccine development and manufacturing). The NNI brings together representatives from multiple agencies to leverage knowledge and resources and involve academia and the private sector as appropriate to promote technology transfer and facilitate commercialization. Strategic collaborations, including public-private-nonprofit partnerships, strengthen key aspects of the R&D ecosystem that will foster industries of the future. In addition to R&D efforts, the NNI is helping to build the nanotechnology workforce that will be needed in the industries of the future, with efforts aimed across the spectrum from K-12 through postgraduate research training.

The NNI has a long history of leveraging efforts through public-private partnerships, centers, and other mechanisms in areas such as microelectronics[17] and advanced composites.[18] Specific examples of investments by NNI participating agencies in industries of the future that are eliciting complementary investments by non-Federal entities include partnerships by BARDA and NIH with pharmaceutical and

[12] https://quantumconsortium.org/
[13] https://q12education.org
[14] https://www.griffissinstitute.org/who-we-work-with/afrl/open-innovation-campus-slicksheet
[15] https://www.griffissinstitute.org/about-us/gi-news/news-story/innovare-advancement-center-led-by-air-force-research-laboratory-info-launches-1m-international-quantum-u-tech-accelerator/printable
[16] https://www.arl.army.mil/opencampus/network-information-sciences-opportunities
[17] https://www.nano.gov/node/895
[18] https://www.nano.gov/node/1340

biomedical companies that have leveraged decades of Federal R&D in lipid and polymer nanotechnology research and billions of dollars in private investment to deliver the first mRNA COVID vaccines less than a year after the sequencing of the SARS-CoV-2 virus,[19] as well as partnerships with companies under the NIH RADx Initiative[20] that have yielded nanotechnology-enabled rapid diagnostic tests for SARS-CoV-2. Other partnerships include NIH's Dental, Oral and Craniofacial Tissue Regeneration Consortium,[21] which is advancing nanotechnology-based approaches for regeneration and reconstruction of dental and oral tissues, and P^{3}Nano, which involves the Forest Service and a consortium of forest products companies working to develop future high-value-added industries supporting rural communities by exploiting applications of nanocellulose.

Investments by NSF, DOE, and NIST in nanotechnology research infrastructure provide vital resources that academia and industry use to advance industries of the future. NSF's National Nanotechnology Coordinated Infrastructure (NNCI) network, for example, is highly leveraged, collecting nearly $30 million per year in fees from over 10,000 users from academia, industry, and government,[22] compared to NSF's approximately $16 million annual investment.[23]

Biotechnology

Recent investments in biotechnology have facilitated complementary investments by non-Federal entities and have helped support new biotechnology products to enhance our health, secure our supply chain, and address needs of the future. The Bioindustrial Manufacturing and Design Ecosystem (BioMADE), created by the Department of Defense in 2020 with $87 million, is a new Manufacturing Innovation Institute that collaborates with public and private entities to advance sustainable and reliable bioindustrial manufacturing technologies.[24] The federal funding will be combined with $187 million in non-federal cost share from companies, universities, nonprofits, and venture capital groups. Already, complementary investments have been made to sustainably create important chemicals, ensure a resilient supply chain, and support a workforce of the future.

Additionally, the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL) is a public-private partnership funded through a $70 million cooperative agreement with the National Institute of Standards and Technology in 2016 to leverage non-federal investments to accelerate biopharmaceutical innovation.[25] NIIMBL is a Manufacturing Innovation Institute that collaborates with the private sector to apply biotechnology innovations to help produce life-saving drugs and products. Partnership with industry, academia, non-profits, and government agencies helps to accelerate innovation, support manufacturing standards to improve safety and efficiency, and train a biopharmaceutical workforce. In additional to biomanufacturing investments, biotechnology investments in BARDA, NIH, ARPA-E, and DARPA have led to partnerships with biotechnology and pharmaceutical companies that have harnessed private investment to build new medicines, materials, diagnostics, and more.

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[19] https://cen.acs.org/pharmaceuticals/drug-delivery/Without-lipid-shells-mRNA-vaccines/99/i8
[20] https://www.nih.gov/research-training/medical-research-initiatives/radx
[21] https://doctrc.org/
[22] NNCI Coordinating Office Annual Report (Year 5), p. 94: https://nnci.net/nnci-annual-report
[23] https://nnci.net/about-nnci
[24] https://www.biomade.org/
[25] https://niimbl.force.com/s/

Implementation Actions and Proposals

OSTP, in fulfillment of the requirement under paragraph (c) of the legislation, has established under the National Science and Technology Council (NSTC) an Industries of the Future Coordination Council as a working group that will meet periodically to coordinate Federal activities in support of industries of the future. The first activity of the Council was to assist in the preparation of this report to Congress.

The membership will be flexible, to allow for new industries of the future to emerge and other industries to mature.

At its establishment, the Council's membership is:

- policy official from OSTP;
- co-chair of the NSTC Subcommittee on Advanced Manufacturing;
- co-chair of the NSTC Subcommittee on Networking and IT R&D;
- co-chair of the NSTC Select Committee on Artificial Intelligence;
- co-chair of the NSTC Subcommittee on Quantum Information Science;
- co-chair of the NSTC Nanoscale Science, Engineering, and Technology Subcommittee; and,
- co-chair of the NSTC Subcommittee on Bioeconomy;

Federal representatives of new and emerging industries of the future may be added as the Council's work evolves. The individuals serving on the Council may rotate among the co-chairs of the individual NSTC groups. The Council will meet periodically, no less frequently than every three months, to coordinate Federal science and technology actions in support of industries of the future.

OSTP and the Council look forward to working with Congress on the FY 2023 budget and future proposals to implement the vision of a Federal government united in support of R&D and other activities on emerging technologies toward realizing industries of the future for the benefit of the American people, especially American workers.

- April 13, 2022