The Networking & Information Technology R&D Program
and the National Artificial Intelligence Initiative Office

SUPPLEMENT TO THE PRESIDENT'S FY2022 BUDGET

A report by the
SUBCOMMITTEE ON NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT
COMMITTEE ON SCIENCE AND TECHNOLOGY ENTERPRISE
and the
MACHINE LEARNING AND ARTIFICIAL INTELLIGENCE SUBCOMMITTEE
COMMITTEE ON TECHNOLOGY
SELECT COMMITTEE ON ARTIFICIAL INTELLIGENCE
of the
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

December 2021

About the National Science and Technology Council

Established by Executive Order on November 23, 1993, the National Science and Technology Council (NSTC) coordinates science and technology (S&T) policy across the Federal research and development (R&D) agencies. Chaired by the President, the membership of the Cabinet-level National Science and Technology Council includes the Vice President, Director of the Office of Science and Technology Policy, and Cabinet Secretaries and Agency Heads with significant S&T responsibilities. A primary objective of the NSTC is to establish clear national goals for Federal S&T investments in a broad array of areas spanning virtually all the mission areas of the Executive Branch. The NSTC prepares R&D strategies that are coordinated across agencies to ensure that the Federal Government's investment packages and policies are smart and aimed at accomplishing multiple national goals. (https://www.whitehouse.gov/ostp/nstc/)

About the Office of Science and Technology Policy

Congress established the White House Office of Science and Technology Policy (OSTP) in 1976 to advise the President and others within the Executive Office of the President on scientific, engineering, and technological aspects of the economy, national security, homeland security, health, foreign relations, and the environment. OSTP leads efforts across the Federal Government to develop and implement sound science and technology policies, plans, programs, and budgets, and it works with the private and philanthropic sectors; state, local, tribal, and territorial governments; the research and academic communities; and other nations toward this end. OSTP also assists the Office of Management and Budget with its annual review and analysis of Federal R&D in budgets. OSTP's Senate-confirmed Director co-chairs the President's Council of Advisors on Science and Technology and the NSTC. (https://www.whitehouse.gov/ostp/)

About the Select Committee on Artificial Intelligence

The Select Committee on Artificial Intelligence advises and assists the NSTC to improve the overall effectiveness and productivity of Federal R&D efforts related to artificial intelligence (AI) to ensure continued U.S. leadership in this field. It addresses national and international policy matters that cut across agency boundaries, and it provides formal mechanisms for interagency policy coordination and development for Federal AI R&D activities. It also advises the Executive Office of the President on interagency AI R&D priorities; works to create balanced and comprehensive AI R&D programs and partnerships; leverages Federal data and computational resources across department and agency missions; and supports a national technical AI workforce. The National Artificial Intelligence Initiative Office (NAIIO) provides technical and administrative support for the Select Committee on AI.

About the Subcommittee on Machine Learning and Artificial Intelligence

The Machine Learning and Artificial Intelligence (MLAI) Subcommittee monitors the state of the art in machine learning (ML) and AI within the Federal Government, in the private sector, and internationally to watch for the arrival of important technology milestones in the development of AI, to coordinate the use of and foster the sharing of knowledge and best practices about ML and AI by the Federal Government, and to consult in the development of Federal MLAI R&D priorities. The NAIIO and the NITRD National Coordination Office jointly coordinate technical and administrative support for the MLAI Subcommittee.

About the Subcommittee on Networking & Information Technology Research & Development

The Networking and Information Technology Research and Development (NITRD) Program has been the Nation's primary source of federally funded work on pioneering information technologies (IT) in computing, networking, and software since it was first established as the High Performance Computing and Communications program following passage of the High Performance Computing Act of 1991. The NITRD Subcommittee of the NSTC Committee on Science and Technology Enterprise guides the multiagency NITRD Program in its work to provide the R&D foundations for ensuring continued U.S. technological leadership and meeting the Nation's needs for advanced IT. The National Coordination Office (NCO) supports the NITRD Subcommittee and its Interagency Working Groups (IWGs). (https://www.nitrd.gov/about/)

About This Document

This document is a supplement to the President's FY2022 Budget Request to Congress. Following Congressional mandate, the Supplement incorporates budgetary and programmatic information for member agencies of the NITRD Program and also, for the first time, of the National Artificial Intelligence Initiative. This report covers FY2020 actual investments, FY2021 enacted, and FY2022 requested funding levels by agency and Program Component Area (PCA) for all NITRD R&D programs, as well as describing the key R&D programs and coordination activities planned for FY2022 by the Federal agencies participating in NITRD. This Supplement also reports specific agency investments for FYs 2020–2022 for advanced wireless communications and for AI and the National AI Research Institutes. A separate appendix, the *FY2022 Federal Cybersecurity R&D Strategic Plan Implementation Roadmap* lists existing and proposed R&D projects that address critical national cybersecurity needs (https://www.nitrd.gov/pubs/FY2022-Cybersecurity-RD-Roadmap.pdf).

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EXECUTIVE OFFICE OF THE PRESIDENT

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

WASHINGTON, D.C. 20502

December 1, 2021

Members of Congress:

I am pleased to share with you the *Networking & Information Technology R&D Program and National Artificial Intelligence Initiative Office Supplement to the President's FY2022 Budget*, and in a separate appendix, the *FY2022 Federal Cybersecurity R&D Strategic Plan Implementation Roadmap*. The NITRD Program, composed of 25 member agencies and more than 60 participating agencies, coordinates Federal research and development (R&D) investments in advanced digital technologies that are essential to the Nation's economic growth and prosperity. The Supplement and Roadmap support the priorities that President Biden directed the Office of Science and Technology Policy to undertake, which will refresh and reinvigorate our national science and technology strategy and set the Nation on a strong course for the next 75 years.

As the Nation's primary source of federally funded IT R&D, NITRD fosters the transition of artificial intelligence, high-performance computing (HPC), and data science into medical breakthroughs and equitable mitigation of climate change; and enables R&D in advanced networking, cybersecurity, and other IT research innovations that strengthen our national security and protect our economy.

New this year, and in response to the National Artificial Intelligence Initiative Act (NAIIA) of 2020, this Supplement provides the status of R&D investments and activities in support of the NAIIA, including details of the National AI Research Institutes. The National AI Research Institutes, formed among multidimensional partnerships of public and private entities, address sector-specific or cross-cutting challenges (e.g., trustworthiness) and translate the research into products, applications, and services.

This year NITRD marks the 30th anniversary of the signing of the High-Performance Computing Act of 1991. This legislation expanded Federal R&D support for HPC, ensuring continued U.S. technological leadership. President Biden has proclaimed the need to advance American S&T leadership for generations to come; the Nation needs cutting-edge technologies that are made in the United States by U.S. workers and new solutions that will propel market-driven change and jump-start economic growth.

I look forward to continuing to work with you to support the President's priorities, of which these vital Federal programs are an important part.

Sincerely,

Eric S. Lander
Director, Office of Science and Technology Policy

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

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Staff: **Kei Koizumi,** Acting Executive Director, NSTC

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National Artificial Intelligence Initiative Office

Director: **Lynne E. Parker,** OSTP

National Coordination Office for Networking & Information Technology Research & Development

Director: **Kathleen (Kamie) Roberts**

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(Principal representatives are listed first)

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Office of Science and Technology Policy (OSTP)
Lynne E. Parker

OTHER PARTICIPATING DEPARTMENTS AND AGENCIES

These Federal departments and agencies participate in NITRD activities and have mission interests in advanced networking and IT R&D and applications, but they are not members of the NITRD Subcommittee.

Department of Agriculture (USDA)
- Agricultural Research Service (ARS)
- Agriculture and Food Research Initiative (AFRI)
- National Institute of Food and Agriculture (NIFA)

Department of Commerce (DOC)
- International Trade Administration (ITA)
- National Telecommunications and Information Administration (NTIA)
- United States Census Bureau (Census)
- U.S. Patent and Trademark Office (USPTO)

Department of Defense (DOD)
- Defense Health Agency (DHA)
- Defense Research and Engineering Network (DREN)
- Joint Artificial Intelligence Center (JAIC)
- Military Services Facilities:
  - Air Force Office of Scientific Research (AFOSR)
  - Army Research Laboratory (ARL)
  - Combat Capabilities Development Command (Army–CCDC)
  - Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance and Reconnaissance Center (Army–C5ISR)
  - C5ISR Space and Terrestrial Communications Directorate (C5ISR S&TCD)
  - High-Performance Computing Modernization Program (Army–HPCMP)
  - Naval Research Laboratory (NRL)
  - U.S. Army Medical Research and Development Command (USAMRDC)
- Office of the Under Secretary of Defense for Research and Engineering (OUSD R&E)
- Test Resource Management Center (TRMC)
- U.S. Army Corps of Engineers (USACE)
- U.S. Cyber Command (USCYBERCOM)

Department of Energy (DOE)
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- Office of Energy Efficiency and Renewable Energy (EERE)
- Office of Electricity (OE)
- Office of Fossil Energy (FE)
- Office of Nuclear Energy (NE)

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- Administration for Community Living (ACL)
- Centers for Disease Control and Prevention (CDC)
- Centers for Medicare and Medicaid Services (CMS)
- Food and Drug Administration (FDA)
- Health Resources and Services Administration (HRSA)
- Indian Health Service (IHS)

HHS (*continued*)
- National Cancer Institute (NCI)
- National Center for Health Statistics (NCHS)
- Substance Abuse and Mental Health Services Administration (SAMHSA)

Department of Homeland Security
- Cybersecurity and Infrastructure Security Agency (CISA)

Department of Justice (DOJ)
- Drug Enforcement Administration (DEA)
- Federal Bureau of Investigation (FBI)

Department of Labor (DOL)
- Bureau of Labor Statistics (BLS)
- Occupational Safety & Health Administration (OSHA)

Department of Transportation (DOT)
- Federal Aviation Administration (FAA)
- Federal Highway Administration (FHWA)
- Federal Motor Carrier Safety Administration (FMCSA)
- Federal Railroad Administration (FRA)
- Federal Transit Administration (FTA)
- Intelligent Transportation Systems Joint Program Office (ITS JPO)
- Maritime Administration (MARAD)
- National Highway Traffic Safety Administration (NHTSA)
- Pipeline and Hazardous Materials Safety Administration (PHMSA)

Department of the Treasury (Treasury)
- Financial Crimes Enforcement Network (FCEN)

Department of Veterans Affairs (VA)

Environmental Protection Agency (EPA)

Federal Communications Commission (FCC)

Federal Trade Commission (FTC)

General Services Administration (GSA)

Intelligence Community
- Intelligence Advanced Research Projects Activity (IARPA)
- National Maritime Intelligence-Integration Office (NMIO)
- Office of Director of National Intelligence (ODNI)

National Transportation Safety Board (NTSB)

Nuclear Regulatory Commission (NRC)

Social Security Administration (SSA)

Note: Any mention in the text of commercial or academic partners in Federal R&D activities is for information only; it does not imply endorsement or recommendation by any U.S. Government agency.

TABLE OF CONTENTS

1. Introduction

Information technology (IT) and its enabling digital technologies in computing, networking, and software have radically transformed human society across the globe over the 75 years since the end of World War II. American innovators, companies, universities, and government together created a prolific science and technology (S&T) research and development (R&D) ecosystem to lead this global transformation. As competition for leadership in high-performance computing (HPC) began to escalate across the world in the 1980s, U.S. legislators felt the imperative to proactively guide and coordinate Federal R&D for HPC, IT, and networking innovations in order to protect American interests. In the High-Performance Computing Act of 1991, Congress launched what is now called the Networking and Information Technology Research and Development (NITRD) Program; Congress has reauthorized and expanded the NITRD Program three times, most recently in the 2017 American Innovation and Competitiveness Act.[1] NITRD celebrates 30 years of innovation and collaboration in December 2021.

The President's Plan to Reinvigorate U.S. S&T

"…The emergence of the digital arena has redefined the ways we innovate, communicate, and experience the world. And the nature of discovery itself has changed by leaps and bounds… I believe it is essential that we refresh and reinvigorate our national science and technology strategy to set us on a strong course for the next 75 years, so that our children and grandchildren may inhabit a healthier, safer, more just, peaceful, and prosperous world… I am tasking you and your colleagues with [addressing] five questions:

1. What can we learn from the pandemic about what is possible—or what ought to be possible—to address the widest range of needs related to our public health?...

2. How can breakthroughs in science and technology create powerful new solutions to address climate change—propelling market-driven change, jump-starting economic growth, improving health, and growing jobs, especially in communities that have been left behind?...

3. How can the United States ensure that it is the world leader in the technologies and industries of the future that will be critical to our economic prosperity and national security?...

4. How can we guarantee that the fruits of science and technology are fully shared across America and among all Americans?...

5. How can we ensure the long-term health of the science and technology ecosystem of our Nation? …"

—From President Biden's letter to Eric Lander, OSTP Director-Nominee, 15 January 2021

The Senate confirmed Dr. Lander as OSTP Director on 28 May.

The NITRD Program's mandate is to coordinate high-impact Federal R&D that identifies, develops, and transitions into use the secure, advanced capabilities in HPC, IT, networking, and software that the Federal Government needs, and to foster vibrant public–private R&D partnerships so that, working together, American scientists, policies, and facilities can capably provide the world-leading IT technologies on which the Nation depends. The Program also seeks to build, support, and leverage a diverse, highly skilled S&T workforce and international alliances. Representatives of the 25 NITRD member agencies,[2] National Science and Technology Council (NSTC), Office of Management and Budget, and White House Office of Science and Technology Policy (OSTP), comprise the NSTC's NITRD Subcommittee, which oversees the NITRD Program with operational assistance from the Program's National Coordination Office (NCO). The President's Council of Advisors on Science and Technology (PCAST) independently reviews the NITRD Program at least every three years.[3]

This report meets NITRD's obligation to submit to Congress annually a Supplement to the President's Budget in which member agencies describe their R&D budget requests and programs and activities for the coming fiscal

[1] https://www.congress.gov/114/plaws/publ329/PLAW-114publ329.pdf; https://www.nitrd.gov/legislation/

[2] See p. ii for a list of current NITRD member agencies.

[3] PCAST's most recent review was in 2020; see https://www.nitrd.gov/pubs/PCAST-NITRD-Report-2021.pdf and p. 12.

year in HPC, IT, and networking. The report also addresses how the NITRD Program and its members plan to support the S&T priorities of the President and OSTP (*see sidebar on page 1*).

Following enactment of the National Artificial Intelligence Initiative Act (NAIIA) of 2020[4] and establishment of the National Artificial Intelligence Initiative Office (NAIIO), this Supplement also meets NAIIO's obligation to submit NAIIA-related budget and program information to Congress as part of the President's annual budget request. Inclusion of National Artificial Intelligence Initiative information in the NITRD Budget Supplement is due to close interweaving of NAIIO and NITRD AI R&D activities. As specified in the Act, the tables in Section 2 include a summarized budget in support of the AI Initiative for the preceding, current, and proposed fiscal years, and a disaggregation of spending for the National AI Research Institutes. Section 5 describes the Institutes in more detail.

NITRD Responses to the Administration's Five Overarching S&T Questions

Many NITRD programs already mesh closely with the thrust of the President's five questions to Dr. Lander as summarized in the sidebar on page 1.[5] In addition, the NITRD Subcommittee and member agencies will expand existing and establish new R&D efforts to address the President's questions. The subsections below summarize some of the key issues and existing NITRD-coordinated R&D efforts that are relevant to the questions' focus areas and/or issues that will need to be addressed in future NITRD budgets and programs.

1. NITRD Coordination of R&D to Address Public Health Needs Now and in the Future

Thirty years of NITRD-coordinated Federal investments in computing, IT, and networking underpinned the 2020–2021 national S&T response to the COVID-19 pandemic. These facilitated rapid vaccine development by several firms and an ongoing search for therapeutics, cures, and fuller understanding of virus mechanics. Historical NITRD-related investments helped many in the Nation to stay connected and continue work, education, medical consults, shopping, etc., while sequestered. NITRD-agency-developed resources—such as supercomputing facilities; modeling and simulation software; and artificial intelligence (AI) and machine-learning (ML) capabilities—helped researchers parse mountains of data to hone in on the best test collections and research paths; helped labs, families, schools, and businesses keep connected via high-speed networks; and helped leverage active government partnerships with academia and industry. As examples, the COVID-19 HPC Consortium brought DOE National Labs, NSF, and NASA together with industry and academic leaders to provide access to the world's most powerful HPC resources in support of COVID-19 research,[6] and agency-supported collaborative research demonstrated the power of HPC to accelerate discovery in the fight against the pandemic in the study, "AI-Driven Multiscale Simulations Illuminate Mechanisms of SARS-CoV-2 Spike Dynamics".[7] Also, modeling, simulation, and predictive analytics helped essential workers, including health workers, by illuminating mechanisms of disease spread, effective protection, stockpiling of critical equipment, supply chain bottlenecks, and the like. NITRD agency R&D continues to develop solutions for public health (*e.g., see sidebar on page 3*) that can be refined and redirected for any national health emergency as required.

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[4] Division E of the National Defense Authorization Act for Fiscal Year 2021, P.L. 116-283 (H.R. 6395), January 1, 2021; https://www.congress.gov/116/crpt/hrpt617/CRPT-116hrpt617.pdf#page=1210

[5] https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/20/a-letter-to-dr-eric-s-lander-the-presidents-science-advisor-and-nominee-as-director-of-the-office-of-science-and-technology-policy/

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

[7] L. Casalino, A. C. Commer, Z Gaieb, *et al*. 2021. *International Journal of High Performance Computing Applications.* https://doi.org/10.1177/10943420211006452.

Learning from COVID-19: Disease Prediction, Prevention, and Communication

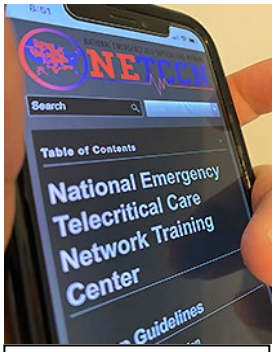
Prediction, Diagnosis, and Prevention of Infectious Disease

The potential exists to move toward a world free from the threat of global pandemics through developing predictive intelligence about future outbreaks via an integrated system of rapid detection, analysis, modeling, and countermeasures. Several Federal agencies are working to improve disease prediction by integrating biological and technical innovations in diagnostics, sensing, modeling, analytics, and human behavior modeling.

To leverage what researchers have learned from the COVID-19 pandemic, NSF has supported a series of interdisciplinary workshops to engage and then provide grants to broad and diverse research communities around Predictive Intelligence for Pandemic Prevention (PIPP). The workshops assembled experts in the biological, engineering, computer and information, and social, behavioral, and economic sciences to catalyze their knowledge regarding forecasting, real-time monitoring, and detection of inflection-point events. The workshops focused on integrating fundamental science and engineering advances such as synergistic biological interactions spanning molecular, organismal, and epidemiological scales; multiscale smart biosensing and data collection technologies; networked sensors; *in situ* computation; computational algorithms and frameworks for intelligent processing, analyzing, and modeling of data; and understanding disease transmission due to human social behavior and attitudes and the drivers of both. See https://www.nsf.gov/events/event_summ.jsp?cntn_id=302023&org=CISE and https://beta.nsf.gov/funding/opportunities/predictive-intelligence-pandemic-prevention-phase-i-development-grants-pipp.

NIH launched its Rapid Acceleration of Diagnostics (RADx℠) initiative in April 2020 to address the urgent public health need for fast, effective diagnostic testing to help stem the spread of COVID-19. RADx calls on scientists and engineers to find innovative ways to speed development, validation, and implementation of rapid, accurate, accessible nationwide COVID-19 testing, with a goal to make millions of tests available each week. It aims to develop a platform that integrates data on individuals and diverse populations from a variety of sources, including test results, self-reported symptoms, and electronic medical record data. Federal agencies partnering with NIH include the Office of the Assistant Secretary of Health, the Biomedical Advanced Research and Development Authority, CDC, DOD, and FDA. RADx components have the following goals: (1) *RADx-TECH:* quickly identify, validate, and scale up production of new technologies for point-of-care and laboratory COVID-19 testing; (2) *RADx-ATP:* identify existing and late-stage testing technologies ready to be scaled up to increase their geographic reach; (3) *RADx-RAD:* support R&D for innovative approaches and new applications of existing approaches to address gaps in COVID-19 testing; (4) *RADx-UP:* engage with and expand COVID-19 testing for underserved and vulnerable communities; and (5) *RADx-Data Hub:* coordinate COVID-19 data management needs. See https://www.nih.gov/research-training/medical-research-initiatives/radx.

Point-to-Point Communication for Noncentralized Clinical Management of Infectious Disease



The NETCCN app provides ability to surge "anywhere-to-anywhere" caregiving in cases of remote or widespread health crises.

In December 2020.The U.S. Army Medical Research and Development Command (USAMRDC) Telemedicine and Advanced Technology Research Center (TATRC) launched its next-generation National Emergency Tele-Critical Care Network, NETCCN. It is a cloud-based health information management system that can create "virtual critical care wards" via smartphones. TATRC developed and tested NETCCN in geographically disperse areas in an accelerated technology push over just a few months. Its goal is to significantly broaden availability of noncentralized clinical care during large-scale health emergencies via *point-to-point*—not hub-and-spoke—live video and asynchronous messaging capabilities that let clinicians exchange information with and provide care to patients virtually. The trials involved care management of some 100 patients by over 200 clinicians and helpers in COVID-19 hot spots in South Dakota, Minnesota, Puerto Rico, and other locations. The NETCCN smartphone app successfully supported patients in their own homes and reduced burdens on hospitals as well as disease exposures for clinicians and patients and their families. This technology promises to have great value within the total fabric of civilian and military healthcare during a disaster. See https://mrdc.amedd.army.mil/index.cfm/media/articles/2020/TATRCs_NETCCN_project_visionary_work.

Still, the experience of the pandemic revealed significant gaps in knowledge, capability, and policy impacting public health that the Nation must address going forward. These include the high costs and low availability of broadband, computing, and health resources in some communities; inadequate communications systems among national, state, regional, and local governments; and needs for greater collaboration in nonclinical technical research (e.g., on rapid testing or physiological monitoring systems) and in sociological research (e.g., on virus-related stress or educational equity). Importantly, the gaps include inadequacies in how the Nation addresses health (including mental health) and related challenges equitably under normal as well as emergency conditions. Solutions include growing partnerships with businesses of all sizes and in all kinds of communities to develop and deploy the innovative health technologies, products, processes, and services that they need.

NITRD Interagency Working Groups (IWGs) with R&D programs relevant to this topic: The AI R&D IWG (*pp. 23–26*); Big Data IWG (*pp. 50–51*); Broadband R&D Team (part of the Large-Scale Networking IWG) (*p. 54*); Computing-Enabled Networked Physical Systems IWG (*pp. 29–31*); Cyber Security and Information Assurance IWG (*pp. 32–34*); High-End Computing IWG, with its focuses on both enabling R&D for high capability computing systems and high-capability computing infrastructure and applications (*pp. 42–43 and 44–46*); Health IT R&D IWG (*pp. 59–60*); Large-Scale Networking IWG (*pp. 52–54)*; Privacy R&D IWG (*pp. 35–36*); and Wireless Spectrum R&D IWG (*pp. 54–56*).

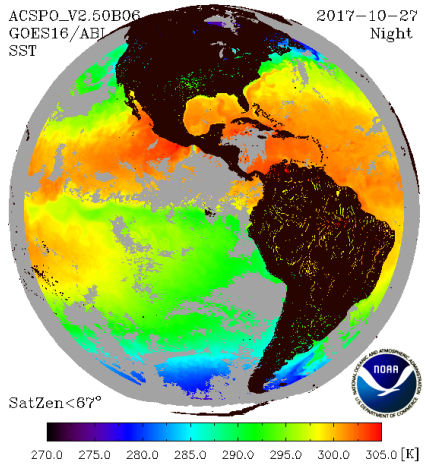
2. NITRD Coordination of R&D Solutions to Equitably Address Climate Change

Several NITRD member or participating agencies, such as the Departments of Defense and Energy, Environmental Protection Agency, National Oceanic and Atmospheric Administration, and National Science Foundation, already have research programs underway or on the drawing boards to prioritize R&D needs for alternatives to current U.S. energy use and greenhouse gas emissions patterns and to assess their impact on the Nation's and the world's climate (*e.g., see sidebar on page 5*). These have downstream consequences for national security, food security, economic security, and societal equity and wellbeing. As with R&D coordination to understand and address the pandemic, R&D coordination to address understanding, mitigating, and reversing climate change will need to be a whole-of-Nation undertaking, and leadership and engagement from the Federal Government will be critical.

The government's efforts will benefit greatly from NITRD's experience and partnerships in IT-related R&D coordination in areas relevant to addressing climate change—especially given the short time horizons for making a positive impact before climate change becomes significantly harder to address. For example, the Nation's depth of expertise in supercomputing and AI/ML, communications, cybersecurity and software, and data analysis (including for environmental sensors) has long been supported by NITRD R&D coordination efforts. These investments will be essential for modeling and analysis of relevant information on the status of polar ice; the health of the world's complex biomes; improved understanding of soil, ocean, and atmospheric conditions; changes in drought and fire and storm patterns; and many other climate indicators and remediations. NITRD capabilities for R&D coordination and collaboration will be valuable in supporting changes in policy and practice to rapidly improve the near- and long-term ability of the planet and its inhabitants to thrive. NITRD and NAIIO also are helping to coordinate agency investments in the National AI Research Institutes that will address many aspects of climate change using AI (see Sections 2 and 5).

Pioneering NITRD Agency Tools to Envisage and Mitigate Climate Change

NITRD members of the AI, HEC, and other IWGs are already applying HPC, AI/ML, and other advanced IT tools to enable breakthrough innovations in the Nation's quest to envisage and mitigate climate change.



GOES-16 nighttime Sea Surface Temperature (SST) composite generated from Advanced Baseline Imager (ABI) data on 2017/10/27. https://star.nesdis.noaa.gov/goesr/product_sst.

NASA (e.g., Center for Climate Simulation[a]) and NOAA (e.g., Center for Satellite Applications and Research[b]), utilize the **Geostationary Operational Environmental Satellite-R series**,[c] among other resources, to provide agency scientists and agency-sponsored academic, industry, and public labs and enterprises an impressively diverse set of integrated HPC, data analysis, and visualization capabilities aimed at improving data accessibility for Earth science research and direct use by both Federal and non-governmental scientists. Such capabilities provide continuous real-time transmission, acquisition, and transformation of satellite data to large-scale observation, modeling, analysis, and high-resolution visualization of data in 2D (e.g., see figure at left), 3D, and video form. Applications include disaster prediction and response (for droughts, hurricanes, fires, etc.); weather and climate forecasting; fisheries, agriculture, and ecosystem monitoring; military and defense planning; economic prediction, e.g., regarding power or tourism needs; and public data- and information-sharing and policymaking. The Air Force–NASA–Navy–NOAA Joint Center for Satellite Data Assimilation recently demonstrated software "supercontainers"[d] for its next-generation system Joint Effort for Data assimilation Integration (JEDI). They are usable on computing systems ranging from laptops to supercomputers to help democratize use of sophisticated satellite data in community-based open science projects. USGS's Landsat also shares its Earth observation data publicly to support local decision-making for natural resources and the environment.[e]

DOE's **National Renewable Energy Laboratory** (NREL) High-Performance Computing User Facility[f] provides HPC capabilities to scientists and engineers working to solve complex computational and data analysis problems related to energy efficiency and cost reductions for renewable energy technologies, including wind and solar energy, energy storage, and large-scale integration of renewables into the electric grid. Eagle is DOE/NREL's latest high-performance computing system dedicated to advancing renewable energy and energy efficiency technologies. DOE/NREL engages with industry and consumers in three key energy R&D and innovation areas:

1. *Integrated energy path*ways to broaden the selection of energy generation types, renewables, storage modes, smart loads, devices, and expanded transportation electrification, all needing to work together, e.g., via AI/ML-managed higher and more complex electricity loads in new, more resilient energy grids.
2. *Electrons to molecules* to support transformation of manufacturing to produce chemicals, fuels, and other products via innovations in biocatalysis, electrocatalysis, and renewable electricity that reduce fossil fuel reliance in production of chemicals, fuels, materials, and energy storage, and drive CO_2 capture/conversion.
3. *Circular economy for energy materials* to reduce wastes in landfills and oceans and preserve resources by designing new energy systems that use sustainable materials that can be reused, recycled, and upcycled within the energy systems, including by designing enzymes that will break down discarded plastics.

DOE/NREL is also working on applying HPC simulation and modeling, data science, and advanced analytics aided by AI/ML to understand when and how buildings[g] use energy and how they interact with the electric grid as a system to predict how to cost-effectively achieve building-related energy efficiency on a large scale.

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[a] https://www.nccs.nasa.gov/; [b] https://www.star.nesdis.noaa.gov/star/aboutSTAR.php; [c] https://www.goes-r.gov/;
[d] https://www.nccs.nasa.gov/news-events/nccs-highlights/Supercontainers;
[e] https://usgs.gov/core-science-systems/nli/landsat; [f] https://nrel.gov/computational-science/hpc-user-facility.html;
[g] Residential and commercial buildings, including their embodied carbon, contribute by some estimates as much as 40% of U.S. CO_2 usage and emissions.

NITRD IWGs with R&D programs relevant to this topic: AI R&D IWG (*pp. 23–26*); Big Data IWG (*pp. 50–51*); Computing-Enabled Networked Physical Systems IWG (*pp. 29–31*); Cyber Security and Information Assurance IWG (*pp. 32–34*); High End Computing IWG, with focuses on enabling R&D for high capability computing systems and on high-capability computing infrastructure and applications (*pp. 42–43 and 44–46*); Large-Scale Networking IWG (*pp. 52–54)*; Privacy R&D IWG *(pp. 35–36*); and Wireless Spectrum R&D IWG (*pp. 54–56*).

3. NITRD Coordination of R&D for World-leading Technologies and Industries of the Future

The President and Congress have recognized the pivotal value to the Nation of leading the world in innovative technologies and applications that will power the industries of the future (IotF). Currently, these include AI, quantum information science (QIS), advanced wireless networks (including fifth-generation networking [5G] and beyond), advanced manufacturing, and biotechnology. To varying degrees, all of these, along with vigorous national and international information-sharing and coordination activities, already have proven invaluable in addressing aspects of the COVID-19 pandemic, including the highly specialized, high-speed manufacturing of vaccines with digital process and quality controls at every stage. Likewise, IotF R&D investments will prove invaluable in tackling climate change, as indicated above. In the broadest sense, American IotF capabilities will be essential to support the future vitality of the Nation in terms of its economic competitiveness vis-à-vis the rest of the world and its ability to protect and defend its borders and vital infrastructure. Just as critically, IotF R&D investments will support the Nation's ability to securely and equitably provide its people with robust Internet-based access to government office-holders and public services; to advanced remote healthcare, education, data-sharing, and research capabilities; and to secure cutting-edge communications for business and personal needs. Modern communication devices, systems, and networks are expected to support a broad range of critical and essential services, which in turn makes resiliency an increasingly important feature in the research, design, and operations of next-generation (NextG) sensing, communications, networking, and computing networks and systems. Innovations along such lines of inquiry require ongoing government leadership and funding; partnerships that multiply available intellectual talent and investment dollars; and coordination mechanisms that help maximize the effectiveness of R&D and minimize duplication of research programs.

NITRD IWGs with R&D programs relevant to this topic: The AI R&D IWG (*pp. 23–26*); Big Data IWG (*pp. 50–51*); Computing-Enabled Networked Physical Systems IWG (*pp. 29–31*); Cyber Security and Information Assurance IWG (*pp. 32–34*); both High End Computing IWGs (*pp. 42-43 and 44–46*); Intelligent Robotics and Autonomous Systems IWG (*pp. 47–49*); Large-Scale Networking IWG (*pp. 52–54)*; Privacy R&D IWG (*pp. 35–36*); and Wireless Spectrum R&D IWG (*pp. 54–56*).

4. NITRD Support for All Americans Sharing in S&T Creation and Rewards

NITRD's Education and Workforce Development (EdW) Program Component Area (PCA) captures Federal agency investments in IT-related science, technology, engineering, and mathematics (STEM) education programs, internships, job training, and recruitment. All NITRD member agencies and IWGs depend on and support activities of the EdW PCA. EdW strategic priorities call for increasing, broadening, and diversifying the STEM education and workforce pipeline. However, given the complexity and urgency of the national mandate for S&T to address today's health, climate, economic, national security, and equity needs, the NITRD agencies also are gearing up to actively focus on expanding racial, ethnic, gender, cultural, ability, economic, and geographic diversity within STEM and IT education opportunities, mentorships, and hiring.

The near-term goal is to integrate into schools, laboratories, factories, and society a larger and more diverse cadre of capable scientists, engineers, and high-tech workers and consumers. Such efforts should help extend the rewards of S&T innovation more equitably into communities across America. Other initiatives taking shape within the NITRD IWGs will help to address diversity, equity, and justice issues in IT research and deployment: Work by the LSN Broadband team aims to make high-speed Internet and linked business, healthcare, education, and civic opportunities more readily available in underserved areas of the country; more data and improved computer modeling will identify areas bypassed by STEM-Ed (and other) programs; software developers aim to improve fairness in a host of AI/ML algorithms, e.g., for image processing; cybersecurity and privacy R&D will help boost confidence in and application of IT solutions; and a rising Federal commitment to support wider geographic location of S&T and AI innovation hubs[8] will help grow the incomes of more communities and families and broaden the inputs into S&T decision making.

NITRD IWGs with R&D programs relevant to this topic: The AI R&D IWG (*pp. 23–26*); Big Data IWG *pp. 50–51*); Broadband R&D Team (*p. 54*); Cyber Security and Information Assurance IWG (*pp. 32–34*); both High End Computing IWGs (*pp. 42–43 and 44–46*); Large-Scale Networking IWG (*pp. 52–54)*; Privacy R&D IWG *pp. 35–36*); Software Productivity, Sustainability, and Quality IWG (*pp. 57–58*); and Wireless Spectrum R&D IWG (*pp. 54–56*).

5. NITRD Support for the Long-term Health of the U.S. S&T R&D Ecosystem

As the President's letter to Dr. Lander underscored, global U.S. leadership in science and technology has relied for decades on a rich ecosystem of people, policies, and institutions. Revitalizing and safeguarding the long-term health of this ecosystem in a rapidly changing, highly competitive world is of utmost importance to the country's future. It will require integrating S&T knowledge-building, policymaking, and infrastructure development measures. It will require addressing scientific, technical, security, and economic issues along with education, equity, and transparency considerations. It will take a unified effort to institutionalize integrity and renewal within the Nation's entire S&T ecosystem, beginning with wide-ranging dialog among all members of the experimental and computational science communities and the public. Creative, pooled funding models for infrastructure building and maintenance, and innovative, inclusive models for education and career development will be needed. Also needed will be voluntary, consensus-based S&T standards, active sharing of resources and tools, and continuing cross-sector relationship-building to foster trust and spark innovation. The Federal Government's leadership and resources will indeed continue to be vital to the long-term vision and vigor of the U.S. S&T ecosystem, but government partnerships with the private sector and across the full range of U.S. communities must be a consistent and dynamic part of the ecosystem. NITRD has a 30-year history of accomplishment in promoting dialog and collaboration among various S&T R&D stakeholders. All of the NITRD IWGs will have unique parts to play in advancing the critical R&D themes of the Nation's S&T ecosystem discussions and activities going forward.

The sidebar on page 8 briefly describes an ambitious concept, "Digital Twin Earth" (DTE), that relies on HPC; AI; masses of observational data; robust cybersecurity, privacy protection, and open-source software; and effective data sharing and visualization to address aspects of all five of the questions President Biden posed to OSTP Director-nominee Eric Lander prior to his Senate confirmation. DTE is a concept that not only U.S. scientists but researchers in other nations are working on enthusiastically; the prospects are great for this kind of complex digital model of the Earth and Earth systems being an invaluable problem-solving tool.

[8] As an example, see https://www.nsf.gov/news/news_summ.jsp?cntn_id=303176.

"Digital Twin Earth": Using the Convergence of Cutting-Edge HPC and IT to Build a Better Future

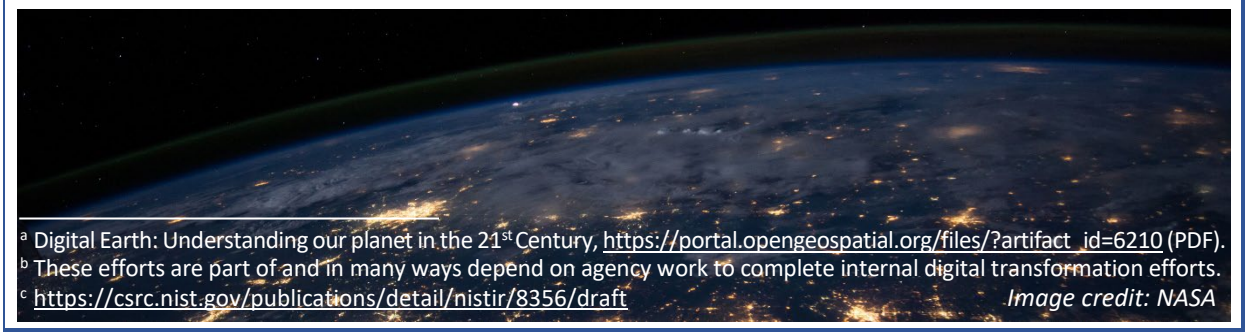
In a 1998 speech, Vice President Al Gore called for a grassroots, multistakeholder effort to build a "Digital Earth," a "multiresolution, three-dimensional representation of the planet into which we can embed vast quantities of geo-referenced data"[a]—and to be able to work with that data. Gore lamented that the (then) 20 years of raw image data of Earth stored by the USGS Landsat satellite was largely unused due to the limited means to display and interact with it. Today, scientists have hugely more powerful computers and digital tools to combine and derive decision support from the myriad data collected by systems across (and above) the globe. The Digital Earth vision that Gore described is becoming a reality due to recent advances in IT capabilities. These include computing capacity and speed, AI and ML, modeling and simulation, imaging and visualization, data collection and privacy protection, data storage and analysis modalities, systems interoperability and metadata standards, and broadband networking and cybersecurity.

The possible uses for a Digital Earth capability are countless, and many align with Administration priorities. They span high-resolution weather, climate change, and climate event modeling; biodiversity preservation; balanced management of oceans, fisheries, and watersheds; control of vector-borne diseases; virtual diplomacy (i.e., border issues); redeployment of military and first responders to areas of greatest need in a crisis; and more. Along with amassing the needed data, the emerging and converging technologies noted above will be essential to enabling and sharing the extremely high-resolution modeling that will allow for realizable solutions to acute Earth-relevant problems.

Today, Gore's vision is called "Digital Twin Earth" (DTE) after the term "digital twin" became widely used in the early 2000s by manufacturing, healthcare, and aerospace engineers. Some aspects of the DTE idea have been realized in virtual-globe browsers, but the vision has not been achieved of a collaborative, fully global linking of systems of digital systems for Earth science and geography-based decision-making. NITRD member agencies (e.g., NASA, NIH, NIST, NOAA, and USGS), are expanding their efforts to build and publicly share components of the DTE knowledge base, and to build in standards for security, interoperability, and trust in their widespread collaborative use.[b] NIST has released for public comment a set of considerations for standards for digital twin technologies.[c] Public "geo-referenced data" from Federal agencies include earthdata.nasa.gov/, svs.gsfc.nasa.gov/, www.nasa.gov/feature/, hdpulse.nimhd.nih.gov/data/, wwwn.cdc.gov/arbonet/maps/ADB_Diseases_Map/, gis.ncdc.noaa.gov/maps/ncei/, www.climate.gov/maps-data, and www.usgs.gov/products/data-and-tools/data-and-tools-topics, among many others.

U.S. industry, academia, and international partners and competitors all are pursuing construction of their own DTE systems at an ever-increasing pace—for both competitive and practical reasons. DTE offers unprecedented capabilities for visualizing, testing solutions to, and ultimately solving complex problems as part of humankind's path to building a better future.

Although composing a Digital Twin Earth is a big thrust of many ongoing Federal research efforts, digital twins may also be conceived of the human body for purposes of personalizing medical treatment or of business or manufacturing practices for purposes of process optimization. In many ways, the digital twin concept is one of the most developed and practical examples today of the convergence of leading-edge IT technologies. The potential applications and benefits are immeasurable.



[a] Digital Earth: Understanding our planet in the 21st Century, https://portal.opengeospatial.org/files/?artifact_id=6210 (PDF).
[b] These efforts are part of and in many ways depend on agency work to complete internal digital transformation efforts.
[c] https://csrc.nist.gov/publications/detail/nistir/8356/draft

Image credit: NASA

The Crosscutting Value to IT R&D of the Administration's Focus on Inclusion

In his June 2, 2021, letter to the Nation upon beginning his tenure as Director of the Office of Science and Technology Policy, Eric Lander stressed the following:[9]

> *...America's future depends on science and technology like never before... To succeed, America will need to draw on all of its assets—chief among them, our unrivaled diversity. After all, scientific progress is about someone seeing questions or answers that no one has seen before—because they bring a different lens, different experiences, different questions, different passions.*
>
> *Yet, science and technology have too often been unwelcoming or inaccessible to many Americans, due to their gender, race, resources, or geography. We must ensure that all Americans can participate fully, including having a voice in shaping our nation's priorities. And, we must ensure that all Americans share equally in the benefits of science and technology.*

It is evident today that Federal IT R&D efforts must expand to involve and benefit once-overlooked sectors and communities. R&D to develop and deploy the groundbreaking IT systems of the future will depend on vigorously cultivating large numbers of researchers and engineers and a tech-savvy citizenry and workforce; excluding people is not an option. As the continuing 2020-2021 coronavirus pandemic has confirmed, innovative S&T developed over decades can greatly help the Nation tackle unexpected crises as well as everyday needs; however, it also showed that the Nation cannot afford—for political, economic, and ethical reasons—to leave any group behind. Federally supported R&D has steadily democratized computing, IT, and advanced wireless communications. Now these technology efforts need to be thoughtfully integrated across the Nation. As the U.S. S&T community seeks "solutions that ease everyday burdens for the American people and spark new jobs and opportunities,"[10] NITRD's record on coordinating HPC and IT R&D of benefit to the Nation is a solid foundation on which to build greater inclusion into IT R&D practices.

NITRD Budget Reporting, Organizational Structures, and Activities

NITRD Program Component Areas

NITRD's annual budget reporting (*see Section 2*) is organized by Program Component Area and agency to facilitate year-to-year budgetary and programmatic comparisons. The PCAs are categories of technical R&D focus supported by NITRD member agency investments. PCAs are the major subject areas under which Federal agencies report their funding requests for the activities that the NITRD Program coordinates. The NITRD Subcommittee and the NCO Director review the NITRD PCAs annually to ensure that the NITRD Program actively addresses evolving IT R&D and policy needs. For FY2022, there is one new NITRD PCA, Electronics for Networking and Information Technology (ENIT). Keeping within the NITRD scope, the ENIT PCA will capture agency investments in micro- and nanoelectronics R&D for advancing, testing, and securing NITRD's core networking and IT silicon and non-silicon hardware assets. The 11 other NITRD PCAs are the same as in FY2021. Section 3 provides full definitions of the NITRD PCAs.

[9] https://www.whitehouse.gov/ostp/news-updates/2021/06/02/hello-world/

[10] https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/20/a-letter-to-dr-eric-s-lander-the-presidents-science-advisor-and-nominee-as-director-of-the-office-of-science-and-technology-policy/

The 12 NITRD PCAs for FY2022 are as follows:

- Artificial Intelligence (AI) R&D PCA
- Computing-Enabled Human Interaction, Communications, and Augmentation (CHuman) PCA
- Computing-Enabled Networked Physical Systems (CNPS) PCA
- Cyber Security and Privacy (CSP) PCA
- Education and Workforce (EdW) PCA
- Electronics for Networking and Information Technology (ENIT) (NEW for FY2022)
- Enabling R&D for High-Capability Computing Systems (EHCS) PCA
- High-Capability Computing Infrastructure and Applications (HCIA) PCA
- Intelligent Robotics and Autonomous Systems (IRAS) PCA
- Large Scale Data Management and Analysis (LSDMA) PCA
- Large Scale Networking (LSN) PCA
  - Advanced Wireless R&D (AWRD) sub-PCA
- Software Productivity, Sustainability, and Quality (SPSQ) PCA

NITRD Interagency Working Groups

NITRD's Interagency Working Groups coordinate the R&D planning and activities that support members' PCA investments. There is a close, though not a strictly one-to-one match between the PCAs and IWGs (*see Figure 1 below and Section 3*). The NITRD IWGs, with rotating agency co-chairs and support from NCO Technical Coordinators, strive to maximize Federal interagency efficiency in conducting high-impact basic research, transferring discoveries to the marketplace, advancing the national IT R&D infrastructure, and strengthening community R&D alliances. IWGs share information and coordinate agency R&D activities via monthly coordination meetings, annual planning meetings, and development of technical strategic plans. The NCO and IWG members review the IWG definitions and strategic R&D priorities annually to ensure they align with the Administration's annual and ongoing priorities. A new Information Integrity R&D IWG was initiated in August 2021 to provide interagency coordination on R&D investments in information integrity. There were no other IWG changes for FY2022. The 12 FY2022 NITRD IWGs and subgroups are as follows:

- Artificial Intelligence R&D (AI) IWG
  - Video and Image Analytics (VIA) team
- Big Data IWG
- Computing-Enabled Networked Physical Systems (CNPS) IWG
- Cybersecurity and Information Assurance (CSIA) IWG
- High End Computing (HEC) IWG
- Health Information Technology R&D (HITRD) IWG
- Information Integrity R&D (IIRD) IWG (NEW in FY2021)
- Intelligent Robotics and Autonomous Systems (IRAS) IWG
- Large Scale Networking (LSN) IWG
  - Broadband Research and Development (BRD) team
  - Joint Engineering Team (JET)
  - Middleware and Grid Interagency Coordination (MAGIC) team
- Privacy R&D (Privacy) IWG
- Software Productivity, Sustainability, and Quality (SPSQ) IWG
- Wireless Spectrum R&D (WSRD) IWG
  - Advanced Wireless Test Platform team

Figure 1 pictures the relationships of the IWGs to the PCAs in which their investments are reported.

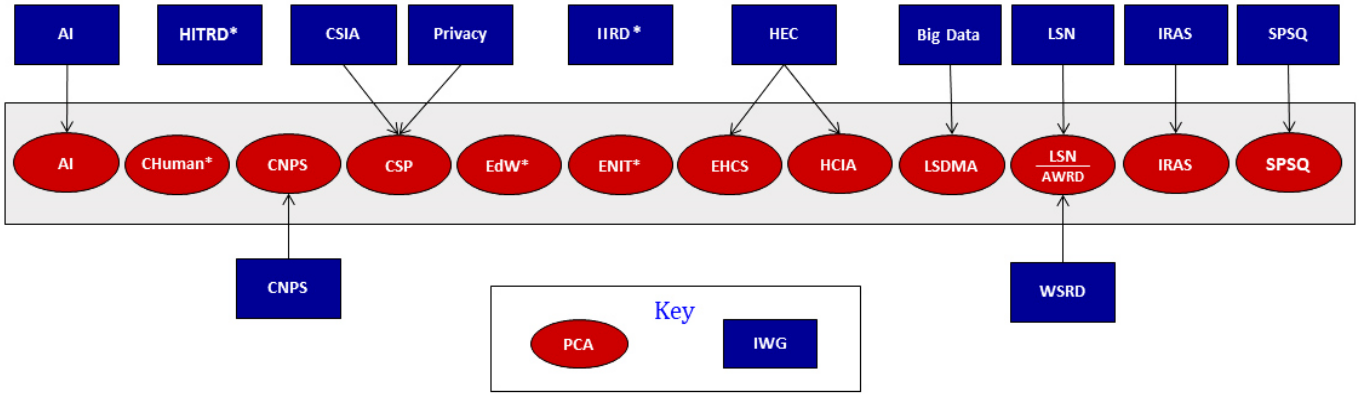


Figure 1. Relationships between the NITRD IWGs and PCAs for FY2022.

Notes: The *HITRD IWG* is not affiliated with a single PCA, and the *Information Integrity R&D IWG* has not been affiliated with a PCA since its initiation in August 2021. The *CHuman, EdW,* and *ENIT PCAs* do not have coordinating IWGs; agencies that invest in R&D in these areas currently do so within other IWGs.

NITRD IWG Roles in Furthering Public-Private R&D Partnerships

The IWGs work throughout the year to promote public-private engagement and partnerships:

- Plan, hold, and report on cross-community and cross-sector technical workshops.
- Present and hold meetings at national and international technical symposiums such as the International Conference for High Performance Computing, Networking, Storage, and Analysis.
- Compile, publish, and update for public use on nitrd.gov resource guides and inventories of Federal R&D programs, e.g., in Broadband, High-end Computing, Smart Cities, Wireless Spectrum, and STEM education and internships.
- Review and update R&D strategic plans, as mandated by Congress or as IWG agency members and participants determine there is a need; these plans serve as guides for not only the Federal IT R&D community but also for the academic and industrial IT R&D communities.

NITRD IWG Coordination with NSTC S&T Committees

NITRD's interdisciplinary R&D agenda creates natural synergies between its IWG efforts and other efforts of the NSTC enterprise, including those of the Committees and Subcommittees listed below:

- Committee on Environment, Subcommittee on Global Change Research
- Committee on National and Homeland Security
  - Special Cybersecurity Operations Research and Engineering Subcommittee
  - Subcommittee on Microelectronics Leadership
  - Subcommittee on Resilience S&T
- Committee on Science, Subcommittee on Quantum Information Science
- Committee on STEM Education, Federal Coordination in STEM Education Subcommittee, Computational Literacy Interagency Working Group
- Committee on Technology
  - Future Advanced Computing Ecosystem (FACE) Subcommittee
  - Machine Learning and Artificial Intelligence (MLAI) Subcommittee
  - Nanoscale Science, Engineering, and Technology Subcommittee
- Select Committee on Artificial Intelligence

For FY2022, the NITRD Program anticipates greater involvement with many of the NSTC S&T committees, and greater focus on data and equity issues in creation and delivery of digital services. NITRD IWG interactions with NSTC and other national bodies in FY2021 into FY2022 include:

- The NITRD AI IWG, with the NSTC Select Committee on AI and the MLAI Subcommittee, coordinated public-private efforts to examine the roles of AI vis-à-vis cloud computing.[11] They are currently examining how AI can improve U.S. competitiveness in advanced manufacturing.
- The NITRD CNPS, LSN, and WSRD IWGs were instrumental in 2020 in organizing and capturing efforts by the National Security Council, National Economic Council, and many Federal agencies, with public input, to devise the R&D sections of the *National Strategy to Secure 5G Implementation Plan*.[12]
- The NITRD HEC IWG and the NSTC FACE Subcommittee coordinated interagency efforts to write a national strategic plan for *Pioneering the Future Advanced Computing Ecosystem*.[13] They are now completing a FACE implementation plan and consolidating ideas for a National Strategic Computing Reserve, a coalition of experts and providers who could quickly provide computational resources in emergencies.

2020 Review of NITRD by the President's Council of Advisors on Science and Technology

Congressional statutes require that the NITRD Program undergo periodic review by the Administration for efficacy. The most recent President's Council of Advisors on Science and Technology (PCAST) review of NITRD was published in January 2021.[14] The PCAST found that, overall, the NITRD Program continues to be a reliable, effective mechanism for coordinating interagency advanced computing, networking, and IT R&D efforts to meet national needs. Among its recommendations, PCAST encouraged the Program to better communicate when and how its program focus areas and investments change to meet evolving needs. Other PCAST recommendations include instituting measures to improve the pace and consistency of NITRD efforts to maintain competitiveness with foreign efforts in networking and IT; prioritizing IT R&D in industries of the future in such fields as AI, QIS, advanced wireless networks, advanced manufacturing, and biotechnology; initiating a structure to coordinate R&D in microelectronics; and expanding Federal agencies' coordination and integration efforts in education and workforce development in IT-relevant STEM fields. The NITRD NCO is working with the NITRD Subcommittee to respond effectively to these recommendations.

Structure of this Supplement

Section 2 provides budget data for NITRD agencies' R&D investments made in FY2020 and enacted in FY2021 (as well as supplementals), and requests for the President's FY2022 Budget in the 12 NITRD PCAs (Table 1). It also provides breakouts of agency budgets that support AI R&D (Table 2), the National AI Research Institutes led by NSF and other agencies (Tables 3–4), and advanced wireless networking R&D (Table 5). A budget analysis subsection highlights changes of greater than $10 million between the FY2021 enacted budgets and FY2022 requests. Sections 3 and 4 describe the major R&D priorities and key activities and programs reported by NITRD agencies under the PCAs and coordinated by the IWGs.[15] Section 5 lists and describes the National AI Research Institutes. A list of abbreviations follows Section 5.

[11] https://www.nitrd.gov/pubs/Recommendations-Cloud-AI-RD-Nov2020.pdf
[12] https://www.ntia.gov/5g-implementation-plan
[13] https://www.nitrd.gov/pubs/Future-Advanced-Computing-Ecosystem-Strategic-Plan-Nov-2020.pdf
[14] https://science.osti.gov/-/media/_/pdf/about/pcast/202012/FINAL_PCAST-NITRD-Report_2021.pdf
[15] Due to space limitations, not all agency programs are listed in the Key Programs and Coordination Activities sections of the PCA and IWG pages. Also, IWG agencies' key programs are listed under only one strategic priority, but they often address more than one priority. Program titles are shown in title case, whereas program types are shown in sentence case.

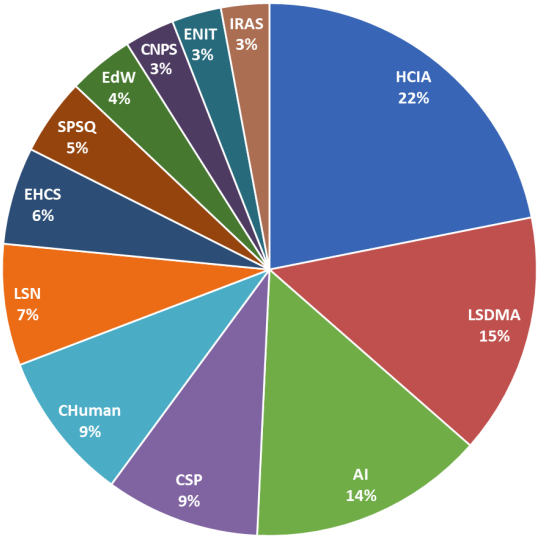
2. Agency NITRD- and NAIIO-Related R&D Investments, FYs 2020–2022

This section reports NITRD R&D budgets by PCA and agency, including overall Federal IT-related R&D investments (Table 1) and R&D investments in three high-priority areas: Artificial Intelligence R&D (Table 2), the National Artificial Intelligence Institutes (Tables 3 and 4, as mandated by the National Artificial Intelligence Initiative Act),[16] and Advanced Wireless Networks (AWN) R&D (Table 5). Tables 1–5 provide agencies' FY2020 actual and supplemental R&D investments, FY2021 enacted and supplemental budgets,[17] and FY2022 budget requests. A budget analysis section following the tables describes changes of investment greater than $10 million, by agency, between the FY2021 enacted budgets and the FY2022 President's Budget Request. Additional NITRD R&D investment information for FY2002–FY2022 is available at https://www.nitrd.gov/apps/itdashboard/.

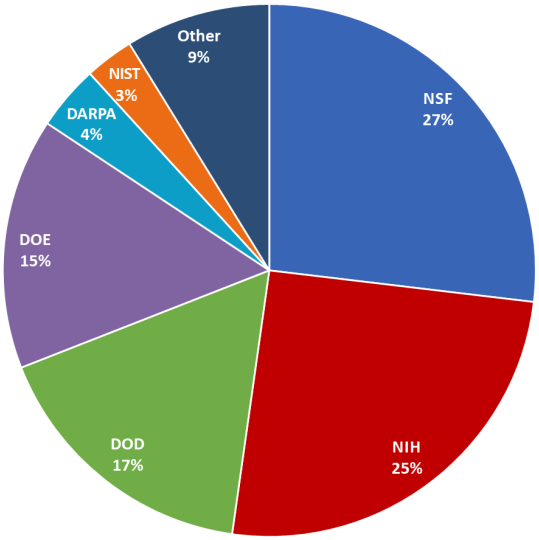
Overview

As Table 1 shows, the President's overall FY2022 budget request for Federal agencies' NITRD-related R&D is $7.8 billion—an increase of approximately 19.6 percent compared to the $6.5 billion *requested* for FY2021. The NITRD agencies' requested nondefense investment in AI R&D for FY2022 (Table 2) is $1.7 billion, an increase of approximately 11.2 percent compared to the $1.5 billion *requested* for nondefense AI R&D for FY2021. All AI Institutes are requesting a total of $108.3 million for FY2022, including NSF, DHS, USDA/NIFA, Department of the Air Force (DAF), and VA investments (Tables 4–5). Agencies' budget requests for FY2022 AWN R&D (Table 5) total $232 million, an increase of approximately 22.8 percent compared to the $189 million *requested* for AWN R&D for FY2021. Charts 1 and 2 (below) show percentages of the total NITRD budget request by PCA and by agency.

Budget Charts



1. FY2022 Budget Request, as percentages of the total NITRD request, by PCA
See the Abbreviations list or p. 10 for spellings of PCA acronyms and p. ii for spellings of agency acronyms.



2. FY2022 Budget Request, as percentages of the total NITRD request, by agency
Other: AHRQ, DHS, DOE/NNSA, DOI, DOT, EPA, FDA, NASA, NIJ, NIOSH, NOAA, NTIA, Treas/FCEN, USDA, VA

[16] The NAIIA National AI Research Institutes are predominantly organized by NSF; however, DAF and VA also fund AI Institutes.

[17] *FY2020 Supplemental estimates*—reported by DOD, NIH, and NSF—are based on funding from the Coronavirus Preparedness and Response Supplemental Appropriations Act, 2020; the Families First Coronavirus Response Act; the Coronavirus Aid, Relief, and Economic Security Act; and the Paycheck Protection Program and Health Care Enhancement Act. *FY2021 Supplemental estimates*—reported by DOD, NASA, NIH, and VA—include supplemental appropriations and funding provided in the American Rescue Plan.

Table 1. Agency Budgets by NITRD PCA, FYs 2020–2022 (p. 1 of 2)

FY2020 Budgets, Actual & Supplemental; FY2021 Budgets, Enacted & Supplemental; and FY2022 Budget Requests ($ in millions)[a]

Agency [b]	Fiscal Year [a]	12 NITRD Program Component Areas												Totals [e]
		AI [c]	CHuman	CNPS	CSP	EdW	ENIT [d]	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
AHRQ	FY20	0.0	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.5
	FY21	*0.0*	*16.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*16.3*
	FY22	**0.0**	**16.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**16.3**
DARPA [f,g]	FY20	--	10.0	0.0	262.9	0.0	0.0	5.1	0.0	0.0	31.9	65.7	0.0	375.6
	FY21	--	*9.9*	*0.0*	*236.2*	*0.0*	*0.0*	*5.1*	*0.0*	*0.0*	*35.2*	*59.2*	*0.0*	*345.5*
	FY22	**--**	**0.0**	**0.0**	**237.1**	**0.0**	**0.0**	**5.1**	**0.0**	**0.0**	**30.4**	**32.9**	**0.0**	**305.5**
DHS	FY20	34.5	0.0	8.6	27.0	1.0	0.0	0.0	0.0	2.7	4.5	16.8	0.0	95.1
	FY21	*31.4*	*0.0*	*6.5*	*26.9*	*1.0*	*0.0*	*0.0*	*0.0*	*5.7*	*1.6*	*12.5*	*0.0*	*85.6*
	FY22	**32.7**	**0.0**	**10.2**	**55.4**	**1.0**	**4.0**	**0.0**	**0.0**	**4.8**	**2.8**	**3.0**	**0.0**	**113.9**
DOD [f,g]	FY20	--	168.9	36.3	225.0	76.9	81.7	47.6	279.7	148.6	144.9	196.0	60.2	1,465.8
	FY20-S	--	0.0	0.0	4.9	0.0	0.0	7.9	0.0	0.0	2.5	10.9	0.0	26.2
	FY21	--	*161.1*	*30.2*	*208.9*	*80.0*	*80.6*	*50.6*	*272.4*	*106.3*	*169.3*	*184.6*	*60.6*	*1,404.7*
	FY21-S	--	*0.0*	*0.0*	*9.9*	*0.0*	*0.0*	*9.9*	*0.0*	*0.0*	*0.0*	*26.6*	*0.0*	*46.4*
	FY22	**--**	**155.2**	**26.5**	**175.4**	**81.2**	**82.3**	**39.3**	**268.8**	**96.5**	**164.1**	**146.7**	**72.5**	**1,308.4**
DOE [h]	FY20	89.9	0.0	1.2	30.0	29.0	40.0	71.1	641.7	17.7	25.7	90.0	0.0	1036.2
	FY21	*149.7*	*0.0*	*0.0*	*32.3*	*30.3*	*40.0*	*131.1*	*655.6*	*16.0*	*8.9*	*91.3*	*0.0*	*1,155.2*
	FY22	**124.8**	**0.0**	**0.0**	**46.1**	**34.0**	**40.0**	**126.9**	**720.0**	**0.4**	**0.0**	**94.0**	**0.0**	**1,186.1**
DOE/NNSA [h]	FY20	20.0	0.0	0.0	0.0	0.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	60.0
	FY21	*25.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*12.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*37.0*
	FY22	**27.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**24.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**51.7**
DOI	FY20	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5
	FY21	*8.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*8.5*
	FY22	**13.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**13.0**
DOT	FY20	10.0	0.0	0.9	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.7	12.1
	FY21	*11.1*	*0.0*	*1.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.5*	*0.8*	*0.0*	*0.4*	*15.8*
	FY22	**11.3**	**0.0**	**1.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.5**	**0.3**	**0.0**	**0.0**	**13.1**
EPA	FY20	0.0	0.0	0.0	0.0	0.0	0.0	3.5	3.0	0.0	0.0	0.0	0.0	6.5
	FY21	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.5*	*3.0*	*0.0*	*0.0*	*0.0*	*0.0*	*6.5*
	FY22	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.3**	**3.5**	**0.0**	**0.0**	**0.0**	**0.0**	**6.8**
FDA	FY20	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.0
	FY21	*46.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*46.0*
	FY22	**50.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**50.0**
NASA	FY20	2.0	0.0	1.5	0.0	0.0	0.0	0.4	66.3	24.7	0.0	0.0	1.5	96.3
	FY21	*2.9*	*0.0*	*1.8*	*0.0*	*0.0*	*0.0*	*2.2*	*65.4*	*22.2*	*0.0*	*0.0*	*1.8*	*96.2*
	FY22	**2.9**	**0.0**	**1.8**	**0.0**	**0.0**	**0.0**	**3.8**	**83.7**	**24.9**	**0.0**	**0.0**	**1.8**	**118.8**
NIH	FY20	112.3	369.4	31.7	7.0	55.9	0.0	64.8	314.1	15.5	626.3	41.5	186.2	1,824.7
	FY20-S	0.8	6.0	0.0	0.0	0.3	0.0	0.2	1.2	0.0	2.2	0.0	2.0	12.7
	FY21	*117.6*	*376.3*	*32.3*	*7.2*	*56.4*	*0.0*	*65.6*	*321.0*	*15.7*	*637.6*	*42.6*	*189.7*	*1,862.0*
	FY21-S	*0.1*	*7.2*	*0.0*	*0.0*	*0.2*	*0.0*	*0.0*	*0.5*	*0.0*	*1.4*	*0.0*	*1.6*	*11.0*
	FY22	**121.8**	**413.8**	**34.3**	**7.4**	**58.7**	**0.0**	**70.0**	**334.9**	**16.8**	**670.3**	**43.6**	**199.2**	**1,970.8**
NIJ	FY20	11.5	0.7	0.0	0.4	1.5	0.0	0.0	0.0	0.0	1.3	0.0	0.0	15.4
	FY21	*11.5*	*0.7*	*0.0*	*0.4*	*1.5*	*0.0*	*0.0*	*0.0*	*0.0*	*1.5*	*0.0*	*0.0*	*15.6*
	FY22	**11.5**	**0.7**	**0.0**	**0.4**	**1.5**	**0.0**	**0.0**	**0.0**	**0.0**	**1.5**	**0.0**	**0.0**	**15.6**
NIOSH	FY20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.3
	FY21	*3.8*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.3*	*0.0*	*0.0*	*0.0*	*7.0*
	FY22	**3.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.3**	**0.0**	**0.0**	**0.0**	**7.0**
NIST	FY20	14.9	13.3	12.8	81.5	6.8	0.0	6.7	9.8	10.8	15.9	20.0	2.3	194.8
	FY21	*25.1*	*14.4*	*13.8*	*84.4*	*6.9*	*0.0*	*9.1*	*9.6*	*11.4*	*16.9*	*20.9*	*3.3*	*215.8*
	FY22	**40.1**	**14.4**	**13.8**	**84.4**	**6.9**	**0.0**	**9.1**	**9.6**	**11.4**	**16.9**	**20.9**	**3.3**	**230.8**

Table 1. Agency Budgets by NITRD PCA, FYs 2020–2022 (p. 2 of 2)

FY2020 Budgets, Actual & Supplemental; FY2021 Budgets, Enacted & Supplemental; and FY2022 Budget Requests ($ in millions) [a]

Agency [b]	Fiscal Year [a]	12 NITRD Program Component Areas												Totals [e]
		AI [c]	CHuman	CNPS	CSP	EdW	ENIT [d]	EHCS	HCIA	IRAS	LSDMA	LSN	SPSQ	
NOAA	FY20	0.8	0.2	0.0	0.0	0.0	0.0	0.0	63.0	0.0	0.0	4.3	3.7	71.9
	FY21	*1.2*	*0.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*65.5*	*0.0*	*0.0*	*4.3*	*3.7*	*74.8*
	FY22	**1.2**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**75.5**	**0.0**	**0.0**	**4.3**	**3.7**	**84.8**
NSF	FY20	315.4	96.1	77.1	105.5	98.8	60.6	171.4	206.8	45.7	203.8	179.3	65.9	1,626.2
	FY20-S	4.2	2.4	4.2	1.5	1.5	0.0	0.4	0.2	0.1	3.9	2.2	0.9	21.3
	FY21	*357.6*	*93.7*	*74.4*	*104.6*	*98.5*	*39.7*	*166.2*	*189.1*	*44.8*	*184.4*	*178.3*	*66.4*	*1,597.4*
	FY22	**497.2**	**107.6**	**141.5**	**119.9**	**125.2**	**106.4**	**177.9**	**204.4**	**63.4**	**249.6**	**217.9**	**80.8**	**2,091.5**
NTIA	FY20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.0	6.2
	FY21	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*9.2*	*0.0*	*9.2*
	FY22	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**10.0**	**0.0**	**10.0**
Treas/FCEN	FY20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FY21	*0.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.5*
	FY22	**0.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.8**
USDA	FY20	128.9	0.0	1.2	0.0	0.1	0.0	0.0	0.0	0.2	0.1	0.0	0.0	130.5
	FY21	*145.2*	*0.0*	*6.2*	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*5.2*	*1.0*	*0.0*	*0.0*	*157.7*
	FY22	**145.2**	**0.0**	**6.2**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**5.2**	**1.0**	**0.0**	**0.0**	**157.7**
VA	FY20	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9
	FY21	*17.9*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*17.9*
	FY21-S	*0.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.5*
	FY22	**24.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**24.7**
TOTALS [e]	FY20	797.5	675.1	171.2	739.3	270.0	182.3	411.1	1,584.3	267.2	1,054.4	619.8	320.4	7,092.7
TOTALS [e]	FY20-S	5.0	8.4	4.2	6.4	1.8	0.0	8.5	1.4	0.1	8.6	13.1	2.9	60.2
TOTALS [e]	*FY21*	*954.9*	*672.6*	*166.2*	*700.9*	*274.7*	*160.3*	*445.4*	*1,581.6*	*233.0*	*1,057.2*	*602.9*	*325.8*	*7,175.4*
TOTALS [e]	*FY21-S*	*0.6*	*7.2*	*0.0*	*9.9*	*0.2*	*0.0*	*9.9*	*67.7*	*0.0*	*1.4*	*26.6*	*1.6*	*57.9*
TOTALS [e]	**FY22**	**1,108.5**	**708.3**	**235.3**	**726.0**	**308.5**	**232.7**	**459.3**	**1,700.4**	**227.0**	**1,136.9**	**573.3**	**361.2**	**7,777.3**

Budget Table 1 Notes

a. **FY20 = FY2020 actual budgets; FY20-S = FY2020 supplemental budgets; FY21 = FY2021 enacted budgets; FY21-S = FY2021 supplemental budgets; and FY22 = FY2022 proposed budgets.** The budget supplemental figures for FY2021 and FY2022 have *not* been used to calculate changes between the FY2021 and FY2022 budget numbers. Please also see footnote 17 on p. 13.

b. Agency sub-departments and offices that reported budgets are as noted here (*see the Abbreviations list at the end of this document*): **DHS:** CG, DHS CWMD, DHS S&T, and DHS TSA; **DOD:** DTRA, MDA, Military Services' research organizations, and OSD; **DOE:** DOE/AITO, DOE/ARPA-E, DOE/CESER, DOE/EERE, DOE/FE, DOE/NE, DOE/OE, and DOE/SC; **DOE/NNSA:** Defense Nuclear Nonproliferation, and Defense Programs; **DOI:** DOI/BSEE, DOI/USBR, and USGS; **DOT:** FAA, FHWA, FMCSA, FRA, FTA, and PHMSA; **NASA**: Aeronautics, Exploration Technology, and Office of Science; **NOAA:** NOAA/ORF and NOAA/PAC; **NSF:** Education and Human Resources, and Research and Related Activities; **USDA:** ARS and NIFA. **NARA** has no active R&D program investments to report for these years.

c. The AI budget reported under the AI PCA is not the complete AI budget; refer also to Tables 3 and 4 and the Budget Analysis at the end of this section.

d. The Electronics for Networking and Information Technology (ENIT) PCA is new for FY2022.

e. Totals might not sum exactly due to rounding.

f. DARPA is a DOD research organization, but it reports its budgets separately from the DOD Services research organizations and the Office of the Secretary of Defense (OSD).

g. DARPA and DOD budget figures for direct AI R&D are not publicly available. See Table 2 for DOD investments in AI R&D under other PCAs.

h. The DOE/NNSA budget is listed separately from that of other DOE offices.

Table 2. Agency Budgets by NITRD PCA for AI R&D,[a] FYs 2020–2022 (p. 1 of 3)

FY2020 Budgets, Actual & Supplemental; FY2021 Budgets, Enacted & Supplemental; and FY2022 Budget Requests ($ in millions)[b]

Agency [a,c]	Fiscal Year[b]	12 NITRD Program Component Areas												Totals [a,g]
		AI [d,e]	CHuman	CNPS	CSP	EdW	ENIT[f]	EHCS[e]	HCIA	IRAS	LSDMA	LSN	SPSQ	
DHS/CWMD	FY20	2.4	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.5	0.0	9.1
	FY21	*2.7*	*0.0*	*1.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.6*	*0.5*	*0.0*	*5.8*
	FY22	**1.1**	**0.0**	**0.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.3**	**0.0**	**0.0**	**2.9**
DHS/S&T	FY20	25.1	0.0	0.0	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.9
	FY21	*21.7*	*0.0*	*0.0*	*20.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*41.8*
	FY22	**24.6**	**0.0**	**0.0**	**42.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**67.5**
DHS/TSA	FY20	7.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4
	FY21	*7.0*	*0.0*	*0.0*	*0.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*7.4*
	FY22	**7.0**	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**7.4**
DOD/OSD[a]	FY20	--	0.7	1.0	15.4	9.7	70.3	15.9	2.1	3.4	10.1	6.2	8.2	143.1
	FY21	--	*3.0*	*0.4*	*12.5*	*10.2*	*72.1*	*6.0*	*1.5*	*2.5*	*7.6*	*8.2*	*7.8*	*131.9*
	FY22	**--**	**0.6**	**0.0**	**4.3**	**0.5**	**63.4**	**5.7**	**0.0**	**0.0**	**4.3**	**3.5**	**0.2**	**82.5**
DOD/USAF[a]	FY20	--	5.0	0.0	0.1	0.0	0.0	0.0	0.0	29.9	0.1	0.1	0.0	35.3
	FY20-S	--	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	FY21	--	*5.0*	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*33.8*	*0.1*	*0.1*	*0.0*	*39.1*
	FY21-S	--	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*0.1*
	FY22	**--**	**4.9**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**31.4**	**0.2**	**0.1**	**0.0**	**36.8**
DOE/AITO	FY20	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5
	FY21	*2.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.5*
	FY22	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5
DOE/ARPA-E	FY20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FY21	*0.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.5*
	FY22	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
DOE/EERE	FY20	51.2	0.0	1.2	25.0	0.0	0.0	3.2	0.0	1.0	0.0	0.0	0.0	81.6
	FY21	*47.4*	*0.0*	*0.0*	*27.3*	*0.0*	*0.0*	*6.0*	*0.0*	*11.5*	*0.0*	*0.0*	*0.0*	*92.2*
	FY22	**41.3**	**0.0**	**0.0**	**11.1**	**0.0**	**0.0**	**6.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**58.4**
DOE/FE	FY20	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.9
	FY21	*27.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*27.1*
	FY22	**10.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**10.2**
DOE/NE	FY20	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	1.6
	FY21	*1.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.5*	*0.0*	*0.0*	*0.0*	*2.1*
	FY22	**1.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**2.3**
DOE/NNSA[e]	FY20	20.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	40.0
	FY21	*25.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*25.0*
	FY22	**27.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**27.7**
DOE/OE	FY20	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6
	FY21	*5.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*5.0*
	FY22	**3.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.0**
DOE/SC	FY20	19.2	0.0	0.0	0.0	0.0	0.0	9.7	37.3	0.0	0.0	0.0	0.0	66.2
	FY21	*65.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*14.9*	*43.9*	*0.0*	*0.0*	*0.0*	*0.0*	*124.4*
	FY22	**66.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**16.5**	**45.4**	**0.0**	**0.0**	**0.0**	**0.0**	**128.6**
DOI/BSEE	FY20	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
	FY21	*1.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.1*
	FY22	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**
DOI/USBR	FY20	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
	FY21	*0.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.3*
	FY22	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**
DOI/USGS	FY20	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3
	FY21	*7.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*7.1*
	FY22	**12.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**12.7**
DOT/FAA	FY20	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
	FY21	*5.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*5.3*
	FY22	**5.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**5.8**

Table 2. Agency Budgets by NITRD PCA for AI R&D,[a] FYs 2020–2022 (p. 2 of 3)

FY2020 Budgets, Actual & Supplemental; FY2021 Budgets, Enacted & Supplemental; and FY2022 Budget Requests ($ in millions)[b]

Agency [a,c]	Fiscal Year[b]	12 NITRD Program Component Areas												Totals [a,g]
		AI [d,e]	CHuman	CNPS	CSP	EdW	ENIT [f]	EHCS [e]	HCIA	IRAS	LSDMA	LSN	SPSQ	
DOT/FHWA	FY20	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
	FY21	*2.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.4*
	FY22	**2.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2.0**
DOT/FMCSA	FY20	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	FY21	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
	FY22	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.4**
DOT/FRA	FY20	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2
	FY21	*2.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.3*
	FY22	**3.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.1**
DOT/FTA	FY20	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	FY21	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
	FY22	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
DOT/PHMSA	FY20	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	FY21	*1.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.2*
	FY22	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
FDA	FY20	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.0
	FY21	*46.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*46.0*
	FY22	**50.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**50.0**
NASA/Aero.[c]	FY20	2.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	3.8
	FY21	*2.9*	*0.0*	*1.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.1*	*5.0*
	FY22	**2.9**	**0.0**	**1.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.1**	**5.0**
NASA/Science	FY20	0.0	0.0	0.0	0.0	0.0	0.0	0.4	3.8	0.0	0.0	0.0	0.0	4.2
	FY21	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.4*	*1.2*	*0.0*	*0.0*	*0.0*	*0.0*	*1.6*
	FY22	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.5**	**1.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.5**
NIH	FY20	112.3	67.6	3.6	2.3	4.9	0.0	23.2	17.9	2.5	60.1	3.2	26.8	324.4
	FY20-S	0.8	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3
	FY21	*117.6*	*68.9*	*3.7*	*2.3*	*4.9*	*0.0*	*23.5*	*18.3*	*2.6*	*61.2*	*3.3*	*27.3*	*333.6*
	FY21-S	*0.1*	*4.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*4.3*
	FY22	**121.8**	**75.7**	**3.9**	**2.4**	**5.1**	**0.0**	**25.1**	**19.1**	**2.7**	**64.3**	**3.4**	**28.7**	**352.2**
NIJ	FY20	11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	12.6
	FY21	*11.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*11.5*
	FY22	**11.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**11.5**
NIOSH	FY20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FY21	*3.8*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.8*
	FY22	**3.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.8**
NIST	FY20	14.9	0.0	0.0	0.0	0.0	0.0	1.7	0.0	3.8	0.0	0.4	0.0	20.8
	FY21	*25.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.3*	*0.0*	*4.0*	*0.0*	*0.4*	*0.0*	*31.8*
	FY22	**40.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2.4**	**0.0**	**4.0**	**0.0**	**0.4**	**0.0**	**46.9**
NOAA/ORF	FY20	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	1.5
	FY21	*1.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.1*
	FY22	**1.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2.1**
NOAA/PAC	FY20	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
	FY21	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.1*
	FY22	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**
NSF	FY20	315.4	43.0	31.2	26.9	11.5	5.4	13.5	17.4	45.7	55.6	23.1	3.6	592.4
	FY20-S	4.2	0.5	0.2	0.5	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	6.3
	FY21	*357.6*	*33.4*	*25.1*	*25.8*	*8.7*	*3.6*	*10.6*	*14.4*	*37.3*	*46.6*	*15.5*	*3.3*	*582.0*
	FY22	**497.2**	**32.1**	**21.5**	**22.4**	**7.0**	**2.9**	**9.2**	**13.9**	**32.6**	**41.9**	**9.2**	**2.7**	**692.6**
Treas./FCEN	FY20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FY21	*0.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.5*
	FY22	**0.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.8**
USDA/ARS	FY20	18.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.7
	FY21	*21.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*21.3*
	FY22	**21.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**21.3**

Table 2. Agency Budgets by NITRD PCA for AI R&D,[a] FYs 2020–2022 (p. 3 of 3)

FY2020 Budgets, Actual & Supplemental; FY2021 Budgets, Enacted & Supplemental; and FY2022 Budget Requests ($ in millions)[b]

Agency [a,c]	Fiscal Year[b]	12 NITRD Program Component Areas												Totals [a,g]
		AI [d,e]	CHuman	CNPS	CSP	EdW	ENIT [f]	EHCS [e]	HCIA	IRAS	LSDMA	LSN	SPSQ	
USDA/NIFA	FY20	110.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	110.2
	FY21	*123.9*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*123.9*
	FY22	**123.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**123.9**
VA	FY20	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9
	FY21	*17.9*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*17.9*
	FY21-S	*0.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.5*
	FY22	**24.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**24.7**
TOTALS [g]	FY20	797.5	116.3	39.7	90.9	26.0	75.7	87.7	79.3	86.5	131.6	33.5	39.6	1,604.4
TOTALS [g]	FY20-S	5.0	4.0	0.2	0.5	0.0	0.0	0.1	0.0	0.1	0.7	0.0	0.0	10.7
TOTALS [g]	*FY21*	*954.9*	*110.2*	*31.2*	*88.6*	*23.7*	*75.8*	*63.7*	*80.4*	*92.1*	*117.1*	*28.0*	*39.6*	*1,705.4*
TOTALS [g]	*FY21-S*	*0.6*	*4.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*4.9*
TOTALS [g]	**FY22**	**1,108.5**	**113.3**	**27.0**	**83.6**	**12.6**	**66.3**	**65.3**	**80.4**	**71.0**	**112.1**	**16.6**	**32.8**	**1,789.5**
Nondefense TOTALS [g]	FY20	797.5	110.6	38.7	75.4	16.3	5.4	71.8	77.1	53.2	121.4	27.2	31.4	1,426.0
Nondefense TOTALS [g]	FY20-S	5.0	4.0	0.2	0.5	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	10.6
Nondefense TOTALS [g]	*FY21*	*954.9*	*102.3*	*30.8*	*75.9*	*13.6*	*3.6*	*57.7*	*78.8*	*55.8*	*109.5*	*19.7*	*31.7*	*1,534.4*
Nondefense TOTALS [g]	*FY21-S*	*0.6*	*4.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*4.8*
Nondefense TOTALS [g]	**FY22**	**1,108.5**	**107.8**	**27.0**	**79.2**	**12.1**	**2.9**	**59.6**	**80.4**	**39.6**	**107.6**	**12.9**	**32.5**	**1,670.2**

AI Budget Table 2 Notes

a. DARPA and DOD direct AI R&D investments are not publicly available; DOD has reported AI R&D investments in PCAs other than AI. The table shows totals for all nondefense investments and for indirect defense investments in AI.

b. **FY20 = FY2020 enacted budgets; FY20-S = FY2020 supplemental budgets; FY21 = FY2021 enacted budgets; FY21-S = FY2021 supplemental budgets; and FY22 = FY2022 proposed budgets.** The budget supplemental figures for FY2021 and FY2022 have *not* been used to calculate changes between the FY2021 and FY2022 budget numbers. Please also see footnote 17 on p. 13.

c. For full names of agency subcomponents (departments and offices), please see the Abbreviations list at the end of this document. NASA/Aero. refers to NASA aeronautics programs.

d. (1) Examples of AI R&D investments *reported under the AI PCA* are R&D on general methods for machine vision; (primarily) machine learning; cybersecurity challenges unique to AI, e.g., ability to exploit flaws in an AI system's goals; algorithms for computational linguistics; and neuromorphic computing architectures or chips optimized for neural nets. (2) Examples of AI investments *reported in other PCAs* are R&D on robots (*reported in IRAS*); the data analysis and management ecosystem (*reported in LSDMA*); broad issues of human-machine interaction (*reported in CHuman*) and cybersecurity research (*reported in CSP*); and general neuromorphic computing (*reported in EHCS*).

e. DOE/NNSA Defense Programs reported AI R&D investments in the EHCS PCA.

f. The Electronics for Networking and Information Technology (ENIT) PCA is new for FY2022.

g. Totals might not sum exactly due to rounding.

Table 3. Agency Budgets for NSF-Led National AI Research Institutes, FYs 2020–2022[a] (p. 1 of 2)

FY2020 Budgets, Actual; FY2021 Enacted Budgets; and FY2022 Budget Requests ($ in millions)

Institutes are Listed by Theme in Alphabetic Order; **= not yet initiated in FY2020**

INSTITUTE NAMES (year launched)	Fiscal Year[b]	NSF	DHS S&T	DOT[c]	USDA/NIFA	TOTALS[d]
Theme: AI and Advanced Cyberinfrastructure						
AI Institute for Intelligent Cyberinfrastructure with Computational Learning in the Environment (ICICLE) (2021)	FY20*					
	FY21	*12.0*				*12.0*
	FY22	**0.0**				**0.0**
Theme: AI-Augmented Learning						
AI Institute for Adult Learning and Online Education (ALOE) (2021)	FY20*					
	FY21	*3.7*				*3.7*
	FY22	**3.7**				**3.7**
AI Institute for Engaged Learning (2021)	FY20*					
	FY21	*4.0*				*4.0*
	FY22	**3.9**				**3.9**
AI Institute for Student–AI Teaming (2020)	FY20	4.0				4.0
	FY21	*4.0*				*4.0*
	FY22	**4.0**				**4.0**
Theme: AI-Driven Innovation in Agriculture and the Food System						
AI Institute for Agricultural AI for Transforming Workforce & Decision Support (Ag-AID) (2021)	FY20*					
	FY21				*4.0*	*4.0*
	FY22				**4.0**	**4.0**
AI Institute for Future Agricultural Resilience, Management, & Sustainability (AI FARMS) (2020)	FY20				3.8	3.8
	FY21				*4.0*	*4.0*
	FY22				**4.0**	**4.0**
AI Institute for Next-generation Food Systems (AIFS) (2020)	FY20				4.2	4.2
	FY21				*4.0*	*4.0*
	FY22				**4.0**	**4.0**
AI Institute for Resilient Agriculture (AIIRA) (2021)	FY20*					
	FY21				*4.0*	*4.0*
	FY22				**4.0**	**4.0**
Theme: AI for Accelerating Molecular Synthesis and Manufacturing						
AI Institute for Molecular Discovery, Synthetic Strategy, & Manufacturing (Molecule Maker Lab) (2020)	FY20	7.5				7.5
	FY21	*0.5*				*0.5*
	FY22	**4.0**				**4.0**
Theme: AI for Advances in Optimization						
AI Institute for Advances in Optimization (AI4Opt) (2021)	FY20*					
	FY21	*4.3*				*4.3*
	FY22	**5.5**				**5.5**
AI Institute for Learning-Enabled Optimization at Scale (TILOS) (2021)	FY20*					
	FY21	*3.1*				*3.1*
	FY22	**3.9**				**3.9**
Theme: AI for Discovery in Physics						
AI Institute for Artificial Intelligence and Fundamental Interactions (2020)	FY20	4.0				4.0
	FY21	*4.0*				*4.0*
	FY22	**4.0**				**4.0**
Theme: AI in Computer and Network Systems						
AI Institute for Edge Computing Leveraging Next-generation Networks (Athena) (2021)	FY20*					
	FY21	*4.0*	*0.5*			*4.5*
	FY22	**4.0**				**4.0**
AI Institute for Future Edge Networks and Distributed Intelligence (AI-EDGE) (2021)	FY20*					
	FY21	*3.8*	*0.4*			*4.2*
	FY22	**3.9**				**3.9**
Theme: AI in Dynamic Systems						
AI Institute for Dynamic Systems (2021)	FY20*					
	FY21	*4.0*	*0.5*			*4.5*
	FY22	**4.5**				**4.5**

Table 3. Agency Budgets for NSF-Led National AI Research Institutes, FYs 2020–2022[a] (p. 2 of 2)

FY2020 Budgets, Actual; FY2021 Enacted Budgets; and FY2022 Budget Requests ($ in millions)

Institutes are Listed by Theme in Alphabetic Order; **= not yet initiated in FY2020**

INSTITUTE NAMES (year launched)	Fiscal Year[b]	NSF	DHS S&T	DOT[c]	USDA/NIFA	TOTALS[d]
Theme: Foundations of Machine Learning						
AI Institute for Foundations of Machine Learning (2020)	FY20	4.9				4.9
	FY21	*3.6*				*3.6*
	FY22	**3.6**				**3.6**
Theme: Human-AI Interaction and Collaboration						
AI Institute for Collaborative Assistance and Responsive Interaction for Networked Groups (AI CARING) (2021)	FY20*					
	FY21	*2.8*				*2.8*
	FY22	**3.9**				**3.9**
Theme: Trustworthy AI						
AI Institute for Research on Trustworthy Artificial Intelligence in Weather, Climate, and Coastal Oceanography [Also called AI for Environmental Sciences (AI2ES) (2020)]	FY20	5.2				5.2
	FY21	*3.2*				*3.2*
	FY22	**3.2**				**3.2**
TOTALS[d]	FY20	25.6	0.0	0.0	8.0	33.6
TOTALS[d]	*FY21*	*57.0*	*1.4*	*0.0*	*16.0*	*74.4*
TOTALS[d]	**FY22**	**52.1**	**0.0**	**0.0**	**16.0**	**68.1**

AI Research Institutes Budget Table 3 Notes

a. FY 2020 was the first year of the AI Institutes, following the 2019 Executive Order 13859 announcing the American AI Initiative.
b. FY20 = FY2020 actual budgets; FY21 = FY2021 enacted budgets; FY22 = FY2022 proposed budgets.
c. DOT has an Interagency Agreement with NSF to support the AI Institutes Program; it has obligated and committed funds under the agreement that have not yet been applied to a specific Institute.
d. Totals might not sum exactly due to rounding. Industry and other private partners will contribute to some AI Institutes (see Section 5).

Table 4. Other Federally Funded AI Institute Budgets, FYs 2020–2022

FY2020 Actual Budgets; FY2021 Enacted Budgets; and FY2022 Budget Requests ($ in millions)

NAMES OF OTHER AGENCIES' INSTITUTES (year launched)	Fiscal Year	TOTALS[a]
DAF[b]–MIT (Massachusetts Institute of Technology) AI Accelerator (2020)	FY20	15.5
	FY21	*15.5*
	FY22	**15.5**
VA National Artificial Intelligence Institute (NAII) (2020)	FY20	10.9
	FY21	*17.9*
	FY22	**24.7**
TOTALS[a]	FY20	26.4
TOTALS[a]	*FY21*	*33.4*
TOTALS[a]	**FY22**	**40.2**

Other Federally Funded AI Institutes Budget Table 4 Notes

a. Totals might not sum exactly due to rounding.
b. The Department of the Air Force (DAF) includes the U.S. Air Force and U.S. Space Force.

Table 5. NITRD Agency Budgets for AWN R&D,[a,b] FYs 2020–2022

FY2020 Budgets, Actual and Supplemental; FY2021 Enacted Budgets; and FY2022 Budget Requests ($ in millions)

Agencies / Fiscal Year	DARPA	DHS S&T	DOD/ Army	DOD/ Navy	DOD/ USAF	NIST	NSF	NTIA	TOTALS[c]
FY20 Actual	34.4	8.2	8.7	9.0	4.3	6.8	130.7	6.2	208.3
FY20 Supplemental[d]	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	1.4
FY21 Enacted	*36.4*	*0.0*	*7.5*	*12.3*	*0.0*	*7.1*	*129.8*	*9.2*	*202.3*
FY21 Supplemental[d]	*0.0*	*0.0*	*0.0*	*0.0*	*9.8*	*0.0*	*0.0*	*0.0*	*9.8*
FY22 Request	**21.9**	**0.0**	**8.4**	**15.8**	**0.0**	**7.1**	**168.9**	**10.0**	**232.1**

AWN Budget Table 5 Notes

a. Figures in Table 5 break out those portions of NITRD member agencies' R&D investments in the LSN PCA that are primarily dedicated to advanced wireless networks. AWN R&D investments are typically coordinated through NITRD's WSRD IWG. (*The FY2021 Budget Supplement referred to AWN investments as advanced communications networks or ACN.*)
b. The FY2021 Supplement was the first time NITRD collected AWN (ACN) R&D numbers; they are not comparable to NITRD budget reporting earlier than in the FY2021 Supplement.
c. Totals might not sum exactly due to rounding.
d. See footnote 17 on p. 13 regarding budget supplementals.

Budget Analysis

Agency Budgets for Artificial Intelligence

In support of Executive Order 13859, "Maintaining American Leadership in Artificial Intelligence,"[18] and the National Artificial Intelligence Research and Development Strategic Plan: 2019 Update,[19] NITRD worked with Federal agencies to establish a process to accurately account for AI R&D investments, given that R&D in AI intersects with multiple PCAs. (Table 2, footnote d, gives examples of distinctions between AI and other PCAs.) The FY2020 budget request set a baseline for reporting and tracking AI R&D investments, consistent with the AI Executive Order. Because of the difference in the reporting process and AI scope newly defined in 2019, the AI investments reported in this FY2022 budget supplement are only comparable to other NITRD-reported AI investments.

Table 2 shows two types of AI R&D investments: (1) those with a primary emphasis on AI R&D, which are reported under the AI PCA, and (2) those with primary emphases in areas other than AI R&D, which are reported in other PCAs. The total FY2022 funding level shown for nondefense AI R&D in Table 2 (last cell in the rightmost column of Table 2), $1,670.2 million, indicates the total of the nondefense Federal programs directly related to AI ($1,108.5 million) and the nondefense AI-related efforts reported in the other PCAs ($561.7 million). This total Federal FY2022 nondefense budget request in AI is an 8.8 percent increase over the FY2021 nondefense enacted investments of $1,534.4 billion and an 11.2 percent increase over the FY2021 nondefense budget *request* of $1.502.5 billion. The total AI R&D funding level of $1,789.5 million (Table 2, rightmost column, six lines from the bottom) includes both nondefense and partial defense investments. In addition to what's counted in the NITRD PCAs for AI R&D, NSF also funds $73.6 million in AI education.

As required by the National Artificial Intelligence Initiative Act of 2020,[20] Tables 4 and 5 report the actual, enacted, and requested budgets of agencies that have established and/or invested in one or more of the National Artificial Intelligence Research Institutes for FYs 2020, 2021, and 2022. The legislation named the National Science Foundation as lead agency for the National AI Research Institutes. With several Federal partners including USDA and DHS, NSF began support of 18 National AI Research Institutes from 2020–2021, which together request a total of $68.1 million for FY2022.[21] DAF and VA began operation of other AI Institutes in 2020 that are not directly affiliated with NSF but closely follow the legislative criteria for the National AI Research Institutes; DAF and VA request $40.2 million for AI Institutes for FY2022. The total FY2022 request for AI Institutes is $108.3 million. Section 5 briefly describes the Institutes.

Agency Budgets for Advanced Wireless Networks

In support of the Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future, NITRD requested that agencies report investments in AWN (referred to in FY2021 as Advanced Communications Networks or ACN) as a portion of the investments reported in the LSN PCA.[22] These AWN investments are reported in Table 5. The combined Federal FY2022 budget request in AWN R&D of $232.1 million represents a 14.7 percent increase over the FY2021 enacted investments and a 22.8 percent increase over the FY2021 budget *request*.

[18] https://www.federalregister.gov/documents/2019/02/14/2019-02544/maintaining-american-leadership-in-artificial-intelligence
[19] https://www.nitrd.gov/pubs/National-AI-RD-Strategy-2019.pdf
[20] Division E of the National Defense Authorization Act for Fiscal Year 2021, P.L. 116-283 (H.R. 6395), January 1, 2021; https://www.congress.gov/116/crpt/hrpt617/CRPT-116hrpt617.pdf#page=1210
[21] The projected 5-year budgets for FY2020–FY2026 for the NSF-led AI Institutes totals $360 million.
[22] See https://www.ntia.doc.gov/category/national-spectrum-strategy

Changes in Overall Agency Budgets, FY2021 to FY2022

The following paragraphs note changes of investment greater than $10 million, by agency and PCA, between the FY2021 enacted budgets and the FY2022 budget requests.

DARPA: The decrease of $40.0 million is due to a decrease of $26.3 million in LSN following the completion of the Secure Handhelds on Assured Resilient networks at the tactical Edge (SHARE) and Dynamic Network Adaptation for Mission Optimization (DyNAMO) programs, with a small increase in CSP and small decreases in several other PCAs.

DHS:[23] The increase of $28.3 million is due to a $28.5 million increase in CSP at DHS S&T primarily in the area of Cyber Data Analytics that includes funding Machine Learning infrastructure and algorithms and tools, zero trust, industrial control systems, and promoting additional cybersecurity research and development, with smaller increases and decreases in other programs and PCAs.

DOD: The decrease of $96.3 million is due to decreases of $37.9 million in LSN, $33.5 million in CSP, $11.3 million in EHCS, and smaller decreases in other PCAs; these decreases are partially offset by an increase of $11.9 million in SPSQ and smaller increases in EdW and ENIT.

DOE:[24] The increase of $30.9 million is due to increases of $64.4 million in HCIA at DOE/SC for efforts in microelectronics, AI, and data infrastructure, among many other efforts across SC, and $25.0 million in CSP at DOE/OE for new funding in the Cyber R&D program for FY2022. These are partially offset by decreases of $16.9 million in AI at DOE/FE; $16.2 million in CSP and $11.5 million in IRAS at DOE/EERE; with smaller increases and decreases in other programs and PCAs, including newly reported investments in ENIT.

DOE/NNSA: The increase of $14.7 million is due to a $12.0 million increase in EHCS for a new activity on advanced memory technology research, per Congressional direction, and a smaller increase in AI.

NASA: The increase of $22.6 million is due to an increase of $18.3 million in HCIA for more computing capacity, enhanced R&D, and synergy between HEC and data systems following NASA Science Mission Directorate's overall data and computing strategy, and smaller increases in EHCS and IRAS.

NIH: The increase of $108.8 million is due to increases of $37.5 million in CHuman for increased research in clinical studies using structured electronic healthcare and related data, $32.7 million in LSDMA to support the Back Pain Consortium (BACPAC) Research Program, $13.9 million in HCIA for new technologies to reconstruct whole-brain images to characterize mammalian and related systems, and smaller increases in all other PCAs.

NIST: The increase of $15.0 million is entirely for an initiative to establish a new public-private partnership to accelerate trustworthy AI while expanding AI research capacities across the NIST laboratories.

NOAA: The increase of $10 million is entirely due to an increase in the HCIA PCA for the Oceanic and Atmospheric Research (OAR) Supercomputing/Climate Competitive Research Initiative Program, Project, and Activity (PPA).

NSF: The increase of $494.1 million is due to increases across all PCAs to enhance fundamental R&D and strengthen U.S. leadership in emerging technologies.

[23] Includes CG, DHS CWMD, and DHS TSA.
[24] Includes the following DOE subunits: AITO, ARPA-E, CESER, EERE, FE, NE, OE, and SC.

3. Key Activities of the NITRD PCAs and IWGs

Artificial Intelligence (AI) Research and Development (R&D) PCA

AI R&D advances the ability of computer systems to perform tasks that have traditionally required human intelligence; this includes R&D in machine learning, computer vision, natural language processing/understanding, intelligent decision support systems, and autonomous systems, as well as the novel application of these techniques to various domains, where not principally covered by other PCAs.

Artificial Intelligence R&D IWG

Participating Agencies: Army, DAF (USAF & USSF), DARPA, DHS, DOD, DOE, DOJ, DOT, FAA, FBI, FDA, GSA, IARPA, NARA, NASA, Navy, NIFA, NIH, NIJ, NIOSH, NIST, NMIO, NOAA, NSA, NSF, NTIA, ODNI, ONC, OSD, OSTP, State, USPTO, VA

The AI R&D IWG coordinates Federal AI R&D and supports activities tasked by both the NSTC Select Committee on AI and the Subcommittee on Machine Learning and Artificial Intelligence. This vital work promotes U.S. leadership and global competitiveness in AI R&D and its applications.

Strategic Priorities and Associated Key Programs

1. Make long-term investments in AI research: Coordinate long-term Federal investments in AI R&D that could lead to transformative AI technologies and breakthroughs across all sectors of society.

Key programs

National AI Research Institutes[25]—*DHS, DOT, NSF, USDA, industry partners*;

Smart Health and Biomedical Research in the Era of Artificial Intelligence and Advanced Data Science—*NIH, NSF*;

Science of Information, Computation, Learning and Fusion; Computational Cognition & Machine Intelligence; and Efficient & Robust Machine Learning programs—*AFOSR*;

AI for Maneuver and Mobility—*ARL, CCDC*;

Synthetic Data Generation, and Enhancing Performance Metrics—*DHS*;

Learning with Less Labeling; Lifelong Learning Machines; Machine Common Sense; and Synergistic Discovery and Design—*DARPA*;

Randomized Algorithms for AI, Data-centric Science at Scale; and Scientific ML and AI—*DOE*;

Bioconvergence and AI Analysis—*DOE, NIST, NSF*;

Broad Agency Announcements: Roadway Winter Maintenance and Traffic Operations; and Computer Vision—*DOT*;

Bridge2AI; and Artificial Intelligence/Machine Learning Consortium to Advance Health Equity and Researcher Diversity (AIM-AHEAD) programs—*NIH;*

Joint AI Center—*DOD*;

Joint Design of Advanced Computing Solutions for Cancer—*DOE, NIH*;

Advanced Air Mobility; Lunar Gateway; and Long-Range Robotic Space Exploration—*NASA*;

Agriculture and Food Research Initiative—*NIFA*;

Autonomy and AI transmission and distribution investment roadmaps—*TRMC*;

[25] See Table 3 in Section 3 and Section 5 for details about the National AI Research Institutes.

Fundamental and Applied Research and Standards for AI Technologies; and Novel Computational Hardware Paradigms for AI—*NIST*;

Information Integration and Informatics; Mathematical and Scientific Foundations of Deep Learning (MoDL); Stimulating Collaborative Advances Leveraging Expertise in the MoDL; and Robust Intelligence—*NSF*;

Mathematical Methods for Deep Learning; Science of Autonomy; Cognitive and Computational Neuroscience; and Machine Learning, Reasoning, and Intelligence—*ONR*;

National Artificial Intelligence Institute: Build and coordinate the VA's AI R&D capacity—*VA*

2. Develop effective methods for human–AI collaboration that attain optimal performance, efficiency, safety, and well-being via advanced AI techniques for human augmentation, visualization, and AI–human interfaces.

Key programs

Autonomous Swarms for Information-aware Mission Operations with Verification; and Interactive Learning for Mission Planning—*AFRL*;

Distributed and Collaborative Intelligent Systems and Technology—*ARL, CCDC*;

Few-Shot Learning; and AI Assistants for Text Search—*DHS*;

International Nobel-Turing Initiative—*AFOSR, DOE, NSF, OSD, and global partners*;

National Robotics Initiative 3.0: Innovations in Integration of Robotics (NRI-3.0)—*DOT, NASA, NIH, NIOSH, NSF, USDA*;

Autonomous Voice Assistant—*NASA*;

Real-time or near-real-time decision-making—*DHS, NSF, NIJ*;

Stimulating Peripheral Activity to Relieve Conditions—*NIH*;

AI Usability and User Trust—*NIST*;

Human-Centered Computing—*NSF*;

Active Interpretation of Disparate Alternatives; Artificial Social Intelligence for Successful Teams; Automated Rapid Certification Of Software; Causal Exploration of Complex Operational Environments; Competency Aware Machine Learning; Explainable Artificial Intelligence; Knowledge-directed AI Reasoning Over Schemas; Science of AI and Learning for Open-world Novelty; and Symbiotic Design of Cyber Physical Systems—*DARPA*;

Manned–Unmanned Teaming; and Assured DevOps of Autonomous Systems (ADAS)—*TRMC*

3. Understand and address the ethical, legal, and societal implications of AI: Develop design methods for trustworthy AI that align with ethical-legal-societal goals and expectations.

Key programs

Fairness in AI—*NSF, Amazon*;

Perceptions of AI/ML—*DHS*;

Driver Facial Privacy—*DOT, NSF*;

Ethical AI—*NASA*;

Agriculture and Food Research Initiative (AFRI)—*NIFA*;

AIM-AHEAD—*NIH*;

AI Risk Management Framework—*NIST*;

Explainable AI; and Bias in AI Systems programs—*NIST, NSF*;

Future of Work at the Human–Technology Frontier (FW-HTF)—*NSF*

4. Ensure the safety and security of AI systems so that they operate in a controlled, well-defined, and well-understood manner.

Key programs

Life Cycle Autonomy Assurance—*TRMC*;

Combat Vehicle Robotics Autonomy Safety Engineering—*Army, CCDC*;

Secure AI—*NIST*;

AI Enterprise Infrastructure and Cybersecurity Subcommittee—*JAIC*;

Trojans in Artificial Intelligence—*IARPA, NIST*;

Cybersecurity; and Software Verification and Validation—*NASA*;

Secure and Trustworthy Cyberspace—*NSF*;

Assured Autonomy; and Guaranteeing AI Robustness against Deception—*DARPA*

5. Develop shared public datasets and environments for AI training and testing to enable discovery, access, and use.

Key programs

Streamlined ML; Stratagem; and Fuel AI—*AFRL*;

Cloud Research Environments—*Census*;

Joint Analytic Computing Environment—*DHS*;

FAIR (findable, accessible, interoperable, and reusable) Data and Models for AI and ML—*DOE*;

National Institute on Aging Genetics of Alzheimer's Disease; Medical Imaging Data Resource Center; Genotype-Tissue Expression; and Trans-Omics for Precision Medicine—*NIH*;

Trusted Spectrum Sharing and Testing—*DOD, NASA, NTIA, NIST, NSF*;

Joint Automated Repository; Spectrum Sharing Models and Measurement Tools; and Smart Manufacturing—*NIST*;

Training Data for Machine Learning to Enhance Patient-Centered Outcomes Research Data Infrastructure; and Synthetic Health Data Generation to Accelerate Patient-Centered Outcomes Research—*ONC*;

Advanced Information Systems Technology; and Advancing Collaborative Connections for Earth System Science—*NASA*;

Convergence Accelerator—*NSF*;

Collecting Autonomy and AI Data at the Tactical Edge; Modeling and Simulation as a Service; and ADAS—*TRMC*;

VA Data Commons—*VA*

6. Measure and evaluate AI technologies through standards and benchmarks to address safety, reliability, accuracy, usability, interoperability, robustness, and security.

Key programs

Common Data Elements: Advance use of healthcare data standards in research (e.g., U.S. Core Data for Interoperability and Fast Healthcare Interoperability Resource)—*NIH*;

Applied Artificial Intelligence/Machine Learning/Deep Learning (AI/ML/DL)—*DHS*;

AI standards development—*NIST, all AI IWG agencies*;

AI validation and evaluation—*NIST*

7. Better understand the national AI R&D workforce needs: Grow the AI R&D workforce to ensure America leads the AI innovation of the future. *See the EdW PCA.*

8. Expand PPPs to accelerate advances in AI and strengthen the Nation's R&D ecosystem. *See also Key Coordination Activities below and Section 5 on the National AI Research Institutes, designed as multidisciplinary, multisector AI R&D, education, and workforce development endeavors.*

Key programs

Fairness in AI—*NSF, Amazon*;

National AI Research Institutes—*DHS, DOT, NSF, USDA, industry partners*;

DAF-MIT AI Accelerator—*DAF, Massachusetts Institute of Technology*;

Innovare Advancement Center—*AFRL, private partners*;

Autonomy Research Collaboration Network—*ARL, DOD*;

Academic/Industry Engagement and Acquisition Subcommittee—*JAIC*;

Digital Assistants for Science and Engineering—*NASA, SBIR/STTR partners*;

Center for Real Time Analytics—*DHS, NSF*;

Science and Technology Research Infrastructure for Discovery, Experimentation, and Sustainability (STRIDES) initiative—*NIH*;

National Cybersecurity Center of Excellence—*NIST, industry partners*;

AI Tech Sprint; and VA National AI Institute—*VA*;

Aviation Safety Information Analysis and Sharing: Analyze flight-recorded data and safety reports for safety incidents—*FAA, NASA, NTSB, and industry partners*;

Collaboration Research Alliance: Effect rapid transition of innovative S&T for Army modernization—*ARL, academia, industry*;

Multidisciplinary University Research Initiative—*OSD, tri-service, academia*

Key Coordination Activities

- Standards for AI: Work with Federal partners to define and establish shared AI standards. *All agencies; NIST serves as U.S. Government AI standards coordinator.*
- *Advanced Information Systems Technology:* Develop and apply AI/ML to Earth Science. *NASA*
- *Computer Vision:* Assess behavior of drivers and pedestrians to improve traffic safety. *FTA, FMCSA, NHTSA, NSF, NIST*
- Science & Technology Partnership Forum: Develop trusted autonomy technologies for use in space. *NASA, NRO, U.S. Space Force*
- Principal Investigator (PI) meetings: Review research, identify new applications, and discuss S&T gaps and barriers. *DARPA, DOD, DOE, DHS, DOT, NASA, NIFA, NIH, NIJ, NIOSH, NIST, NSA, NSF*
- *Joint Artificial Intelligence Center:* Coordinate military service and defense agency AI adoption efforts. *DOD, OSD*
- Video and Image Analytics (VIA) Team of the AI IWG: Document the Open Media Processing Framework. *DHS, FBI, FHWA, NIJ, NIST, NSF*
- Joint All-Domain Command and Control: Experiment with AI to connect sensors across military services into a single network. *Army, Navy, USAF*
- Artificial Intelligence & Technology Office: Coordinate AI R&D across the DOE Enterprise. *DOE*
- *Smart and Connected Communities*: Support AI R&D to solve problems facing U.S. communities. *NSF and local government agencies*

Computing-Enabled Human Interaction, Communication, and Augmentation (CHuman) PCA

CHuman R&D advances information technologies that enhance people's ability to interact with IT systems, other people, and the physical world; this includes R&D in social computing, human–human and human–machine interaction and collaboration, and human and social impacts of IT.[26]

Reporting Agencies: AHRQ, CDC, CMS, DOD, Navy, NASA, NIH, NIJ, NIOSH, NIST, NOAA, NSF, ONC, USAF, USDA

Strategic Priorities and Associated Key Programs

1. Develop cohesive sociotechnical systems that support collaboration and innovation, including systems that help people manage, verify, and disseminate information online; systems that help teams, crowds, and organizations coordinate productively; and systems that integrate diverse human teams having knowledge of both constructive and malicious human behaviors with ubiquitous computing, networking, data analytic, and knowledge representation systems.

Key programs

Clinical decision support (CDS) initiative: Develop grants and contracts to assist healthcare providers move patient-centered outcomes research into practice—*AHRQ, CMS, CDC, VA*;

Care transition research grants: Fund research to produce evidence and evidence-based tools to improve care transitions—*AHRQ*;

Human-Centered Computing: Fund research in human-computer interaction (HCI), taken broadly, integrating knowledge across disciplines—such as the social and behavioral sciences with computer and information sciences—in order to design new computing systems to amplify diverse humans' physical, cognitive, and social capabilities to accomplish individual and collective goals; to assess benefits, effects, and risks of computing systems; and to understand how human, technical, and contextual aspects of systems interact to shape those effects—*NSF*;

Explainable AI and Bias in AI Systems programs: Conduct foundational research to build trust in AI systems by improving explainability, avoiding bias, and preventing discrimination—*NIST*;

Fairness in AI: Fund computational research focused on fairness in AI, with the goal of contributing to the acceptance and deployment of trustworthy AI systems—*NSF, Amazon*;

Health IT safety research grants: Fund research on safe health IT practices specifically related to design, implementation, usability, and safe use of health IT by all users, including patients—*AHRQ*;

NRI-3.0: Build on the NRI program to support fundamental research that will accelerate the development and use of integrated robot systems, including systems that work seamlessly beside or cooperatively with people to assist them in every aspect of life—*DOT, NASA, NIH, NIOSH, NSF, USDA*;

Safe Use of Robotics in the Workplace: Evaluate potential benefits and risks of robots in the workplace and develop interventions and guidance for safe, effective human–robot interactions—*NIOSH*

2. Improve interfaces between humans and intelligent systems, including robots, intelligent agents, autonomous vehicles, and machine-learning systems, to accomplish complex missions.

[26] There is no IWG for this PCA; the NITRD Subcommittee and other IWGs coordinate CHuman activities.

Key programs

Usability grants: Focus on designing and implementing intuitive digital healthcare systems that readily support clinical workflow—*AHRQ*;

National Artificial Intelligence Research Institute on Human-AI Interaction and Collaboration: Support research on all the modalities through which people can collaborate with intelligent machines toward common goals—*NSF, industry partners*;

Human Systems Integration Architecture for Increasingly Earth-Independent Mission Operations: Enable crews to address mission anomalies using intelligent systems on spacecraft, and human-in-the-loop planning and coordination for unmanned aerial systems—*NASA*;

Intelligent Multi-UxV Planner w/Adaptive Collaborative Control Technologies: Allow a human operator and teams of autonomous machines to work together to accomplish missions—*USAF*;

Operations at Scale Against Adversaries: Use human–machine teaming with open-systems architecture to facilitate the use of any communications standard (e.g., NATO standardization agreement/STANAG 4586) to connect air, land, maritime vehicles, and potentially, cyber and space command and control—*USAF*;

Innovative Platform for Objective Monitoring of Instrumental Activities of Daily Living (IADL): Design and commercialize a robust platform for objective, continuous remote monitoring of IADLs in older adults at risk for dementia or Alzheimer's disease—*NIH*;

Machine Learning for HIV Prevention: Improve automation of secure data collection and prediction of individuals at high risk for infection as part of HIV prevention strategies—*NIH*;

Fecobionics Device: Develop a simulation tool to map colonic and anorectal neuromuscular function in a single examination as a replacement for multiple tests for anorectal function—*NIH*;

Person-Centered Mobile Apps for Alzheimer's Disease and Alzheimer's Disease-Related Dementia Family Caregivers: Improve patient self-care management, and reduce physiological, social, and psychological burdens for family caregivers through remote interactions with clinicians and support personnel—*NIH*

3. Promote education and workforce development in understanding human–IT interactions. In conjunction with investments in the EdW PCA, develop new instructional materials and teacher professional development models based on evolving educational and technological practices. *See the EdW PCA.*

Key Coordination Activities

- *Patient-Reported Outcomes (PRO) Learning Collaborative*: Meet annually with grantees to share innovative health IT strategies on how to collect and use PRO data in ambulatory care settings. *AHRQ*
- *National Webinars*: Broadcast recurring public webinars on health IT-related topics for grantees, healthcare providers, and researchers. *AHRQ*
- *Clinical Decision Support (CDS) Connect Work Group*: Gather stakeholder input regarding repositories and standards-based tools through public, patient-centered monthly meetings that feature presentations from CDS Connect users. *AHRQ, CDC, CMS, NIH, VA*

Computing-Enabled Networked Physical Systems (CNPS) PCA

CNPS R&D advances information technology-enabled systems that integrate the cyber/information, physical, and human worlds; this includes R&D of cyber-physical systems, Internet of Things, and related complex, high-reliability, real-time, networked, and hybrid computing and engineered systems.

Computing-Enabled Networked Physical Systems IWG

Participating Agencies: Army, BLS, DOE/OE, DOT/ITS JPO, FDA, FHWA, ITA, NASA, Navy, NIFA, NIH, NIST, NRC, NSA, NSF, NTIA, ONR, OSD, OSTP, USACE, USAF

The CNPS IWG coordinates Federal R&D to advance and assure integrated IT-enabled cyber, physical, and human systems. This spans complex, high-reliability, safety-/security-critical, real-time computing and engineered systems with varying degrees of autonomy and human–system interaction in such uses as automated vehicles, smart grids, manufacturing, intelligent defense systems, and smart cities.

Strategic Priorities and Associated Key Programs

1. Develop core science and engineering for CNPS technologies including unified foundations, models and analysis tools, system capabilities, interoperability standards, assurance approaches, and architectures.

Key programs

Develop the core research needed to engineer complex cyber-physical systems (CPS), some of which may also require dependable, high-confidence, or provable behaviors—*DHS, FHWA, NIFA, NIH, NSF*;

Support research projects that take a systems-oriented approach to development of novel computing and networking technologies, or to the enhancement of existing systems in any of several dimensions, or that explore new ways to make use of existing technologies—*NSF, NTIA*;

Develop state-of-the-art measurement solutions, reliable testing and certification methods, and robust implementation practices for scalable, interoperable, safe, secure, reconfigurable, reproducible, and resilient cyber-physical systems and Internet of Things (IoT) solutions and testbeds—*NIST, NSF*;

Secure design methodologies for trusted execution of high-assurance systems—*ONR*;

Support spectrum monitoring and surveying over the entire lifecycle of new radio technologies—*NTIA*

2. Support creation of new and emerging ideas for CNPS to enable safety and security spanning system design, development, and verification, including applications of digital twins, formal methods, and other concepts emerging from the CNPS IWG as well as related NITRD IWGs.

Key programs

Develop new concepts for transforming existing systems to integrate real-time learning and control for new environments and operating modes, and create supporting verification approaches that reconcile concepts of model-based verification with formal methods—*DHS, FHWA, NASA, NIFA, NIH, NSF*;

Support and enable automated vehicles to interact and communicate with infrastructure and other vehicles via cooperative driving automation—*DHS, DOD, DOT, FHWA, FMCSA, FTA, ITS JPO, MARAD, NASA, NHTSA, NSF*;

Leverage the development of lightweight simulation language and metrics to measure the quality of an adversarial influence strategy, and design models to simulate attacker and defender uses of ML—*ARL, NSA, NSF, OUSD R&E*;

Develop formal methods to automatically interrogate and extract interpretable formal models from deep neural networks, with a focus on providing an interrogation capability and framework that will answer queries from a domain expert—*NSA*;

Develop formalized multimodal data integration modeling and robust predictive analytic platforms to propel biomedical research into a new paradigm and offer *in silico* patient avatars from the totality of medical evidence available for precision medicine—*NIH*;

Develop rigorous and reproducible methodologies for designing and implementing correct-by-construction systems and applications with provable guarantees—*NASA, NSF*

3. Support advances in smart cities and communities by investing in multidisciplinary, multisector collaborations that leverage CNPS applications for solutions in areas such as public health and well-being, transportation and mobility, energy, smart infrastructure, agricultural and rural connectivity, emergency management, resilience, public safety, and water management.

Key programs

Accelerate the creation of the scientific and engineering foundations that will enable smart and connected communities to bring about new levels of economic opportunity and growth, safety and security, health and wellness, and overall quality of life—*FHWA, NIFA, NSF*;

Promote the formation, growth, and advancement of project teams of community leaders and private-sector innovators for replicable smart city solutions and teams-of-teams for smart city technology blueprints for transportation, public safety, data, and other application areas—*ITA, NASA, NIST, NSF, NTIA*;

Convene leaders of the Global City Teams Challenge leadership teams, industry, cities, state and regional associations, industry leaders, R&D researchers and universities, States, and Federal agencies to encourage innovation and collaboration to solve complex smart cities issues—*DHS S&T, NIST, NSF, NTIA*;

Establish a research and action competition in the Smart and Connected Communities domain designed to build a more cohesive research-to-innovation pipeline—*DHS S&T, DOE, NSF*;

Provide increased food and nutritional security and more viable and thriving rural communities through development of high-output and efficient controlled-environment urban agriculture systems—*NIFA, NSF*;

Coordinate the development of urban air mobility with the community through ecosphere working groups, including leveraging and supporting Smart Cities and Communities (SCC) efforts and blueprints—*FAA, ITA, NASA, NIST, industry partners*

4. Leverage CNPS R&D investment to facilitate multisector technology transfer to public and private systems.

Key programs

Support integration of cooperative driving automation R&D with new transportation system management and operations strategies—*DHS, DOD, FHWA, FMCSA, FRA, FTA, ITS JPO, MARAD, NHTSA, NSF*;

Enable consensus-based automated driving systems safety measurement methods for use by industry—*NHTSA, NIST*;

Support high-impact transition-to-practice activities in CPS and SCC programs—*FHWA, NSF*;

Develop and integrate computer and information science and engineering (S&E) approaches to support the advancement of health and medicine to better support the wide-ranging healthcare needs of the American people—*NIH, NSF*;

Stimulate CNPS-related innovations in the private sector and strengthen the role of Federal R&D in support of small businesses—*NIFA*

5. Promote inclusive education, training, and career development through curricula that integrates CNPS and by providing scientists and researchers venues for communication and collaboration. *See the EdW PCA.*

Key Coordination Activities

- *CPS Principal Investigator meetings:* Meet annually to assemble CPS researchers and multiple agency partners to review CPS research results. *DOD, DOE, DHS, DOT, NASA, NIFA, NIH, NIST, NSA, NSF*
- *All of Us*: Establish a one-million-volunteer participant group reflecting the Nation's genealogical and health diversity to contribute health data to leverage technology advances in genomics, computing, and data analytics, and to capitalize on mobile health technology. *NIH, public and private partners*
- *Global Cities Team Challenge Action Clusters:* Engage stakeholders to develop best practices and projects for foundational elements of smart cities ecosystems including such domains as agricultural and rural smart systems, smart buildings, smart regions, and smart states. *DHS, NASA, NIFA, NIST, NSF, NTIA*

Cyber Security and Privacy (CSP) PCA

CSP R&D advances protection of information, information systems, and people from cyber threats and prevention of adverse privacy effects arising from information processing; this includes R&D to deter, detect, prevent, counter, respond to, recover from, and adapt to threats to the availability, integrity, and confidentiality of information and information systems, along with R&D to address privacy goals of individuals and society related to direct and indirect effects of information processing.[27]

Cyber Security and Information Assurance (CSIA) IWG

Participating Agencies: Army, DARPA, DHS, DOE/CESER, DOT, IARPA, Navy, NIH, NIJ, NIST, NRC, NSA, NSF, OSD, Treasury, USAF

The CSIA IWG coordinates Federal R&D to protect information and information systems from cyber threats. This R&D supports the security and safety of U.S. information systems that underpin a vast array of capabilities and technologies in many sectors, including power generation, transportation, finance, healthcare, manufacturing, and national security.

Strategic Priorities and Associated Key Programs[28]

Federal cybersecurity R&D is a substantial portfolio. This section provides thematical highlights of the main lines of research pursued by those programs, mapped against the CSIA strategic priorities. The programs are listed in the accompanying FY2022 Federal Cybersecurity R&D Strategic Plan Implementation Roadmap.[29]

Defensive Areas

1. Deter: Develop methods to assess adversary levels of effort, results, and risks; provide for effective and timely attribution of malicious cyber activities to their sources; design robust investigative tools; and support information-sharing for attribution.

Key programs

Cyber deception—*ARL, DOE/CESER, ONR*;

Cyber attribution—*AFRL, DARPA*;

Active social engineering defense and attribution—*DARPA, NSF*;

Autonomous and agile cyber defense—*ARL, C5ISR, NSF, ONR, OSD*

2. Protect: Develop technologies to limit system vulnerabilities through design, construction, and verification, and to enforce security though techniques such as authentication, access control, and cryptography.

Key programs

Automated and autonomous cyber defense and operations—*ARL, C5ISR, DOE/CESER, NSA, NSF, ONR, OSD*;

Assured systems—*AFRL, DARPA, NIST, NSA, NSF, ONR*;

Resilient cyber, cyber-physical, and IoT systems—*AFRL, ARL, C5ISR, DARPA, DHS, DOE/CESER, HPCMP, NIH, NIST, NSA, NSF, ONR*;

Application, network, mobile, and hardware security—*AFRL, ARL, C5ISR, DARPA, DHS, DOE/CESER, NIST, NSA, NSF, ONR, OSD*;

[27] Both the CSIA and Privacy R&D IWGs report budgets under the CSP PCA.

[28] See Federal cybersecurity R&D priorities in https://www.nitrd.gov/pubs/Federal-Cybersecurity-RD-Strategic-Plan-2019.pdf.

[29] https://www.nitrd.gov/pubs/FY2022-Cybersecurity-RD-Roadmap.pdf

Configuration and vulnerability management—*DARPA, NIST, NSA, NSF*

3. Detect: Develop technologies to ensure that system owners and users have situational awareness and understanding of ongoing activities and can reliably detect malicious cyber activities.

Key programs

Cyber situational awareness—*AFRL, ARL, C5ISR, DARPA, DOE/CESER, HPCMP, NSA, OSD*;

Cyber maneuver and adaptation—*ARL*;

Malware detection and mitigation—*DHS, DOE/CESER, NIST, NSF, ONR*;

Machine learning for security—*DARPA, DOE/CESER, NIST, NSA, NSF, OSD*

4. Respond: Develop technologies to provide real-time assessment of system anomalies, provide adaptive response to disruptions, sustain critical functions, and enable automated recovery.

Key programs

Autonomous, agile, and adaptive cyber response technologies—*AFRL, ARL, C5ISR, DARPA, DOE/CESER, NSA, NSF, ONR, OSD*;

Countering cyber attacks—*DARPA, NSF, OSD*

Priority Areas

5. Artificial Intelligence: Develop solutions that enable automated cyber defense, minimize susceptibility of AI systems to attacks, and ensure that AI systems are explainable.

Key programs

AI for cybersecurity—*AFRL, ARL, C5ISR, DARPA, DOE/CESER, HPCMP, NIST, NSA, NSF, ONR, OSD*;

Cybersecurity of AI—*ARL, C5ISR, NIST, NSA, NSF, OSD*;

Standards for AI—*NIH, NIST*

6. Quantum Information Science: Develop technologies for securing quantum software and hardware and for developing countermeasures against quantum-based attacks.

Key programs

Quantum programming and protocols—*AFRL, DOE/CESER, NSF*;

Quantum-resistant cryptography—*NIST, NSF*

7. Trustworthy Distributed Digital Infrastructure: Develop technologies to provide secure and resilient communication and computing infrastructures that incorporate advanced wireless, cloud computing, IoT, and CPS resources.

Key programs

Wireless and network security—*AFRL, ARL, C5ISR, DARPA, DHS, DOE/CESER, NIST, NSF, NSA, OSD*;

Protection of cyber-physical and IoT systems—*AFRL, DHS, DOE/CESER, NSA, NSF, ONR*

8. Privacy: Develop solutions to enable privacy-protecting data processing and analytics and to provide for recovery from privacy violations.

Key programs *(See also the Privacy R&D IWG)**:***

Cryptography for privacy—*DOE/CESER, NSA, NSF*;

Privacy Framework—*NIST*

9. Secure Hardware and Software: Develop technologies to assure that the design and operation of IT hardware and software can be verifiably trusted and cannot be maliciously compromised.

Key programs

Software assurance—*AFRL, DARPA, DHS, DOE/CESER, NIST, NSA, NSF, ONR, OSD*;

Formal verification of software and hardware—*AFRL, DARPA, NSF, ONR*;

Secure microprocessors and IoT—*AFRL, NSA, NSF*

10. Education and Workforce Development: Develop and accelerate adoption of effective educational programs to prepare the Nation, at all education levels and in all sectors of society, for possible careers in cybersecurity and for safe and secure use of cyberspace. The following agencies have programs in these areas: *AFRL, DOE/CESER, NIST, NSA, NSF, ONR, OSD*

Key Coordination Activities

- Prepare the *Federal Cybersecurity R&D Strategic Plan Implementation Roadmap*: Provide annually as directed by the Cybersecurity Enhancement Act of 2014. *All CSIA IWG agencies*
- *Cryptographic standards development. NIST, NSA*
- *Standards development and standards setting:* Engage with national and international bodies (e.g., 3GPP, IETF, ISO, ANSI, IEEE) in developing and setting cybersecurity standards. *NIST, NSA, OSD*
- *Collaborative research with academia and industry:*
  - Cyber Research Alliance. *ARL, C5ISR*
  - Cyber Resilient Energy Delivery Consortium. *DOE/CESER*
  - Cyber-physical systems security. *DARPA, DOT, NIST, NSF*
  - National Cybersecurity Center of Excellence. *NIST*
  - Cyber/cyber-physical security public working groups. *NIST*
- *Cyber technology demonstrations. DARPA, NIST, NSA, OSD*
- Cybersecurity and privacy research workshops. *NSF*
- *DOD Cyber Community of Interest*: Provide oversight and coordination among DOD cyber S&T programs. *AFRL, ARL, C5ISR, DARPA, NSA, ONR, OSD*
- *National Centers of Academic Excellence in Cybersecurity. CISA, USCYBERCOM, DOD, NIST, NSF, NSA*
- *National Initiative for Cybersecurity Education (NICE) and annual NICE Conference/Expo*. Lead a robust multisector ecosystem for education and training, promotion of careers, and sustained development of a diverse skilled workforce in cybersecurity. *NIST, Community and Interagency Coordinating Councils*
- *CyberCorps Scholarship for Service, Advanced Technological Education programs. NSF*
- *Advanced Course in Engineering–cybersecurity. AFRL, NSA*
- *International collaborations:*
  - Science programs with Israel, Brazil, and Ireland. *NSF*
  - The Technical Cooperation Program Command, Control, Communications, Cyber, Information Systems Group with Australia, Canada, New Zealand, and the United Kingdom. *AFRL, ARL, C5ISR, NSA, ONR, OSD*
  - Cyber Research, Prototyping, and Transition of Capability Steering Group. *AFRL, ARL, NSA, OSD, Defence Science and Technology Laboratory (UK)*

Privacy Research and Development IWG

Participating Agencies: Army, Census, DHS, FTC, NARA, Navy, NIH, NIST, NSA, NSF, NTIA, OSD, USAF

The Privacy R&D IWG coordinates Federal R&D aimed at preventing adverse privacy effects arising from information processing, including R&D of privacy-protecting information systems and standards. This R&D supports advances in large-scale data analytics that can improve healthcare, eliminate barriers to education and employment, and increase efficiencies in the transportation and financial sectors while minimizing risks to individual privacy and possible harms such as discrimination, loss of autonomy, and economic losses.

Strategic Priorities and Associated Key Programs

1. Understand privacy desires and impacts.

Key programs

Develop models and conduct studies to understand peoples' privacy needs in different contexts—*Census, NIH, NIST, NSA, NSF*

2. Develop system design methods that incorporate privacy requirements and controls.

Key programs

Apply formal privacy safeguards to the 2020 Census and American Community Survey—*Census*;

Develop practical approaches for implementing privacy protections in data analytics systems—*Census, NIH, NIST, NSA, NSF*;

Provide methods for secure, privacy-preserving access to precision medicine data—*NIH, NSF*;

Develop privacy framework and standards-based tools and privacy engineering practices—*NIST*

3. Develop techniques to assure that information use is consistent with privacy rules.

Key programs

Build encryption for privacy protections—*NIH, NSA, NSF*;

Determine privacy engineering and technical standards for privacy—*NIST, NSA*

4. Develop solutions to enable user-driven controls and actions over data collection, use, and deletion.

Key programs

Protect privacy in networking, mobile computing, and the IoT—*NSA, NSF*;

Advance data sharing under patient consent—*NIH, NSF*

5. Develop solutions for minimizing privacy risks while maximizing utility of data analytics.

Key programs

Adopt differential privacy for the 2020 Census—*Census*;

Develop techniques to assure privacy protections in analytical and ML systems—*NIH, NIST, NSA, NSF*;

Develop secure and private collaboration environments—*Census, NIH, NSF*

6. Develop solutions for recovery from privacy violations.

Key programs

Develop techniques to mitigate privacy violations and support privacy recovery—*NIST, NSF*

Key Coordination Activities

- *NIST Privacy Engineering Collaboration Space:* Actively support this online forum for sharing use cases and tools to advance privacy engineering. *All Privacy R&D IWG agencies*
- *Workshops:* Continue the annual workshops on privacy research topics such as privacy controls, privacy framework, algorithmic transparency, and consumer privacy protections. *FTC, NIST, NSF*
- *Federal Privacy Council:* Participate actively in this interagency forum organized to improve the privacy practices of Federal agencies. *FTC, NIST, NSF*
- *Technical privacy guidelines:* Develop and coordinate recommendations, guidelines, and standards for privacy-preserving technologies and privacy risk assessment methodologies. *Census, NIST*
- *International collaborations:*
  - Engage in international privacy standards development. *NIST*
  - Co-fund privacy research activities with the Netherlands, Ireland, and Israel. *NSF*

Education and Workforce (EdW) PCA

EdW R&D advances the use of information technology to improve education and training; this includes IT to enhance learning, teaching, assessment, and standards, as well as preparation of next-generation cyber-capable citizens and professionals. Investment planning is also guided by the 2018 Federal STEM Education five-year plan, *Charting a Course for Success: America's Strategy for STEM Education*.[30,31]

Reporting Agencies: Census, DAF (USAF & USSF), DHS, DOC, DOD, DOE/NNSA, DOE/SC, DOJ, DOT, FCC, FTC, HHS, NASA, Navy, NIFA, NIH, NIST, NSA, NSF, ODNI, ONC, SSA, USGS, VA

Strategic Priorities and Associated Key Programs

1. Ensure a consistent flow of skilled workers capable of using the tools and methods of the economy of the future by creating opportunities to teach and learn computational literacy and computational thinking at all educational levels. Opportunities must span multiple STEM and IT domains; actively support diversity and inclusion; and include internships, fellowships, and early-career research opportunities.

Key programs

AFRL Scholars Program: Offer stipend-paid internships for K–12 educators, high school students, and undergraduate, and graduate-level students pursuing STEM degrees—*AFRL*;

Census Academy: Set up and develop a virtual hub for teaching/learning data skills for all skill levels—*Census*;

Science, Mathematics, And Research for Transformation Scholarship-for-Service Program: Combine educational and workforce development opportunities for bachelors, masters, and PhD students to gain technical skills in critical STEM fields and support the DOD mission—*DOD*;

Student access to HPC resources (*various programs*): Provide access to HPC resources to undergraduate, graduate, doctoral, and post-doctoral students to pursue research and applications and solve complex science, medical, and engineering problems—*DOE/NNSA, DOE/SC, HPCMP, NIH, NIST, NSF*;

Research, training, and fellowship programs in biomedical and health informatics, quantitative and computational biology, and allergies and infectious disease data science—*NIH*;

Brain-based Neurorobots: Introduce high school students to neuroscience, neurocomputation, and AI concepts using robots controlled by computer simulations of biological brains—*NIH*;

Coding it Forward Civic Digital Fellowship: Provide 10 weeks of hands-on experience with biomedical data-related challenges—*NIH*;

Graduate Fellowship Program: Support doctoral students in STEM research to advance NIJ's mission—*NIJ*;

NIST International and Academic Affairs Office: Offer STEM-related educational experiences ranging from K–12 to postdoctoral research associateships related to the NIST mission—*NIST*;

K–12 bootstrapping activities: Initiate STEM activities with high schools that are feeders for HBCUs—*NSA*;

Computer Science for All Research and Researcher-Practitioner Partnerships (RPPs): Fund research and RPPs to bring computer science and computational thinking to all schools at the pre-K–12 levels—*NSF*;

[30] https://trumpwhitehouse.archives.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

[31] There is no IWG for this PCA; the NITRD Subcommittee and other IWGs coordinate EdW activities directly.

Computer Science Principles–Cyber: Develop cybersecurity instructional materials aligned with the College Board's Advanced Placement® Computer Science Principles exam and course framework—*NSF*;

Computing in Undergraduate Education: Fund teams of institutions of higher education in reenvisioning the role of computing in interdisciplinary collaboration within their institutions—*NSF*;

Research Experience for Undergraduates and CyberCorps® Scholarship for Service: Fund research experiences for undergraduates (for CyberCorps, providing tuition for cybersecurity studies in exchange for a Federal employment condition), including by groups long underrepresented in STEM and IT fields—*DOD, NIH, NSF*;

JROTC Cyber Academy: Pilot a 10-week program modeled on the Air Force JROTC Flight Academy—*NSF*;

Computer and Information Science and Engineering Graduate Fellowships: Increase the number of diverse, domestic graduate students pursuing research and innovation careers in computer science, computer engineering, and information science—*NSF*;

Cyberinfrastructure for Sustained Scientific Innovation: Supply and sustain the necessary resources such as software libraries, tools, and platforms to support teaching and research—*NSF*;

NSF Research Traineeship: Explore ways for graduate students in research-based master's and doctoral degree programs to develop the skills, knowledge, and competencies needed to pursue a range of STEM careers, particularly in high-priority areas—*NSF*;

Computational Center for Earth Sciences: Allow students to work on USGS real-world science projects via internships and class projects, and co-develop STEM scientific computing curricula with academia—*USGS*

2. Prepare all Americans, through computational thinking and literacy lifelong learning programs in the workplace and community, to successfully participate in the economy and society of the future.

Key programs

Education and community development programs: Include development of a technology- and data-savvy workforce ready for jobs within the food and agricultural sciences—*AFRI, NIFA*;

Machine Learning Bootcamp: Develop and execute intensive ML "bootcamps" for civilian and military scientists and engineers and acquisition leaders to build the needed workforce—*AFRI, AFRL*;

Learning Health System Mentored Career Development: Train clinician and research scientists to conduct patient-centered research to improve quality of care and patient outcomes—*AHRQ, Patient-Centered Outcomes Research Institute*;

Exascale Computing Project training program: Ensure that the scientific community can regularly receive training to exploit new technologies and best practices—*DOE*;

Office of Science Early Career Research Program: Provide support to researchers during the early, often most formative, career years—*DOE*;

Intelligent Transportation Systems (ITS) Professional Capacity Building Program: Provide free training to practitioners, students, and instructors to help build skills in ITS technologies—*DOT*;

Leverage professional and academic development programs to increase the knowledge and skills of the workforce, including encouraging and rewarding publishing in academic journals—*HPCMP*;

NASA Digital Transformation team: Identify means (either existing or that need development) to upskill the NASA workforce (e.g., management, mission area experts, scientists, researchers) in AI—*NASA*;

Augmented Reality System (for clinical caregivers) and National Neuroscience Curriculum Initiative Synapse (for medical professionals): Provide tools to upskill existing healthcare workers—*NIH*;

NICE Workforce Framework for Cybersecurity: Provide a common taxonomy for use by learners, educators, and employers to address life-long learning in cybersecurity work roles or career pathways—*NIST*;

Future of Work at the Human Technology Frontier: Fund convergent research to understand and develop the human-technology partnership, including understanding the risks and benefits of new technologies on workers and work, and fostering lifelong and pervasive learning—*NIOSH, NSF*;

Data Science Corps: Provide practical experiences, teach new skills, and offer learning opportunities in different settings in data science—*NSF*;

Faculty Early Career Development Program and Research Initiation Initiative programs: Support research independence among early-career academicians in computer and information S&E—*NSF*;

Training-based Workforce Development for Advanced Cyberinfrastructure: Prepare, nurture, and grow the Nation's scientific research workforce for creating, utilizing, and supporting advanced cyber-infrastructure to enable and potentially transform fundamental science and engineering research—*NSF*

3. Promote coordination and collaboration among Federal agencies and business, educational, and nonprofit communities to develop a persistent and robust U.S. IT education ecosystem including educational programs, tools, and technologies.

Key programs

Science and Technology Policy Fellowships: Empower partnerships with industry and government—*DHS*;

Enhance training of clinician and research scientists to conduct health IT-related research, develop new evidence, and improve the quality and safety of care—*AHRQ, NIH, NSF*;

Research on Emerging Technologies for Teaching and Learning: Fund exploratory and synergistic research in emerging technologies (e.g., AI, robotics, and immersive or augmenting technologies) for teaching and learning in the future—*NSF*;

Broadening Participation in Computing Alliances: Extend the national and regional collaborations of academic institutions, educators, professional societies, community organizations, and industrial partners to increase the number and diversity of college graduates in computationally intensive disciplines—*NSF*;

DAF-MIT AI Accelerator: Research fundamental advances in AI to improve Air Force operations and address societal needs—*DAF, Massachusetts Institute of Technology*;

U.S. Naval Academy Research: Collaborate with other universities to provide Academy students with research experience—*DOD, academic partners*;

Academic/Industry Engagement and Acquisition Subcommittee: Maximize outreach to traditional and nontraditional partners to develop and incorporate agile methods for training and tools—*JAIC*;

Innovare Advancement Center: Build alliances aiming to innovate in critical areas—*AFRL, academia, industry*;

Open Campus: Build enduring research partnerships to solve key Army challenges—*ARL, academia, industry*;

Predictive Science Academic Alliance: Engage the academic community in advancing science-based modeling and simulation—*DOE/NNSA*;

National AI Research Institutes:[32] Advance AI innovation across issues of national importance including education and human resource development—*DHS, DOT/FHWA/ITS JPO, NSF, USDA, industry partners*;

AI Tech Sprints and National Artificial Intelligence Institute: Incentivize a whole-of-nation AI-able ecosystem to address veterans' health challenges—*VA, academic and industry partners*;

HPC performance-based, incentive-based contracting: Support the hiring of HPC subject matter experts from various sources such as small businesses and universities—*HPCMP*;

Supporting Teachers in Responsive Instruction for Developing Expertise in Science (STRIDES) project: Set up novel partnerships to broaden teachers' access to/training on the latest data science services and tools—*NSF*;

Data and Technology Advancement National Service Scholar Program: Recruit data and computer scientists from industry to work on grand challenge biomedical problems—*NIH*;

National Cybersecurity Center of Excellence: Partner with industry, government agencies, and academic institutions to enable the creation of practical guidance and cybersecurity solutions—*NIST*;

NICE Interagency and Community Coordinating Councils: Assemble representatives of Federal agencies, State governments, academic (K–12 and higher education), and industry entities to consult, communicate, and coordinate on projects aimed at cybersecurity education, training, and workforce development—*NIST*;

Joint Center for Quantum Information and Computer Science: Assemble computer scientists, quantum information scientists, and communication scientists to conduct world-class research in QIS—*NIST, NSA*;

OnRamp II: Continue work to foster educational partnerships between NSA and academic institutions to promote a strong and diverse STEM pipeline—*NSA*;

GenCyber: Provide summer cybersecurity camp experiences for K–12 students and teachers—*NSA, NSF*;

Big Data Regional Innovation Hubs: Engage local and state governments, local industry and nonprofits, and regional academic institutions in big data research and education to address fundamental issues in data science research and training with a focus on regional issues—*NSF*;

Big Data Scientist Training Enhancement Program: Provide a graduate-level fellowship program that delivers training in understanding, managing, and applying big data and modeling in health services, clinical, and/or bioinformatics research settings, aimed at innovation to improve healthcare—*NCI, VA*

[32] See also Section 5 on the National AI Research Institutes.

Electronics for Networking and Information Technology (ENIT) PCA

Note: This NITRD PCA was approved by the NITRD Subcommittee and by NSTC in May 2021 for addition to the NITRD family of PCAs. FY2022 preliminary agency investments in the ENIT PCA are included in the budget tables in Section 2. Detailed information on agency activities for the ENIT PCA will be included online and in the FY2023 NITRD Supplement to the President's Budget.

ENIT R&D advances micro- and nanoelectronics design, architecture, validation, and testing across the networking and information technology hardware design stack; this includes methodologies for scalable energy-efficient systems, silicon and/or non-silicon technologies, and implementations in computing and communications architectures.

Enabling R&D for High-Capability Computing Systems (EHCS) PCA

EHCS R&D advances high-capability computing and development of fundamentally new approaches in high-capability computing; this includes R&D in hardware and hardware subsystems, software, architectures, system performance, computational algorithms, data analytics, development tools, and software methods for extreme data- and compute-intensive workloads.

High End Computing (HEC) IWG

Participating Agencies: DOD, DARPA, DOE/NNSA, DOE/SC, NASA, NIH, NIST, NOAA, NSA, NSF, OSD, USGS

The HEC IWG coordinates Federal R&D that extends U.S. leadership in advanced computing and enables transformative research to support the Nation's economic competitiveness, security, and leadership in science and engineering. EHCS research ensures the development of technologies critical to preparing for the next computing revolution and to overcoming challenges critical to ensuring continued progress in computing capabilities while ensuring that these technology advancements support national priorities. Advances in high-capability computing (HCC) impact the full spectrum of devices and open innovation prospects in areas such as precision medicine, advanced manufacturing, and autonomous machines.

Strategic Priorities and Associated Key Programs

1. Research and develop the innovative approaches and technologies that are critical to the delivery of extreme-scale heterogeneous computing systems to increase scientific insight and accelerate new discoveries.

Key programs

Exascale Computing Project (ECP): Continue to prepare for the sustainable delivery of the exascale software and systems—*DOE/NNSA, DOE/SC*;

Investigate interconnect and network technologies and explore advanced architectures—*DOE/NNSA*;

Research and develop the software stack for highly heterogenous HCC, and develop domain-aware AI algorithms, programming tools, and runtime environments to support new AI workflows—*DOE/SC*;

Benchmark emerging architectures to understand limits of scalability for strategic applications—*HPCMP*;

Advance extreme-scale computing systems: Enhance testbed computing programs to test various architecture options, and continue to modernize applications by developing algorithms and preparing scientific applications to ensure software performance and portability on new architectures—*NASA*;

Develop new methods to compress and store data to simplify computation access to these resources—*NIH*;

Study scaling and efficiency of current and future algorithms for various computing architectures, including performance I/O, scaling, and using AI to tune parameters for codes—*DOD, DOE/SC, NASA, NOAA, NSF*;

Principles and Practices of Scalable Systems program: Support research to increase scalability in large-scale parallel computer systems—*NSF*

2. Research and develop technologies to make breakthroughs in HCC's most pressing challenges and pioneer new digital and nondigital computing frontiers to take computing beyond Moore's Law for fueling innovations and discoveries that will shape the future computing ecosystem.

Key programs

Develop AI-enabled high-performance simulation and computing technologies—*DOE/NNSA*;

Continue research to advance quantum computing, information science, and networking—*DOE/NNSA, DOE/SC, NASA, NIST, NSA, NSF*;

Develop software tools or bio-inspired algorithms for neuromorphic computing—*DOE/SC, NIST*;

Develop superconducting, optoelectronic computation devices—*NIST*;

Explore and adapt highly integrated high-performance architectures and non–von Neumann architectures to strategic applications and exploit state-of-the-art neuromorphic and deep learning accelerators for traditional, edge, and physics-based ML—*HPCMP, NRL*

3. Research and develop new approaches and techniques to improve programmability, portability, and usability of high capability computing to boost the productivity of the HCC ecosystem.

Key programs

ECP: Continue to develop programming models to address performance portability for next-generation node architectures—*DOE/SC*;

Leverage Federal agency research, development, and demonstrations of algorithms, tools, libraries, workflows, data management, data analysis, and visualization to enable DOD productivity on next-generation architectures—*HPCMP*;

Develop data and computing services in the cloud, and support code porting and algorithm development projects for software performance and portability on new architectures—*NASA*;

Build a cloud-based data science ecosystem, including tools—*NIH*;

Identify software abstractions for parallelism targeting high-end heterogeneous compute node at scale—*NIST*;

Software Engineering for Novel Architectures: Continue to support this program to refactor critical codes such that newer, nontraditional architecture can be leveraged for increased performance—*NOAA*

4. Develop the future HEC workforce. *See the EdW PCA.*

Key Coordination Activities

- Enhance research in cancer and drug discovery with HCC capabilities: Continue collaborations in analytics, and tools and support projects. *DOE/NNSA, DOE/SC, NIH*
- *Project 38:* Explore vendor-agnostic architectural options. *DOE/NNSA, DOE/SC, NSA*
- *NSTC Subcommittee on Future Advanced Computing Ecosystem (FACE):* Participate in the work of the Subcommittee and support drafting of the FACE Strategic Plan implementation roadmap. *HEC IWG agencies, other agencies*

High-Capability Computing Infrastructure and Applications (HCIA) PCA

HCIA investments advance operation and utilization of systems and infrastructure for high-capability computing, including computation- and data-intensive systems and applications; directly associated software, communications, storage, and data management infrastructure; and other resources supporting high-capability computing.

High End Computing IWG

Participating Agencies: DOD, DOE/NNSA, DOE/SC, NASA, NIH, NIST, NOAA, NSA, NSF, OSD, USGS

In addition to coordinating EHCS R&D, the HEC IWG coordinates Federal activities to provide HCC systems and infrastructure (including expertise necessary to effectively use the HCC systems) and develop algorithms and applications to accelerate scientific discoveries and technological innovations in areas such as advanced weapons, materials discovery and design, energy applications, Earth and space science, early-stage research of advanced technologies, detection and treatment of diseases, forecasting and hazard response planning, and many other S&E applications vital to our Nation.

Strategic Priorities and Associated Key Programs

1. Acquire, operate, and provide to researchers HCC systems with the varying capabilities required to meet critical national needs and support research and education across all S&E areas.

Key programs

Continue operations and provide leadership-class HCC at Leadership Computing Facilities Argonne (Theta, Aurora) and Oak Ridge (Summit, Frontier), and deploy the Perlmutter supercomputer at the National Energy Research Scientific Computing Center—*DOE/SC*;

DOD Supercomputing Resource Centers: Provide computing capacity and capability to the DOD community at various levels of classification and provide HPC in Cloud—*HPCMP*;

NASA High-End Computing Portfolio: Provide HCC capability to NASA S&E communities and computational projects—*NASA*;

Provide HCC for AI/DL research—*NIST*;

Research and Development High Performance Computing System: Provide researchers and collaborators access to HCC systems—*NOAA*;

Provide and support HCC through the Leadership-Class Computing program and the National Center for Atmospheric Research–Wyoming Supercomputing Center program; HCC resources through the Advanced Computing Systems and Services program; and campus HCC clusters through the Major Research Instrumentation program—*NSF*;

Advanced Research Computing: Provide computational platforms for development and exploration of scientific codes—*USGS*

2. Develop algorithms and applications software for current and next-generation HCC platforms to maintain and improve the performance of existing codes to support and advance applications vital to the Nation's security and economy and individual well-being.

Key programs

Scientific Discovery through Advanced Computing partnerships: Maximize effective use of current HCC platforms for science, and continue to prepare algorithms, applications, and workflows for current and next-generation HCC platforms—*DOE/SC*;

Develop DOD multiphysics applications and enhance and optimize applications and algorithms to address DOD research, development, test and evaluation, and acquisition engineering requirements—*HPCMP*;

Modeling, Analysis, and Prediction: Modernize models, port codes, and refactor major applications to next-generation HCC platforms—*NASA*;

Develop analytics and algorithms, and support multiscale modeling of biomedical processes for improved disease treatment and advancing understanding of the human body—*NIH*;

Develop algorithms, modeling tools, and computation methods for measurement science applications—*NIST*;

Computational and Data-Enabled Science and Engineering program: Support research in new algorithms and techniques in computational and data analysis to enable major S&E breakthroughs—*NSF*;

Continue to develop and enhance applications and models for hazard response and forecasting and develop the pipelines involving simulations and analytics—*USGS*

3. Develop and provide an HCC ecosystem to a diverse user community, including facilities and resources, and enhance the infrastructure and ecosystem needed to support U.S. leadership in S&E.

Key programs

DOE allocation programs: Provide researchers access to and support in using leadership computing facility resources—*DOE/SC*;

Provide DOD users computational tools, enterprise administration and user support, computational expertise, HCC in the cloud interfaces, and HCC systems and networking—*HPCMP*;

Develop and provide computing and data services in the cloud to NASA S&E and open science projects—*NASA*;

STRIDES initiative: Create an interoperable data ecosystem by federating the NIH cloud-enabled data platform to provide accessible computational and data storage capabilities for biomedical research—*NIH*;

Support the Partnership to Advance Throughput Computing; the Cyberinfrastructure for Sustained Scientific Innovation Program to develop integrated cyberinfrastructure software and data services; and the Extreme Science and Engineering Discovery Environment (XSEDE) to provide support for HCC, storage, visualization, and data services—*NSF*;

Provide on-premises/cloud hybrid HCC systems, data management services, and file systems—*USGS*

4. Develop resources and tools to lower barriers to HCC access, improve usability, and support collaborations as means to increase productivity and impact. (*See also Key Coordination Activities.*)

Key programs

Develop and provide ECP software development kits to the community, and continue to support the DOE National Energy Research Scientific Computing Center and Oak Ridge and Argonne

Leadership Computing Facilities, including training, outreach, and application readiness for future system upgrades—*DOE/SC*;

HPC Portal: Develop intuitive interfaces to provide users seamless and secure access to DOD HCC environments, including cloud—*HPCMP*;

Develop web-based HPC application interfaces and continue to consolidate code repositories and support open source code development and use of GitHub to enhance collaboration and enable community development—*NASA*;

Develop tools for modeling and analysis for biomedical research—*NIH*;

XSEDE: Support outreach and educational activities to lower barriers to access for students and underrepresented groups—*NSF*;

Establish a framework for an Earth-system predictive capability that integrates data, models, and tools incorporating modern information technologies—*USGS*

Key Coordination Activities

- *HCC and HCC resources:* Provide and support the HCC systems and the HCC resources necessary for effective use of HCC systems. *DOE/SC, HPCMP, NASA, NIH, NSF, USGS*
- *Provide HCC compute core hours*[33] *for applications vital to the Nation. DOE/SC, HPCMP, NASA, NIH, NSF*
- *Hydro-Terrestrial Earth Systems:* Develop a community computational testbed. *DOE/SC, NSF, USGS*

[33] Term for the number of processor units (cores) used to run a simulation multiplied by the duration of the job in hours.

Intelligent Robotics and Autonomous Systems (IRAS) PCA

IRAS R&D advances intelligent robotic systems; this includes R&D in robotics hardware and software design and application, machine perception, cognition and adaptation, mobility and manipulation, human–robot interaction, distributed and networked robotics, and increasingly autonomous systems.

Intelligent Robotics and Autonomous Systems IWG

Participating Agencies: Army, DHS, DOD, DOI, DOJ, DOT, FAA, NASA, Navy, NIH, NIJ, NIOSH, NIST, NMIO, NRC, NRO, NSA, NSF, OSD, USAF, USDA

The IRAS IWG coordinates Federal R&D in accelerating the development and use of IRAS in workplaces, hospitals, communities, and homes. IRAS targets R&D for robust, safe, ethical, resilient, and efficient robots and advanced robotics systems that assist people in their work and everyday lives.

Strategic Priorities and Associated Key Programs

1. Advance safe, efficient human-robot teaming and interactions to increase quality of work and life.

Key programs

Mind, Machine, and Motor Nexus; and Robust Intelligence—*NSF*;

Space Technology Research Grants; and Aeronautics University Leadership Initiative—*NASA*;

NRI-3.0—*DOT, NASA, NIH, NIOSH, NSF, USDA*;

Inclusive Design Challenge; and Complete Trip–ITS4US Deployment Program—*DOT/FHWA/ITS JPO;*

Robot-Assisted Cognitive Training for Socially Isolated Older Adults with Mild Impairment; and Social Assistive Robot Interface for People with Alzheimer's and Other Dementia to Aid in Care Management—*NIH*;

Risk Factors with Robot-Related Workplace Injuries; Safety Features and Interventions; and Human-Robot Interface and Safety Communication—*NIOSH*;

Research on countering unmanned aircraft systems—*NIJ*;

Performance of Human-Robot Interaction—*NIST*;

Cognitive Systems for Human-Machine Teaming; and Science of Autonomy—*Navy*

2. Improve intelligent physical systems to robustly sense, model, act, plan, learn, and behave ethically in complex and uncertain situations.

Key programs

Dynamical Systems and Control Theory—*USAF*;

AI for Maneuver and Mobility; and Convergence of Lethality, Protection, and Autonomy to Dominate Ground Combat—*Army*;

Game-Changing Development; Smart and Autonomous Systems for Space; and NASA Innovative Advanced Concepts—*NASA*;

Helping to End Addiction Long-term programs—*NIH*;

Safety Standards, Certifications, and Regulations; and Research-based Workplace Fatality Investigations and Injury Surveillance—*NIOSH*;

Measurement Science for Manufacturing Robots—*NIST*;

Performance of Human–Robot Interaction—*DOD, NIST, NRL*;

Foundational Research in Robotics; and Future of Work at the Human–Technology Frontier—*NSF*;

Assured Development and Operations of Autonomous Systems; Autonomous Mobility Through Intelligent Collaboration; and Science of Autonomy—*OSD, tri-services, academic and industry partners*

3. Advance wearable robotic fabrics and systems, including exoskeletons and exosuits.

Key programs

Army Futures Command Exoskeleton Capabilities Development—*Army*;

Compliant and Configurable Soft Robotics Engineering—*DOD, NSF*;

AI to Address Chronic Disease—*NIH*;

NASA Space Technology Research Grant—*NASA*;

Automated Exo-Suit Ergonomic Assessment—*Navy*;

Exoskeletons for Construction, Manufacturing, Mining, and Healthcare—*NIOSH*;

Mobility Performance of Robotic Systems—*NIST*;

Disability and Rehabilitation Engineering—*NSF*

4. Improve resilience in robotics and its applications.

Key programs

Combat Vehicle Robotics Autonomy Engineering Evaluation Testing—*Army*;

Applied Information Systems Research; Concepts for Ocean Worlds Life Detection Technology; and Space Technology Research Grants—*NASA*;

Smart and Connected Health—*NIH, NSF*;

Hardiness of robotic systems in harsh mining environments—*NIOSH*;

Agility Performance of Robotic Systems—*NIST*;

Critical Tests for Machine Understanding for Human-Machine Teaming—*OSD*

5. Promote ethics and broader participation in robotics.

Key programs

Bridge2AI—*NIH*;

Research on Emerging Technologies for Teaching and Learning—*NSF*

Key Coordination Activities

- *PI meetings*: Review research, identify new applications, and discuss S&T gaps and barriers. *AFOSR, DHS, DOD, DOE, DOT, NASA, Navy, NIFA, NIH, NIOSH, NIST, NSA, NSF, ONR, USDA*
- *Advanced Robotics for Manufacturing Institute*: Develop open-source, interoperable performance metrics and test methods. *Army, NASA, Navy, NIOSH, NIST, USAF, and academic and industry partners*
- Metrics, Evaluation, and Software Infrastructure: Develop open source metrics, performance test methods, and interoperability. *Army, Navy, NIST, USAF, and industry partners*
- *Lunar Surface Innovation Consortium*: Advance lunar surface exploration. *NASA, academic and industry partners*
- *OSHA–NIOSH Alliance Program:* Increase workplace safety related to intelligent and autonomous systems, share technical knowledge and best practices, improve hazard

awareness, and identify research on collaborative robot technologies and systems. *NIOSH, OSHA, industry partners*

- *Safety and other standards development*: ASTM Committees E54 on Homeland Security Applications and F48 on Exoskeletons and Exosuits; Manufacturing Robot and other Safety Standards: Develop/set terminology, safety, and performance standards for robots, industrial vehicles, exoskeletons, mobile manipulators, etc. *DHS, DOD, DOE, DOI, DOJ, FAA, NIH, NIOSH, NIST, NRC, NRL, OSHA, State*
- *Drone Safety Standards:* Participate in the Unmanned Aircraft Systems Standardization Collaborative, and add worker safety considerations to the ANSI Roadmap. *ANSI, DHS, DOI, FAA, ITA, NASA, NIST*
- *Trusted Autonomy:* Identify and prioritize development of self-sustaining and reliable technologies that are certified for mission use. *DOD, NASA, NRL, NRO, USAF*
- *Stocktake Autonomy and AI Working Group:* Engage in bilateral efforts on autonomy and AI-enabled brigade support; collaboration infrastructure and enablers; joint autonomy and AI toolbox; and research in autonomous and AI-based systems. *OUSD R&E, DOD Service Labs, Defence Science and Technology Laboratory (UK)*
- *Technology Cooperation Sub-Committee (TCSC) Autonomy and AI Working Group:* Work bilaterally with the Republic of Korea (ROK) on cyber and drone defense, autonomous situation awareness, scalable teaming, unmanned ground robots. *DOD service labs, OUSD R&E, ROK ADD*

Large Scale Data Management and Analysis (LSDMA) PCA

LSDMA R&D advances extraction of knowledge and insights from data; this includes R&D of the capture, curation, provenance, management, access, analysis, and presentation of large, diverse, often multisource, data.

Big Data (BD) IWG

Participating Agencies: Army, Census, DARPA, DHS, DOE/NNSA, DOE/SC, NARA, NASA, NIH, NIST, NOAA, NRO, NSA, NSF, OSD, USAF, USGS

The BD IWG coordinates Federal R&D to enable effective analysis, decision-making, and discovery based on large, diverse, real-time data. LSDMA R&D expands big data, data science capabilities to collect, store, access, reuse, analyze, and provide governance for big data accelerating scientific discovery and innovation, providing the foundation for algorithm-driven businesses, and creating new capabilities critical to the Nation.

Strategic Priorities and Associated Key Programs

1. Maximize the use of large-scale data resources through foundational research of innovative tools and methodologies to solve problems of national and societal importance.

Key programs

Cloud Research Environments—*Census*;

Cybersecurity and Critical Infrastructure—*DHS*;

Chios-Permissioned Blockchain—*DHS, NIST, NSF*;

Research in *in situ* data management, storage system and I/O, data analysis and visualization, and codesign of AI/ML technologies with data models, applications, and emerging hardware—*DOE/SC*;

Helping to End Addiction Long-term Initiative—*NIH*;

Transdisciplinary Research in Principles of Data Science; Computational and Data-Enabled Science and Engineering; and Principles and Practice of Scalable Systems—*NSF*

2. Advance the trustworthiness, reliability, accuracy, performance, generalizability, and ethical integrity of data-driven discovery and decision making to better support innovation in S&T and IotF.

Key programs

Semantic Forensics—*DARPA*;

National AI Research Institute for Trustworthy AI—*DHS, NSF*;

Fundamental research into scientific machine learning—*DOE/SC*;

NCI Cancer Research Data Commons—*NIH*;

Harnessing the Data Revolution: Institutes for Data-Intensive Research in Science and Engineering Phase I, Secure and Trustworthy Cyberspace—*NSF*;

AI risk management framework—*NIST*

3. Facilitate the discoverability, interoperability, and reusability of diverse data that are scalable and agile enough to meet the needs of innovation.

Key programs

Next-Generation Secure Multiparty Computation Architectures; Real-time Analytics for Multi-latency Multiparty, Metroscale Networks; and Rapid Deployment Research and Development Capabilities—*DHS*;

FAIR Data and Models for AI & ML—*DOE/SC, NIH*;

Cloud Based Interoperability Platforms—*NIH*;

Big Data Governance and Metadata Management: Develop scalable a FAIR data standard framework and a series of data quality standards—*NIST*;

Convergence Accelerator; Cyberinfrastructure for Emerging Science and Engineering Research; EarthCube; and Cyberinfrastructure for Sustained Scientific Innovation (interoperability and reuse of data)—*NSF*

4. Support real-time analytics by reducing latency between data ingest, analysis, and decision-making.

Key programs

Warfighter Analytics using Smartphones for Health—*DARPA*;

Real-Time Machine Learning—*DARPA, NSF*;

Real-time Analytics for Multi-latency, Multi-party, Metro-scale Networks—*DHS*;

Develop data and compute infrastructure; and research data reduction and co-design of data analysis and reuse at scientific user facilities—*DOE/SC*;

Develop methods and analytics for biomedical usage such as real-time risk modeling of postoperative complications and predicting heart failures—*NIH*;

Cyberinfrastructure for Sustained Scientific Innovation (real-time ML and analytics)—*NSF*

5. Build the current and next generation workforce necessary to develop, support, and use all aspects of big data. *See the EdW PCA.*

6. Transition research to practice by translating R&D into operational tools and technologies that enhance U.S. economy, security, and well-being.

Key programs

Rapid Deployment Research and Development Capabilities—*DHS*;

Small Business Innovation Research: Complex Data—*DOE/SC*;

Genomic sequencing to aid pediatric/prenatal diagnosis—*NIH*;

Convergence Accelerator (tracks on Open Knowledge Network; AI and Future Work; and Enabling AI Innovation via Data and Model Sharing)—*NSF*

Key Coordination Activities

- *Subcommittee on Open Science:* Participate in interagency coordination of policy around data management and open science. *BD IWG agencies, other agencies*
- *Follow-up work on findings of the 2021 workshop and report on federally supported data repositories:* Work with other agencies to address the points made in the workshop and make progress on this key data issue. *BD IWG agencies, other agencies*
- *National AI Research Institutes:* Focus on larger-scale, longer-time-horizon challenges in foundational and use-inspired AI research, and help accelerate the transition of AI innovations into use in many economic sectors. *DHS, DOT/FHWA/ITS JPO, NSF, USDA, industry partners*
- *Cooperation between the NITRD AI R&D IWG and NITRD Big Data IWG*: Much of current AI is about ML/DL using Big Data, and AI techniques can help in the management of Big Data and in extraction of knowledge and insights from data; thus, the two IWGs meet jointly in regularly scheduled meetings throughout the year. *NITRD AI R&D and Big Data IWGs*

Large Scale Networking (LSN) PCA

LSN R&D advances networking technologies and services; this includes R&D in networking architectures, wireless networks, software-defined networks, heterogeneous multimedia networks, testbeds, grid and cloud research and infrastructure, network service and cloud computing middleware, identity management, and end-to-end performance enhancement and performance measurement.[34]

Advanced Wireless R&D Sub-PCA

Advanced Wireless R&D includes Federal spectrum-related R&D investments that promote efficient use of wireless spectrum through advanced technologies and systems.

Large Scale Networking IWG

Participating Agencies: Army, DARPA, DOD, DOE/SC, DREN, FCC, NASA, Navy, NIH, NIST, NOAA, NSA, NSF, NTIA, ODNI, OSD, USAF, USDA, USGS

The LSN IWG coordinates Federal R&D in networking technologies and services, including network architectures, wired and wireless network infrastructures, grid and cloud middleware research, and communication protocols, to enable robust transfer of data among ground, sea, air, and space systems.

Strategic Priorities and Associated Key Programs

1. Develop concepts, techniques, architectures, and protocols for future networks.

Key programs

Provide connectivity/communications in contested and congested environments—*C5ISR*, *DARPA, NTIA*;

Assess THz viability for use in Air Force airborne environments—*AFRL*;

Advance quantum communications and networking—*AFRL, DOE/SC, NIST, NSF*;

Secure data sharing between coalitions across mobile tactical networks—*DARPA*;

Deploy next-generation high-performance wide area networks—*DOE/SC, DREN*;

Incorporate AI/ML aspects for better adaptation to the communications layer in convergent networks—*NSF*, *ONR*;

Develop new technologies, programmable measurement techniques, methodologies, resilient and intelligent next-generation networks and systems, and testbeds and demonstration capabilities (e.g., 5G architecture and in-network computing and storage)—*DARPA*, *DOD, DOE/SC, DREN, NIST, NOAA, NSA, NSF*

2. Develop cloud infrastructure enhancements.

Key programs

Connect tactical information across multiple domains on-demand, at scale, and securely—*AFRL, DARPA*;

Operationalize N-Wave cloud broker services and support direct connects to commercial cloud—*DREN, NOAA*;

Develop roadmaps for adoption of cloud computing technologies and commercial cloud use—*DOE/SC, NIST*;

[34] Both the LSN and WSRD IWGs report under the LSN PCA.

Conduct network technology and systems R&D, develop new hardware for future cloud systems, advance reproducibility research for cloud systems, and examine the edge-to-cloud continuum—*DOD, NSA, NIST, NSF*

3. Develop enhanced, next-generation network architecture capabilities for data analytics.

Key programs

Provide command and control and situational awareness capabilities—*DARPA, AFRL*;

Enhance advanced, distributed computing architecture capabilities and next-generation supercomputing support for science needs—*DOE/SC, DREN*, *NOAA, NSF*;

Develop end-to-end, virtualized, programmable, self-optimizing network architecture—*DARPA, NSF, ONR*;

Advance the design of edge computing and edge networking infrastructure, and develop scalable platforms for data analytics for emerging IoT devices—*NSF*;

Enable standards for robust and state-of-the-art public safety communications analytics—*NIST*;

Explore the capabilities of AI/ML to enhance data analytics on 5G/NextG networks—*NSA, NSF*

4. Develop, evaluate, and standardize technologies to achieve security and resilience in emerging wireless networks and multidomain internets and to protect core network infrastructure.

Key programs

Support research advances as well as development and testing of resilient and intelligent NextG systems—*DOD, NIST, NSF, industry partners*;

Enhance cybersecurity awareness, protections, and capabilities through developing new services and/or tools (e.g., cybersecurity for IoT, and AI tools)—*AFRL, C5ISR, DHS S&T, DOE/SC, DREN, NIST, NOAA, NSF, ONR*;

Support cyber technology innovations for trustworthy and secure networks (e.g., 5G and trustworthy AI), data and supply chain security, and infrastructure monitoring—*C5ISR, DHS S&T, DOE/SC, NIST, NSA, NSF, ONR*

5. Develop technology, standards, testbeds, and tools to improve wireless networks.

Key programs

Develop nontraditional waveforms and technologies for resilient communications—*C5ISR, DARPA, NSF*;

Deploy and operate nationwide testbeds supporting performance monitoring and protocol development—*AFRL, DOE/SC, NSF*;

Develop techniques to improve trust, performance, and robustness of wired and wireless networked sensors and control systems—*NIST, NSF*;

Expand wireless service and deploy rapid, mobile site deployments—*NOAA*;

Develop and operate testbeds supporting test and evaluation of radio access network disaggregation technologies; develop and operate testbeds supporting test and evaluation of open-source implementations of next-generation network components; and develop standards for evolution of spectrum sharing between 5G/NextG systems and other incompatible radio systems—*NSF*, *NTIA*;

5G Co-existence Testbed (sub-6GHz and mm wave): Develop fundamental measurement and calibration methods for hybrid (radiated plus cabled) test approaches that include beamforming; and support metrology for emerging 5G spectrum sharing, wireless coexistence, interference characterization and modeling, physical security, and standards development—*NIST*

Key Coordination Activities

- *Pursue distributed infrastructure architectures* that integrate instruments, sensors, computers, storage, and networks into a coherent whole. *DOD, DOE/SC, DREN, NIST, NOAA, NSA, NSF*
- *Advance integration of advanced wireless with large scientific instruments. DOD, DOE/SC, DREN, NIST, NOAA, NSA, NSF*
- *LSN Broadband Research and Development Team:* Coordinate strategies to address disparities in nationwide broadband access, adoption, and usage, and update the National Broadband Research Agenda. *Census, DOE/SC, DOI, DOL, FCC, NIJ, NIST, NSF, NTIA, OSD, USDA*
- *LSN Joint Engineering Team (JET) team:*[35] Coordinate R&D activities in networking, advanced technologies, end-user requirements, user interfaces, research and storage networks, end-to-end big data testbeds and metrics, trusted Internet connections, and tools. *DOE/SC, DREN, FCC, NASA, NIH, NIST, NOAA, NRL, NSF, NTIA*
- *Middleware and Grid Interagency Coordination Team (MAGIC) team:*[35] Coordinate activities in identity management, distributed computing, middleware, cloud, and grid computing services and information exchanges; standards and implementation; resource architecture, access, and management best practices; and security and privacy. *ARS, DOE/SC, FCC, NIST, NRL, NSF*

Wireless Spectrum R&D (WSRD) IWG

Participating Agencies: Army, DARPA, DEA, DHS, DOD, DOE/NNSA, DOE/SC, DOJ, FAA, FCC, FDA, NASA, Navy, NIJ, NIST, NOAA, NSF, NTIA, OSD, USAF

The WSRD IWG coordinates Federal spectrum-related R&D activities to facilitate efficient, effective R&D investments that promote efficient use of wireless spectrum through advanced technologies and systems.

Strategic Priorities and Associated Key Programs

1. Expand communications capacity through the dynamic use of multiple frequency bands, modulation techniques, or spectrum sharing methods.

Key programs

Develop air-to-air capability for long-range ultrabroadband terahertz communications; understand mmWave channel characteristics in real-life deployments; and demonstrate effective, secure unmanned aircraft system and wideband communications in mmWave bands—*AFRL, DOE/NE, NIST, NSF, NTIA*;

Develop laser airborne terminals with RF networking for increased capacity and robustness and capabilities to move data into and out of space; infuse RF capabilities in higher frequency bands; characterize channel effects; and improve beacon transmission and data collection—*AFRL, NASA, NIST, NRL, NSF, USAF*;

Deliver adaptable waveforms that are tailored to the mission and spectral environment; and manage interference with tactical infrastructure—*AFRL, Army CCDC C5ISR S&TCD, DARPA, NASA, Navy*;

Enable wireless communications that are spectrum-efficient, energy-efficient, secure, and adaptable for co-location and relocation through development of new methods, models, and measurements, along with appropriate definitions of spectrum efficiency across space, frequency,

[35] Both the JET and MAGIC teams hold information-sharing meetings among Federal and non-Federal participants.

and time, including for new 5G systems—*C5ISR S&TCD, DARPA, DHS, DOE/NE, DEA, DOD, FCC, NIST, NSF*, *NTIA*;

Develop mid-band propagation modeling and analyze effects of radar sharing with new 5G systems—*DOD, NSF, NTIA*

2. Identify and support capabilities for devices to monitor their spectrum environments and adapt in real time, including threat assessments and vulnerability detection.

Key programs

Electromagnetic Spectrum Monitoring: Share spectrum situational awareness using ML, visualization, and network-based techniques for collaborative planning and decentralized decision making; and develop infrastructure and best practices to acquire data and facilitate data sharing—*AFRL, DARPA, DHS S&T, DOE/NE, FCC, NIST, NSF, NTIA, OSD*;

Develop signal processing techniques for passive and active RF sensors to detect and remove and/or mitigate effects of RF interference—*NASA, NSF*;

Develop ML techniques for spectrum access systems and environmental sensing capability sensors and systems for signal classification—*DARPA, DOD, DEA, FCC, DOE/NE, NIST, NSF, NTIA*;

Address fundamental needs of spectrum sharing via spectrum sensing and modeling; address wireless coexistence metrology; and develop new metrology tools for 5G communications systems to ensure trusted spectrum sharing—*NIST, NSF*;

Implement innovative approaches to enhance communication and network security, including RF, analog, mixed signal, protocol, and/or algorithmic techniques—*NSF*;

Conduct integration and independent testing of new and emerging technologies (e.g., IoT, 5G)—*DHS S&T*

3. Develop trustworthy data-driven algorithms and analytics to inform spectrum policy and management.

Key programs

Use data science and ML to eliminate assumption-driven decision making— *NSF, NTIA*;

Develop algorithms to support cognitive management of multiple radios operating in the same environment—*DEA, DOJ, NSF*;

Leverage sensing data to access spectrum, and leverage AI frameworks to ensure effective spectrum utilization and coordination—*NSF*;

Develop algorithms using RF data, and develop curated data sets and methodology for AI/ML—*NIST, NSF*;

Utilize frequency selection and analytical techniques to improve NASA's spectrum access—*NASA*

4. Pursue R&D leading to robust, resilient, and reliable spectrum-dependent systems and networks that promote electromagnetic spectrum compatibility, coexistence, and reuse.

Key programs

Provide secure tactical intranetworking for military communications through multibeam directional connectivity and airborne data exchange between security domains, and improve unmanned aircraft system security measures—*AFRL, DOE/NE, Navy, NSA*;

Deploy experimental networks and explore trust and coexistence between different types of wireless networks; expand to 5G wideband encryption and optimized massive-MIMO security; and enable anti-jamming, low probability of detection, interception, and exploitation—*DEA, DHS, DOE/NE, NSF*;

Support research advances as well as development and testing of resilient and intelligent nextG systems—*DOD, NIST, NSF, industry partners*;

Develop new ways to evaluate, deploy, and protect wireless systems; use AI/ML to enable an autonomous communication infrastructure; and leverage AI frameworks to ensure effective spectrum utilization and coordination—*NIST, NSF*;

Develop new metrology to support development and evaluation of industrial IoT—*NIST*;

Develop evaluation methods for 5G-and-beyond system integration in mission-critical applications, adequate test methods for 5G-enabled medical devices, and medical device wireless coexistence evaluation methods for emerging technologies—*FDA*

5. Accelerate deployment of spectrum R&D into usable tools via testing, modeling, and simulation.

Key programs

Hybrid RF–Optical Link Adaptation Risk-reduction; and Stockbridge Controllable Contested Environment—*AFRL, FAA, NASA, NRL*;

Platforms for Advanced Wireless Research; and National Radio Dynamic Zones—*NSF*;

5G Coexistence Testbed—*NIST*;

Establish accurate measurements, system calibrations, technology, and models to address challenges in next-generation wireless communications, spectrum sharing, and wireless coexistence; develop testing methods in measurement science; and maintain publicly available web-based tools—*DOE/NE, NIST, NTIA*;

Enhance DOE National Laboratory test facilities, e.g., Next Generation Wireless Test Bed—*DOE/NE*; Future Cities Testing—*DOE/NE*; and Extreme Environments Testing—*DOE/NNSA*;

Develop realistic deep generative (ML) models for RF waveforms and key performance indicators to support rapid interference testing and characterization of black-box communication systems—*NIST*

Key Coordination Activities

- *Advanced Wireless Test Platform Working Group:* Organize interagency coordination on wireless test platforms to ensure access to a nationwide set of diverse testbeds. *DHS CISA, DHS S&T, DOD, DOE/SC, DOT, FCC, NASA, NIST, NOAA, NSF, NTIA*
- *5G Millimeter-Wave Channel Model Alliance:* Facilitate global *efforts* to define the radio channels where next-generation 5G wireless will operate. *NIST, NSF, NTIA*
- *Spectrum Innovation Zones:* Enable testing of new *wireless* devices, communication techniques, networks, systems, and services in real environments. *FCC, NSF*
- *National Advanced Spectrum and Communications Test Network:* Coordinate spectrum-sharing and coexistence studies among Federal, academic, and industry spectrum users; supply robust tests and validated measurement data to develop, evaluate, and deploy spectrum sharing technologies. *DOD, NASA, NIST, NOAA, NSF, NTIA*

Software Productivity, Sustainability, and Quality (SPSQ) PCA

SPSQ R&D advances timely and affordable development and sustainment of low-defect, low-vulnerability software; this includes R&D to significantly improve software production processes; productivity, quality, and understanding of the economics of software and its development; sustainability, measurement, assurance, and adaptability; and guarantees of essential requirements such as security, privacy, usability, reliability, and autonomy.

Software Productivity, Sustainability, and Quality IWG

Participating Agencies: Army, BLS, CDC, DHS, FDA, GSA, IARPA, NASA, Navy, NIH, NIJ, NIST, NOAA, NRC, NSA, NSF, NTIA, OSD, USAF

The SPSQ IWG coordinates Federal R&D to achieve orders-of-magnitude reduction in software defects and the time and cost of developing and sustaining software. The U.S. Government and the national economy depend on increasingly complex software; improved software development technology is essential to U.S. innovation, to leadership in emerging technologies, and to security and prosperity.

Strategic Priorities and Associated Key Programs

1. Advance timely, affordable development and sustainment of low-defect, low-vulnerability software through transformative research in design, production and evolution, verification, operation, utilization, and evaluation of computer software.

Key programs

Software Foundations: Support transformative research in design, verification, operation, utilization, and evaluation of computer software, including in software S&E to transform relationships between requirements, design, and evolution; formal methods for specification, development, and verification of software systems; and design and implementation of programming languages and compilers—*DOD, NASA, NSF*;

Software Engineering for Novel Architectures: Employ existing techniques and develop and deploy new ones to productively rewrite and refactor software models for nontraditional architectures and future exascale computers—*DOD, DOE, NASA, NOAA, academic partners*;

Secure Software Engineering: Fund basic and applied research on techniques, methods, and tools for detecting and mitigating software vulnerabilities and malware through software analysis and testing; formal methods to represent vulnerabilities; designed-in security and privacy capabilities during software development; and more—*AFRL, NASA, NIST, NSF, ONR*;

Conduct research and develop guidelines on the use of hardware roots of trust to secure information and information systems—*DOD, NASA, NIST*;

Tools to Quantify and Assure Agile Software Development: Automate testing and analyses; enhance rapid development of and acquire secure software; and automate evidence generation and construction of assurance arguments—*AFRL, NSF*;

Cyberinfrastructure for Sustained Scientific Innovation: Support research that addresses emerging needs in scientific software cyberinfrastructure and serves large, multidisciplinary research communities—*NASA, NSF*

2. Advance software productivity, sustainability, and quality in high-priority areas such as AI, computational science and engineering, cybersecurity, and future software-defined networking.

Key programs

Novel Optically Diverse Applications: Research and develop prototypes that will scale early-cycle cyber vulnerability assessments, including of embedded systems, by using learning algorithms to automate the process—*AFRL*;

System-Wide Safety Project: Develop, deploy, and transfer technology to support software assurance and productivity in aerospace systems that are software-intensive and increasingly autonomous—*AFRL, DOD, FAA, NASA, industry partners*;

Software Supplements: Make strategic investments to enable biomedical analysis software to be enhanced for open science and use in the cloud—*NIH*;

Software Assurance Metrics, Tool Evaluation, and Advanced Testing: Provide standard reference data for flawed and fixed code through the Software Assurance Reference Dataset, and run a periodic evaluation of static analysis tools; and mathematically define selection of attributes to reduce the cost and increase the effectiveness of high-assurance software—*IARPA, NASA, NIST, NRC, NSA*;

AI and Software Engineering: Advance software development processes and techniques for development of DL-based applications and systems. Also, apply AI to improving software development tasks, analysis of existing software and restructuring of software systems, and using statistical language techniques from natural language for software—*NASA, NIST, NSF, ONR*;

Software Asset Management Standards and Guidelines: Develop a sustainable, standardized approach to collect and maintain inventories of software, including software patches, from endpoints—*DHS, DOD, NASA, NIST*

3. Develop the current and future SPSQ workforce by supporting STEM education and training; by supplying and sustaining the necessary resources such as software libraries, tools, and platforms to support teaching and research; and by advancing software proficiency and development capabilities in government organizations and government-led projects. *See the EdW PCA.*

Key Coordination Activities

- *Earth System Prediction Capability:* Coordinate across the Federal environmental research and operational prediction communities to improve global prediction, including by identifying hardware and software challenges and R&D needs. *DOE, Navy, NASA, NOAA, NSF, USAF*
- *Joint Federated Assurance Centers*: Support robust, secure software development. *DOD, USAF*
- *International collaborations*:
  - Global Alliance for Genomics and Health: Work with global members in developing data-sharing standards in genomics and healthcare, and provide research funding for essential software components. *NIH*

4. Other NITRD Interagency Coordination Activities

Health Information Technology R&D (HITRD) IWG[36]

Participating agencies: AHRQ, Army, CDC, CMS, DOD, FDA, HHS, HRSA, NIH, NIST, NSF, ONC, VA

The HITRD IWG coordinates R&D aimed at improving the health of Americans by advancing technologies that support personalized health screening, monitoring, diagnosis, and treatment; disease prevention; emergency response; broad access to healthcare information and resources; and building and sustaining a diverse and highly skilled health IT workforce.

Strategic Priorities and Associated Key Programs

1. Accelerate R&D and implementation of next-generation accessible, interoperable, reconfigurable health IT tools, devices, and services to enhance disease self-monitoring, diagnosis, treatment, and prevention, and reduce regulatory and administrative burdens.

Key program areas

Develop and implement clinical decision support systems—*AHRQ, CDC, CMS, NIH, VA*;

Develop, test, and implement open-source, clinician- and patient-facing medical applications, reusable technologies, and fast healthcare interoperability resources—*ACL, AHRQ, CMS, HRSA, IHS, NIH, ONC, SAMHSA, VA*;

Accelerate the use of standardized application programming interfaces and third-party applications to reduce the effort it takes to access, exchange, and use electronic health information—*AHRQ, NIH, ONC*;

Collect, exchange, and integrate patient-generated digital health data into an electronic health record (EHR) system—*AHRQ, NIH, NSF, ONC, USAMRDC*;

Design real-time systems to semiautonomously or completely control medical devices for monitoring and treatment—*NIH, NSF, USAMRDC, VA*;

Improve advanced medical care at a distance that connects specialty providers with patient data and EHR integration for situational awareness—*USAMRDC, VA*;

Implement and evaluate consensus-based recommendations for best practices—*AHRQ, CDC, FDA*;

Support next-generation Health IT technologies that enable faster and safer development of new products for the bioeconomy—*FDA, NIST, NSF*

2. Promote findable, accessible, interoperable, reusable health and biomedical data to support development of new insights from AI.

Key program areas

Utilize advance computing resources and data to enhance clinical trials and discover new approaches for optimizing health—*AHRQ, NIH, NSF*;

Develop interoperable, standards-based, secure medical architecture for data and devices to enhance decisions using AI—*FDA, NIST, NSF, ONC, USAMRDC*;

Validate and refine claims-based data to identify patients' risk and status—*ACL, AHRQ, NCHS, NIH, ONC*;

[36] Distinct from other IWGs, HITRD IWG agencies report funding to various PCAs—including CHuman, CNPS, EdW, and IRAS—depending on the focus areas of the agencies.

Support the development of cloud-based data and analysis ecosystems to enhance research and development including supporting research networks for prevention, surveillance, monitoring, and conducting clinical studies—*NIH, NIOSH, NSF, USAMRDC*;

Enhance the semantic interoperability of medical devices—*NIH, NIST, NSF, ONC, USAMRDC*;

Develop advanced Internet-of-Things networking frameworks and evaluation testbeds to enhance the collection of information about health status from the lived environment—*NIST, NSF*;

Generate large, diverse data and methods to enhance pandemic prediction—*NIH, NSF, USAMRDC*;

Advance the findability, accessibility, interoperability, and reuse of health data and metadata standards—*AHRQ, CDC, DHA, FDA, NIH, ONC, VA*

3. Develop appropriate privacy-preserving, secure methods and data transfer strategies, and support implementation of standards and certification to enhance trust and confidence in health and biomedical systems.

Key program areas

Secure remote patient monitoring and medical image exchange—*FDA, NIH, NIST, NSF, USAMRDC*;

Enhance certification by developing standards, implementation specifications, certification criteria, and testing specifications—*FDA, NIST, ONC*;

Create new methods for secure data sharing and transfers that support privacy and security—*DOD, NSF*

4. Provide education and training opportunities to build the diverse, highly skilled, interdisciplinary health IT workforce of the future. *See the EdW PCA.*

Key Coordination Activities

- *Implement the 21st Century Cures Act*, including the Brain Research through Advancing Innovative Neurotechnologies, Cancer Moonshot, and Precision Medicine Initiative. *FDA, IARPA, NIH, NSF, ONC*
- *Implement the Federal Health IT Strategic Plan 2020-2025*: Follow this Federal Government guidance for using health IT to promote secure access of all parties to electronic health information to improve patient health, including through education and training programs. *All HITRD agencies*
- *Advance the use of AI in healthcare. All HITRD agencies*
- *Promote the Safe and Trustworthy Computing and Smart and Connected Health programs. NIH, NSF*
- *Coordinate the health-IT related response to the COVID-19 pandemic. All HITRD agencies*

5. Overview of the National Artificial Intelligence Research Institutes

Introduction

In passing the National Artificial Intelligence Initiative Act of 2020,[37] Congress recognized that advances in AI will strengthen innovation across multiple sectors, including, but not limited to health, education, manufacturing, agriculture, security, energy, and environment. NAIIA calls for NSF to lead Federal agencies in providing investments to jump-start these innovations through National AI Research Institutes ("AI Institutes"). The investments will address sector-specific or cross-cutting challenges (e.g., trustworthiness) relevant to the application of AI in those sectors or in AI systems broadly and translate the research into products, applications, and services.

The NAIIA requires, among other provisions, that the AI Institutes be formed among multi-dimensional partnerships of public and private entities; address the ethical, societal, safety, and security implications of AI R&D; and support interdisciplinary R&D across multiple institutions of higher education, development of interdisciplinary education activities, and development of an AI workforce across all U.S. communities, including those that are historically underrepresented in S&T. As of August 2021, Institutes address multiple AI R&D themes, and the Institutes' numerous partners are located in 40 states and several countries.

This section serves as the FY2022 annual report on the status of the series of AI Institutes as called for in the National Artificial Intelligence Initiative Act of 2020. The subsections below provide an overview of NSF-led and other AI Institutes launched since NAIIA was enacted. Tables 3 and 4 in Section 2 provide the actual, enacted, and requested investments by Federal agencies for both NSF-led and other agencies' AI Institutes for FYs 2020–2022.

NSF-Led AI Institutes, by R&D Theme

NSF established five initial AI Institutes in 2020 spanning five research themes with a projected investment over five years of approximately $20 million each in planned partnerships with several other Federal agencies. In 2021, NSF established nine additional Institutes spanning six research themes, also at about $20 million over five years.[38] Institute themes span both fundamental AI R&D and R&D for AI-driven innovation in specific domains. Through a joint program with NSF, USDA/NIFA established two AI Institutes each in 2020 and 2021[39] addressing AI-driven innovation in agriculture and the food system, with similar investment, bringing the roster of AI Institutes to 18. The summary descriptions below of NSF-led AI Institutes—grouped by R&D themes—name Institute focus areas, funding, lead and participating institutions, and private partners and collaborators as of August 2021.[40]

Theme: AI in Computer and Network Systems

AI Institute for Edge Computing Leveraging Next-Generation Networks (also known as Athena)—DHS, NSF (2021)

Focus: Develop edge computing with groundbreaking AI functionality while keeping complexity and costs under control. Bringing together a world-class, multidisciplinary team of scientists, engineers, statisticians, legal scholars and psychologists from seven universities, it will transform

[37] https://www.congress.gov/116/bills/hr6395/BILLS-116hr6395enr.pdf#page=1147: Title LII, Secs. 5201 ff.
[38] https://nsf.gov/news/special_reports/announcements/082620.jsp and https://nsf.gov/news/news_summ.jsp?cntn_id=303176
[39] https://nifa.usda.gov/press-release/artificial-intelligence-research and https://nifa.usda.gov/press-release/usda-nifa-and-nsf-invest-220m-artificial-intelligence-research-institutes
[40] https://nsf.gov/news/ai/AI_map_standard.pdf includes frequent updates to participants in the NSF-led AI Institutes.

the design, operation and service of future systems from mobile devices to networks. It is committed to educating and developing the workforce, cultivating a diverse next generation of edge computing and network leaders whose core values are driven by ethics and fairness in AI. As a nexus point for the community, this institute will spearhead collaboration and knowledge transfer, translating emerging technical capabilities to new business models and entrepreneurial opportunities.

Funding: ~$20 million total over five years.

Primary Organization: Duke University

Other Principal Organizations:

- Massachusetts Institute of Technology
- North Carolina A&T State University
- Princeton University
- University of Illinois
- University of Illinois Urbana-Champaign
- University of Michigan Ann Arbor
- University of Washington
- University of Wisconsin-Madison
- Yale University

Partners/Collaborators:

- 5NINES
- AT&T
- Edge Micro
- Microsoft
- Motorola Solutions
- North Carolina School of Science and Mathematics
- Town of Cary, NC
- The STEM Early College at North Carolina A&T State University

More Information: https://athena.duke.edu/

AI Institute for Future Edge Networks and Distributed Intelligence (AI-EDGE)—DHS, NSF (2021)

Focus: Leverage the synergies between networking and AI to design future generations of wireless edge networks that are highly efficient, reliable, robust and secure. New AI tools and techniques will be developed to ensure that these networks are self-healing and self-optimized. Collaboration over these adaptive networks will help solve long-standing distributed AI challenges making AI more efficient, interactive, and privacy preserving for applications in sectors such as intelligent transportation, remote healthcare, distributed robotics, and smart aerospace. It will create a research, education, knowledge transfer, and workforce development environment that will help establish U.S. leadership in next-generation edge networks and distributed AI for many decades to come.

Funding: ~$20 million total over five years.

Primary Organization: The Ohio State University

Other Principal Organizations:

- Carnegie Mellon University
- Northeastern University
- Purdue University
- University of Illinois
- University of Illinois Urbana-Champaign
- University of Massachusetts
- University of Michigan
- University of Texas
- University of Washington
- University of Wisconsin

Partners/Collaborators:

- Air Force Research Laboratory (NY)
- Air Force Research Laboratory (OH)
- Army Research Laboratory
- AT&T Labs
- IBM Watson Research Center
- Microsoft
- Naval Research Laboratory
- Qualcomm (CA)
- Qualcomm (NJ)
- University of Illinois

More Information: https://aiedge.osu.edu/

Theme: AI for Advances in Optimization

AI Institute for Advances in Optimization (AI4Opt)—NSF, Industry Partner (2021)

Focus: Revolutionize decision making on a large scale by fusing AI and mathematical optimization into intelligent systems that will achieve breakthroughs that neither field can achieve independently. The Institute will create pathways from high school to undergraduate and graduate education and workforce development training for AI in engineering that will empower a generation of under-represented students and teachers to join the AI revolution. It will also create a sustainable ecosystem for AI, combining education, research, entrepreneurship, and the public at large. The Institute will demonstrate foundational advances on use cases in energy, resilience and sustainability, supply chains, and circuit design and control. It has innovative plans for workforce education and broadening participation, including substantial leadership from a collaborating minority-serving institution.

Funding: ~$20 million total over five years, including partial funding by Intel.

Primary Organization: Georgia Institute of Technology

Other Principal Organizations:

- Clark Atlanta University
- Spelman College
- University of California
- University of Southern California
- University of Texas

Partners/Collaborators:

- Amazon Robotics
- Atlanta Public Schools
- Georgia Center of Innovation for Logistics
- Georgia Dept. of Economic Development
- Girls Academic Leadership Academy
- Gurobi Optimization
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- Midcontinent Independent Systems Operator (MISO)
- Oak Ridge National Laboratory
- Ryder
- UPS

More Information: https://www.ai4opt.org/

AI Institute for Learning-Enabled Optimization at Scale (TILOS)—NSF, Industry Partner (2021)

Focus: Aim to "make impossible optimizations possible" by addressing the fundamental challenges of scale and complexity. Learning-enabled optimization will be applied in several technical focus areas vital to the Nation's health and prosperity, including semiconductor chip design, robotics and networks. The research agenda is accompanied by plans for workforce development and broadening participation at all academic levels, from middle school to advanced research levels, including community outreach efforts to promote AI.

Funding: ~$20 million total over five years, including partial funding by Intel.

Primary Organization: University of California San Diego

Other Principal Organizations:

- Massachusetts Institute of Technology
- National University
- University of Pennsylvania
- University of Texas
- Yale University

Partners/Collaborators:

- A Reason to Survive (ARTS)
- Allen Institute for Artificial Intelligence
- Ansys, Inc.
- Arm, Ltd.
- Brain Corporation
- Cadence Design Systems
- Facebook
- FIRST
- Girl Scouts San Diego
- IBM
- Mentor Graphics (Siemens)
- Microsoft
- Nvidia
- Planck Aerosystems, Inc.
- SACNAS
- Samsung Austin R&D Center, TX
- Samsung Strategy & Innovation Center
- Silicon Integration Initiative, Inc.
- Sweetwater Union High School District
- Synopsis, Inc.
- TuSimple, Inc.
- Western Digital CHIPS Alliance
- XiLinx Inc.

More Information: https://tilos.ucsd.edu

Theme: AI and Advanced Cyberinfrastructure

AI Institute for Intelligent Cyberinfrastructure with Computational Learning in the Environment (ICICLE)—NSF (2021)

Focus: Build the next generation of cyberinfrastructure that will make AI easy for scientists to use and promote its further democratization. It will transform the AI landscape of today by bringing in scientists from multidisciplinary backgrounds to create a robust, trustworthy, and transparent national cyberinfrastructure that is ready to "plug-and-play" in areas of societal importance such as "smart food sheds", precision agriculture, and animal ecology. The Institute will develop a new generation of the workforce with sustained diversity and inclusion at all levels.

Funding: ~$20 million total over five years.

Primary Organization: The Ohio State University

Other Principal Organizations:

- Case Western Reserve University
- IC-FOODS
- Indiana University
- Iowa State University
- Rensselaer Polytechnic Institute
- University of California, Davis
- University of California, San Diego
- University of Delaware
- Texas Advanced Computing Center
- University of Utah
- University of Wisconsin–Madison

Partners/Collaborators:

- AccessComputing
- Agricultural Data Coalition
- AI FARMS
- AIFS
- Brookhaven National Laboratory
- CNH Industrial
- Computing Alliance of Hispanic-Serving Institutions
- Expanding Pathways in Computing Alliance
- Fermi National Accelerator Laboratory
- I Love Farmers Markets
- IAIFI
- Indiana University, Jetstream
- Information Sciences Institute
- Lawrence Livermore National Laboratory
- Max Planck Institute (Germany)
- Microsoft AI for Earth
- Mid-Ohio Food Collective
- Molecular Sciences Software Institute
- National Center for Women and IT
- National Ecological Observatory Network—Battelle

- Nationwide Children's Hospital
- Princeton University
- Science Gateways Community Institute
- Southern California Earthquake Center
- The Findings Group
- Trusted CI Institute
- U.S. Fish and Wildlife Service
- University of North Carolina
- University of Stuttgart (Germany)
- WildMe

More Information: https://icicle.osu.edu/

Theme: AI-Augmented Learning

AI Institute for Adult Learning and Online Education (ALOE)—NSF, Industry Partner (2021)

Focus: Lead the country and the world in the development of novel AI theories and techniques for enhancing the quality of adult online education, making this mode of learning comparable to that of in-person education in STEM disciplines. Fundamental research in use-inspired AI is grounded in theories of human cognition and learning supported by evidence from large-scale data, evaluated on a large variety of testbeds, and derived from the scientific process of learning engineering. Along with partners in the technical college systems and educational technology sector, ALOE will advance online learning using virtual assistants to make education more available, affordable, achievable, and equitable.

Funding: ~$20 million total over five years, including partial funding by Accenture.

Primary Organization: Georgia Research Alliance

Other Principal Organizations:

- Arizona State University
- Drexel University
- Georgia State University
- Georgia Tech Research Corporation
- Harvard University
- Technical College System of Georgia
- University of North Carolina Greensboro

Partners/Collaborators:

- Boeing
- IBM
- IMS Global
- Wiley

More Information: https://aialoe.org/

AI Institute for Engaged Learning—NSF (2021)

Focus: Advance natural language processing, computer vision and machine learning to engage learners in AI-driven narrative-centered learning environments. Rich AI-driven virtual agents and powerful multimodal sensing capabilities will support learners and yield transformative advances in STEM teaching and learning. The Institute will serve as a nexus for in-school and out-of-school STEM education innovation, empowering and engaging diverse learners and stakeholders to ensure that AI-driven learning environments are ethically designed to promote equity and inclusion.

Funding: ~$20 million total over five years.

Primary Organization: North Carolina State University

Other Principal Organizations:

- Digital Promise Global (CA)
- Digital Promise Global (Washington DC)
- Indiana University
- Kenan-Flagler Business School, University of North Carolina
- University of North Carolina
- Vanderbilt University

Partners/Collaborators:

- AI for Teachers
- Boys & Girls Clubs of Bloomington, IN
- Boys & Girls Clubs of the Coastal Plain
- Code.org
- Computer Science Teachers Association
- Computing Research Association
- CSForALL
- Durham Public Schools
- EngageCSEdu
- Greater Clark County Schools, IN
- Indiana School for the Deaf
- Loogootee Community School Corp.
- Metro Nashville Public Schools
- Metropolitan School District of Wayne Township, IN
- Monroe County Community School Corporation, IN
- Nextech
- North Carolina Department of Public Instruction
- North Carolina Museum of Natural Sciences
- Pitt County Schools, NC
- STARS Computing Corps
- Wake County Public School System, NC
- WonderLab Museum of Science, Health, and Technology

More Information: https://www.aiengage.org/

AI Institute for Student–AI Teaming—NSF (2020)

Focus: Develop groundbreaking AI that helps both students and teachers to work and learn together more effectively, and equitably, while helping educators focus on what they do best: inspiring and teaching students. The vision is to develop engaging "AI partners" that will observe, participate in, and facilitate collaborative STEM learning conversations by interacting naturally through speech, gesture, gaze, and facial expression in real-world classrooms and remote learning settings.

Funding: ~$20 million total over five years

Primary Organization: University of Colorado Boulder

Principal Organizations:

- Brandeis University
- Colorado State University
- Georgia Institute of Technology
- University of California Berkeley
- Worcester Polytechnic Institute
- University of California Santa Cruz
- University of Illinois at Urbana-Champaign
- University of Wisconsin-Madison

Partners/Collaborators:

- Curve10
- Denver Public Schools
- Project Voyce
- SparkFun
- St. Vrain Valley Schools, CO
- The Op Ed Project

More Information: https://www.colorado.edu/research/ai-institute/

Theme: AI-Driven Innovation in Agriculture and the Food System

AI Institute for Future Agricultural Resilience, Management, and Sustainability (AI-FARMS)—USDA-NIFA (2020)

Focus: Advance AI research in computer vision, machine learning, soft object manipulation and intuitive human-robot interaction to solve major agricultural challenges including labor shortages, efficiency and welfare in animal agriculture, environmental resilience of crops, and the need to safeguard soil health. The institute features a new joint Computer Science+Agriculture degree and global clearinghouse to foster collaboration in AI-driven agriculture research.

Funding: ~$20 million total over five years.

Primary Organization: University of Illinois at Urbana-Champaign

Other Principal Organizations:

- Donald Danforth Plant Science Center
- Michigan State University
- Tuskegee University
- University of Chicago

Partners/Collaborators:

- Agco
- Agrela Ecosystems
- Benson Hill
- EarthSense
- IBM Research
- John Deere
- Microsoft
- Strawn Pork
- Syngenta Crop Protection

More Information: https://digitalag.illinois.edu/research/aifarms/

AI Institute for Next-Generation Food Systems (AIFS)—USDA-NIFA (2020)

Focus: Integrate a holistic view of the food system with AI and bioinformatics to understand biological data and processes, addressing issues of molecular breeding to optimize traits for yield, crop quality, and pest/disease resistance; agricultural production, food processing and distribution, and nutrition. Major emphasis is on inclusive education and outreach approaches to build a diverse, next-generation workforce.

Funding: ~$20 million total over five years.

Primary Organization: University of California, Davis

Other Principal Organizations:

- Cornell University
- University of California Agriculture and Natural Resources
- University of California, Berkeley
- University of Illinois Urbana-Champaign

Partners/Collaborators:

- ADM Global headquarters, IL
- AGR Partners
- BASF
- Better Food Ventures
- Better Ventures
- Bow Capital
- Culinary Institute of America, Copia
- Digestiva
- Farm Foundation
- FoodShot Global
- FTW Ventures
- Mars, Inc.
- MISTA
- Novozymes (N. America Headquarters)
- Nuritas, Ltd. (Ireland)
- Process Integration & Predictive Analytics
- Sacramento City College
- The March Fund
- The Production Board
- The Rockefeller Foundation (headquarters)
- ThermoFisher Scientific
- Thomas Jefferson Foundation
- UC Davis Plant Breeding Center
- UC Davis Seed Biotechnology Center
- USDA Agricultural Research Service
- West Hills College Coalinga CA

More Information: https://aifs.ucdavis.edu/

AI Institute for Resilient Agriculture (AIIRA)—USDA-NIFA (2021)

Focus: Transform agriculture through innovative AI-driven digital twins that model plants at an unprecedented scale. This approach is enabled by advances in computational theory, AI algorithms, and

tools for crop improvement and production for resiliency to climate change. In addition, AIIRA will promote the study of cyber-agricultural systems at the intersection of plant science, agronomics, and AI; power education and workforce development through formal and informal educational activities, focusing on Native American bidirectional engagement and farmer programs; and drive knowledge transfer through partnerships with industry, producers, and Federal and State agencies.

Funding: ~$20 million total over five years.

Primary Organization: Iowa State University

Other Principal Organizations:

- Carnegie Mellon University
- George Mason University
- Iowa Soybean Association
- New York University
- University of Arizona
- University of Missouri
- University of Nebraska-Lincoln (UNL)

Partners/Collaborators:

- Agriculture Genome to Phenome Initiative
- Bayer
- Big Data in a Box
- BioConnect Iowa
- Bloomfield Robotics
- Cornell AgriTech and Agricultural Experiment Station
- Corteva Agriscience
- CSIRO, Australia
- CyVerse
- Dryland Genetics
- EarthSense, Inc.
- EnGenious Ag
- ETALYC, Inc.
- Federal Statistical Research Data Center at Iowa State University
- Genomes to Fields Initiative
- Grow Pittsburgh
- International Plant Phenotyping Network (Germany)
- Iowa Corn Growers Association
- Iowa Economic Development Authority
- Iowa Fruit and Vegetable Growers Assn.
- John Deere
- Microsoft
- Midwest Big Data Hub
- Mineral Google, X, The Moonshot Factory
- N. American Plant Phenotyping Network
- NSF Transdisciplinary Research In Principles Of Data Science (TRIPODS) Institute at University of Arizona
- Oak Ridge National Laboratory
- Omni Analytics Group
- NSF-USDA/NIFA AI Institutes: AIFS, AI-FARMS
- Practical Farmers of Iowa
- Raven Applied Technology
- RocketML, Inc.
- The Data and Software Carpentries
- The University of Tokyo (Japan)
- University of Nebraska Lincoln, Center for Resilience in Agricultural Working Landscapes and NSF National Research Traineeship
- USDA Agricultural Research Service
- Vermeer Corp.

More Information: https://aiira.iastate.edu/

AI Institute for Agricultural AI for Transforming Workforce and Decision Support (AgAID)—USDA-NIFA (2021)

Focus: Integrate AI methods into agriculture operations for prediction, decision support, and robotics-enabled agriculture to address complex agricultural challenges. This Institute uses a unique adopt-adapt-amplify approach to develop and deliver AI solutions to agriculture that address pressing challenges related to labor, water, weather and climate change. AgAID involves farmers, workers, managers and policymakers in development of these solutions as well as AI

training and education, which promotes equity by increasing the technological skill levels of the next-generation agricultural workforce.

Funding: ~$20 million total over five years.

Primary Organization: Washington State University

Other Principal Organizations:

- Carnegie Mellon University
- Heritage University
- IBM Research
- Innov8 Ag
- Oregon State University
- University of California
- University of Virginia
- Wenatchee Valley College

Partners/Collaborators:

- AgTech Insight
- Allan Brothers
- Almond Board of California
- CA Department of Water Resources
- Cascadia Innovation Corridor (Canada)
- Central Valley Community Foundation
- Chemeketa, OR, Community College
- Columbia Basin College
- Environmental Defense Fund
- G. S. Long
- Grassland, CA, Irrigation District
- Leibniz Institute for Agricultural Engineering & Bioeconomy (Germany)
- Linn-Benton Community College
- Merced College
- Merced Irrigation District
- Mercer Ranches
- Microsoft
- Okanogan Irrigation District
- Turlock, CA, Irrigation District
- University of British Columbia (Canada)
- University of Technology Sydney (Australia)
- Valencia Polytechnic University (Spain)
- Verdant Robotics
- Walla Walla County, CA, Conservation District
- Washington Department of Ecology
- Washington Mint Commission
- Washington Tree Fruit Commission
- Washington Wine Grape Commission
- Wilbur-Ellis
- Wonderful Orchards
- Yakama Nation Tribal School
- Zirkle Fruit Company

More Information: https://agaid.wsu.edu/

Theme: AI for Accelerating Molecular Synthesis and Manufacturing

AI Institute for Molecular Discovery, Synthetic Strategy, and Manufacturing (also known as Molecule Maker Lab)—NSF (2020)

Focus: Develop new AI-enabled tools to accelerate automated chemical synthesis and advance the discovery and manufacture of novel materials and bioactive compounds. The institute also serves as a training ground for the next generation of scientists with combined expertise in AI, chemistry, and bioengineering.

Funding: ~$20 million total over five years

Primary Organization: University of Illinois at Urbana-Champaign

Other Principal Organizations:

- Pennsylvania State University
- Rochester Institute of Technology

Partners/Collaborators:

- Northwestern University
- Allchemy, Inc.

More Information: https://moleculemaker.org/

Theme: AI for Discovery in Physics

AI Institute for Artificial Intelligence and Fundamental Interactions—NSF (2020)

Focus: Incorporate workforce development, digital learning, outreach, and knowledge transfer programs to develop AI methods that integrate the laws of physics as a guiding framework to advance physics knowledge—from the smallest building blocks of nature to the largest structures in the universe—and galvanize AI research innovation to broaden societal impacts.

Funding: ~$20 million total over five years

Primary Organization: Massachusetts Institute of Technology (MIT)

Other Principal Organizations:

- Harvard University
- Northeastern University
- Tufts University

Partners/Collaborators:

- Amazon
- Argonne National Laboratory
- CERN (Switzerland)
- DeepMind (UK)
- Fermilab
- IBM
- Jefferson Laboratory
- LIGO Scientific Collaboration
- Microsoft Research
- MIT Bates Computing Center
- MIT-IBM Watson AI Lab
- Nvidia
- Salesforce
- Sony (Japan)
- X, The Moonshot Factory
- Xilinx
- Yandex (Russia)

More Information: https://iaifi.org/

Theme: AI in Dynamic Systems

AI Institute for Dynamic Systems—DHS, NSF (2021)

Focus: Enable innovative research and education in fundamental AI and machine learning theory, algorithms and applications specifically for safe, real-time learning and control of complex dynamic systems. The core motivation for this institute is to integrate physics-based models with AI and machine learning approaches, leading the way towards data-enabled ethical, efficient, and explainable solutions for real-time sensing, prediction, and decision-making challenges across science and engineering.

Funding: ~$20 million total over five years.

Primary Organization: University of Washington

Other Principal Organizations:

- Boise State University
- Columbia University
- Harvard University
- Montana State University
- Portland State University
- Seattle University
- University of Alaska
- University of Hawaii
- University of Nevada

Partners/Collaborators:

- Boeing Advanced Research Center
- Pacific Northwest National Laboratories

More Information: http://dynamicsai.org/

Theme: Foundations of Machine Learning

AI Institute for Foundations of Machine Learning—NSF (2020)

Focus: Address major theoretical challenges in AI, including next-generation algorithms for deep learning, neural architecture optimization, and efficient robust statistics. Major online coursework and research initiatives will bring current AI tools to thousands of students and professionals across the country. The Dell Medical School at University of Texas at Austin will test algorithms developed in the Institute to expedite turnaround time for medical imaging diagnostics. Several major businesses have signed on to transfer Institute research into practice.

Funding: ~$20 million total over five years

Primary Organization: University of Texas at Austin

Other Principal Organizations:

- Microsoft Research
- University of Washington
- Wichita State University

Partners/Collaborators:

- City of Austin
- Dell Technologies
- Facebook
- Internet Archive
- Netflix
- Texas Advanced Computing Center
- University of Texas at Austin Dell Medical School
- YouTube

More Information: https://www.ifml.institute/

Theme: Human-AI Interaction and Collaboration

AI Institute for Collaborative Assistance and Responsive Interaction for Networked Groups (AI-CARING)—NSF, Industry Partners (2021)

Focus: Seek to create a vibrant, fully developed discipline focused on personalized, longitudinal (over months and years) collaborative AI systems that learn individual models of human behavior and how they change over time and use that knowledge to better collaborate and communicate in caregiving environments. The collaborative AI Partners in Care developed as part of this Institute will help support a growing population of older adults to sustain independence, improve quality of life, and increase effectiveness of care coordination across the care network.

Funding: ~$20 million total over five years, including partial funding from Amazon and Google.

Primary Organization: Georgia Institute of Technology

Other Principal Organizations:

- Carnegie Mellon University
- Oregon Health and Science University
- Oregon State University
- University of Massachusetts Lowell

Partners/Collaborators:

- Achieva
- American Association of Retired Persons
- Apple
- Briarcliff Oaks
- Cathedral Towers, Inc.
- Chatham University
- Emory University
- Facebook
- Hello Robot
- Jewish Healthcare Foundation
- Morehouse School of Medicine
- NASA, TX, and Jet Propulsion Laboratory, CA

- National Center for Women and IT
- National Church Residences, Trinity Towers
- NIST
- Northern Essex Community College
- Nvidia
- Oak Ridge National Laboratory
- People Power
- Pittsburgh Healthcare System
- Sandia National Laboratories
- St. Anne's Terrace, Inc.
- Stanley Healthcare
- Toyota Research Institute, CA
- University of Pittsburgh
- UPMC Enterprises
- VA

More Information: http://ai-caring.org/

Theme: Trustworthy AI

AI Institute for Research on Trustworthy AI in Weather, Climate, and Coastal Oceanography (also known as AI Institute for Artificial Intelligence for Environmental Sciences, or AI2ES)—NSF (2021)

Focus: Assemble researchers in AI, atmospheric and ocean science, and risk communication to develop user-driven trustworthy AI that addresses pressing concerns in weather, climate, and coastal oceanography and coastal hazards prediction. With AI certificate programs aimed at workforce skills, the institute is providing the research and training necessary for the future workforce to deliver the advances needed to deal with forecasting and prediction challenges.

Funding: ~$20 million total over five years

Primary Organization: University of Oklahoma, Norman Campus

Other Principal Organizations:

- Colorado State University
- Del Mar College
- National Center for Atmospheric Research/University Corporation for Atmospheric Research
- North Carolina State University
- Texas A&M University Corpus Christi
- University at Albany, SUNY
- University of Washington

Partners/Collaborators:

- City of Corpus Christi
- DHS
- Disaster Technologies. Inc.
- DOT Department of Environmental Conservation
- Google
- IBM (The Weather Company)
- Joint Typhoon Warning Center
- National Hurricane Center
- National Park Service
- NOAA: National Severe Storms Lab Storm Prediction Center, Earth System Research Labs Global Systems Lab, National Geodetic Survey, Operational Oceanographic Products & Services, and Cooperative Institute for Environmental Services Global Systems Lab)
- Nueces County, TX, Coastal Parks
- Nvidia
- NY Independent Systems Operator
- NY Power Authority
- NY Thruway
- Oklahoma Climate Survey
- Texas Coastal Offices of the National Weather Service
- Texas Commission on Environmental Quality
- Texas DOT
- Texas General Land Office

More Information: https://www.ai2es.org/

Other AI Institutes

In addition to the 18 National AI Research Institutes described above that are directly affiliated with and overseen by the National Science Foundation, there are two other AI Institutes in operation in the Nation that have been established by other Federal agencies that meet the overall criteria established by the National Artificial Intelligence Initiative Act of 2020. These AI Institutes are described briefly below.

DAF AI Institute: DAF–MIT AI Accelerator (2020)

The goal of the DAF–MIT AI Accelerator is to create a state-of-the-art, end-to-end, sustainable pipeline for AI technology to give the U.S. Air Force, U.S. Space Force, and the United States broadly a competitive advantage in the defense and civilian sectors by conducting fundamental research to enable rapid prototyping, scaling, and the ethical application of AI algorithms and systems. This work, including ten 3-year projects, makes eligible Air Force datasets publicly accessible as an important aspect of researching and developing new AI systems. The projects advance AI research in areas such as weather modeling and visualization, optimization of training schedules, rapid disaster response, narrower projects such as multimodal vision for synthetic aperture radar, and enhancing autonomy for augmenting and amplifying human decision-making. The AI Accelerator leverages universities, small businesses, and traditional defense and nontraditional commercial ventures collaborating with the Air Force and Space Force in multidisciplinary teams to develop and ensure the ethical use of advanced AI technologies that can be rapidly adopted by DOD and the Nation to address important societal needs.

More Information: https://aia.mit.edu/

VA National AI Institute with an R&D Focus on Veterans (2020)

The goal of the Veterans Affairs National AI Institute is to develop AI research and development capabilities in the VA to support Veterans, their families, survivors, and caregivers. The Institute designs and collaborates on large-scale AI R&D initiatives, national AI policy, and partnerships across agencies, industries, and academia. Current work includes pilot projects to demonstrate size, scope, and magnitude of capabilities that deliver positive real-world outcomes for Veterans. These flagship projects, which are designed with Veteran input, will utilize VA data and emphasize particular AI areas such as deep learning, explainable AI, privacy-preserving AI, and AI for multiscale time series. As the VA's capacity and portfolio of AI research increases, the VA plans to create a pipeline for AI research to transition to validation, user acceptance, and eventually enterprise implementation.

More Information: https://www.research.va.gov/naii/

ABBREVIATIONS

3GPP	3rd Generation Partnership Project (of standards organizations that develop mobile telecom protocols)
5G	5th-generation cellular wireless technology
ACL	HHS Administration for Community Living
ACN	Advanced Communications Networks
ADAS	Assured Development and Operation of Autonomous Systems project (OUSD-R&E)
AFOSR	Air Force Office of Scientific Research (DOD)
AFRI	Agriculture and Food Research Initiative (USDA)
AFRL	Air Force Research Laboratory (DOD)
AHRQ	Agency for Healthcare Research and Quality (HHS)
AI	artificial intelligence (and NITRD PCA and IWG)
AI/ML	AI and machine learning
AIM-AHEAD	AI/ML Consortium to Advance Health Equity and Researcher Diversity (NIH)
ANSI	American National Standards Institute
ARL	Army Research Laboratory (DOD)
ARS	Agricultural Research Service (USDA)
ASTM	Developer of voluntary consensus standards
AWN	Advanced wireless networks
AWRD	Advanced wireless R&D (NITRD sub-PCA)
BD	Big Data (NITRD IWG)
BLS	U.S. Bureau of Labor Statistics (DOL)
BRD	Broadband R&D (LSN subgroup)
C5ISR	Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance Center (DOD/Army)
C5ISR S&TCD	C5ISR Space & Terrestrial Communi-cations Directorate (DOD/Army)
CCDC	Combat Capabilities Development Command (DOD/Army)
CDC	Centers for Disease Control and Prevention (HHS)
CDS	Clinical decision support
Census	U.S. Census Bureau (DOC)
CG	Coast Guard (DHS)
CHuman	Computing-Enabled Human Interaction, Communication & Augmentation (NITRD PCA)
CMS	Centers for Medicare and Medicaid Services (HHS)
CNPS	Computing-enabled Networked Physical Systems (NITRD PCA)
COVID-19	novel coronavirus disease strain that caused the global pandemic that began in 2020
CPS	cyber-physical systems
CSIA	Cybersecurity and Information Assurance (NITRD IWG)
CSP	Cyber Security and Privacy (NITRD PCA)
DAF	U.S. Department of the Air Force (USAF and USSF combined)
DARPA	Defense Advanced Research Projects Agency (DOD)
DEA	Drug Enforcement Administration
DHA	Defense Health Agency (DOD)
DHS	Department of Homeland Security
DHS CISA	DHS Cybersecurity and Infrastructure Security Agency
DHS CWMD	DHS Countering Weapons of Mass Destruction Office
DHS S&T	DHS Science and Technology Directorate
DHS TSA	DHS Transportation Security Administration
DL	deep learning
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOE/AITO	DOE Artificial Intelligence and Technology Office
DOE/ARPA-E	DOE Advanced Research Projects Agency–Energy
DOE/CESER	DOE Office of Cybersecurity, Energy Security, and Emergency Response
DOE/EERE	DOE Office of Energy Efficiency and Renewable Energy
DOE/FE	DOE Office of Fossil Energy
DOE/NE	DOE Office of Nuclear Energy
DOE/NNSA	DOE National Nuclear Security Administration
DOE/OE	DOE Office of Electricity
DOE/SC	DOE Office of Science
DOI	Department of the Interior
DOI/BSEE	DOI Bureau of Safety and Environmental Enforcement
DOI/USBR	DOI U.S. Bureau of Reclamation
DOJ	Department of Justice
DOL	Department of Labor

DOT	Department of Transportation
DREN	Defense Research and Engineering Network (DOD)
DTE	Digital Twin Earth
DTRA	Defense Threat Reduction Agency (DOD)
ECP	Exascale Computing Project
EdW	Education and Workforce (NITRD PCA)
EHCS	Enabling R&D for High-Capability Computing Systems (NITRD PCA)
EHR	electronic health record
ENIT	Electronics for Networking and Information Technology (NITRD PCA)
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration (DOT)
FACE	Future Advanced Computing Ecosystem (NSTC Subcommittee and Strategic Plan)
FAIR	findable, accessible, interoperable, and reusable
FBI	Federal Bureau of Investigation (DOJ)
FCC	Federal Communications Commission
FCEN	Financial Crimes Enforcement Network (Treasury)
FDA	Food and Drug Administration (HHS)
FHIR	Fast Healthcare Interoperability Resources
FHWA	Federal Highway Administration (DOT)
FMCSA	Federal Motor Carrier Safety Administration (DOT)
FRA	Federal Railroad Administration (DOT)
FTA	Federal Transit Administration (DOT)
FTC	Federal Trade Commission
FW-HTF	Future of Work at the Human Technology Frontier (NSF)
FY	fiscal year
GOES[-R]	Geostationary Operational Environmental Satellite [R-Series]
GSA	General Services Administration
HBCUs	Historically Black Colleges & Universities
HCC	high-capability computing
HCI	human–computer interaction
HCIA	High-Capability Computing Infra-structure and Applications (NITRD PCA)
HEC	High End Computing (term & NITRD IWG)
HHS	Department of Health & Human Services
HITRD	Health Information Technology R&D (NITRD IWG)
HIV	human immunodeficiency virus
HPC	high-performance computing
HPCMP	High-Performance Computing Modernization Program (DOD/Army)
HRSA	Health Resources and Services Administration (HHS)
IARPA	Intelligence Advanced Research Projects Activity (ODNI)
IEEE	Institute of Electrical and Electronics Engineers (esp. IEEE Standards Assn.)
IETF	Internet Engineering Task Force (standards organization)
IHS	Indian Health Service (HHS)
IoT	Internet of Things
IotF	Industries of the Future
IRAS	Intelligent Robotics and Autonomous Systems (NITRD PCA and IWG)
ISO	International Organization for Standardization
IT	information technology
ITA	International Trade Administration (DOC)
ITS	intelligent transportation systems
ITS JPO	Intelligent Transportation Systems Joint Program Office (DOT)
IWG	Interagency Working Group
JAIC	Joint Artificial Intelligence Center (DOD)
JET	Joint Engineering Team (LSN IWG)
JROTC	Junior Reserve Officers' Training Corps
LSDMA	Large Scale Data Management and Analysis (NITRD PCA)
LSN	Large Scale Networking (NITRD PCA, IWG)
MAGIC	Middleware and Grid Interagency Coordination team (of the LSN IWG)
MARAD	Maritime Administration (DOT)
MDA	Missile Defense Agency (DOD)
MIMO	multiple-input multiple-output
MIT	Massachusetts Institute of Technology
ML	machine learning
NAII	National AI Institute (VA)
NAIIO	National Artificial Intelligence Initiative Office (OSTP)
NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NASA/Aero	NASA Aeronautics Research Mission Directorate
NASA/Science	NASA Science Mission Directorate
NCHS	National Center for Health Statistics (HHS)
NCI	National Cancer Institute (NIH)
NCO	NITRD's National Coordination Office
Next-G	Next-generation
NHTSA	National Highway Traffic Safety Administration (DOT)

NICE	National Initiative for Cybersecurity Education (NIST)
NIFA	National Institute of Food and Agriculture (USDA)
NIH	National Institutes of Health (HHS)
NIJ	National Institute of Justice (DOJ)
NIOSH	National Institute for Occupational Safety and Health (HHS/CDC)
NIST	National Institute of Standards and Technology (DOC)
NITRD	Networking and Information Technology Research and Development (Program and NSTC Subcommittee)
NMIO	National Maritime Intelligence-Integration Office (DOD)
NOAA	National Oceanic and Atmospheric Administration (DOC)
NOAA/ORF	NOAA Operations, Research, Facilities
NOAA/PAC	NOAA Procurement, Acquisition, Construction
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory (DOE)
NRI-3.0	National Robotics Initiative 3.0: Innovations in Integration of Robotics, 3rd generation
NRL	Naval Research Laboratory (DOD)
NRO	National Reconnaissance Office
NSA	National Security Agency (DOD)
NSF	National Science Foundation
NSTC	National Science and Technology Council
NTIA	National Telecommunications and Information Administration (DOC)
NTSB	National Transportation Safety Board
ODNI	Office, Director of National Intelligence
OMB	Office of Management and Budget
ONC	Office of the National Coordinator for Health Information Technology (HHS)
ONR	Office of Naval Research (DOD)
OSD	Office of the Secretary of Defense
OSHA	Occupational Safety and Health Administration (DOL)
OSTP	White House Office of Science and Technology Policy
OUSD R&E	Office of the Undersecretary of Defense for Research and Engineering
PCA	Program Component Area
PCAST	President's Council of Advisors on Science and Technology
PHMSA	Pipeline and Hazardous Materials Safety Administration (DOT)
PI	principal investigator
QIS	quantum information systems
R&D	research and development
RADx℠	Rapid Acceleration of Diagnostics (NIH)
RF	radio frequency
ROK ADD	Republic of Korea Agency for Defense Development
S&E	science and engineering
S&T	science and technology
SAMHSA	Substance Abuse and Mental Health Services Administration (HHS)
SBIR/STTR	U.S. Small Business Innovation Research and Technology Transfer programs
SCC	Smart Cities and Communities
SPSQ	Software Productivity, Sustainability, and Quality (NITRD PCA and IWG)
SSA	Social Security Administration
State	Department of State
STEM	science, technology, engineering, and mathematics
STRIDES	Science and Technology Research Infrastructure for Discovery, Experimentation, and Sustainability (NIH)
STRIDES	Supporting Teachers in Responsive Instruction for Developing Expertise in Science (NSF)
TCSC	Republic of Korea–U.S. Defense pact Technology Cooperation Subcommittee
Treas[ury]	Department of the Treasury
TRMC	DOD Test Resource Management Center
UC	University of California
UK	United Kingdom (Britain)
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force (part of DAF)
USAMRDC	U.S. Army Medical Research and Development Command (DOD)
USCYBERCOM	U.S. Cyber Command (DOD)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey (DOI)
USPTO	U.S. Patent and Trademark Office (DOC)
USSF	U.S. Space Force (part of DAF)
VA	Department of Veterans Affairs
VIA	Video and Image Analytics (NITRD AI IWG task force)
WSRD	Wireless Spectrum Research & Development (NITRD IWG)
XSEDE	Extreme Science and Engineering Discovery Environment (NSF)

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