Annual Report on Technology Transfer:
Approach and Plans, Fiscal Year 2022 Activities and Achievements

U.S. Department of Commerce

Report prepared by:

National Institute of Standards and Technology

National Oceanic and Atmospheric Administration

National Telecommunications and Information Administration

Institute for Telecommunication Sciences

Pursuant to the

Technology Transfer Commercialization Act of 2000 (P.L. 106-404)

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FOREWORD

This report summarizes technology transfer activities and achievements of the Department of Commerce's (DOC) federal laboratories for fiscal year (FY) 2022, and provides statistical information from FY 2018 through FY 2022. At DOC, technology transfer is a significant part of the mission and programmatic activities of the National Institute of Standards and Technology (NIST), the National Oceanic and Atmospheric Administration (NOAA), and the National Telecommunications and Information Administration's (NTIA) Institute for Telecommunication Sciences (ITS). Accordingly, this report focuses on the activities of these agencies.

This report has been prepared as required by 15 U.S.C. § 3710(f). All federal agencies that operate or direct one or more federal laboratories, or conduct other activities under 35 U.S.C. §§ 207 and 209, are subject to the requirements of this statute.

NIST, NOAA, and NTIA's ITS technology transfer offices have contributed to the organization and preparation of the material reported. An electronic version of this report and versions from previous fiscal years are available online.

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1 DEPARTMENT OF COMMERCE OVERVIEW

Technology transfer plays an important role in the Department of Commerce's (DOC) mission to promote job creation, economic growth, sustainable development, and improved standards of living for all Americans. DOC works in partnership with businesses, universities, other Federal agencies and their laboratories, state, tribal and local governments, and communities to promote innovation and improve the nation's overall competitiveness in the global economy. DOC pursues these objectives through policies and programs directed at strengthening the nation's economic infrastructure, facilitating the development of cutting-edge science and technology, providing critical scientific information and data, and managing national resources.

DOC conducts research and development (R&D) in areas of science and technology at the laboratory facilities of NIST, NOAA, and NTIA's ITS. Technology transfer, which is a key part of the programmatic activities in these laboratories, connects technological advances of DOC's science and engineering programs to the U.S. economy.

DOC is also responsible for organizing technology transfer activities across federal agencies. DOC through NIST supports the interagency technology transfer community by serving as Co-Chair of the National Science and Technology Council's Lab-to-Market Subcommittee (L2M), host agency for the Federal Laboratory Consortium (FLC), and convener of the Interagency Working Group for Technology Transfer (IAWGTT) and the Interagency Working Group on Bayh-Dole (IAWGBD).

DOC through NIST serves as a Co-Chair and the Executive Secretariat for the National Science and Technology Council's Lab-to-Market subcommittee. L2M sets the high-level strategy for increasing the efficiency at which federally funded technologies move out of the laboratories and into the market. Strategies currently include identifying administrative and regulatory impediments, increasing engagement with innovation ecosystems, sponsoring innovative technology transfer tools and services, and finding gaps in the R&D continuum. Implementing these strategies is accomplished through the work of several other groups such as the FLC, IAWGTT, IAWGBD, and SBIR Policy Committee.

DOC coordinates the IAWGTT through NIST-hosted interagency discussion on policy, new approaches to technology transfer, and lessons learned from agency technology transfer programs.[1] The IAWGTT was established in 1987 by Executive Order 12591, Section 7, to "convene an interagency task force comprised of the heads of representative agencies and the

[1] Agencies participating in the IAWGTT, established pursuant to Executive Order 12591 of April 10, 1987, include the Department of Agriculture, Department of Commerce, Department of Defense, Department of Energy, Department of Health and Human Services, Department of Homeland Security, Department of the Interior, Department of Transportation, Department of Veterans Affairs, Environmental Protection Agency, and National Aeronautics and Space Administration.

directors of representative Federal laboratories, or their designees, in order to identify and disseminate creative approaches to technology transfer from Federal laboratories."

NIST also serves as the host agency for the FLC, which provides a network for federal labs to develop strategies and opportunities for linking technologies and expertise with the marketplace. The FLC operates as a quasi-governmental body, founded in statute (15 U.S.C. § 3710), that shares technology transfer best practices, develops promotional materials, facilitates partnerships, and organizes networking events. The mission of the FLC is "to increase the impact of federal laboratories' technology transfer for the benefit of the U.S. economy, national security and society."[2]

As the agency tasked with promulgating the Bayh-Dole regulations, DOC through NIST also coordinates the IAWGBD.[3] The IAWGBD reviews and discusses issues related to Bayh-Dole, including potential amendments to the Bayh-Dole regulations and aligning agency policies. Over the last two years, the IAWGBD has been focused heavily on the implementation of changes to the iEdison reporting system. iEdison is an interagency system used by dozens of agencies and bureaus to facilitate the reporting of inventions and patents that were conceived or first actually reduced to practice using extramural federal research funding. The new NIST-managed system, modernizing and updating the system previously managed by NIH, launched on August 9, 2022. NIST's improvements to iEdison are expected to bring increased reporting compliance and improved tracking of the utilization of these federally funded inventions including information on where resulting products are being manufactured.

More information about DOC technology transfer is available on the following websites:

NIST | NOAA | ITS

This annual report provides comprehensive statistics on technology transfer activities of DOC laboratories, including information regarding invention disclosures, intellectual property (i.e., patents and licenses), cooperative research and development agreements (CRADAs), and other technology transfer mechanisms. Examples of successful downstream results, such as commercially significant technologies from technology transfer activities, are also highlighted.

Section 10 of the Technology Transfer Commercialization Act of 2000 (P.L. 106-404, codified at 15 U.S.C. § 3710(f)), requires each federal agency that operates or directs one or more federal laboratories or conducts activities under 35 U.S.C. §§ 207 and 209 to report annually to the Office of Management and Budget (OMB) on the agency's technology transfer activities. The

[2] https://federallabs.org/about/who-we-are/mission-vision

[3] The IAWGBD was formed to facilitate a response to 35 U.S.C. 206 and included representatives from across the federal government including individuals from 14 federal agencies, the Executive Office of the President, and the White House Office of Science and Technology Policy.

OMB's Circular A-11 also requires this information. The tables in the following sections present the required data.[4]

1.1 Statutorily Required Combined Metric Tables

Table 1: DOC Invention Disclosures and Patenting

Metric	FY2022
Invention Disclosures Received	72
Total Patent Applications Filed	27
U.S.	27
Foreign	0
Total Patent Cooperation Treaty (PCT) Applications Filed	8
Total Patents Issued	26
U.S.	26
Foreign	0

[4] In April 2020, the Interagency Working Group on Technology Transfer released the document, Guidance for Preparing Annual Agency Technology Transfer Reports Under the Technology Transfer Commercialization Act. Agencies independently decided whether to implement the new guidance in their FY 2020 and FY 2021 reports. DOC decided to implement the new guidance in its FY 2020 report. In this report, the statutorily required metrics only report FY 2020 data due to the new guidance's metrics and redefinitions. The additional metrics still display 5 years' worth of data because their definitions did not change. Technology transfer data is typically adjusted over time to account for new information resulting from changes in reporting procedures, patent decisions, programmatic changes, and the like. With the new metrics and definitions, previous years' data will not be added or updated. The metrics outside the statutory requirements were adjusted, where necessary, to reflect the most accurate estimates for each year reported.

Table 2: DOC Licensing

Metric	FY 2022
Invention Licenses, Total Active	42
New Invention Licenses	11
New Invention Licenses Granted to Small Businesses	8
Income Bearing Licenses, Total Active	33
New Income Bearing Licenses	0
Exclusive, Total Active	15
Partially Exclusive, Total Active	0
Non-Exclusive, Total Active	18
Other Licenses, Total Active	0
New Other Licenses	0
New Other Licenses Granted to Small Businesses	0
Elapsed Amount of Time for Granting Invention Licenses	
Average (months)	n/a
Minimum (months)	n/a
Maximum (months)	n/a
Licenses Terminated for Cause	0

Table 3: DOC Income from Licensing[5]

Metric	FY 2022
Invention License Income	$210,610
Other License Income	$0
Total Earned Royalty Income (ERI)	$210,610
ERI from Top 1% of Licenses	n/a
ERI from Top 5% of Licenses	n/a
ERI from Top 20% of Licenses	n/a
Minimum ERI	n/a
Maximum ERI	n/a
Median ERI	n/a
Disposition of ERI	
Average Percentage Distributed to Inventors	n/a
Average Percentage Distributed to Lab/Agency	n/a

Table 4: DOC Collaborative Relationships

Metric	FY 2022
Total Active CRADAs	2,240
New CRADAs	1,814
New CRADAs Involving Small Businesses	929
Other Collaborative Agreements	2,739

[5] Aggregate DOC-level data on Earned Royalty Income (ERI) are not available due to aggregate values reported by DOC bureaus. Bureau-level data are available within each bureau's chapter of this report.

1.2 OTHER PERFORMANCE MEASURES DEEMED IMPORTANT[6]

1.2.1 Scientific and Technical Publications

Technology transfer mechanisms include more than just counting CRADAs, patents, and licenses. Scientific and technical publications are also included and counted as technology transfer. In FY 2022, NIST, NOAA, and ITS researchers published 2,957 scientific and technical papers in peer-reviewed journals.

Table 5: DOC Scientific and Technical Publications[7]

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
NIST	1,415	1,396	1,509	1,419	1,160
NOAA	1,794	1,895	1,755	1,804	1,783
ITS	11	11	14	10	14
Department Total	3,220	3,302	3,278	3,233	2,957

[6] To improve consistency across reports published by DOC and other federal agencies, NIST is reviewing how it reports data on the technical areas of federal patents and publications. These efforts are ongoing and future reports will update this information.

[7] This report revises previously reported values for the number of publications for NIST and the department total for FY 2020 and FY 2021. Previously, the number of NIST publications was reported as 1,345 for FY 2020 and 1,509 for FY 2021, these numbers are revised to 1,509 for FY 2020 and 1,419 for FY 2021. Additionally, the department total is revised from 3,114 in FY 2020 and 3,323 in FY 2021 to 3,278 in FY 2020 and 3,233 in FY 2021.

2 NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

NIST has a broad mission: to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

Rapidly evolving sectors like nanotechnology, biotechnology, homeland security, information technology, and advanced manufacturing need sophisticated technical support systems in order to flourish and grow. Therefore, an important part of accomplishing NIST's mission is to anticipate future measurement and standards needs of U.S. industry. NIST laboratories develop measurement techniques, test methods, standards, reference materials, reference data, and other technologies and services that support U.S. industry, scientific research, and the activities of many other federal agencies. In carrying out its mission, NIST works directly with industry partners (individual companies and consortia), universities, standards organizations, other domestic and foreign associations, and other government agencies.

2.1 APPROACH AND PLANS FOR TECHNOLOGY TRANSFER

NIST designs its technology transfer activities to disseminate the results of fundamental research, measurements, and standards research to industry and other interested parties. In order to provide leading-edge scientific and technical work, NIST is required to have expertise in multiple disciplines, maintain high levels of collaboration with organizations and people with diverse capabilities, and have highly specialized facilities and tools. For more than a century, laboratories at NIST (and its direct predecessor agency, the National Bureau of Standards) have successfully collaborated with others to provide the measurement techniques and technical tools needed by America's innovators.

NIST broadly defines technology transfer as the overall process by which NIST knowledge, facilities or capabilities in measurement science, standards and technology promote U.S. innovation and industrial competitiveness in order to enhance economic security and improve quality of life.[8]

NIST's definition of technology transfer reflects the many ways NIST reaches its external partners. The definition includes, *inter alia*: 1) the act of transferring knowledge from one individual to another by means of mentoring, training, documenting, or collaborating; and 2) commercialization, which allows the adoption of a technology into the private sector through a business or other organization.

NIST designed its technology transfer program to improve processes and work products directly through collaborations.

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[8] https://www.nist.gov/director/congressional-and-legislative-affairs/fy-2019-presidential-budget-request-summary-1

The mission of NIST's Technology Partnerships Office (TPO) is to serve its NIST customers by leading technology transfer processes that NIST researchers use to develop innovations from concept to practical application. TPO structures collaborative relationships between NIST researchers and regional, national, and global partners, fosters entrepreneurship and small business growth, and provides economic analysis to support the process. TPO serves its interagency customers by leading collaborative and consensus-building efforts for developing frameworks and best practices that enable all federal technology transfer offices to succeed in advancing their missions through partnerships and transferring technologies from lab to market.

TPO's vision is to facilitate the best possible outcome for each NIST research innovation and provide dynamic interagency leadership for technology transfer policy and analysis.

The following summarizes different technology transfer mechanisms NIST uses to promote innovation and to disseminate technologies that result from its research.

2.2 STATUTORILY REQUIRED METRIC TABLES

Table 6: NIST Invention Disclosures and Patenting

Metric	FY 2022
Invention Disclosures Received	69
Total Patent Applications Filed	27
U.S.	27
Foreign	0
Total Patent Cooperation Treaty (PCT) Applications Filed	8
Total Patents Issued	25
U.S.	25
Foreign	0

Table 7: NIST Licensing[9]

Metric	FY 2022
Invention Licenses, Total Active	36
New Invention Licenses	11
New Invention Licenses Granted to Small Businesses	8
Income Bearing Licenses, Total Active	27
New Income Bearing Licenses	0
Exclusive, Total Active	14
Partially Exclusive, Total Active	0
Non-Exclusive, Total Active	13
Other Licenses, Total Active	0
New Other Licenses	0
New Other Licenses Granted to Small Businesses	0
Elapsed Amount of Time for Granting Invention Licenses	
Average (months)	11
Minimum (months)	1
Maximum (months)	29
Licenses Terminated for Cause	0

[9] "Active" means an agreement in force at any time during the fiscal year. Invention licenses include licenses to pending patent applications. Elapsed Amount of Time for Granting Invention Licenses is defined as the time between the date of license application and the date of license execution. The date of license application is the date the laboratory formally acknowledges the written request for a license from a prospective licensee and agrees to enter into negotiations.

Table 8: NIST Income from Licensing

Metric	FY 2022
Invention License Income	$98,022
Other License Income	$0
Total Earned Royalty Income (ERI)	$98,022
ERI from Top 1% of Licenses	$22,029
ERI from Top 5% of Licenses	$22,029
ERI from Top 20% of Licenses	$22,029
Minimum ERI	$173
Maximum ERI	$22,029
Median ERI	$6,250
Disposition of ERI	
Percentage Distributed to Inventors	43%
Percentage Distributed to Lab/Agency	57%

Table 9: NIST Collaborative Relationships[10]

Metric	FY 2022
Total Active CRADAs	2,181
New CRADAs	1,795
New CRADAs Involving Small Businesses	917
Other Collaborative Agreements	2,738

2.3 Other Important NIST Performance Measures

In addition to the previously discussed methods of transferring technology (i.e., patents, licenses, and CRADAs), NIST researchers routinely transfer technological innovations through the mechanisms discussed below.

2.3.1 Scientific and Technical Publications

NIST research results are published in a variety of formats including technical papers and reports, data, and software. These research outputs are made available to industry, academia, other agencies, and the public through various repositories and websites.

[10] CRADAs include: bilateral agreements, consortia agreements, industry-led agreements, NVLAP accreditations, and calibrations. Other Collaborative Agreements include: material transfer agreements and guest researcher agreements.

NIST authors published 1,160 manuscripts in fiscal year (FY) 2022 in peer-reviewed journals. The number of times that a manuscript is cited by other authors serves as an indicator of technology transfer. In calendar year (CY) 2022, NIST-authored manuscripts that were published in peer-reviewed journals during the past five years (CY 2018–2022) garnered 28,621 citations.[11]

Table 10: NIST Publishing Activities – Papers[12]

	FY 2020	FY 2021	FY 2022
Number of NIST Papers	1,509	1,419	1,160
Number of NIST Paper Citations (CY)	n/a	36,882	28,621

NIST is the self-publisher of over 15 Technical Series publications (TechPubs) consisting of technical reports, recommendations, practice guides and standards, industry handbooks, and other documents. NIST produced 290 TechPubs in FY 2022. The number of times that a publication is downloaded serves as an indicator of technology transfer. In CY 2022, NIST TechPubs that were published during the past five years (CY 2018–2022) were downloaded over 3.1 million times.[13] Of these publications, those with the subject area of computer and information security standards and guidelines were downloaded thousands of times every day.[14]

Table 11: NIST Publishing Activities - Technical Report Series

	FY 2020	FY 2021	FY 2022
Number of NIST TechPubs Published	232	225	290
Number of NIST TechPubs Downloads (CY)	n/a	2,840,058	3,114,035

NIST researchers published 123 data products in FY 2022, including datasets and software. The volume of downloaded data products serves as an indicator of technology transfer. In CY 2022, there were 36 terabytes[15] (TB) of data downloaded from NIST datasets located in the NIST Data

[11] NIST peer-reviewed publication data were retrieved from queries of the Web of Science (WoS) database on November 14, 2022. These data do not represent a comprehensive count of all NIST publications. This reporting includes only NIST-authored publications that are captured by the WoS search queries. Publications that are not indexed in the WoS database are not included in this reporting.

[12] Data as of November 14, 2022.

[13] Download statistics of NIST Technical Series Publications consist of the number of unique visitors (“downloads”) for each publication, for instance, a count of requests to display PDF content from a unique IP address. Requests from spiders and web crawlers are not used to determine visitors.

[14] NIST is responsible for developing information security standards and guidelines, including minimum requirements for federal information systems per statutory responsibilities under the Federal Information Security Modernization Act (FISMA), 44 U.S.C. § 3551 et seq., Public Law (P.L.) 113-283.

[15] Download statistics of NIST datasets are derived directly from usage metrics generated on the NIST Data Portal.

Portal. The number of repositories added to the NIST Open-Source Code Portal, where public users search and explore open-source software developed by NIST and collaborators, serves as an indicator of technology transfer. In FY 2022, 95 repositories[16] were added to the NIST Open-Source Code Portal. These data products are generated as part of the NIST mission, spanning multiple disciplines of scientific, engineering and technology research.

Table 12: NIST Publishing Activities – Data and Software[17]

	FY 2020	FY 2021	FY 2022
Number of NIST Datasets & Software Published	132	128	123
Quantity of NIST Data (direct download) from NIST Data Portal (CY)	n/a	14 TB	36 TB
Number of Repositories added to the NIST Open-Source Code Portal	143	68	95

NIST also publicizes its planned, ongoing, and recently completed work in outlets followed by the organizations with interests aligned to NIST's research and services, such as the trade and technical press. In addition to news releases, websites, social media posts, and contacts with the media, NIST issues a bi-weekly e-mail roundup of its latest news, called *Tech Beat*.

2.3.2 Participation in Documentary Standards Committees

Documentary standards are shared sets of rules that specify, for example, a test method or measurement method, a product's properties, or standard practices. Econometric studies have reported that standards contribute significantly to economic growth, and a significant study concluded, development of standards is integral to innovation; documentary standards contribute to economic growth at least as much as do patents; and the macroeconomic benefits of the development of standards extend beyond the benefits to the companies that use the standards.[18]

During FY 2022, 579 members of the NIST staff were involved with 328 standards organizations. Such participation helps NIST respond to the needs of the private sector and enables its scientists and engineers to bring NIST technology and know-how directly into standards-setting bodies.

[16] NIST Open-Source Code Portal Repository data were retrieved from the Repo Creation History chart. These data do not represent a comprehensive count of all NIST data repositories. These data refer to the number of repositories added to the portal in the reporting fiscal year; it is not a cumulative number.

[17] Data as of November 16, 2022.

[18] Peter Swann, G.M., Report for the UK Department of Business, Innovation, and Skills (BIS), 2010 https://www.gov.uk/government/publications/economics-of-standardisation-update-to-report.

Table 13: NIST Participation in Documentary Standards[19]

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Number of Participating NIST Staff	423	440	400	547	579
Number of Standard Organizations with NIST Participants	116	112	112	350	328

The NIST Standards Coordination Office (SCO) maintains the Standards Committee Participation Database for employees to report their participation, including leadership positions within standards organizations.

2.3.3 Standard Reference Data

NIST's Standard Reference Data (SRD) Program provides critically evaluated numeric data to scientists and engineers for use in technical problem solving, research, and development. Many types of reference data are extremely important in engineering structures, optimizing chemical processes, and other industrial applications. NIST extracts SRD from scientific and technical literature or develops them from measurements conducted at its laboratories that are carefully evaluated for accuracy and reliability. NIST currently maintains 65 SRD databases that cover many areas of science, including analytical chemistry, atomic and molecular physics, biotechnology, and materials sciences.

In FY 2022, the NIST SRD Program distributed 2,842 e-commerce orders, 7,999 units sold via distributor, 124 active distributor agreements, 17 active site licenses, 81 active internet subscriptions, 20 units shipped to the user, and 3,805 products downloaded from the NIST website (1,618 free downloads, 2,187 paid downloads).

[19] Starting in FY 2021, the data for the reported number of participianting NIST staff and number of standard organization with NIST participants come from a new database platform.

Table 14: NIST Standard Reference Data Program[20]

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Products Available (Databases)	92	90	74	74	65
E-Commerce Orders	2,670	2,613	2,908	3,200	2,842
Units Sold via Distributor	8,413	9,880	7,905	8,499	7,999
Active Distributor Agreements	157	125	115	118	124
Active Site Licenses	17	30	15	19	17
Active Internet Subscriptions	50	41	140	69	81
Units Shipped via UPS	146	82	57	50	20
Products Downloaded from the NIST Website	3,910	3,812	4,578	4,449	3,805
Free Downloads	1,099	1,100	1,484	1,369	1,618
Paid Downloads	2,811	2,712	3,094	3,080	2,187

2.3.4 Standard Reference Materials

Standard Reference Materials (SRMs) are a definitive source for various measurements in the United States. Measurements made using SRMs can be traced to a common and recognized set of basic standards that provide the basis for measurement compatibility among different laboratories. The certified property values for SRMs often depend on the development of unique measurement capabilities within NIST. In FY 2022, NIST made available 1,121 SRMs and from these, sold 28,777 units.

Table 15: NIST Standard Reference Materials

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Units Available	1,140	1,130	1,114	1,116	1,121
Units Sold	31,503	29,955	27,319	28,065	28,777

2.3.5 User Facilities – Research Participants

NIST operates two unique and valuable laboratory facilities that support U.S. industry, academic institutions, and other NIST and government laboratories. These facilities, the Center for Nanoscale Science and Technology (CNST) and the NIST Center for Neutron Research

[20] NIST reviewed the classification of its available SRD products in FY 2022. NIST determined that 65 of the products available were correctly classified as SRDs while the other products were reclassified as non-SRD products (e.g., data compilations, bibliographic collections). Of the 65 SRD-classified products, 49 were free downloads or web portals and 14 were fee-based products.

(NCNR), allow NIST customers to tap directly into NIST measurement expertise to solve problems.[21]

The CNST supports the development of nanotechnology from discovery to production. It operates in a national shared-use nanofabrication and measurement facility (the NanoFab), complemented by a multidisciplinary research staff creating next-generation tools for advancing nanotechnology. The NCNR is a national user facility that provides cold and thermal neutron measurement capabilities to researchers from academia, industry, and other government agencies.

NIST user facility "research participants" are those who directly participate in an NCNR experiment or CNST project. Research participants include those who use the facility on-site or remotely, and their collaborators on the experiment or project. In FY 2019, CNST began reporting the number of distinct facility users versus the previously reported number of research participants.[22] In FY 2022, there were 198 distinct facility users at CNST and 1,857 research participants at NCNR.

Table 16: NIST Research Participants

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
CNST	3,415	314	230	184	198
NCNR	2,742	2,923	3,068	2,576	1,857

2.3.6 Postdoctoral Researchers

Technology transfer includes the people who perform the actual research and development. NIST postdoctoral researchers, or "postdocs," play an important role in transferring NIST technology and expertise. NIST adheres to the National Science Foundation's Proposal and Award Policies and Procedures Guide's standard of a postdoctoral researcher. In FY 2022, NIST hosted 120 postdocs. Of these, 71 were based at the NIST Gaithersburg, Maryland campus; 44 were located in Boulder, Colorado; 1 was located at Hollings Marine Laboratory; and the remainder were located at the Joint Institute for Laboratory Astrophyics (JILA).

[21] The NCNR was shut down on February 3, 2021, in response to an incident where a single fuel element overheated and was damaged. On March 10, 2023, the Nuclear Regulatory Comission concluded that NIST had satisfied the safety requirements to restart the reactor and authorized NIST to restart the NCNR research reactor.

[22] The change in reporting is due to organizational restructuring. CNST merged with the Physical Measurement Laboratory in FY 2019.

Table 17: NIST Postdoctoral Researchers

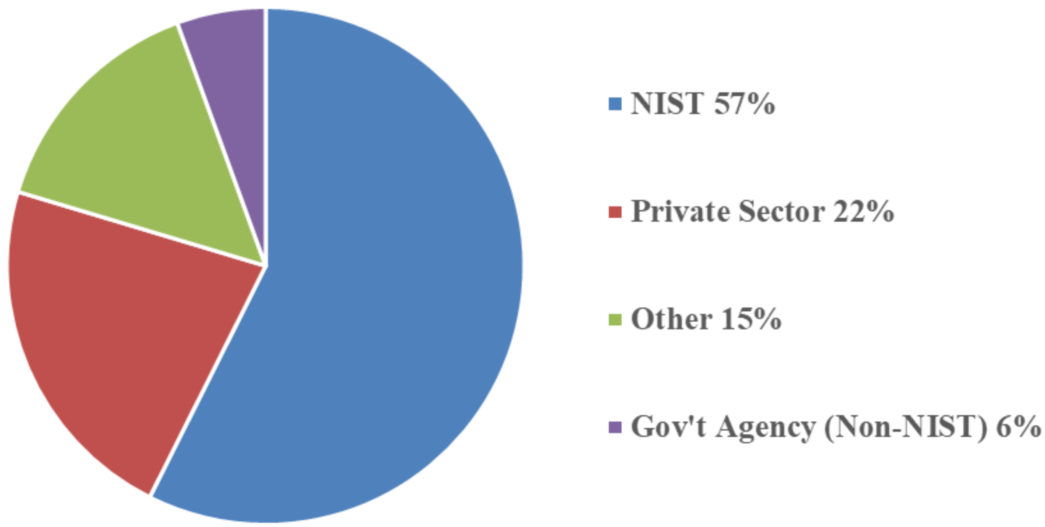
	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
NIST Postdocs, Total (NRC)	153	165	154	132	120
Gaithersburg campus	91	110	103	94	71
Boulder campus	44	35	40	33	44
Joint Institute for Laboratory Astrophysics [(a)]	10	13	7	5	4
Joint Quantum Institute [(b)]	3	1	0	0	0
Hollings Marine Laboratory [(c)]	1	3	4	0	1
Institute for Bioscience and Biotechnology Research [(d)]	3	2	0	0	0
Joint Initiative for Metrology in Biology[(e)]	1	1	0	0	0

(a) Joint Institute for Laboratory Astrophysics (JILA) was founded in 1962 as a joint institute of CU-Boulder and NIST. JILA is located at the base of the Rocky Mountains on the CU-Boulder campus in the Duane Physics complex.
(b) The Joint Quantum Institute (JQI) was founded in September 2006 as a collaboration between the University of Maryland and NIST, with additional support from the Laboratory for Physical Sciences, a government facility in College Park.
(c) The Hollings Marine Laboratory (HML) is a world-class research facility in Charleston, South Carolina. HML's mission is to provide science and biotechnology applications to sustain, protect, and restore coastal ecosystems, with emphasis on links between environmental condition and the health of marine organisms and humans.
(d) The Institute for Bioscience and Biotechnology Research (IBBR) is a joint research enterprise created to enhance collaboration among the University of Maryland College Park, the University of Maryland Baltimore, and NIST.
(e) The Joint Initiative for Metrology in Biology (JIMB) is co-led by Stanford University and NIST and is designed to enable significant improvements in the accuracy and comparability of vital data used to make important research, regulatory, clinical, and manufacturing quality control decisions.

The number of postdocs is a significant measure of technology transfer; at the conclusion of their tenure, they take what they have learned and apply it to their next employment. NIST surveyed 54 FY 2022 NIST National Research Council (NRC) program postdocs. Of these, 57% continued research careers with NIST,[23] 22% percent moved to the private sector, 15% pursued other opportunities such as becoming independent researchers, and 6% moved to non-NIST government agencies. No surveyed postdocs moved to academia in FY 2022.

[23] Researchers who left their postdoc positions and stayed at NIST became career conditional / term employees or non-career conditional or term employees (i.e. contractors or guest researchers).

Figure 1: Tracking NIST Researchers after Initial Postdoc Tenure at NIST (FY 2022)



2.3.7 Guest Researchers

In addition to postdocs, each year thousands of researchers visit NIST to participate in collaborative projects. NIST hosts many term appointment researchers and non-NIST employees working as guest researchers, collaborators, and student fellows. Similar to postdoctoral researchers, many guest researchers seek career opportunities in academia, the private sector, or federal agencies after their tenure at NIST. While some guest researchers' NIST projects may result in inventions, all guest researchers leave NIST with technical and research skills that place them on the cutting edge of their disciplines. Each researcher takes the skills and knowledge and aspires to apply them in innovative ways in their careers. Paramount among these skills are the knowledge requirements and processes needed to collaborate with federal laboratories and the federal resources available to assist companies in creating and developing new and improved technologies.

In FY 2022 there were 2,498 guest scientists and engineers working at NIST. Fewer guest researchers visited NIST due to the COVID-19 pandemic and travel restrictions.

Table 18: NIST Guest Researchers

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Guest Scientists and Engineers	3,221	3,180	2,701	2,371	2,498

2.3.8 Accreditation Services

The NIST National Voluntary Laboratory Accreditation Program (NVLAP) is a voluntary, fee-supported program to accredit private sector laboratories' competency to perform measurement tests or calibrations. In FY 2022, NVLAP accredited 623 laboratories.

Table 19: NIST Accreditation Services

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
NVLAP Accreditations	674	674	644	650	623

2.3.9 Calibration Services

The NIST laboratories provide unique physical measurement services for their customers, including calibration services, special tests, and measurement assurance programs. NIST designs its calibration services to help manufacturers and users of precision instruments achieve the highest possible levels of measurement quality and productivity. NIST calibrations often serve as the basis for companies that provide commercial calibration services and calibration equipment. The NIST on a Chip project established in 2018 aims to streamline a host of calibration services by making chip-scale calibration technologies available to end-users, with the goal of reducing the need for traditional calibration services provided on-site at NIST. In FY 2022, NIST performed 14,013 calibration tests.

Table 20: NIST Calibration Services

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Number of Calibration Tests Performed	11,771	11,519	9,225	13,568	14,013

2.3.10 Education Outreach Programs and Partnerships

NIST has received recognition as a vital contributor to the efforts to improve science, technology, engineering, and mathematics (STEM) education in the United States. As part of its mission, and to help create a long-term and well-qualified workforce for standards and measurement research, NIST has several educational outreach programs and partnerships that enrich basic research programs such as:

- the Summer Undergraduate Research Fellowship (SURF) program;
- the Summer High School Internship (SHIP) program;
- the Pathways Program;
- the NIST Summer Institute for Middle School Science Teachers; and
- the Professional Research Experience Program (PREP).

In FY 2022, 156 students participated in the SURF program, 44 students participated in SHIP, 56 students participated in the Pathways Program, 23 individuals participated in the Summer Institute for Middle School Science Teachers, and 531 students participated in PREP.

Table 21: NIST STEM Education Participation

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
SURF[(a)]	212	173	0	146	156
SHIP	64	55	0	54	44
Pathways Program	85	71	77	48	56
Summer Institute for Middle School Science Teachers[(b)]	0	24	23	24	23
PREP	200	360	174	425	531

(a) NIST did not hold the SURF or SHIP programs in FY 2020.
(b) NIST did not hold the Summer Institute for Middle School Science Teachers in FY 2018.

2.3.11 Conferences, Seminars, and Workshops

Some of the most important mechanisms for technology dissemination are communication, education, and interaction among researchers, developers, and users of technology. NIST hosts numerous conferences, workshops, and other meetings each year to facilitate the transfer of technology.

In FY 2022, the NIST Conference Program arranged 35 conferences, both in person and virtual, that attracted 23,706 researchers to NIST's facilities in Gaithersburg, Maryland, and Boulder, Colorado. NIST's Office of Weights and Measures, which promotes uniformity in U.S. weights and measures laws, regulations, and standards, trained 1,294 weights and measures administrators, laboratory metrologists, and field enforcement officials. In addition to formal trainings, NIST staff respond to email, telephone, and mail inquiries from researchers requesting information and details about NIST technical developments and research results.

Table 22: NIST Conferences, Seminars, and Workshops[24]

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
NIST Conference Center					
Conferences and Workshops	101	78	74	40	35
Attendance	8,772	8,596	7,747	17,943	23,706
Office of Weights and Measures - Metrology Training					
Total Students	902	666	2,057	2,084	1,294
Seminar Attendance	523	441	101	0	125
Webinar Attendance	379	225	1,948	1,954	1,134
Workshop Attendance	0	0	8	130	35

[24] This report revises the number of Total Students and Workshop Attendance reported for FY 2021. The number of Total Students in FY 2021 was previously reported as 2,083 and is now revised to 2,084. The value of Workshop Attendance in FY 2021 was previously reported as 129 but is revised to 130.

2.3.12 Trends in Technology Transfer Office Activity

To better understand the year-to-year activity of its technology transfer office, NIST tracks the average number of days to both file a patent application and approve a CRADA. In FY 2022, the average number of days between the receipt date of an invention disclosure and the filing date of the first non-provisional patent application was 612 days. In most cases, NIST files a provisional patent application before a non-provisional filing. Therefore, the duration reported here reflects a time period that starts with an invention disclosure, includes the filing of a provisional patent application, and ends with the filing of a non-provisional patent application, which usually occurs close to 365 days after the provisional application filing date. The average CRADA approval time was 76 days.

Table 23: NIST Activity Trends

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Average Number of Days to File a Non-Provisional Patent Application[(a)]	337	408	450	488	612
Average Number of Days to Approve a CRADA[(b)]	91	129	109	92	76

(a) The time between the receipt date of an invention disclosure and the filing date of the first non-provisional patent application filed by NIST.
(b) The time between the receipt of the memo related to the award of a CRADA and the time of approval for the memo.

2.3.13 Small Business Innovation Research (SBIR)

NIST's SBIR program funds science and technology-based small businesses in the United States. The program offers qualified small businesses the opportunity to propose innovative ideas that align with NIST research and development and have the potential for commercialization. In FY 2022, NIST awarded 12 Phase I SBIR awards and 7 Phase II SBIR awards. Additionally, NIST awarded 4 Fast-Track awards, which are a combination of Phase I and Phase II awards.

Table 24: NIST SBIR Award Count

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Phase I SBIR Awards	12	12	12	11	12
Phase II SBIR Awards	10	7	8	6	7
Fast-Track Awards	0	0	0	0	4

2.3.14 Economic Assessment

Economists at NIST published two peer-reviewed articles relating to technology transfer in FY 2022:

1. Hall MJ (2022). "New technology transfer metrics for the National Institute of Standards and Technology." *The Journal of Technology Transfer*. https://doi.org/10.1007/s10961-022-09947-9

Abstract: New technology transfer metrics relevant to the National Institute of Standards and Technology (NIST) are presented in this paper. From a public sector management perspective, these metrics are important because they extend the current measures of technology transfer to include metrics that are unrelated to the size of the federal laboratory in question. This extension allows for a more meaningful comparison of some aspects of technology transfer activities at federal laboratories with differing sizes, missions, and policies. This paper applies proposed measures of technology transfer to data on NIST's technology transfer activities, compares these metrics across multiple organizations, provides suggestions for the interpretation of these metrics, describes limitations of these metrics, and suggests areas for future research.

2. Hall MJ, Link AN, Schaffer M (2022). "An economic analysis of standard reference materials." *The Journal of Technology Transfer*. https://doi.org/10.1007/s10961-022-09960-y

   Abstract: Standard Reference Materials® (SRMs®) are high-technology infrastructural elements developed and distributed by the U.S. national metrology institute, the National Institute of Standards and Technology. SRMs are used throughout the economy to enhance production efficiency by reducing information asymmetries and thereby reducing transaction costs between affected parties. To date, the domestic market demand for SRMs in the United States has not been studied. Thus, the purpose of this paper is to estimate a market demand model for SRMs; the empirical results show that market demand is cyclical, that is it increases with positive changes in multifactor productivity.

In addition to the NIST economists' assessments, NIST contracted with an independent, third-party research firm to conduct an economic impact analysis of NIST's Communications Technology Laboratory (CTL) Public Safety Communication Research (PSCR) division's $300 million in research investments from the Public Safety Trust fund. The analysis focuses on how the R&D investments by NIST PSCR to perform critical public safety communications R&D translate into broader impacts to the United States, including jobs, earnings, value added, and total economic output. PSCR's R&D investments resulted in economic output in 33 of the 50 states, for a total economic output of $807.1 million (in 2022 dollars) and 6,043 new jobs. For more information about the NIST PSCR Economic Impact Analysis and to view the 33 state profiles and report, please visit: https://www.nist.gov/ctl/pscr/commercialization/economic-impact.

2.3.15 Challenge and Prize Competitions

NIST's Communications Technology Laboratory (CTL) and Engineering Laboratory (EL) host prize competitions under the America COMPETES Act authority (15 U.S.C. § 3719) to spur ideation and innovation from public solvers. The laboratories use prize competitions to advance manufacturing robotics (EL) and public safety communications (CTL) research by engaging individuals, industry, academia, and organizations in a rapid, more collaborative means than traditional funding opportunities. In FY 2022, NIST awarded 209 cash prizes totaling $2,452,500 to 161 teams. NIST launched or completed the following nine prize competitions in FY 2022:

1. Differential Privacy Temporal Map Challenge
2. The Mobile Fingerprinting Innovation Technology (mFIT) Challenge
3. First Responder UAS Triple Challenge: 3.1 FastFind - UAS Search Optimized
4. First Responder UAS Triple Challenge: 3.2 LifeLink - UAS Data Relay
5. First Responder UAS Triple Challenge: 3.3 Shields Up! Securing Public Safety UAS Navigation and Control
6. First Responder UAS Indoor Challenge
7. CommanDING Tech Challenge: Command Dashboard Integrating Next-Gen Technology Challenge for Public Safety
8. First Responder Smart Tracking Challenge
9. 2022 Agile Robotics for Industrial Automation Competition (ARIAC)

Several of the above prize challenges had culminating phases focused on contestants developing a business or commercialization strategy surrounding their prototypes. Some prize challenges provided additional awards to help finalists connect to commercialization resources and advance their early-phase innovations.

NIST also aided the United States and United Kingdom's joint government-partnership to deliver a set of prize challenges to unleash the potential of privacy-enhancing technologies (PETs) that enables organizations to analyze sensitive data while providing improved privacy protections. In FY 2022, the first phase of the PETs Prize Challenge: Advancing Privacy-Preserving Federated Learning occurred, with three awards made to the U.S. teams totaling $55,000 in prizes.

2.3.16 Commercialization Programs and Support for External Researchers

NIST's Communications Technology Laboratory (CTL) has piloted two commercialization programs to support the commercialization of external researchers' technology:

1. Federal Funding Opportunity Focused on Commercialization:

   NIST offered a unique federal funding opportunity—*2020-NIST-PSIAP-TABA-01, NIST Public Safety Innovation Accelerator Program (PSIAP) – Follow-on Funding for Technical and Business Assistance and Demonstration Projects with Public Safety Agencies*—focused on advancing early phase prototypes to more advanced technology readiness levels.

   Acknowledging the technology development and life cycle gap from early-stage research and prototypes to publicly available technology, NIST provided this funding opportunity to entities with a previous federal award to advance awardees' research and prototypes further and accelerate needed improvements in communications technology for first responders. The funding opportunity provided additional funding to entities to either: (1) more rapidly advance their prototypes through needed technical and business assistance or (2) conduct a demonstration project with a partnering public safety agency to provide additional testing and research.

NIST awarded 10 recipients and their partnering public safety agencies, totaling $1,997,602 in funding to advance their communication technology for public safety. All recipients are currently scheduled to wrap-up their demonstration projects by end of FY 2023.

2. Virtual Accelerator for Public Safety Communications Technology

   NIST designed the Pulse Accelerator to help emerging communications technology companies accelerate growth and development that supports the public safety and first responder sectors. Working together in a collaborative program, the 28 selected participants, across three rounds of the accelerator (FY 2021 and FY 2022), engaged directly with specialists and experts from business, technology and public safety to develop a commercialization plan for their technology innovation. A comprehensive questionnaire designed to assess what impact the Pulse Accelerator had on the participating businesses will wrap-up in FY 2023. Preliminary results have shown that following their participation in the Accelerator, 10 of the 28 participants have received 14 SBIR/STTR awards totaling more than $3,487,655 in funding from other federal agencies. These SBIR and STTR awardees will further develop their innovative communication technology while they conduct innovative research with the federal government. Additionally, it is anticipated that one Accelerator participant's planned business expansion with the State of Colorado will create 372 new jobs with an average salary of $143,000 annually.

2.3.17 Awards

In its simplest form, technology transfer is achieved through dissemination of research results via publication, participation in professional societies, and other activities. As part of these activities and in addition to the NIST and DOC awards, NIST staff received the following prestigious awards during FY 2022:

USRA Q2B Applied NISQ Computing Paper Award for 2021
Lucas Brady

2022 Neutron Scattering Society of America Service Award
Paul Butler

ASHRAE Fellow
W. Stuart Dols

Dave Tree Distinguished Service Award
Piotr Domanski

Proulx Early Career Award
Ryan Falkenstein-Smith

Leadership in Forensic Science Award from the Washington Academy of Science for Leadership in Forensic Science
Barbara Guttman

Johns Hopkins University Outstanding Instructor Award
William Healy

Department of Commerce FY 2021 Real Property Portfolio Award
Adam Jacoff

Washington Academy of Sciences (WAS) 2022 Leadership Award in Manufacturing Engineering
Kevin Jurrens

Fellow of the Washington Academy of Science
Raghu Kacker

Johns Hopkins University Outstanding Instructor Award
Mark Kedzierski

Fellow of the Neutron Scattering Society of America
Susan Krueger

ASTM International Additive Manufacturing Young Professional Award
Brandon Lane

Elected ASCE Structural Engineering Institute Fellow
Marc Levitan

Engineering New Record - Top 25 Newsmakers of 2021 - Award of Excellence
Marc Levitan

ASME 2022-2023 Early Career Leadership Intern Program to Serve Engineering (ECLIPSE)
Lin Lingnan

ASTM Additive Manufacturing Award of Excellence in Research
Yan Lu

Presidential Rank Award of Distinguished Senior Professional
Chuck Majkrzak

Distinguished Member of the American Society of Civil Engineers
Therese McAllister

2021 ASTM Additive Manufacturing Award of Excellence in Standardization
Shawn Moylan

Clifford G. Shull Prize
Dan Neumann

President of the ASCE Geo-Institute
Sissy Nilolaou

Excellence in Research in Applied Mathematics Award from the Washington Academy of Science
Paul Patrone

Fellow of the Neutron Scattering Society of America
Don Pierce

SME 30 Under 30
Maxwell Praniewicz
2022 Neutron Scattering Society of America Service Award
William Ratcliff

The Ret. General Michael V. Hayden Lifetime Achievement Award
Ron Ross

Fellow of the Washington Academy of Science
Kamran Sayrafian

Department of Commerce FY 2021 Real Property Portfolio Award
David Schmitt

Elected to the 2022 Class of the AIMBE College of Fellows
Ram D. Sriram

2022 Women in Biometrics Award, Security Industry Association
Diane Stephens

ASTM Award of Appreciation
Paul Stutzman

Physics World 2021 Breakthrough of the Year, First Place
John Teufel, Shlomi Kotler, Ezad Shojaee, Alex Kwiatkowski, Shawn Geller, Scott Glancy, and Manny Knill

Clarivate Highly Cited Researcher, Cross-Field
Hui Wu

2022 Washington Academy of Science (WAS) 2022 Excellence in Research Award in Chemical Engineering
Jiann Yang

DOC SEE Ambassador
David Yashar

ASTM International Award of Merit
Robert Zarr

Clarivate Highly Cited Researcher, Chemistry
Wei Zhou

Service and Leadership Award at the 2022 Federal Identity Forum
NIST's Information Technology Image Group

2022 Communicators Award of Distinction for Video Animation and Communicators Award of Distinction in the Technology for Online Video from Academy of Interactive & Visual Arts
NIST's Public Affairs Office and Information Technology Laboratory

2.4 SUCCESS STORIES DEMONSTRATING DOWNSTREAM OUTCOMES FROM NIST TECHNOLOGY TRANSFER ACTIVITIES

2.4.1 The Journey to Commercialize Cutting-Edge Sensor Technology

In the early 2000s, Abhishek Motayed found his way to the NIST campus as a contractor, working in what became the Material Measurement Laboratory (MML). Abhishek completed his PhD in electrical engineering and transitioned over to the NIST post-doctoral, guest research staff. His work shifted toward a focus on advanced sensors and nanotechnology. The program around this research grew from the ground up, papers were published, and patents were filed. Abhishek and his team carved the path for leading-edge, sensor technology.

The foundation was built, but Abhishek wanted to tackle a new challenge in that of commercialization. It requires a mountain of effort to propel a technology to market, but he felt that he had the in-depth, subject matter expertise to transform the associated patents into products. Abhishek thought that this technology would greatly benefit society and felt that others might not appreciate the impact of the technology as much as the inventor himself. So, in 2012, Abhishek left NIST to become his own spokesperson and developed a start-up company, N5 Sensors, to license the technology. An inter-institutional agreement was soon formed, negotiated by the University of Maryland, leading to the intellectual property being owned by multiple hosts.

Abhishek knew that a start-up tech company required many levels of funding to succeed. As N5 Sensors began to grow from concept to a brick-and-mortar facility, Abhishek pursued all available avenues to ensure continued progress. Since he had previously worked at NIST, he was eligible to apply for the NIST-Science and Technology Entrepreneurship Program (N-STEP). N-STEP, a program that was developed through a NIST/TEDCO partnership, provides a funding platform for NIST alum who want to further pursue their translational research and the commercialization of NIST technologies.

Abhishek felt like N-STEP was a great fit for his sensor-based technology as it would allow him to expand upon his business acumen and would provide him an additional funding channel, which was extremely critical in advancing the technology toward the commercialization stage.

Being a first-time entrepreneur is quite challenging and commercializing a product is very difficult, especially with early validation and manufacturing.

As N5 Sensors continued to grow, Abhishek decided to pivot the business from a focus on manufacturing sensors to a focus on solutions to better society by implementing their sensors into new technologies. Two major solutions were created out of the base technology: a rugged, networked wildfire detection and air quality monitoring system and a wearable chemical threat detection system for the military and emergency responders.

Abhishek plans to continue to expand and grow N5 Sensors by providing solutions for societal problems using cutting-edge technology. From concept to practical application, Abhishek has taken his technology from the drawing board to the manufacturing facility, showing that the commercialization journey doesn't end once the lab coat is put away.

2.4.2 NIST Launches New iEdison System for Reporting Federally Funded Inventions

To promote the transfer of technology from laboratory to marketplace, NIST has redesigned the online platform where organizations report their taxpayer-funded inventions. The new Interagency Edison system, or iEdison, includes a modernized user interface and new functionality and security features that will make it easier for government grantees and contractors to comply with the reporting requirements of the Bayh-Dole Act.

The Bayh-Dole Act requires that awardees inform the federal government of inventions arising from federal support. In addition to reporting their inventions, organizations use iEdison to request extensions and waivers, report progress and inform the government of its limited use rights to patents on taxpayer-funded inventions.

"The inventions listed in iEdison create immense economic value for the nation, support jobs and improve our quality of life," said Mojdeh Bahar, NIST's associate director for innovation and industry services. "The new upgrades to the iEdison system will help inventors, awardees and the government manage these investments efficiently and transparently."

The updated iEdison system includes a modernized user interface and new messaging features that make it easier for organizations to communicate with their funding agencies. It also includes an expanded application programming interface, or API, that will allow organizations to automate some reporting tasks. In addition, the new system is integrated with information systems at the U.S. Patent and Trademark Office for easier updating of patent information.

"These upgrades will make it easier for recipients to comply with their reporting obligations and for federal agencies protect the public's investment in research and development," said Bethany Loftin, NIST's project leader for the iEdison system and interagency and iEdison specialist within the Technology Partnerships Office at NIST.

NIST began working on the update in December 2019. The legacy NIH system shut down on August 2, 2022, and the new system, hosted by NIST, went live on August 9.

2.4.3 NIST Researchers Link Cutting-Edge Gravity Research to Safer Operation of Construction Cranes

Stephan Schlamminger—a physicist at NIST—and his colleagues describe a surprising link between their equation for G, the gravitational constant that determines the strength of the attraction between massive objects, and the maneuvers required for crane operators at a construction site to safely and quickly transport heavy loads, in an article posted online on February 17, 2022, in the American Journal of Physics.

The equation that Schlamminger derived provides guidance about how to minimize or quickly dampen the amount by which the wire twists back and forth. If the amount is small, it's easier to locate and measure the position of the wire, which translates into a more accurate measure of G. Schlamminger was eager to immediately publish the result. But then he got to thinking: The finding would interest only a small number of people, those who measure G using the torsional pendulum method.

Schlamminger, of course, wasn't initially thinking about construction cranes. But he remembered a conversation he had when he was a postdoc about 15 years ago, while working on a similar project to measure G at the University of Washington in Seattle. Schlamminger's advisor had asked him if he knew about the tricks of the crane operator.

Operating a crane isn't for the faint-hearted. Swing a thousand-pound chunk of steel too fast or too far and someone can get killed. But in just two carefully choreographed maneuvers, a skilled crane operator can pick up a heavy load and bring it to a dead stop, without any dangerous swinging, to exactly the right destination. Moreover, a crane's cable and the load can be modeled as a vertical pendulum that moves to and fro in a manner similar to the way that a torsional pendulum twists and untwists. The time that it takes for the pendulum to complete one cycle of this motion is called the period.

Applying the equation he had derived for the torsional pendulum, Schlamminger found he could predict the strength and timing of the changes in velocity crane operators need to apply to the trolley—the wheeled mechanism that moves loads horizontally along a rail.

If a crane operator transports a load that's at rest and moves it a relatively short distance, the equation suggests this prescription for stopping the load at the right spot: The operator should initially apply a velocity opposing the motion of the crane's trolley and then apply exactly the same velocity in the opposite direction exactly one pendulum period later.

If the operator has to pick up a load initially at rest and move it a relatively large distance—tens of meters—the equation provides different guidance to account for the crane's larger swinging motion in this scenario: The operator should initially apply a force that accelerates the crane trolley from rest to a certain velocity and then apply a second change in trolley speed, doubling that velocity, half a period later.

Things get more complicated if the load has some initial swinging motion of its own, independent of the crane. In such cases, the two times at which the operator applies a force to bring the load under control are no longer exactly half a period or one period apart, but the equation still provides the appropriate times for action.

"I believe that well trained operators can perform these maneuvers," to more safely transport construction loads, said NIST engineer Nicholas Dagalakis, who developed the mathematical models and optimized the design of NIST's RoboCrane. Dagalakis was not a coauthor of the study.

Although veteran crane operators instinctively know about the strategies the NIST researchers developed, and computerized control of the trolley incorporates these motions, this appears to be the first time the crane maneuvers have been described by a mathematical formalism, per Schlamminger. "This is really a rich application that is worth sharing with the world," he added.

2.4.4 NIST Develops Genetic Material for Validating Mpox Tests

In an effort to help speed the expansion of mpox testing in the U.S., NIST produced a material that can help ensure the accuracy of tests for the disease. NIST made the material, which contains gene fragments from the virus that causes the disease but is noninfectious and safe to handle, freely available for use by test manufacturers and testing laboratories.

Mpox, formerly known as monkeypox, is spread by close contact and can cause fever, flu-like symptoms and skin lesions. More than 3,500 cases of mpox have been confirmed in the United States since the outbreak began in late May, and the World Health Organization declared mpox to be a global health emergency.

Testing is necessary to identify the extent of an outbreak and contain it, and to properly care for people who have caught the disease and those who may have been exposed. The mpox test, like the most sensitive test for COVID-19, uses a technique called polymerase chain reaction, or PCR, to detect genetic sequences from the virus that causes the disease.

Because the material from NIST contains those genetic sequences, laboratories can use it as a positive control—that is, a sample that should cause a positive result if their test is working properly. As the U.S. Centers for Disease Control and Prevention (CDC) worked to expand the nation's testing capacity, the material from NIST filled a growing need.

"Positive control materials are critical for ensuring the reliability of diagnostic tests," said Victoria Olson, the CDC's deputy director of laboratory science and safety. "Having a reliable supply of high-quality control material from a trusted source like NIST will help us mount an effective testing program more quickly."

NIST made this material freely available to any test manufacturer or testing laboratory worldwide. Technical information and instructions for requesting the material are available on the NIST website.

2.4.5 Nanomagnets Can Choose a Wine, and Could Slake AI's Thirst for Energy

Human brains process loads of information. When wine aficionados taste a new wine, neural networks in their brains process an array of data from each sip. Synapses in their neurons fire, weighing the importance of each bit of data—acidity, fruitiness, bitterness—before passing it along to the next layer of neurons in the network. As information flows, the brain parses out the type of wine.

Scientists want artificial intelligence (AI) systems to be sophisticated data connoisseurs too, and so they design computer versions of neural networks to process and analyze information. AI is catching up to the human brain in many tasks, but usually consumes a lot more energy to do the same things. Our brains make these calculations while consuming an estimated average of 20 watts of power. An AI system can use thousands of times that. This hardware can also lag, making AI slower, less efficient and less effective than our brains. A large field of AI research is looking for less energy-intensive alternatives.

Scientists at NIST and their collaborators have developed a new type of hardware for AI that could use less energy and operate more quickly—and it has already passed a virtual wine-tasting test—in a study published in the journal Physical Review Applied.

As with traditional computer systems, AI comprises both physical hardware circuits and software. AI system hardware often contains a large number of conventional silicon chips that are energy thirsty as a group: Training one state-of-the-art commercial natural language processor, for example, consumes roughly 190 megawatt hours (MWh) of electrical energy, roughly the amount that 16 people in the U.S. use in an entire year. And that's before the AI does a day of work on the job it was trained for.

A less energy-intensive approach would be to use other kinds of hardware to create AI's neural networks, and research teams are searching for alternatives. One device that shows promise is a magnetic tunnel junction (MTJ), which is good at the kinds of math a neural network uses and only needs a comparative few sips of energy. Other novel devices based on MTJs have been shown to use several times less energy than their traditional hardware counterparts. MTJs also can operate more quickly because they store data in the same place they do their computation, unlike conventional chips that store data elsewhere. Perhaps best of all, MTJs are already important commercially. They have served as the read-write heads of hard disk drives for years and are being used as novel computer memories today.

Though the researchers have confidence in the energy efficiency of MTJs based on their past performance in hard drives and other devices, energy consumption was not the focus of the present study. They needed to know in the first place whether an array of MTJs could even work as a neural network. To find out, they took it for a virtual wine-tasting.

Scientists with NIST's Hardware for AI program and their University of Maryland colleagues fabricated and programmed a very simple neural network from MTJs provided by their collaborators at Western Digital's Research Center in San Jose, California.

Just like any wine connoisseur, the AI system needed to train its virtual palate. The team trained the network using 148 of the wines from a dataset of 178 made from three types of grapes. Each virtual wine had 13 characteristics to consider, such as alcohol level, color, flavonoids, ash, alkalinity and magnesium. Each characteristic was assigned a value between 0 and 1 for the network to consider when distinguishing one wine from the others.

"It's a virtual wine tasting, but the tasting is done by analytical equipment that is more efficient but less fun than tasting it yourself," said NIST physicist Brian Hoskins.

Then it was given a virtual wine-tasting test on the full dataset, which included 30 wines it hadn't seen before. The system passed with 95.3% success rate. Out of the 30 wines it hadn't trained on, it only made two mistakes. The researchers considered this a good sign. "Getting 95.3% tells us that this is working," said NIST physicist Jabez McClelland.

The point is not to build an AI sommelier. Rather, this early success shows that an array of MTJ devices could potentially be scaled up and used to build new AI systems. While the amount of energy an AI system uses depends on its components, using MTJs as synapses could drastically reduce its energy use by half if not more, which could enable lower power use in applications such as "smart" clothing, miniature drones, or sensors that process data at the source.

"It's likely that significant energy savings over conventional software-based approaches will be realized by implementing large neural networks using this type of array," said McClelland.

2.4.6 With Fuzzy Nanoparticles, Researchers Reveal a Way to Design Tougher Ballistic Materials

Researchers at the National Institute of Standards and Technology (NIST) and Columbia Engineering have discovered a new method to improve the toughness of materials that could lead to stronger versions of body armor, bulletproof glass and other ballistic equipment.

In a study published in Soft Matter, the team produced films composed of nanometer-scale ceramic particles decorated with polymer strands (resembling fuzzy orbs) and made them targets in miniature impact tests that showed off the material's enhanced toughness. Further tests unveiled a unique property not shared by typical polymer-based materials that allowed the films to dissipate energy from impacts rapidly.

The polymers that constitute most of the high-impact plastics today consist of linear chains of repeating synthetic molecules that either physically intertwine or form chemical bonds with each other, forming a highly entangled network. The same principle applies to most polymer composites, which are often strengthened or toughened by having some nonpolymer material mixed in. The films in the new study fall into this category but feature a unique design.

The films are made of tiny glass spheres, called silica nanoparticles, each covered with chains of a polymer known as polymethacrylate (PMA). To produce these polymer-grafted nanoparticles (PGNs), Sanat Kumar's—Columbia University professor of chemical engineering and study co-author—lab grew PMA chains on the curved surface of the nanoparticles, rendering one end of each chain stationary.

Shorter, or lower molecular mass, chains on the PGNs are constrained by neighboring chains. The lack of motion means they do not interact much. But higher molecular mass polymers, which fan out farther from the spherical nanoparticles, have more elbow room to move, until they become entangled with other chains. Between these two lengths, there is an intermediate molecular mass where polymers are free to move but are also not long enough to knot up.

This phenomenon was useful for the material's initial purpose, which was permitting gases to move through it quickly. But Edwin Chan—NIST materials research engineer and study co-author—and others at NIST sought to find out how this unique property would affect toughness. With the help of Kumar's lab, the researchers tested samples of varying molecular masses.

At NIST, the researchers opened fire on the PGN composite films of different molecular masses with a technique known as Laser-Induced Projectile Impact Testing, or LIPIT. These high-velocity impact tests involved propelling 10-micrometer-wide (about four-thousandths of an inch) spherical projectiles toward the targets at velocities of nearly 1 kilometer per second (more than 2,200 miles per hour) with a laser.

They determined the velocity of the projectile in transit and on impact through images captured with a camera and strobe light flashing every 100 nanoseconds (billionths of a second). From there, the team had what it needed to calculate the energy it took to tear through the film, a quantity directly tied to toughness.

The authors of the study found that the PGN composite films were generally tougher than solely PMA. But what was perhaps more interesting was that intermediate molecular mass yielded the toughest film.

In purely polymeric materials, longer chains tend to create a greater number of tangles. And more tangles translate to greater toughness, up to the point where the material is completely tied up. However, the LIPIT tests revealed that the films could defy traditional polymer behavior. The toughest samples had chains far shorter than the length for full entanglement, meaning that tangles were not the only factor driving toughness.

Chris Soles—NIST materials research engineer and study co-author—and his colleagues suspected that the reason was the decreased packing between the chains at the intermediate molecular masses, which could have created a situation where polymers could wriggle about more freely and create friction with neighboring chains — a potential avenue for dissipating energy from a high impact.

Seeking to pin down the underlying source of the toughness and test their hypothesis, the team members used equipment at the NIST Center for Neutron Research to assess the motion of the polymers.

These tests confirmed that the intermediate molecular mass chains attached to the nanoparticles displayed an ability to move and then reach a relaxed state in just a few picoseconds (trillionths of a second). These enhanced movements of the intermediate chains dissipated energy more readily than either the short (no tangles) or long (highly entangled) PMA chains. This finding backed the team's intuition, especially when taken along with the LIPIT tests.

The results of this study hint at the existence of a sweet spot with respect to the length of polymers fixed to the curved surface of particles that could boost material toughness. The finding may not be limited to PMA either.

3 NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

The National Oceanic and Atmospheric Administration's (NOAA) mission is to understand and predict changes in climate, weather, oceans, and coasts; to share that knowledge and information with others; to conserve and manage coastal and marine ecosystems and resources. This mission will become ever more critical in the 21st century as national issues related to climate change, limited freshwater supply, ecosystem management, and homeland security intensify.

The NOAA technology and innovation enterprise consists of more than 50 laboratories, programs, and offices headquartered in Silver Spring, MD, and staffed across the United States, supporting NOAA's four service-based Line Offices: the National Marine Fisheries Service, the National Ocean Service, the National Weather Service, and the National Environmental Satellite, Data, and Information Service, as well as thematic programs including Climate, Aquaculture, Arctic, Ocean Exploration and Research, Weather and Air Quality, and Ocean Acidification. While the service-based Line Offices each have an R&D component, the entire enterprise is also supported by a dedicated R&D Line Office: the Office of Oceanic and Atmospheric Research.

Research across NOAA's laboratories is primarily aimed at improving the ability of the operational components to accomplish their respective missions. Recent examples demonstrating the direction of NOAA's research are severe storm (hurricane, tornado, derecho winds) and drought forecasting; forecasts for renewable energy siting; predicting freshwater resources; tsunami warnings; air quality measurement; solar emission forecasting; monitoring and estimating of fish stocks and species health; coastal habitat monitoring and pollution; invasive species monitoring; coral reef health; ocean acidification; coastal/ocean disaster response and restoration; charting ocean bottom topography; and a wide variety of climate research and the impacts of a changing climate on human health, coastal zone management, and oceans. Research results are routinely transitioned to NOAA's operational components to improve prediction, management, and other mission activities.

NOAA supports a network of 20 Cooperative Institutes at 70 universities and research institutions across 28 states and the District of Columbia. Some Cooperative Institutes are located near NOAA laboratories or science centers, creating a strong, long-term collaboration between federal and university scientists. The work done through the Cooperative Institutes directly supports NOAA's mission activities and results in similar technology transfer opportunities. NOAA's Technology Partnerships Office (TPO) works closely with the technology transfer offices from the Institutes to jointly manage intellectual property and seek out licensing partners.

3.1 APPROACH AND PLANS FOR TECHNOLOGY TRANSFER

The vast majority of NOAA's transfer of technology outside of the organization happens through peer-reviewed scientific publications and the provision of data and software-based decision-support tools which are delivered directly to the public and stakeholders in service to the NOAA mission of protecting lives and property. The remainder of NOAA's technology transfers are the result of partnerships, grants, and other formal technology transfer mechanisms such as patent license agreements.

The following is an overview of NOAA's technology transfer activity, both formal and informal, during FY 2022.

3.1.1 Program and Portfolio Management

The NOAA TPO, housed under the NOAA Office of Oceanic and Atmospheric Research (OAR), manages a central technology transfer program for all NOAA Labs, Centers, Programs, and external partners.

In 2017, the NOAA TPO developed a revised five-year strategic plan to ensure the program is effectively serving its customers and management. The Plan was refined in 2018 to more closely align with the Department of Commerce Strategic Plan and was included in our annual report. The NOAA TPO will likely update this strategic plan again in FY 2023 to better align with NOAA goals.

The following are selected reports of progress accomplished in FY 2022:

Goal 1: Enhance Innovation within NOAA and the Nation

Activity 1.2: Increase the number of CRADAs with U.S. Private Sector

Progress Update:

NOAA CRADA activity rebounded further in FY 2022 to pre-pandemic numbers. Active CRADA numbers have slightly decreased from FY21 as some projects that were delayed during COVID were able to be completed. The NOAA TPO continues to educate staff internally and to engage with the U.S. private sector at selected events. The NOAA TPO has also been directly engaged in the execution of NOAA's new Science and Technology Focus Area Strategies to support public-private partnerships.

Goal 2: Enhance Job Creation within the U.S. Economy

Activity 2.2: Increase adoption rate for NOAA technologies

Progress Update:

The NOAA TPO has been a key driver in the internal effort to standardize NOAA's approach to licensing software and data products. The NOAA TPO has submitted a revised draft of the NOAA Administrative Order on Cooperative Research and Development and Invention Licensing Agreements Under the Federal Technology Transfer Act of 1986 for approval. This new Order outlines the general principles NOAA will follow for technology dissemination.

The NOAA TPO has also been directly engaged in the development of a new NOAA Administrative Order which provides guidance for software licensing and public distribution. The Order has been drafted and is in the review and approval phase.

Both documents will lead to a more coherent and coordinated approach to releasing NOAA's software and data products to industry and to the public.

Goal 3: Enhance Resilience and Security

Task 3.2: Increase public private partnerships in Aquaculture

Progress Update:

Currently, 18 of NOAA's 51 active CRADAs (35%) are in Aquaculture.

We have had a lot of success growing the number of CRADAs in this area and we will continue to assist with developing CRADAs and Facility Use Agreements to grow our public private partnerships in Aquaculture in our role of supporting partnerships across the NOAA Science and Technology focus areas.

Goal 4: Improve Integration, Function, and Profile of the NOAA TPO

Task 2: Increase NOAA TPO input to Intra and Interagency Groups

Progress Update:

The NOAA TPO participates in each of the five new strategy teams and leads one of the strategy teams under the Lab to Market subcommittee of the National Science and Technology Committee within the Office of Science and Technology Policy. The NOAA TPO has been actively engaged with the NOAA Science Council and actively engaging in different committees where appropriate to bring awareness to our activities.

3.2 STATUTORILY REQUIRED METRIC TABLES

NOAA was awarded one (1) patent, and three (3) provisional applications were filed in 2022.

NOAA researchers disclosed three hardware inventions.

The licensing portfolio consists of six (6) active invention licenses, two of which have been executed through university partners. The NOAA-issued invention licenses include three exclusive licenses, and three non-exclusive licenses, all of which are income-bearing. NOAA now maintains an active portfolio of ten patented technologies, seven of which are being marketed for licensees or are being actively commercialized.

Table 25: NOAA Invention Disclosures and Patenting

	FY 2022
Invention Disclosures Received	3
Total Patent Applications Filed	0
U.S.	0
Foreign	0
Total Patent Cooperation Treaty (PCT) Applications Filed	0
Total Patents Issued	1
U.S.	1
Foreign	0

Table 26: NOAA Licensing

	FY 2022
Invention Licenses, Total Active	6
New Invention Licenses	0
New Invention Licenses Granted to Small Businesses	0
Income Bearing Licenses, Total Active	6
New Income Bearing Licenses	0
Exclusive, Total Active	1
Partially Exclusive, Total Active	0
Non-Exclusive, Total Active	5
Other Licenses, Total Active	0
New Other Licenses	0
New Other Licenses Granted to Small Businesses	0
Elapsed Amount of Time for Granting Invention Licenses	
Average (months)	n/a
Minimum (months)	n/a
Maximum (months)	n/a
Licenses Terminated for Cause	0

Table 27: NOAA Income from Licensing

	FY 2022
Invention License Income	$112,588
Other License Income	$0
Total Earned Royalty Income (ERI)	$112,588
ERI from Top 1% of Licenses	$102,388
ERI from Top 5% of Licenses	$102,388
ERI from Top 20% of Licenses	$102,388
Minimum ERI	$10,200
Maximum ERI	$102,388
Median ERI	$56,294
Disposition of ERI	
Percentage Distributed to Inventors	31%
Percentage Distributed to Lab/Agency	69%

Table 28: NOAA Collaborative Agreements

	FY 2022
Total Active CRADAs	51
New CRADAs	17
New CRADAs Involving Small Businesses	12
Other Collaborative Agreements	1

3.3 Other Important NOAA Performance Measures

3.3.1 Publications:

In FY 2022, peer-reviewed publications by NOAA federal scientists totaled 1783.[25] The following charts show the breakdown of publications, including publications from NOAA and NOAA-funded sources. Table 29 shows the number of publications by research unit as a

[25] NOAA publications data for 2022 were derived on December 13, 2022, using queries through the Web of Science database. As a result of variations in titles and nomenclature, these data **do not** provide a comprehensive measure of all NOAA publications. This reporting includes only those publications by NOAA scientists that were captured by the search queries.

percentage of all NOAA-authored publications in FY 2022.[26] A single publication with authors from one or more line offices is counted as a publication for each line office.

Table 29: NOAA Publications

Quarter (FY 2022)	Authored Articles
Q1	793
Q2	821
Q3	813
Q4	763
Total FY 2022	3,190

3.3.2 Science on a Sphere®

Science On a Sphere® (SOS) is a room-sized, global display system (US Patent 6,937,210) that uses computers and video projectors to display planetary data onto a six-foot diameter sphere, analogous to a giant animated globe. Researchers at NOAA developed Science On a Sphere® as an educational tool to help illustrate Earth System science to people of all ages. Animated images of atmospheric storms, climate change, and ocean temperature can be shown on the sphere, which is used to explain complex environmental processes in a way that is simultaneously intuitive and captivating.

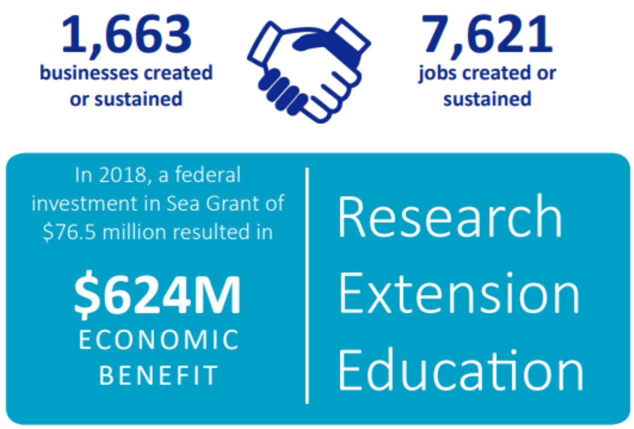


Table 30: SoS Installations

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
SOS Installations					
Total Number in Operation	155	165	169	177	183
New Domestic	3	7	5	4	4
New International	8	8	3	4	6
Total New Installs	11	15	8	8	10

[26] Due to a delay in indexing in Web of Science, not all Q4 articles are included in this report.

3.3.3 NOAA-Funded (Extramural) R&D - NOAA Sea Grant

The National Sea Grant College Program was established by the U.S. Congress in 1966 and works to create and maintain a healthy coastal environment and economy. The Sea Grant network consists of a federal/university partnership between the National Oceanic and Atmospheric Administration (NOAA) and 34 university-based programs in every coastal and Great Lakes state, Puerto Rico, and Guam. The network draws on the expertise of more than 3,000 scientists, engineers, public outreach experts, educators, and students to help citizens better understand, conserve and utilize America's coastal resources.

3.4 SUCCESS STORIES DEMONSTRATING DOWNSTREAM OUTCOMES FROM NOAA TECHNOLOGY TRANSFER ACTIVITIES

The following is an overview of NOAA's technology transfer activity, both formal and informal, during Fiscal Year 2022.

Partnership with Jupiter Intelligence to advance ecosystem models, and water level predictions

NOAA and climate analytics company, Jupiter Intelligence, signed a formal agreement to advance understanding of coastal ecosystems, precipitation, and water level predictions. The goal of the partnership is to support the community response to coastal risks to mitigate the effects of climate change.

Through a new agreement to explore research areas of joint interest, NOAA scientists will provide scientific data and expertise related to ecosystem changes, with a focus on the use of nature-based solutions in coastal restoration. Jupiter will explore cutting-edge approaches to scale local study results and test hypotheses on expanded geographical areas.

The partnership will also focus on methods to improve seasonal and annual precipitation and coastal water level predictions. Jupiter will offer expertise on cloud computing and numerical methods that NOAA will seek to apply in operations.

Jupiter provides physical climate analytics for risk management and resiliency planning in the public and private sectors. Customers use Jupiter's climate analytics for applications that include capital planning, risk management, site selection, design requirements, supply chain management, investment and asset valuations, and shareholder disclosures.

NOAA and Jupiter share the goal of improving resilience for the most vulnerable and under-resourced populations.

Exploring the Pacific Arctic Seasonal Ice Zone with Saildrone USVs

More high-quality, in situ observations of essential marine variables are needed over the seasonal ice zone to better understand Arctic (or Antarctic) weather, climate, and ecosystems. To better assess the potential for arrays of uncrewed surface vehicles (USVs) to provide such observations, five wind-driven and solar-powered Saildrones were sailed into the Chukchi and Beaufort Seas following the 2019 seasonal retreat of sea ice. They were equipped to observe the surface oceanic and atmospheric variables required to estimate air-sea fluxes of heat, momentum and carbon dioxide. Some of these variables were made available to weather forecast centers in real time. Our objective here is to analyze the effectiveness of existing remote ice navigation products and highlight the challenges and opportunities for improving remote ice navigation strategies with USVs. We examine the sources of navigational sea-ice distribution information based on post-mission tabulation of the sea-ice conditions encountered by the vehicles. The satellite-based ice-concentration analyses consulted during the mission exhibited large disagreements when the sea ice was retreating fastest (e.g., the 10% concentration contours differed between analyses by up to ∼175 km).

Attempts to use Saildrone observations to detect the ice edge revealed that in situ temperature and salinity measurements varied sufficiently in ice bands and open water that it is difficult to use these variables alone as a reliable ice-edge indicator. Devising robust strategies for remote ice zone navigation may depend on developing the capability to recognize sea ice and initiate navigational maneuvers with cameras and processing capability onboard the vehicles.

NOAA teams up with Viking to conduct and share science aboard new Great Lakes expedition voyages

NOAA plans to expand its research in the Great Lakes region as the agency teams up with the travel company Viking to carry scientists aboard new expedition voyages planned to begin in 2023.

As part of the Cooperative Research and Development Agreement, NOAA scientists will join Viking expeditions in the Great Lakes to conduct research focused on changes in the region's weather, climate, ecosystems and maritime heritage resources. NOAA scientists will also serve on the Viking Scientific Advisory Committee.

Eruption highlights how NOAA technological innovation powers public safety, economic development, and scientific discovery

When a volcano in the South Pacific Ocean erupted in January 2022, NOAA researchers were well-equipped to study the multi-hazard event by sky and by sea. Key technologies and strategic partnerships made it possible for NOAA to issue warnings that saved lives around the world, while also collecting scientific data that will improve forecasting models and disaster response for future events.

Blasts from the Hunga Tonga – Hunga Ha'apai volcano launched ash and toxic gas high into the stratosphere to altitudes above 30 km. The plume of material formed an umbrella cloud 500 km wide and triggered record-breaking amounts of lightning strikes. The violent eruption provided a rare opportunity for scientists to learn more about sulfur dioxide gas emissions in the stratosphere.

The Hunga Tonga - Hunga Ha'apai volcano erupted on 15 January 2022. Source: Tonga Geological Services

As the sulfur plume traveled westward, researchers from NOAA Chemical Sciences Laboratory, CIRES, and the University of Houston gathered on La Réunion island in the Indian Ocean, about 8,000 miles away from the initial volcanic blast. The plan was to use specially-designed balloons to lift lightweight aerosol sensors high up into the stratosphere, where they could collect air quality data as the plume passed overhead. NOAA's satellites tracked the movement of the volcanic cloud, and the scientific team worked quickly to prepare.

The scientific sensors attached to the balloons were Portable Optical Spectrometers, or POPS. POPS were invented at NOAA's Chemical Sciences Laboratory and then licensed to a small manufacturing company called Handix Scientific. Licensing the technology meant that the device could be improved, commercialized, and made available to researchers worldwide in large quantities. Thanks to this successful technology transfer, NOAA scientists were able to quickly order and ship many units of POPS and complete their mission.

A week after the explosion, the plume arrived above the island's high-altitude Maïdo Atmospheric Observatory. The research team was ready with their equipment. Scientists successfully launched the balloons and are now using the data to refine atmospheric models. This series of events marked the quickest scientific response to a volcanic eruption to date, and the data will improve researchers' collective understanding of how volcanic explosions affect the Earth's atmosphere. Without the licensing agreement in place, this once-in-a-lifetime opportunity would have been lost.

Meanwhile, half a world away in the Pacific Ocean Basin, the eruption generated ocean waves that rippled around the planet and set off widespread tsunami advisories. The alerts were triggered by a network of Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys, which are positioned strategically throughout the ocean and send real-time data to tsunami warning centers. After the volcanic eruption, DART buoys recorded the propagating tsunami waves and prompted critical tsunami alerts for many coastlines that were later flooded.

DART buoys detect tsunami waves and transmit real-time sea level information measurements back to the Tsunami Warning Centers. Source: NOAA

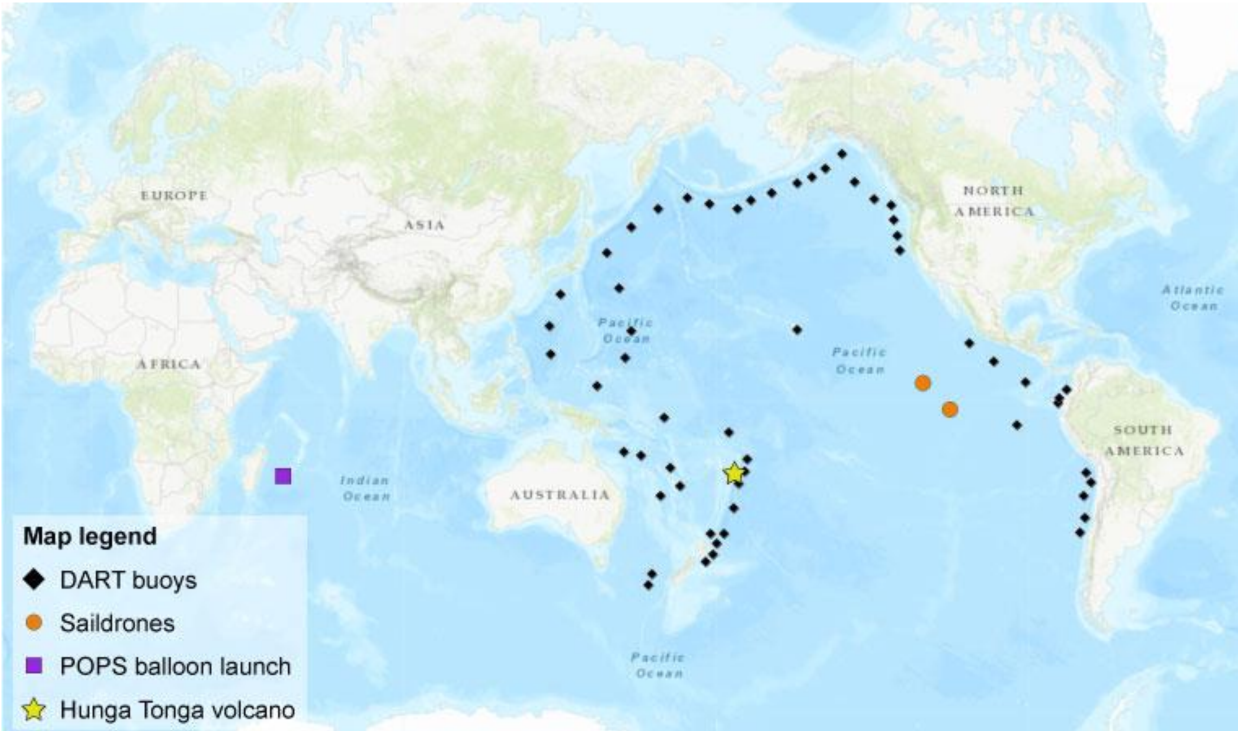
The DART buoy system was originally designed and developed at the NOAA Pacific Marine Environmental Laboratory. The system was patented and licensed to a private company, Science Applications International Corporation, so they could market and sell DART buoys worldwide. This invaluable network has been in place for decades and is a critical component of the life-saving NOAA Tsunami Warning System.

At the time of the volcano eruption, while the DART buoy network recorded tsunami wave data, two uncrewed ocean drones happened to be positioned in the Pacific Ocean collecting data for a NOAA research mission. The mission was one of many ongoing collaborations between NOAA and the drone manufacturer, Saildrone. NOAA's public-private research partnership with Saildrone allows the two collaborators to share ideas, expertise, and other materials while they jointly conduct research and further develop drone technologies that benefit society. This research partnership has produced significant economic benefits for Saildrone, and has provided the basis for ongoing NOAA missions using Saildrone vehicles.

A Saildrone collects data beneath the Golden Gate Bridge, alongside a NOAA research vessel. Source: Saildrone

The Saildrones that were deployed in the Pacific Ocean during the volcanic explosion were able to detect jumps in atmospheric pressure and capture crucial information in an observationally-sparse region of the ocean. This data is particularly valuable because only about 5% of tsunamis are generated from volcanic activity, rather than earthquakes. The high-resolution measurements from the drones, coupled with the records from the DART buoys, will help scientists better understand these types of rare events and incorporate volcano-induced tsunamis into the model used to inform hazard response to tsunamis.

Impacts of climate change are affecting communities worldwide, and scientists predict that many types of natural disasters and hazards are likely to become even more intense in the coming decades. A core part of NOAA's mission is to build a Climate Ready Nation, in which people share an understanding of climate change and work together to address the climate crisis. Innovative technologies and strategic research partnerships are central to accomplishing this mission because they allow NOAA to deliver cutting-edge research and science-driven services that help build community resilience, promote economic growth, and keep people safe.



Map showing the positions of DART buoys, NOAA Saildrones, and the POPS launch, relative to the Hunga Tonga volcano. Source: NOAA

Technologies and research partnerships enabled NOAA's multifaceted, unprecedented response to the Hunga Tonga – Hunga Ha'apai volcanic eruption. The NOAA Technology Transfer Program within the Technology Partnerships Office helps NOAA scientists set up cooperative research agreements, such as the collaboration with Saildrone. These partnerships allow NOAA scientists and private sector partners to work together to conduct research and transform new science into products and services that benefit the public.

NOAA uses array of marine and air uncrewed tools to improve hurricane forecast models

Throughout the 2023 hurricane season, NOAA will work with numerous partners to gather coordinated air-sea and atmospheric measurements in a hurricane from uncrewed ocean and aerial drones. NOAA will use a suite of innovative technologies to sample the ocean and atmosphere near each other in real-time and collect high-resolution data from all parts of the hurricane environment. This data could help forecasters better understand the forces that drive hurricanes so they can warn communities earlier.

Technologies involved in these unprecedented sampling efforts include Saildrones and Altius-600 drones. The Saildrones involved in this research mission were specially modified to support hurricane research and developed through a CRADA partnership between NOAA and Saildrone, Inc. The Altius-600 drone was created by a small business called Area I, supported by SBIR research and development funding from the Department of Defense. The drone technology was later procured and further developed through a NOAA SBIR Phase III award.

NOAA technology used to research deep-sea volcanic and hyrdothermal activity

As part of the ongoing Tonga Eruption Seabed Mapping Project, a team of scientists conducted a deep-water survey to better understand the impacts of the January 2022 Hunga Tonga-Hunga Ha'apai volcanic eruption on the ocean environment. The research team used a technology developed by NOAA's Pacific Marine Environmental Lab (PMEL) to determine the level of ongoing volcanic and hydrothermal activity within the post-eruption caldera. The Miniature Autonomous Plume Recorder (MAPR) instruments made it possible for scientists to capture direct measurements of the water column up to 300 meters deep. This is the first time that such a survey has been conducted entirely remotely, using an uncrewed surface vessel that was operated and monitored by engineers and scientists located across the globe.

A SeaKit engineer on the dock in Tonga mounting the PMEL MAPRs onto a specifically designed cage to fit on the USV Maxlimer. Source: Sea-Kit International/NIWA/Nippon Foundation

4 NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION: INSTITUTE FOR TELECOMMUNICATION SCIENCES

The Institute for Telecommunication Sciences (ITS) is the nation's spectrum and communications lab. ITS manages the telecommunications technology research and engineering programs of NTIA. ITS basic research in radio science provides the technical foundation for NTIA's policy development and spectrum management activities and enhances scientific knowledge and understanding in cutting-edge areas of telecommunications technology. ITS also serves as a principal federal resource for solving telecommunications concerns of other federal agencies, state and local governments, private corporations and associations, and international organizations through Interagency Agreements (IAAs) and CRADAs. Roughly three-quarters of ITS research programs are undertaken under such agreements. This includes assisting the FCC and federal defense, public safety, and other agencies that use federal and non-federal spectrum.

4.1 APPROACH AND PLANS FOR TECHNOLOGY TRANSFER

ITS efforts in technology transfer and commercialization foster cooperative telecommunications research in areas where U.S. companies can directly benefit from improved competitiveness and market opportunities. ITS uses three principal means for achieving technology transfer:

- Cooperative research and development through CRADAs and IAAs;
- Technical publications, open data,s and open source software tools; and
- Leadership and technical contributions in the development of telecommunications standards

Over the past several years, ITS has adopted a multimodal approach to transferring proven technical methods into widespread use within the wider spectrum community. "Technical publications" under this approach include both traditional peer-reviewed manuscripts published as Technical Reports, journal articles, or conference papers as well as peer-reviewed video journal articles and NTIA technical videos.

For 20 of the past 24 years, ITS has also hosted the International Symposium on Advanced Radio Technologies (ISART), a U.S. government–sponsored conference that brings together government, academia, and industry leaders for the purpose of collaborating on groundbreaking developments and applications of advanced radio technologies. Presentations, video archives, and proceedings are available online.

The theme of ISART 2022 was *Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-Making*. The fully virtual conference was held over four days in June 2022 and attracted a record 280 attendees

4.2 STATUTORILY REQUIRED METRIC TABLES

Since FY 2008, ITS no longer licenses software technology. Instead, software is made available via open-source download. ITS reports zero licensing and income from licensing activity.

Table 31: NTIA ITS Invention Disclosures and Patenting

Metric	FY 2022
Invention Disclosures Received	0
Total Patent Applications Filed	0
U.S.	0
Foreign	0
Total Patent Cooperation Treaty (PCT) Applications Filed	0
Total Patents Issued	0
U.S.	0
Foreign	0

Table 32: NTIA ITS Licensing[27]

Metric	FY 2022
Invention Licenses, Total Active	0
New Invention Licenses	0
New Invention Licenses Granted to Small Businesses	n/a
Income Bearing Licenses, Total Active	0
New Income Bearing Licenses	0
Exclusive, Total Active	0
Partially Exclusive, Total Active	0
Non-Exclusive, Total Active	0
Other Licenses, Total Active	0
New Other Licenses	0
New Other Licenses Granted to Small Businesses	n/a
Elapsed Amount of Time for Granting Invention Licenses	
Average (months)	n/a
Minimum (months)	n/a
Maximum (months)	n/a
Licenses Terminated for Cause	n/a/

[27] Since FY 2008, ITS no longer licenses software technology. Instead, software is made available via open-source download. ITS reports zero licensing and income from licensing activity.

Table 33: NTIA ITS Income from Licensing

Metric	FY 2022
Invention License Income	n/a
Other License Income	n/a
Total Earned Royalty Income (ERI)	n/a
ERI from Top 1% of Licenses	n/a
ERI from Top 5% of Licenses	n/a
ERI from Top 20% of Licenses	n/a
Minimum ERI	n/a
Maximum ERI	n/a
Median ERI	n/a
Disposition of ERI	
Percentage Distributed to Inventors	n/a
Percentage Distributed to Lab/Agency	n/a

4.3 Collaborative Relationships for Research and Development

ITS is authorized under the Federal Technology Transfer Act of 1986 (FTTA) to enter into CRADAs with private industry, universities, and other interested parties. ITS CRADAs protect proprietary information, grant patent rights, and provide user licenses to private entities. They also provide the legal basis for shared use of government facilities and resources with the private sector.

In FY 2022, as it has for decades, ITS participated in CRADAs with private-sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. The CRADAs provide ITS with insights into industry’s needs for productivity growth and competitiveness. This enables ITS to adjust the focus and direction of its programs for effectiveness and value. The private industry partner benefits by gaining access to the results of research in commercially important areas that it would not otherwise be able to undertake.

Table 34: NTIA ITS Collaborative Agreements

Metric	FY 2022
Total Active CRADAs	8
New CRADAs	2
New CRADAs Involving Small Businesses	0
Other Collaborative Agreements	0

4.4 OTHER IMPORTANT NTIA ITS PERFORMANCE MEASURES

4.4.1 Technical Publications

Publication has historically been the means through which ITS has transferred research results to other researchers, the commercial sector, and government agencies. ITS technical reports and monographs published by NTIA and peer-reviewed articles in scientific journals have become standard references in several telecommunications areas. Technical publication remains a principal means for ITS technology transfer, but "publication" has come to encompass multiple media. ITS has released peer-reviewed video journal articles and NTIA technical videos, software packages, and datasets for download. Downloads of traditional manuscripts have been decreasing as downloads in other categories increase.

Technical publications are released after an internal peer review process; manuscript release is managed by the ITS Editorial Review Board (ERB). In FY 2022, 57% of manuscripts released through the ERB process were published in scientific journals or conference proceedings and 43% were published as NTIA reports. While official NTIA publications allow greater in-depth analysis of research results, journal articles and conference papers often have greater reach in transferring new tools and discoveries.

Led by the ERB, ITS is finalizing procedures for technical peer review of technical publications in non-traditional media.

4.4.1.1 Technical Publications Downloaded or Viewed

ITS makes all of its publications available to the public through its web site and provides online users with advanced search capabilities to locate relevant publications by keyword. To ensure a meaningful and realistic metric, ITS counts actual downloads of traditional manuscript PDFs rather than pageviews of the bibliographic summaries. Video publications not published in peer-reviewed scientific video journals are published on the NTIA YouTube channel. Software and data sets are made available either through the ITS website or the NTIA GitHub repositories. In FY 2022, ITS technical publications of all kinds in all media were downloaded or viewed 16,792 times.

4.4.1.2 Multimodal Transfer of Technical Methods

High-precision measurements are key to creating and validating radio propagation models. ITS and its predecessors have been collecting measurement data for more than a century, creating a unique expertise in measurement science and techniques which has been leveraged by other agencies seeking data needed to coordinate with commercial entrants into spectrum bands being opened for federal-nonfederal sharing. Using a multimodal approach to technical publication allows ITS to target audiences of differing scientific literacy through different media to amplify the reach of the best practices in measurements message and expand message penetration.

The complementary series of publications aimed at dissemination of measurement best practices began with NTIA Special Publication SP-09-460 "Seminar Series on Spectrum Measurement Theory and Techniques," first published in FY 2009 and originally distributed on CD. It is now available on YouTube. Each of the 20 one-hour videos in this series combines a tutorial on a particular aspect of radio spectrum measurement technique or theory with a hands-on demonstration using actual measurement hardware and radio signals.

In FY 2019, ITS published TM-19-535 "Best Practices for Radio Propagation Measurements," a traditional NTIA Technical Memorandum which was adopted by the Defense Spectrum Organization's (DSO) Spectrum Sharing Test & Demonstration (SST&D) program as a required resource to reduce the uncertainties of propagation measurement campaigns by commercial entrants seeking to coordinate sharing with DOD. In FY 2020 and FY 2021, ITS published in a peer-reviewed video journal two video-illustrated articles that delve deeply and in detail into specific radiofrequency measurement techniques described in TM-19-535; these articles garnered 7,630 views in FY 2022.

4.4.2 Software and Data Downloads

Increasingly, technology transfer occurs through the publication of software rather than traditional technical reports. ITS makes several software and data tools available via open source download. Reliable and robust methods of counting downloads of these tools took some time to develop; earlier, simpler software tools were offered as .zip files from the ITS public website, but over the past five years ITS increased its use of the GitHub open source code hosting platform, and by FY 2022 ITS had published 31 public repositories. While this allows more interaction with potential users of the software and can perhaps be said to broaden the audience, the open source paradigm also makes it more difficult to understand the impact of the software. As there is presently no generally accepted impact metric for GitHub repositories, ITS has added a count of the number of public repositories and a count of packages downloaded as proxies until a more generally accepted impact metric is defined.

4.4.2.1 Propagation Prediction

ITS is, and has been for decades, a world leader in the development of models and methods for accurate prediction of radio propagation. Propagation prediction algorithms are freely shared through publication. In addition, software developed to predict propagation for planned communications systems through input of specific parameters to these algorithms has been developed and shared over the years, and some data sets that can be used to test and validate propagation prediction models are also available. The majority of downloads of ITS software/data are for propagation prediction tools. Open-sourcing trusted and authoritative propagation models meets a critical need for spectrum sharing.

4.4.2.2 Spectrum Monitoring Software

The NTIA Spectrum Monitoring program is creating a new spectrum monitoring paradigm to enable distributed, persistent, and automated monitoring with the following: heterogeneous and low cost sensors, standardized interfaces, open source software implementations, common metadata, automated provisioning/deployment/maintenance, and data analytics incorporating artificial intelligence and machine learning. ITS works to test and integrate new sensing technologies and algorithms in the lab and the field and collaborate via open source code development. Code repositories released to the public include LTE measurement utilities (gr-ltetrigger), RF measurement metadata best practices (sigmf-ns-ntia), and NTIA software implementations associated with the IEEE 802.15.22.3 Spectrum Characterization and Occupancy (SCOS) standard (scos-sensor, scos-actions, and scos-usrp). In FY 2022, NTIA expanded by adding three additional spectrum-monitoring repositories (i.e., scos-tekrsa, tekrsa-api-wrap, and Preselector).

4.4.2.3 Audio Quality Testing

ITS has developed a family of no-reference speech quality and intelligibility estimators and is providing software implementations to industry, researchers, and other agencies via GitHub. These estimators (called WAWEnets) leverage convolutional neural networks, which are a specialized and very efficient type of deep neural network. This allows accurate speech quality and intelligibility estimates without access to any reference signal, thus expanding the utility of the tool to include real-time endpoint monitoring in the field.

Two earlier ITS-developed objective estimators of speech intelligibility are freely available for download from the ITS web site and from GitHub. These tools follow the paradigm of the Modified Rhyme Test (MRT) but consume a tiny fraction of the resources required by the conventional MRT. The Articulation Band Correlation MRT (ABC-MRT) provides excellent estimates of MRT intelligibility results (Pearson correlations of .95–.99) for narrowband speech transmissions. The ABC-MRT16, released in FY 2017, not only updated the audition model, but also extended the estimator to cover wideband, superwideband, and fullband speech systems. The ITS web site also offers a large variety of audio recordings that support the use of these tools.

4.4.2.4 Video Quality Measurement Software

ITS began researching objective video quality models in FY 1988, to address the needs of U.S. industry to understand the complex relationship between digital video technologies, networks, and video quality. Rapid advances in video and network technologies make this a moving goal. ITS video quality research produces improved methods for human testing as well as objective metrics that provide users an inexpensive alternative to human testing. ITS distributes software for various tasks related to subjective testing (including subject screening, subjective test control, image filtering, color calibration, statistical analyses, and merging multiple subjective datasets onto a single scale), as well as software implementing objective metrics.

Objective metrics that predict human perception of video quality in real-time would allow live video streams to optimize the tradeoff between bandwidth and quality. This would impact in-service use cases like broadcast video, video surveillance, video conferencing, video analytics, telehealth, and online gaming. Early ITS research focused on objective metrics that compare the current video to a pristine original, culminating in a series of objective video quality metrics (VQM) that are included in ATIS and ITU standards. The VQM software was downloaded 39 times, forked once, and cloned 58 times from GitHub in FY 2022. Downloads of the VQM software have been steadily decreasing as its age and changes in technology make it less relevant.

Most contemporary video distribution technologies only have access to the current video signal (e.g., a pristine original never existed) and this presents a difficult challenge. Despite decades of research, existing no reference (NR) metrics remain too inaccurate for U.S. industry applications. Part of the problem is that NR metric researchers had not previously considered two key industry requirements. First, to be exploitable, NR metrics must provide root cause analysis (RCA). Most industry applications for NR metrics involve identifying and mitigating specific impairments. Second, the external validity (and thus reliability) of an NR metric depends on its ability to assess camera capture impairments.

ITS has intensified research on NR objective metrics over the past five years, but international experts agree that widespread collaboration is needed to build reliable NR metrics. In FY 2022, ITS expanded the NRMetricFramework public GitHub repository first made available in FY 2020 to provide additional support for NR metric research. The repository was released to the public domain—to support collaborative R&D into NR metrics for image and video quality and stimulate an open exchange of ideas, information, and research—to accelerate development of the robust and trusted NR metrics industry needs to more efficiently use increasingly crowded bandwidth. The NRMetricFramework repository contains all of the tools, information, and statistical methods needed to begin research on this difficult problem. This repository has been forked twice and downloaded 32 times.

The NRMetricFramework repository reports on the performance of 36 previously published NR metrics on modern camera systems using a robust corpus of 9,833 media files. These independent analyses address industry concern that NR metric developers publish exaggerated performance claims. The repository contains all of the code and information needed to reproduce these analyses. In addition, the repository contains NR metric *Sawatch*, which was developed by ITS as a baseline NR metric for future collaborative development. *Sawatch* adheres to industry specifications of providing RCA and being able to analyze camera capture impairments. Finally, the repository contains new statistical methods for analyzing the performance of subjective tests and NR metrics.

4.4.2.5 Consumer Digital Video Library Users Downloading Clips

The Consumer Digital Video Library (CDVL), a web site hosted and maintained by ITS, provides researchers access to high quality, uncompressed video clips royalty-free for use in video processing and video quality product development and testing. CDVL enables an open data solution that protects content owners' rights, hosts large records (up to 0.5 TB), and provides generous terms for users. The technical committee for this collaborative project includes industry and academic representatives as well as ITS staff. ITS launched the site in 2010 with 1000 clips; additions by ITS and other collaborators have increased the collection to tens of thousands of clips for a total of 12 TB of data available to industry, academic, and government researchers.

The CDVL website software was replaced in Q1 of FY 2021 to comply with new security policies and to accommodate an increasing volume of data as the site has become increasingly important to the wider research community. The updated website allows researchers to share entire experiments as open data. Significant recent additions include two new experiments conducted by ITS to support research of video quality metrics. The first experiment depicts noise produced by cameras in low light environments. ITS analyses of existing metrics indicates noise quality analysis metrics cannot be used with modern camera systems. The second experiment depicts typical compression artifacts produced by modern video streaming systems. These experiments will facilitate video quality metric research, by demonstrating impairments that are not detected by current metrics. In FY 2022, 740 unique records were downloaded from the new website, by a total of 230 users. The total number of media files downloaded by each user is difficult to calculate, because 18% of the downloaded records were datasets with hundreds of images or videos. ANSI T1.801.01 and ITU-R Rec. BT.802 standard video sequences comprised 9% of the downloaded records. These videos were filmed in the mid-1990s and are no longer available from ATIS or the ITU. Self-reported demographics indicate the applications were 51% academic, 32% industry, 1% government, and 16% personal, with the remainder unreported. Users must register for each download or upload session. The number of registrants who perform downloads each year was selected as the most significant measure of the impact of this resource.

Table 35: NTIA ITS Software and Data Downloads

Metric	FY 2022
Technical Publications Released	14
Technical Publications Downloaded	16,792
Consumer Digital Video Library Users Downloading	230
Video Quality Metric Software Users Downloading	39
Propagation Modeling Software Downloads	1,199
Other Software/Data Downloads	273
Public GitHub Repositories	31

4.4.3 Development of Telecommunication Standards

ITS works with industry to apply research results to the development of telecommunication performance standards and guidelines. For several decades, ITS has provided leadership and technical contributions to organizations, both national and international, responsible for developing telecommunication standards. ITS's technical inputs are relied upon as technically advanced and sound, and as unbiased by commercial interests.

ITS works collaboratively with the International Telecommunication Union (ITU), the 3rd Generation Partnership Project (3GPP), the Wireless Innovation Forum (WInnForum), the Internet Engineering Task Force (IETF), and Inter-American Telecommunications Commission (CITEL) to develop, interpret, analyze, and implement standards and regulations. This method of technology transfer directly addresses improvement and protection of U.S. competitiveness in telecommunications. For example, a plurality of the technical recommendations of the International Communication Union Radiocommunication (ITU-R), a treaty organization, are based on research conducted at ITS. Also, key national quality-of-service standards developed under the American National Standards Institute (ANSI) T1 committee for video, audio, and digital data, incorporate research results obtained at ITS. ITS continues to chair numerous committees and working groups in the ITU, 3GPP, and other telecommunication standards organizations, providing technical leadership that is trusted by the commercial-sector participants.

ITS actively contributes to ITU efforts around best practices for video quality assessment. In FY 2022, ITS continued to lead and participate in the Video Quality Experts Group (VQEG), an open venue where technical experts collaborate to develop subjective test methods for new video technologies. VQEG independently validates objective video quality metrics, which is a necessary step in the standards development process. VQEG meetings are co-located with meetings of the Intersector Rapporteur Group (IRG) for Audiovisual Quality Assessment (IRG-AVQA) of the ITU. This allows more technical experts to follow and contribute to ITU recommendations.

In FY 2022, NTIA staff held 88 positions in 9 standards bodies, including 18 Chair/Co-Chair/Vice-Chair positions. NTIA staff filled key leadership positions in the ITU-T, including Head of the U.S. Delegation to Study Group (SG) 11 (Signalling requirements, protocols, test specifications and combating counterfeit products), Chair of the Telecommunication Standardization Advisory Group (TSAG), and Vice-Chair of Q1/17 (Security standardization strategy and coordination). NTIA staff also filled key leadership positions in the ITU-R, including Head of the U.S. Delegation to Study Group (SG) 1 (Spectrum management) and SG3 (Radiowave Propagation); Head of Delegation to SG1 Working Party (WP) 1A; Head of Delegation to SG5 WP 5B and 5C; International Chair of SG5 WP 5C and 5D; Deputy Head of Delegation to SG7 and SG7 WP 7C; International Chair and U.S. Chair of SG3 WP 3K; U.S. Chair of Working Parties 3J and 3L; and Chair of Correspondence Groups CG-3L-7 (Radio Noise), CG-3J-11 (Reference Standard Atmospheres), and CG-3K-3M-9 (Aeronautical Propagation). Within the Inter-American Telecommunications Commission (CITEL), NTIA holds Vice-Chair position within the Permanent Consultative Committee I for Telecommunications/ICT (PCC.I) Working Group for the Preparation and Follow-up of the WTSA, WCIT and WTDC; Deputy Head of Delegation to the Permanent Consultative Committee II (PCC.II) for Radiocommunications; and International Working Group Chair of the CITEL PCC.II Working Group relative to CITEL's Preparation for World Radiocommunication Conferences.

4.5 SUCCESS STORIES DEMONSTRATING DOWNSTREAM OUTCOMES FROM NTIA ITS TECHNOLOGY TRANSFER ACTIVITIES

To date, major contributions to the Citizens Broadband Radio Service (CBRS), including testing and evaluation of Spectrum Access Systems (SAS) and Environmental Sensing Capability (ESC) sensors; spectrum monitoring; advanced antennas for wireless systems; remote sensing and global positioning (GPS) technologies; active holographic sensing with high resolution laser radar (lidar); autonomous networks for unmanned aerial vehicles (UAVs); objective audio and video Quality of Experience (QoE) metrics; and broadband air-interface and core network capabilities for Long Term Evolution (LTE) mobile communications, have been achieved through CRADAs. These have aided U.S. efforts to rapidly introduce new socially constructive communications technologies.

4.5.1 Table Mountain Research

ITS manages the Table Mountain Radio Receiving Zone of the Research Laboratories of the Department of Commerce located in Boulder County, Colorado, an area designated by federal and state law as a Radio Quiet Zone. Quiet zones are protected by restrictions on radiofrequency radiation in their vicinity so as to minimize possible impact on the research operations that are highly sensitive to interference. This quiet zone managed by ITS is the only one presently available on a consistent basis for collaborative research among government, academia, and industry, and between the different government agencies.

The Advanced Communications Test Site (ACTS) within the quiet zone supports fundamental research, engineering studies, and experiments into the nature, interaction, and evaluation of telecommunication devices, systems, and services. A unique feature of the ACTS is an automated system for perform emission measurements on radar systems.

Of increasing importance to the Nation are CRADAs that ITS occasionally enters into with manufacturers of advanced radar systems. NTIA administers the Radio Frequency Spectrum Standards applicable to federal radio stations and systems. This includes the Radar Spectrum Engineering Criteria (RSEC)—federal regulations that ensure an acceptable degree of electromagnetic compatibility among radar systems, and between such systems and those of other radio services sharing the radio frequency spectrum to promote efficient spectrum use. Interference free spectrum sharing between radars and commercial communications systems has emerged as a serious technical challenge to expanding the commercial use of spectrum.

All U.S. government radar systems must meet emission limits imposed by the NTIA RSEC as described in the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management ("Redbook," incorporated by reference in 47 CFR 300). The ITS-published Technical Report "Measurement procedures for the radar spectrum engineering criteria (RSEC)" describes the required method for certifying compliance.

ITS enters into CRADAs with manufacturers of new radars to perform emission measurements and provide a report which can be used for system certification. This allows ITS to collect valuable information on newly emerging radar technologies and ensure that the RSEC are kept up to date. The RSEC CRADAs allow NTIA to retain anonymized waveform recordings that are used to automate RSEC compliance analysis. The RSEC were last revised in 2005 and are currently undergoing revision to incorporate new radar technologies characterized through ITS RSEC CRADAs.

Annually NTIA, NOAA, NIST, universities, private companies, and other organizations conduct research at the ACTS under a variety of agreements (IAAs, Reimbursables, CRADAs). The work accomplished at the ACTS provides unique opportunities for cooperative learning and discovery, with the outcomes frequently becoming seeds of commercial and Government successes.

- In FY 2022, ITS used the ACTS to perform comprehensive measurements to address technical concerns about possible interference between 5G base stations operating at 3700–3980 MHz and radio altimeters (radalts) operating at 4200–4400 MHz. The Department of Defense convened many stakeholders from government, industry, academia, and standards bodies to peer-review the design of the research program. Wideband, wide dynamic range emission spectra and three-dimensional aerial radiation patterns of 5G base stations from all the manufacturers known to be deploying this 5G equipment in the U.S. were measured using an ITS-developed calibrated airborne measurement system. The data indicated that currently deployed 5G base stations are filtered effectively against out-of-band emissions in the radalt band and that airborne radiation patterns show measurably, significantly less power than is found in 5G base station main antenna beams directed toward handsets at ground level. The results of this testing were summarized in NTIA Technical Report TR-22-562, "Measurements of 5G New Radio Spectral and Spatial Power Emissions for Radar Altimeter Interference Analysis." ITS also published a video showing, even more succinctly, the putative problem, the setup for airborne measurements, and a sampling of some of the measurements. All of the effective isotropic radiated power data was made publicly available at DOI:10.5281/zenodo.7150540. Widespread dissemination of this data, with its authoritative provenance and traceability, is supporting the FAA's development of recommendations for filtering of radalts used in commercial and civil aviation.
- In FY 2022, ITS continued to expand its support of NOAA's Radio Frequency Interference Monitoring System (RFIMS) program at the ACTS to add capacity for 5G testing. ITS continued to assist NOAA in understanding Meteorological Satellite (MetSat) radio frequency (RF) downlink technical performance, in the face of spectrum sharing requirements with continually evolving commercial systems. The ACTS hosts a functionally equivalent MetSat Operations Center that mimics NOAA's two main operational MetSat sites and serves as a testbed to assess the degree to which terrestrial cellular interference can affect MetSat data downlink operations. The test bed also allows testing of commercial RFIMS systems for compliance with interference protection standards defined for the various federal MetSat assets, whether the commercial wireless systems seeking to share this spectrum are LTE (4G), 5G, 6G, or beyond. Since the mobile network operator has elected to deploy 5G in the RFIMS operating range, system enhancements were required. ITS assisted NOAA in verifying these changes as a part of the RFIMS 5G Capability Assessment completed in FY 2022.
- In FY 2022, several companies used the ACTS under CRADAs to safely test and demonstrate LIDAR technologies under development in atmospheric conditions and at distances relevant to potential applications, and to fully test the functionality of new antenna designs during product development. Some CRADA partners conducted scaled demonstrations for missions relevant to U.S. government organizations. Applications for technologies under test at the ACTS include:
    - beam control for directed energy, free space optical communication, and laser radar and imaging applications;

- millimeter wave communications;
- low power mobile radar systems;
- mobile relay systems for high bit rate data links;
- long distance lidar system performance;
- detection and tracking of crosswinds and wind shear; and
- multi-function digital holographic imaging.

- For the past thirteen years, the University of Colorado’s Research and Engineering Center for Unmanned Vehicles has used the ACTS under a CRADA to safely and accurately test collective and autonomous sensing and communication technologies, to facilitate 4D sight through a ground-to-space sensing column with unmanned aircraft systems (UAS) operating in the atmosphere, integrated with ground-based and space-based observation systems. These capabilities are intended to be applied to a myriad of purposes ranging from improved climate and weather forecasting to better-informed government policymaking. The program was paused mid FY 2022 due to wildfire concerns and is expected to resume as soon as new safety procedures are agreed on.

4.5.2 Innovative Commercial Services

In FY 2022, ITS continued conducting critical research, development, testing, and evaluation (RDT&E) of the Citizens Broadband Radio Service (CBRS). ITS research, technology transfer, and testing has been critical to the successful commercial deployments of CBRS in the highly desirable 3.5 GHz spectrum. A decade of ITS efforts cleared the way for the $4.6 billion auction of licenses within CBRS in 2020, from research on technical feasibility of sharing between high power radars and commercial services that began in 2010 through conformance and compliance testing of the Spectrum Access System (SAS) and Environmental Sensing Capability (ESC) components of CBRS. This work to address and resolve technical issues of interference potentials, protection thresholds, and propagation predictions, widely published and freely transferred to Industry, laid the foundation for mid-band sharing and CBRS.

In FY 2022, ITS continued to work with the FCC (through interagency agreements), industry (through CRADAs), and the standards group WInnForum (through membership) to improve the SAS certification test system in preparation for delivering the test harness to the FCC. As part of the post-3.5 GHz Priority Access License auction (FCC Auction 105) spectrum relocation fund programs approved by OMB and Congress, ITS is participating in a multi-year program with DoD Defense Information Systems Agency (DISA) and others aimed at developing tools and capabilities to determine the effectiveness of the innovative CBRS sharing arrangements. ITS is taking a lead role in the Shared Spectrum Ecosystem Assessment (SEA) project by developing the firmware and software for deployable sensor technology. In FY 2022, ITS deployed the first prototypes of mobile sensors capable of validating CBRS band spectrum occupancy and assessing aggregate spectrum usage; the sensor control and data collection software has been transferred to the public domain through GitHub and is freely available for use in other bands of interest for sharing.

In FY 2022, ITS continued a multi-year project with the DOD Chief Information Officer (CIO), using 3.45 GHz pre-auction spectrum relocation funds authorized by OMB and Congress, to develop plans for improving propagation models for mid-band spectrum. This critically important research will continue through FY 2027 with post-auction funds from the successful 3.45 GHz auction (FCC Auction 110). Improving the ability of propagation models to predict how mid-band radio signals propagate through various environments will increase the efficiency of spectrum use by both federal and commercial users. ITS's mid-band propagation improvement program will include significant inputs and information sharing with other federal agencies, academia, and the commercial sector, and open source sharing of measurements, modeling, and code.

4.5.3 Telecommunication Standards

Models used to predict wireless propagation are fundamental to enabling spectrum sharing. The International Telecommunication Union – Radiocommunication Sector (ITU-R), an international treaty organization, has as its primary objective to ensure interference-free operations of radiocommunications systems. The ITU-R publishes internationally standardized propagation prediction models that are used to harmonize spectrum assignments internationally and to manage space-related spectrum assignments. Growing spectrum crowding demands increased accuracy and granularity of these models, which are developed through the participation of technical committees from all the treaty nations.

ITS leads efforts at ITU-R Study Group 3 (Radiowave Propagation) to ensure that U.S. interests and policy objectives are given due consideration by international technical experts and to promote informed decisions founded on physics and mathematics. ITS holds two of the four International Chairs of Study Group 3, and acts as Head of the U.S. Delegation to the Study Group 3 meetings. At the May 2019 meetings of SG3, ITS put forth a major revision of Recommendation P.528, *A propagation prediction method for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands*, along with a corresponding open source software implementation of the model—both of which were adopted by Study Group 3. ITS released as open source the reference implementation source code, a compiled DLL, and a pre-built executable that launches a graphical front end for this software implementation. Throughout FY 2021, ITS chaired a Study Group 3 Correspondence Group (CG-3K-3M-9) on aeronautical propagation, which looked at extending the upper frequency limit of ITU-R P.528 to include millimeter wave frequencies. This frequency extension was in support of WRC-23 agenda items 1.8[28] and 1.10[29], where sharing studies are being performed to examine the possibility of new sharing assignments and usage of existing frequency allocations involving aeronautical systems. This work culminated in an update to Recommendation ITU-R P.528, along with a major release of software products at the July 2021 Study Group 3 meeting. Input

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[28] Resolution 171 (WRC-19) and Resolution 155 (Rev WRC-19), https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000D0027PDFE.pdf

[29] Resolution 430 (WRC-19), https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000D0010PDFE.pdf

was collected from the user community and minor updates released to GitHub, stimulating additional collaborative input that is expected to bear fruit as another major release after the July 2021 SG3 meetings.

During FY 2021, the International Civil Aviation Organization (ICAO) acknowledged the value of the ITS-contributed update by incorporating the updated revision of Recommendation P.528 into updates to their internal frequency assignment software. In addition, members of ICAO reach out to ITS for technical assistance with the model, as well as requesting additional improvements in Recommendation P.528 to support the diversity of existing aeronautical systems—improvements that ITS proposed to Study Group 3 during the August 2020 meetings. The National Oceanic and Atmospheric Administration (NOAA) also adopted the ITS P.528 companion graphical user interface (GUI) software to support their work on frequency sharing between NOAA assets and possible future aeronautical commercial cellular systems, such as HIBS (High altitude IMT Base Stations). Furthermore, one output of the 2019 World Radio Conference (WRC19) was a proposal for sharing studies between existing aeronautical systems and newly proposed commercial deployments at select millimeter wave (mmWave) frequencies. ITS is chairing the Correspondence Group that will be developing and proposing updated air-to-ground propagation prediction models for millimeter wave frequencies at the next WRC.

ITS additionally led a Study Group 3 Correspondence Group (CG-3L-3) on radio noise. This culminated in a revision to Recommendation ITU-R P.372, *Radio Noise*, a Recommendation which is also cited by the Radio Regulations. Updates to P.372 include information on the background levels of radio noise in the frequency range from 0.1 Hz to 100 GHz, taking into account radio noise emitted by lightning, atmospheric gases, clouds, rain, the Earth's surface, the galaxy, and man-made sources; updated higher-resolution figures conveying the global levels of atmospheric radio noise for different months of the year and hours of the day; and ITS contributed software that allows researchers to programmatically obtain atmospheric radio noise values given primary location and time of year and day.

Direct participation by ITS in the 3rd Generation Partnership Project (3GPP), the dominant cellular communications standards development organization, allows NTIA to advance U.S. commercial, economic, and government interests by providing technical input to promote strong unbiased standards that support fair competition in next generation/5G cellular technologies. For a number of years, ITS has provided technical guidance to other government agencies in advocating for standardization of service features specific to public safety, emergency communications, and transportation. In particular, ITS represents the Department of Transportation and the Department of Defense Undersecretary for Research and Engineering's interests in 5G within 3GPP. In FY 2022, ITS continued to provide U.S. Government stakeholders a comprehensive understanding of the 3GPP New Radio (5G NR—the global standard for the air interface of 5G networks) capabilities, the services 5G NR was built to deliver, and deployment scenarios in both licensed and unlicensed spectrum for the evolution to 5G. In addition, in FY 2022, ITS attended TSG SA1 and SA3 working groups and provided briefings on agency-specific concerns with regard to standardization developments with respect to spectrum sharing, vehicle-to-everything communication, non-terrestrial networks, unmanned aerial vehicle and cyber security topics relative to security vulnerabilities in 4G and 5G systems architecture.

Direct participation by ITS in IEEE 802.15.22.3 led to standardization of the Spectrum Characterization and Occupancy Sensing (SCOS) standard. SCOS will allow broader availability and usage of spectrum sensing information from different sources by establishing a high-level architecture to support different technologies and deployments. In FY 2021, ITS entered into research collaborations with the multi-agency Sharing Ecosystem Assessment (SEA) program funded by DoD/DISA and coordinated through the National Advanced Communications Test Network (NASCTN) and the National Science Foundation (NSF) Spectrum Innovation Initiative (SII), to explore using widespread SCOS deployments to characterize and assess spectrum occupancy and make the data available to support more efficient and effective spectrum use. In FY 2022, the NASCTN SEA team designed and installed three prototype SCOS sensors.

4.5.4 Video Quality Research

Both CDVL and the VQM tools are used by industry and academia for research into new techniques for transmitting video. Lack of access to appropriate video footage to test new video distribution technologies was a significant impediment to video processing R&D until the launch of CDVL. Approximately half of CDVL's content is contribution quality footage that characterizes the broadcast use case. This footage allows users to test codecs, to evaluate new display technologies, or to develop and evaluate new standards. For example, ITU-T Study Group 12 has used CDVL clips for research into the development of parametric models and tools for multimedia quality assessment.

The remainder of CDVL's content targets other use cases: 13% standard test sequences and experiments from ITU, ATIS, or VQEG; 15% academic experiments distributed as open data; and 18% simulated public safety content; real public safety content is nearly impossible to obtain for research due to litigation concerns. Since first responders use consumer grade electronics, promoting development and standardization of commercial video technologies that meet public safety requirements through access to this simulated content has the potential to save lives as well as money.

In FY 2022, ITS supported industry discussions within VQEG that pursue new or improved ITU Recommendations. First, the ITU-T Rec. P.910 spatial information (SI) and temporal information (TI) metrics, developed by ITS in 1994, was recently updated to address ambiguities triggered by rapid advances in video technology. U.S. industry wants to continue using SI and TI to categorize video content when analyzing the response of new video products and services. To support this effort, ITS led discussions and distributes validation test sequences on CDVL. Second, ITS participated in ITU discussions on a VQEG vetted, improved method to screen human subjects during video quality testing. Third, VQEG will use ITU-T Rec. T.35 to embed standard video quality metadata in video streams. These video quality assessments are available in most modern video equipment; the missing element is a mechanism to propagate this information through the video processing pipeline.

5 SUMMARY

This report details the results of the FY 2022 collaborative technology activities and technology transfer successes of the Department of Commerce agency laboratories at NIST, NOAA, and NTIA ITS. The report demonstrates that as technology advances and the economy changes, DOC federal laboratories play a critical role in providing the United States with a competitive advantage and bolstering the U.S. economy through the transfer and commercialization of innovative technologies. Technology transfer is an essential DOC mission, and the report highlights how well the DOC labs are in position to be competitive in the global markets.