Annual Report on Technology Transfer:

Approach and Plans, Fiscal Year 2023 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

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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) 2023, and provides statistical information from FY 2019 through FY 2023. 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 reporting requirements of this section.

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). 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 monthly NIST-hosted interagency meetings and through facilitating ongoing discussions on policy, new approaches to technology transfer, and lessons learned from agency technology transfer programs.[1] The IAWGTT was established in 1987 by

[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.

Executive Order 12591, Section 7, to "convene an interagency task force comprised of the heads of representative agencies and the 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, a nationwide network of over 300 federal laboratories and research centers, 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 by 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 policy and implementation issues related to the Bayh-Dole Act and the associated Bayh-Dole regulations and facilitates aligning of agency policies. The IAWGBD has been working on updates to the Bayh-Dole Act's implementing regulations for several years. On March 24, 2023, these updated regulations were finalized and published in the Federal Register.[4] Additionally, 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 and utilization of inventions and patents that were conceived or first actually reduced to practice by awaredees using extramural federal research and development funding. The new NIST-managed iEdison system, modernizing and updating the system previously managed by NIH, was 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

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

[3] The IAWGBD was formed to facilitate consistency in the development of agency policies related to the Bayh-Dole Act and its implementing regulations. It includes representatives from across the federal government including individuals from 16 Departments and independent federal agencies.

[4] https://www.federalregister.gov/documents/2023/03/24/2023-06033/rights-to-federally-funded-inventions-and-licensing-of-government-owned-inventions

This annual report provides comprehensive statistics on technology transfer activities of DOC laboratories, including information regarding invention disclosures, intellectual property (IP) protection and licensing, 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 OMB's Circular A-11 also requires this information. The tables in the following sections present the required data.[5]

1.1 STATUTORILY REQUIRED COMBINED METRIC TABLES

[5] 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 tables presenting statutorily required metrics report data from FY 2020 to FY 2023 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 1: DOC Invention Disclosures and Patenting

Metric	FY 2020	FY2021	FY2022	FY 2023
Invention Disclosures Received	70	67	72	62
Total Patent Applications Filed	36	80	27	31
U.S.	36	41	27	31
Foreign	0	0	0	0
Total Patent Cooperation Treaty (PCT) Applications Filed	3	3	8	8
Total Patents Issued	25	34	26	25
U.S.	25	34	26	25
Foreign	0	0	0	0

Table 2: DOC Licensing

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Invention Licenses, Total Active	52	44	42	41
New Invention Licenses	15	9	11	9
New Invention Licenses Granted to Small Businesses	12	2	8	5
Income Bearing Licenses, Total Active	34	33	33	36
New Income Bearing Licenses	6	3	0	3
Exclusive, Total Active	19	17	15	17
Partially Exclusive, Total Active	0	0	0	0
Non-Exclusive, Total Active	15	16	18	19
Other Licenses, Total Active	0	0	0	0
New Other Licenses	0	0	0	0
New Other Licenses Granted to Small Businesses	0	0	0	0
Elapsed Amount of Time for Granting Invention Licenses	n/a	n/a	n/a	n/a
Average (months)	n/a	n/a	n/a	n/a
Minimum (months)	n/a	n/a	n/a	n/a
Maximum (months)	n/a	n/a	n/a	n/a
Licenses Terminated for Cause	0	0	0	0

Table 3: DOC Income from Licensing[6]

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Invention License Income	$191,178	$105,571	$210,610	$46,400
Other License Income	$0	$0	$0	$0
Total Earned Royalty Income (ERI)	$187,578	$105,571	$210,610	$46,400
ERI from Top 1% of Licenses	n/a	n/a	n/a	n/a
ERI from Top 5% of Licenses	n/a	n/a	n/a	n/a
ERI from Top 20% of Licenses	n/a	n/a	n/a	n/a
Minimum ERI	n/a	n/a	n/a	n/a
Maximum ERI	n/a	n/a	n/a	n/a
Median ERI	n/a	n/a	n/a	n/a
Disposition of ERI				
Average Percentage Distributed to Inventors	n/a	n/a	n/a	n/a
Average Percentage Distributed to Lab/Agency	n/a	n/a	n/a	n/a

Table 4: DOC Collaborative Relationships

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Total Active CRADAs	2,014	2,357	2,359	2,362
New CRADAs	1,647	1,813	1,814	1,870
New CRADAs Involving Small Businesses	977	921	929	850
Other Collaborative Agreements	2,952	2,849	2,849	2,848

[6] 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[7]

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 2023, NIST, NOAA, and ITS researchers published 4,125 scientific and technical papers in peer-reviewed journals.

Table 5: DOC Scientific and Technical Publications[8]

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
NIST	1,396	1,509	1,419	1,160	1,046
NOAA	1,895	1,755	1,804	1,783	3,064
ITS	11	14	10	14	15
Department Total	3,302	3,278	3,233	2,957	4,125

[7] 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.

[8] 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 promote the dissemination of the results of fundamental research and measurements sciences, and to promote standards related programs 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.[9]

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.

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

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

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 2020	FY 2021	FY 2022	FY 2023
Invention Disclosures Received	64	55	69	55
Total Patent Applications Filed	35	80	27	29
U.S.	35	41	27	29
Foreign	0	0	0	0
Total Patent Cooperation Treaty (PCT) Applications Filed	3	3	8	8
Total Patents Issued	25	32	25	25
U.S.	25	32	25	25
Foreign	0	0	0	0

Table 7: NIST Licensing[10]

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Invention Licenses, Total Active	46	38	36	35
New Invention Licenses	12	7	11	9
New Invention Licenses Granted to Small Businesses	12	n/a	8	5
Income Bearing Licenses, Total Active	28	27	27	30
New Income Bearing Licenses	6	1	0	3
Exclusive, Total Active	15	14	14	16
Partially Exclusive, Total Active	0	0	0	0
Non-Exclusive, Total Active	14	13	13	14
Other Licenses, Total Active	0	0	0	0
New Other Licenses	0	0	0	0
New Other Licenses Granted to Small Businesses	0	0	0	0
Elapsed Amount of Time for Granting Invention Licenses				
Average (months)	18	2	11	9
Minimum (months)	1	2	1	2
Maximum (months)	25	2	29	14
Licenses Terminated for Cause	0	0	0	0

[10] "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 2020	FY 2021	FY 2022	FY 2023
Invention License Income	$79,344	$36,399	$98,022	$27,418
Other License Income	$0	$0	$0	$0
Total Earned Royalty Income (ERI)	$79,344	$36,399	$98,022	$27,418
ERI from Top 1% of Licenses	$45,000	$10,000	$22,029	$6,000
ERI from Top 5% of Licenses	$45,000	$10,000	$22,029	$6,000
ERI from Top 20% of Licenses	$45,000	$10,000	$22,029	$6,000
Minimum ERI	$1,250	$1,250	$173	$400
Maximum ERI	$45,000	$10,000	$22,029	$6,000
Median ERI	$5,000	$3,859	$6,250	$2,470
Disposition of ERI				
Percentage Distributed to Inventors	42%	56%	43%	67%
Percentage Distributed to Lab/Agency	58%	44%	57%	33%

Table 9: NIST Collaborative Relationships[11]

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Total Active CRADAs	1,968	2,135	2,300	2,300
New CRADAs	1,633	1,789	1,795	1,853
New CRADAs Involving Small Businesses	973	956	917	838
Other Collaborative Agreements	2,952	2,618	2,848	2,848

2.3 Other Important NIST Performance Measures

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

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

2.3.1 Scientific and Technical Publications

NIST research results are published or made widely available 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.

NIST authors published 1,046 manuscripts in fiscal year (FY) 2023 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) 2023, NIST-authored manuscripts that were published in peer-reviewed journals during the past five years (CY 2019–2023) garnered 26,404 citations.[12]

Table 10: NIST Publishing Activities – Papers[13]

	FY 2020	FY 2021	FY 2022	FY 2023
Number of NIST Papers	1,509	1,419	1,160	1,046
Number of NIST Paper Citations (CY)	n/a	36,882	28,621	26,404

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 283 TechPubs in FY 2023. The number of times that a publication is downloaded can serve as an indicator of the effectiveness of technology transfer. In CY 2023, NIST TechPubs that were published during the past five years (CY 2019–2023) were downloaded over 4.1 million times.[14] Of these publications, those with the subject area of computer and information security standards and guidelines were downloaded thousands of times every day.[15]

[12] NIST peer-reviewed publication data were retrieved from queries of the Web of Science (WoS) database. 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.

[13] Data as of December 15, 2023.

[14] Download statistics of NIST Technical Series Publications consist of the number of unique visitors ("downloads") for each publication, i.e., 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.

[15] 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.

Table 11: NIST Publishing Activities - Technical Report Series

	FY 2020	FY 2021	FY 2022	FY 2023
Number of NIST TechPubs Published	232	225	290	283
Number of NIST TechPubs Downloads (CY)	n/a	2,840,058	3,114,035	4,188,584

NIST researchers published 161 data products in FY 2023, including datasets and software. The volume of downloaded data products serves as an indicator of technology transfer. In CY 2023, there were 190 terabytes[16] (TB) of data downloaded from NIST datasets located in the NIST Data 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 2023, 94 repositories[17] 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[18]

	FY 2020	FY 2021	FY 2022	FY 2023
Number of NIST Datasets & Software Published	132	128	123	161
Quantity of NIST Data (direct download) from NIST Data Portal (CY)	n/a	14 TB	36 TB	190 TB
Number of Repositories added to the NIST Open-Source Code Portal	143	68	95	94

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

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

[17] 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.

[18] Data collection method from January 2023 through November 2023 more accurately reflects downloads across repository holdings.

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 developed by experts that specify agreed upon ways to carry out a technical process. For example, a standard could specify a test method or a measurement method or standard practices, or even specify a material's properties or product's properties. Econometric studies have reported that standards contribute significantly to economic growth and technological advancement. A significant study concluded that the 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.[19]

During FY 2023, 442 members of the NIST staff were involved with 331 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.

Table 13: NIST Participation in Documentary Standards[20]

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Number of Participating NIST Staff	440	400	547	579	442
Number of Standard Organizations with NIST Participants	112	112	350	328	331

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

[19] 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.

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

evaluated for accuracy and reliability. NIST currently maintains 75 SRD databases that cover many areas of science, including analytical chemistry, atomic and molecular physics, biotechnology, and materials sciences.

In FY 2023, the NIST SRD Program distributed 1,933 e-commerce orders, 7,831 units sold via distributor, 174 active distributor agreements, 10 active site licenses, 60 active internet subscriptions, 57 units shipped to the user, and 3,542 products downloaded from the NIST website (1,679 free downloads, 1,863 paid downloads).

Table 14: NIST Standard Reference Data Program

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Products Available (Databases)	90	74	74	65	75
E-Commerce Orders	2,613	2,908	3,200	2,842	1,933
Units Sold via Distributor	9,880	7,905	8,499	7,999	7,831
Active Distributor Agreements	125	115	118	124	174
Active Site Licenses	30	15	19	17	10
Active Internet Subscriptions	41	140	69	81	60
Units Shipped via UPS	82	57	50	20	57
Products Downloaded from the NIST Website	3,812	4,578	4,449	3,805	3,542
Free Downloads	1,100	1,484	1,369	1,618	1,679
Paid Downloads	2,712	3,094	3,080	2,187	1,863

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 2023, NIST made available 1,103 SRMs and from these, sold 27,400 units.

Table 15: NIST Standard Reference Materials

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Units Available	1,130	1,114	1,116	1,121	1,103
Units Sold	29,955	27,319	28,065	28,777	27,400

2.3.5 User Facilities – Research Participants

NIST operates two unique and valuable laboratory user 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 (NCNR), allow NIST customers to tap directly into NIST measurement expertise to conduct research and 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 2023, there were 200 distinct facility users at CNST and 1,407 research participants at NCNR.

Table 16: NIST Research Participants

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
CNST	314	230	184	198	200
NCNR	2,923	3,068	2,576	1,857	1,407

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 2023, NIST hosted 118 postdocs. Of these, 93 were based at the NIST Gaithersburg, Maryland campus; 25

[21] The NCNR was temporarily 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 Commission 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.

were located in the NIST Boulder, Colorado campus; and the remainder were located at the JILA, also in Boulder, Colorado.

Table 17: NIST Postdoctoral Researchers

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
NIST Postdocs, Total (NRC)	165	154	132	120	118
Gaithersburg campus	110	103	94	71	93
Boulder campus	35	40	33	44	25
JILA [(a)]	13	7	5	4	4
Joint Quantum Institute [(b)]	1	0	0	0	0
Hollings Marine Laboratory [(c)]	3	4	0	1	0
Institute for Bioscience and Biotechnology Research [(d)]	2	0	0	0	0
Joint Initiative for Metrology in Biology[(e)]	1	0	0	0	0

(a) 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.

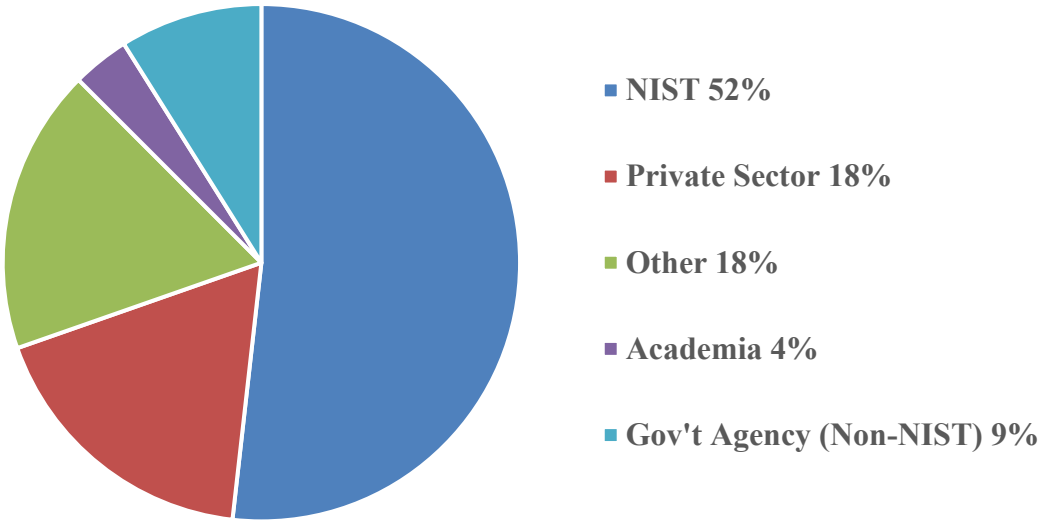
(d) The Institute for Bioscience and Biotechnology Research (IBBR) is a joint research enterprise created to enhance collaboration among the University of Maryland College Park, the University of Maryland Baltimore, and NIST.

(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 56 FY 2023 NIST National Research Council (NRC) program postdocs. Of these, 52% continued research careers with NIST,[23] 18% percent moved to the private sector, 18% pursued other opportunities such as becoming independent researchers, 4% move to Academic positions, and 6% moved to non-NIST government agencies.

[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 2023)



2.3.7 Guest Researchers

In addition to postdocs, each year thousands of guest 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 2023 there were 2,724 guest scientists and engineers working at NIST.

Table 18: NIST Guest Researchers

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Guest Scientists and Engineers	3,180	2,701	2,371	2,498	2,724

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 2023, NVLAP accredited 627 laboratories.

Table 19: NIST Accreditation Services

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
NVLAP Accreditations	674	644	650	623	627

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 2023, NIST performed 8,701 calibration tests.

Table 20: NIST Calibration Services

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Number of Calibration Tests Performed	11,519	9,225	13,568	14,013	8,701

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 NIST Summer Institute for Middle School Science Teachers; and
- the Professional Research Experience Program (PREP).

In FY 2023, 172 students participated in the SURF program, 52 students participated in SHIP, 26 individuals participated in the Summer Institute for Middle School Science Teachers, and 547 students participated in PREP.

Table 21: NIST STEM Education Participation

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
SURF[(a)]	173	0	146	156	172
SHIP	55	0	54	44	52
Summer Institute for Middle School Science Teachers[(b)]	24	23	24	23	26
PREP	360	174	425	531	547

(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 and promote the transfer of technology and sharing of technical information.

In FY 2023, the NIST Conference Program arranged 44 conferences, both in person and virtual, that attracted 17,394 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 1,153 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 2019	FY 2020	FY 2021	FY 2022	FY 2023
NIST Conference Center					
Conferences and Workshops	78	74	40	35	44
Attendance	8,596	7,747	17,943	23,706	17,394
Office of Weights and Measures - Metrology Training					
Total Students	666	2,057	2,084	1,294	1,153
Seminar Attendance	441	101	0	125	171
Webinar Attendance	225	1,948	1,954	1,134	982
Workshop Attendance	0	8	130	35	0

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 2023, 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 632 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 86 days.

Table 23: NIST Activity Trends

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Average Number of Days to File a Non-Provisional Patent Application[(a)]	408	450	488	612	632
Average Number of Days to Approve a CRADA[(b)]	129	109	92	76	86

(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.

[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.

(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 2023, NIST awarded 10 Phase I SBIR awards and 5 Phase II SBIR awards.

Table 24: NIST SBIR Award Count

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Phase I SBIR Awards	12	12	11	12	10
Phase II SBIR Awards	7	8	6	7	5

2.4 Success Stories Demonstrating Downstream Outcomes From NIST Technology Transfer Activities

2.4.1 New DNA Biosensor Could Unlock Powerful, Low-Cost Clinical Diagnostics

DNA can signal the presence of or predisposition to a slew of diseases, including cancer. The ability to flag down these clues, known as biomarkers, allows medical professionals to make critical early diagnoses and provide personalized treatments. The typical methods of screening can be laborious, expensive or limited in what they can uncover. A new biosensor chip that boasts an accurate and inexpensive design may increase accessibility to high-quality diagnostics.

The biosensor, developed by researchers at the National Institute of Standards and Technology (NIST), Brown University and the French government-funded research institute CEA-Leti, identifies biomarkers by measuring how binding occurs between DNA strands and the device. What sets it apart from other similar sensors is its modular design, which lowers costs by making it easier to mass produce and allowing the most expensive components to be reused.

In a paper posted online, the researchers presented results of a study that demonstrates the device's high sensitivity and precision despite its modularity, which is typically associated with diminished performance.

Like other DNA biosensors, the device takes advantage of the fact that a single DNA strand, when not paired with another within the familiar double helix, is primed for chemical bonding. Part of the device is coated with single strands of DNA. When these "probes" encounter DNA biomarkers that have a corresponding, or complementary, genetic sequence, the two strands bind, sending a signal that is picked up by the device.

“To make the measurement, we need two DNA molecules. We place one strand on our sensor that is complementary to the target DNA, that’s the proverbial needle in the haystack,” said NIST researcher Arvind Balijepalli, a co-author of the study.

When a strand of target DNA binds to a probe, it induces a voltage shift that a semiconductor device, called a field-effect transistor (FET), can measure. These voltage shifts can occur hundreds of times a second as the molecules pop on and off the sensor.

Because of its high time resolution, this approach can tell you not only whether a DNA strand is bound to a probe, but how long it takes to connect and disconnect—a factor called binding kinetics that is key for discerning different markers that may bind to the same probe to varying degrees.

And with this method, you don’t need much space to measure a lot.

“This is a very scalable technique. In principle, we can have hundreds if not thousands of sensors in an area of one square millimeter integrated into a device the size of a smartphone, which is much less cumbersome than some of the technology currently used in the clinic,” Balijepalli said.

FET-based methods have yet to hit the mainstream, however. A significant stumbling block is their single-use nature, which until now has seemed a necessity but increases their cost.

Similar to how your radio becomes increasingly noisy as you drive away from a radio station, electrical signals also get noisier the longer they have to travel within electronics. The unwanted random noise picked up along the way makes the signal harder to measure.

To limit noise, DNA probes in FET-based sensors are normally attached to the transistor directly, which converts the signal into readable data. The drawback is that the probes are spent after being exposed to a sample, and thus the whole device is as well.

In the study, Balijepalli and his colleagues increased the distance between the probes and the transistor so that the more expensive elements of the circuitry could be reused. The upfront penalty was that the distance could increase the amount of noise; however, there was much to be gained from the design choice, even beyond the cost savings.

“If the reader is reusable, we can build more sophisticated technology into it and get higher precision out of the readings, and it can interface with the inexpensive and disposable sensing element,” Balijepalli said.

Because they anticipated that the modular design would diminish the biosensor’s sensitivity, the researchers took a page out of the Internet of Things (IoT) playbook, which accommodates

the losses associated with wireless devices. The NIST authors paired their circuitry with a specific type of extremely low-power FET developed at CEA-Leti that is used in smartwatches, personal assistants and other devices to amplify signals and compensate for the lost sensitivity.

To test the performance of their device, they placed it in liquid samples containing DNA strands associated with exposure to harmful ionizing radiation. Complementary DNA probes adorned electrodes wired to the FET. Across several samples, they varied the amount of target DNA.

The researchers found that the binding kinetics were sensitive enough to make accurate measurements even at low concentrations. Overall, the performance of the modular design matched that of integrated, nonmodular FET-based biosensors.

The next step in their research is to find out if their sensor can perform similarly with varying DNA sequences caused by mutations. Since many diseases are caused by or associated with mutated DNA, this capability is essential for clinical diagnostics.

Other studies may evaluate the sensor's ability to detect genetic material associated with viruses, such as COVID-19, that could hint at infection.

In the meantime, the new technology could represent a viable foundation to build upon.

"There's an opportunity to develop more sophisticated modular sensors that are much more accessible without sacrificing high quality measurements," Balijepalli said.

2.4.2 This Simple Material Could Scrub Carbon Dioxide From Power Plant Smokestacks

How can we remove carbon dioxide, a greenhouse gas, from fossil-fuel power plant exhaust before it ever reaches the atmosphere? New findings suggest a promising answer lies in a simple, economical and potentially reusable material analyzed at the National Institute of Standards and Technology (NIST), where scientists from several institutions have determined why this material works as well as it does.

The team's object of study is aluminum formate, one of a class of substances called metal-organic frameworks (MOFs). As a group, MOFs have exhibited great potential for filtering and separating organic materials—often the various hydrocarbons in fossil fuels—from one another. Some MOFs have shown promise at refining natural gas or separating the octane components of gasoline; others might contribute to reducing the cost of plastics manufacturing or cheaply converting one substance to another. Their capacity to perform such separations comes from their inherently porous nature.

Aluminum formate, which the scientists refer to as ALF, has a talent for separating carbon dioxide (CO_2) from the other gases that commonly fly out of the smokestacks of coal-fired power plants. It also lacks the shortcomings that other proposed carbon filtration materials

have, said NIST's Hayden Evans, one of the lead authors of the team's research paper, published in the peer-reviewed journal Science Advances.

"What makes this work exciting is that ALF performs really well relative to other high-performing CO2 adsorbents, but it rivals designer compounds in its simplicity, overall stability and ease of preparation," said Evans, a chemist at the NIST Center for Neutron Research (NCNR). "It is made of two substances found easily and abundantly, so creating enough ALF to use widely should be possible at very low cost."

The research team includes scientists from the National University of Singapore; Singapore's Agency for Science, Technology and Research; the University of Delaware; and the University of California, Santa Barbara.

Coal-fired power plants account for roughly 30% of global CO2 emissions. Even as the world embraces other energy sources such as solar and wind power that do not generate greenhouse gases, finding a way to reduce the carbon output of existing plants could help mitigate their effects while they remain in operation.

Scrubbing the CO2 from flue gas before it reaches the atmosphere in the first place is a logical approach, but it has proved challenging to create an effective scrubber. The mixture of gases that flows up the smokestacks of coal-fired power plants is typically fairly hot, humid and corrosive — characteristics that have made it difficult to find an economical material that can do the job efficiently. Some other MOFs work well but are made of expensive materials; others are less costly in and of themselves but perform adequately only in dry conditions, requiring a "drying step" that reduces the gas humidity but raises the overall cost of the scrubbing process.

"Put it all together, you need some kind of wonder material," Evans said. "Here, we've managed to tick every box except stability in very humid conditions. However, using ALF would be inexpensive enough that a drying step becomes a viable option."

ALF is made from aluminum hydroxide and formic acid, two chemicals that are abundant and readily available on the market. It would cost less than a dollar per kilogram, Evans said, which is up to 100 times less expensive than other materials with similar performance. Low cost is important because carbon capture at a single plant could require up to tens of thousands of tons of filtration material. The amount needed for the entire world would be enormous.

On a microscopic scale, ALF resembles a three-dimensional wire cage with innumerable small holes. These holes are just large enough to allow CO2 molecules to enter and get trapped, but just small enough to exclude the slightly larger nitrogen molecules that make up the majority of flue gas. Neutron diffraction work at the NCNR showed the team how the individual cages in the material collect and fill with CO2, revealing that the gas molecules fit inside certain cages within ALF like a hand in a glove, Evans said.

Despite its potential, ALF is not ready for immediate use. Engineers would need to design a procedure to create ALF at large scales. A coal-fired plant would also need a compatible process to reduce the humidity of the flue gas before scrubbing it. Evans said that a great deal is already understood about how to address these issues, and that they would not make the cost of using ALF prohibitive.

What to do with the CO2 afterward is also a major question, he said, though this is a problem for all carbon-capture materials. There are research efforts underway to convert it to formic acid—which is not only a naturally occurring organic material but also one of the two constituents of ALF. The idea here is that ALF could become part of a cyclic process where ALF removes CO2 from the exhaust streams, and that captured CO2 is used to create more formic acid. This formic acid would then be used to make more ALF, further reducing the overall impact and cost of the material cycle.

“There is a great deal of research going on nowadays into the problem of what to do with all the captured CO2,” Evans said. “It seems possible that we could eventually use solar energy to split hydrogen from water, and then combine that hydrogen with the CO2 to make more formic acid. Combined with ALF, that’s a solution that would help the planet.”

2.4.3 To Break New Ground With Frequency Combs, a NIST Innovation Plays With the Beat

An improvement to a Nobel Prize-winning technology called a frequency comb enables it to measure light pulse arrival times with greater sensitivity than was previously possible — potentially improving measurements of distance along with applications such as precision timing and atmospheric sensing.

The innovation, created by scientists at NIST, represents a new way of using frequency comb technology, which the scientists have termed a “time programmable frequency comb.” Up until now, frequency comb lasers needed to create light pulses with metronomic regularity to achieve their effects, but the NIST team has shown that manipulating the timing of the pulses can help frequency combs make accurate measurements under a broader set of conditions than has been possible.

“We’ve essentially broken this rule of frequency combs that demands they use a fixed pulse spacing for precision operation,” said Laura Sinclair, a physicist at NIST’s Boulder campus and one of the paper’s authors. “By changing how we control frequency combs, we have gotten rid of the trade-offs we had to make, so now we can get high-precision results even if our system only has a little light to work with.”

The team’s work is described in the journal Nature.

Often described as a ruler for light, a frequency comb is a type of laser whose light consists of many well-defined frequencies that can be measured accurately. Looking at the laser’s spectrum on a display, each frequency would stand out like one tooth of a comb, giving the

technology its name. After earning NIST's Jan Hall a portion of the 2005 Nobel Prize in Physics, frequency combs have found use in a number of applications ranging from precision timekeeping to finding Earth-like planets to greenhouse gas detection.

Despite their many current uses, frequency combs do possess limitations. The team's paper is an attempt to address some of the limitations that arise when using frequency combs to make precise measurements outside the laboratory in more challenging situations, where signals can be very weak.

Since shortly after their invention, frequency combs have enabled highly accurate measurements of distance. In part, this accuracy stems from the broad array of frequencies of light the combs use. Radar, which uses radio waves to determine distance, is accurate to anywhere from centimeters to many meters depending on the signal's pulse width. The optical pulses from a frequency comb are far shorter than radio, potentially allowing measurements accurate to nanometers (nm), or billionths of a meter—even when the detector is many kilometers from the target. Use of frequency comb techniques could eventually enable precise formation flying of satellites for coordinated sensing of Earth or space, improving GPS, and supporting other ultra-precise navigation and timing applications.

Distance measurement using frequency combs requires two combs whose lasers' pulse timing is tightly coordinated. The pulses from one comb laser are bounced off a faraway object, just as radar uses radio waves, and the second comb, slightly offset in repetition period, measures their return timing with great accuracy.

The limitation that comes with this great accuracy relates to the amount of light that the detector needs to receive. By nature of its design, the detector can only register photons from the ranging laser that arrive at the same time as pulses from the second comb's laser. Up to now, due to the slight offset in repetition period, there was a relatively lengthy period of "dead time" between these pulse overlaps, and any photons that arrived between the overlaps were lost information, useless to the measurement effort. This made some targets hard to see.

Physicists have a term for their aspirations in this case: They want to make measurements at the "quantum limit," meaning they can take account of every available photon that carries useful information. More photons detected means greater ability to spot fast changes in distance to a target, a goal in other frequency comb applications. But for all its accomplishments to date, frequency comb technology has operated far from that quantum limit.

"Frequency combs are commonly used to measure physical quantities such as distance and time with extreme accuracy, but most measurement techniques waste the great majority of the light, 99.99% or more," Sinclair said. "We have instead shown that by using this different control method, you can get rid of that waste. This can mean an increase in measurement speed, in precision, or it allows using a much smaller system."

The team's innovation involves the ability to control the timing of the second comb's pulses. Advances in digital technology permit the second comb to "lock on" to the returning signals, eliminating the dead time created by the previous sampling approach. This occurs despite the fact that the controller must find a "needle in a haystack"—the pulses are comparatively brief, lasting only 0.01% as long the dead time between them. After an initial acquisition, if the target moves, the digital controller can adjust the time output such that the second comb's pulses speed up or slow down. This allows the pulses to realign, so that the second comb's pulses always overlap with those returning from the target. This adjusted time output is exactly twice the distance to the target, and it is returned with the pinpoint precision characteristic of frequency combs.

Animation with two rows of offset pulses that show the relationship between the two combs' pulses, then a third row shows how changing the timing of the second row can make the offset pulses line up with each other.

The upshot of this time-programmable frequency comb, as the team calls it, is a detection method that makes the best use of the available photons—and eliminates dead time.

"We found we can measure the range to a target fast, even if we only have a weak signal coming back," Sinclair said. "Since every returning photon is detected, we can measure the distance near the standard quantum limit in precision."

Compared to standard dual-comb ranging, the team saw a 37-decibel reduction in required received power—in other words, only requiring around 0.02% of the photons needed previously.

The innovation could even enable future nanometer-level measurements of distant satellites, and the team is exploring how its time-programmable frequency comb could benefit other frequency comb sensing applications.

2.4.4 NIST to Standardize Encryption Algorithms That Can Resist Attack by Quantum Computers

In 2022, NIST selected four algorithms designed to withstand attack by quantum computers. Now the agency has begun the process of standardizing these algorithms—the final step before making these mathematical tools available so that organizations around the world can integrate them into their encryption infrastructure.

In 2023, NIST released draft standards for three of the four algorithms it selected in 2022. NIST planned to release a draft standard for FALCON, the fourth algorithm, in about a year from that initial release.

NIST called on the worldwide cryptographic community to provide feedback on the draft standards by November 2023.

“We’re getting close to the light at the end of the tunnel, where people will have standards they can use in practice,” said Dustin Moody, a NIST mathematician and leader of the project. “For the moment, we are requesting feedback on the drafts. Do we need to change anything, and have we missed anything?”

Sensitive electronic information, such as email and bank transfers, is currently protected using public-key encryption techniques, which are based on math problems a conventional computer cannot readily solve. Quantum computers are still in their infancy, but a sufficiently powerful one could solve these problems, defeating the encryption. The new standards, once completed, will provide the world with its first tools to protect sensitive information from this new kind of threat.

NIST’s effort to develop quantum-resistant algorithms began in 2016, when the agency called on the world’s cryptographic experts to submit candidate algorithms to NIST’s Post-Quantum Cryptography Standardization Project. Experts from dozens of countries submitted 69 eligible algorithms by the November 2017 deadline.

NIST then released the 69 candidate algorithms for experts to analyze, and to crack if they could. This process was open and transparent, and many of the world’s best cryptographers participated in multiple rounds of evaluation, which reduced the number of candidates.

Although quantum computers powerful enough to defeat current encryption algorithms do not yet exist, security experts say that it’s important to plan ahead, in part because it takes years to integrate new algorithms across all computer systems.

Each new publication is a Federal Information Processing Standard (FIPS) concerning one of the four algorithms NIST selected in July 2022:

- CRYSTALS-Kyber, designed for general encryption purposes such as creating secure websites, is covered in FIPS 203, which was released in August 2024.
- CRYSTALS-Dilithium, designed to protect the digital signatures we use when signing documents remotely, is covered in FIPS 204, which was released in August 2024.
- SPHINCS+, also designed for digital signatures, is covered in FIPS 205, which was released in August 2024.
- FALCON, also designed for digital signatures, is slated be covered in FIPS 206.

The publications provide details that will help users implement the algorithms in their own systems, such as a full technical specification of the algorithms and notes for effective implementation. Additional guidance will be forthcoming in companion publications, Moody said.

While these three will constitute the first group of post-quantum encryption standards NIST creates, they will not be the last.

In addition to the four algorithms NIST selected last year, the project team also selected a second set of algorithms for ongoing evaluation, intended to augment the first set. NIST will publish draft standards next year for any of these algorithms selected for standardization. These additional algorithms—likely one or two, Moody said—are designed for general encryption, but they are based on different math problems than CRYSTALS-Kyber, and they will offer alternative defense methods should one of the selected algorithms show a weakness in the future.

This need for backups was underscored last year when an algorithm that initially was a member of the second set proved vulnerable: Experts outside NIST cracked SIKE with a conventional computer. Moody said that the break was unusual only in that it came relatively late in the evaluation process. “It was mainly an indication that our process is working as it should,” he said.

The team members also want to make sure they have considered all the latest ideas for post-quantum cryptography, particularly for digital signatures. Two of the three post-quantum methods for digital signatures selected thus far are based on a single mathematical idea called structured lattices. Should any weaknesses in structured lattices emerge, it would be helpful to develop additional approaches that are based on other ideas. The NIST team recently requested submissions of additional signature algorithms that cryptographers have designed since the initial 2017 submission deadline, and the team plans to evaluate these submissions through a multi-round public program to be conducted over the next few years. The 40 submissions that met the acceptance criteria are posted here.

Eventually, the completed post-quantum encryption standards will replace three NIST cryptographic standards and guidelines that are the most vulnerable to quantum computers: FIPS 186-5, NIST SP 800-56A and NIST SP 800-56B.

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 2023.

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 partnership with the U.S. Patent and Trademark Office, there has been an effort to raise IP awareness across NOAA. This three-phased approach, which began in FY23 Q2, started first by conducting interviews with scientists and engineers across NOAA labs to understand the perceived barriers to obtaining intellectual property protection. The second phase, rolled out in FY23 Q3, was developing training materials that are focused on the perceived barriers at NOAA. The third phase, deployed across NOAA in FY23 Q4 into FY24 Q1, is delivering intellectual property training to the NOAA workforce. Early survey results from the training have shown a positive reception to the materials and additional metrics of success will be analyzed to ensure maximum effectiveness.

The NOAA TPO welcomed a new Technology Transfer Specialist, Jennifer Stewart, who is located at the NOAA Southwest Fisheries Science Center in La Jolla, CA. Jennifer comes to NOAA with 12 years of Technology Transfer experience from the U.S. Navy. This position will be the first technology transfer position deployed at a NOAA lab facility.

The NOAA TPO has acquired its first IP docketing system to better track the intellectual property portfolio and assist with scaling the IP portfolio with increased IP awareness within the organization.

The NOAA TPO implemented a recommended Standard Operating Procedure for writing, publishing, and promoting website announcements that describe new NOAA Cooperative Research and Development Agreements (CRADAs). This included the creation of a new searchable web page showcasing NOAA's CRADA partnerships, as well as seven website announcements describing new CRADAs, some which have garnered significant attention from the media and internal NOAA audiences. This procedure and partnerships web page were created in response to agency leadership's call for the NOAA TPO to highlight the value of NOAA's CRADAs and encourage the development of additional partnerships.

3.2 STATUTORILY REQUIRED METRIC TABLES

NOAA was awarded zero (0) issued patents. Two (2) patent applications, and three (3) provisional patent applications were filed in 2023.

NOAA researchers disclosed seven (7) 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 one (1) exclusive license, and five (5) non-exclusive licenses, all of which are income-bearing. NOAA now maintains an active portfolio of ten patented technologies, seven (7) of which are being marketed for licensees or are being actively commercialized.

In FY23 NOAA entered into 17 new CRADAs which support a variety of Line Offices at NOAA to include eight (8) new CRADAs within NOAA Fisheries and nine (9) within NOAA's National Ocean Service, the National Weather Service, and the National Environmental Satellite, Data, and Information Service.

Table 25: NOAA Invention Disclosures and Patenting

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Invention Disclosures Received	6	12	3	7
Total Patent Applications Filed	1	0	0	2
U.S.	1	0	0	2
Foreign	0	0	0	0
Total Patent Cooperation Treaty (PCT) Applications Filed	0	0	0	0
Total Patents Issued	0	2	1	0
U.S.	0	2	1	0
Foreign	0	0	0	0

Table 26: NOAA Licensing

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Invention Licenses, Total Active	6	6	6	6
New Invention Licenses	0	2	0	0
New Invention Licenses Granted to Small Businesses	0	2	0	0
Income Bearing Licenses, Total Active	6	6	6	6
New Income Bearing Licenses	0	2	0	0
Exclusive, Total Active	0	3	1	1
Partially Exclusive, Total Active	0	0	0	0
Non-Exclusive, Total Active	0	3	5	5
Other Licenses, Total Active	0	0	0	0
New Other Licenses	0	0	0	0
New Other Licenses Granted to Small Businesses	0	0	0	0
Elapsed Amount of Time for Granting Invention Licenses				
Average (months)	n/a	n/a	n/a	n/a
Minimum (months)	n/a	n/a	n/a	n/a
Maximum (months)	n/a	n/a	n/a	n/a
Licenses Terminated for Cause	0	0	0	0

Table 27: NOAA Income from Licensing

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Invention License Income	$111,834	$69,173	$112,588	$18,982
Other License Income	$0	$0	$0	$0
Total Earned Royalty Income (ERI)	$108,234	$69,173	$112,588	$18,982
ERI from Top 1% of Licenses	$102,734	$69,173	$102,388	$13,500
ERI from Top 5% of Licenses	$102,734	$69,173	$102,388	$13,500
ERI from Top 20% of Licenses	$102,734	$69,173	$102,388	$13,500
Minimum ERI	$500	$69,173	$10,200	$2,000
Maximum ERI	$102,734	$69,173	$102,388	$13,500
Median ERI	$27,959	$69,173	$56,294	$3,482
Disposition of ERI				
Percentage Distributed to Inventors	34%	32%	31%	52%
Percentage Distributed to Lab/Agency	66%	68%	69%	48%

Table 28: NOAA Collaborative Agreements

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Total Active CRADAs	46	57	51	57
New CRADAs	14	18	17	17
New CRADAs Involving Small Businesses	4	4	12	12
Other Collaborative Agreements	0	1	1	0

3.3 Other Important NOAA Performance Measures

3.3.1 Publications:

In FY 2023, peer-reviewed publications by NOAA federal scientists totaled 3064. 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 percentage of all NOAA-authored publications in FY 2023. 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 2023)	Authored Articles
Q1	921
Q2	737
Q3	761
Q4	645
Total FY 2023	3,064

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.

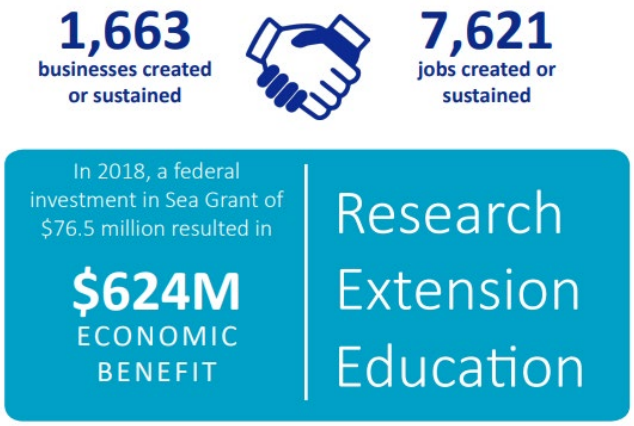


Table 30: SoS Installations

	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
SOS Installations					
Total Number in Operation	165	169	177	183	185
New Domestic	7	5	4	4	2
New International	8	3	4	6	2
Total New Installs	15	8	8	10	4

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 2023.

NOAA and Indigenous tribal partner advance aquaculture with science

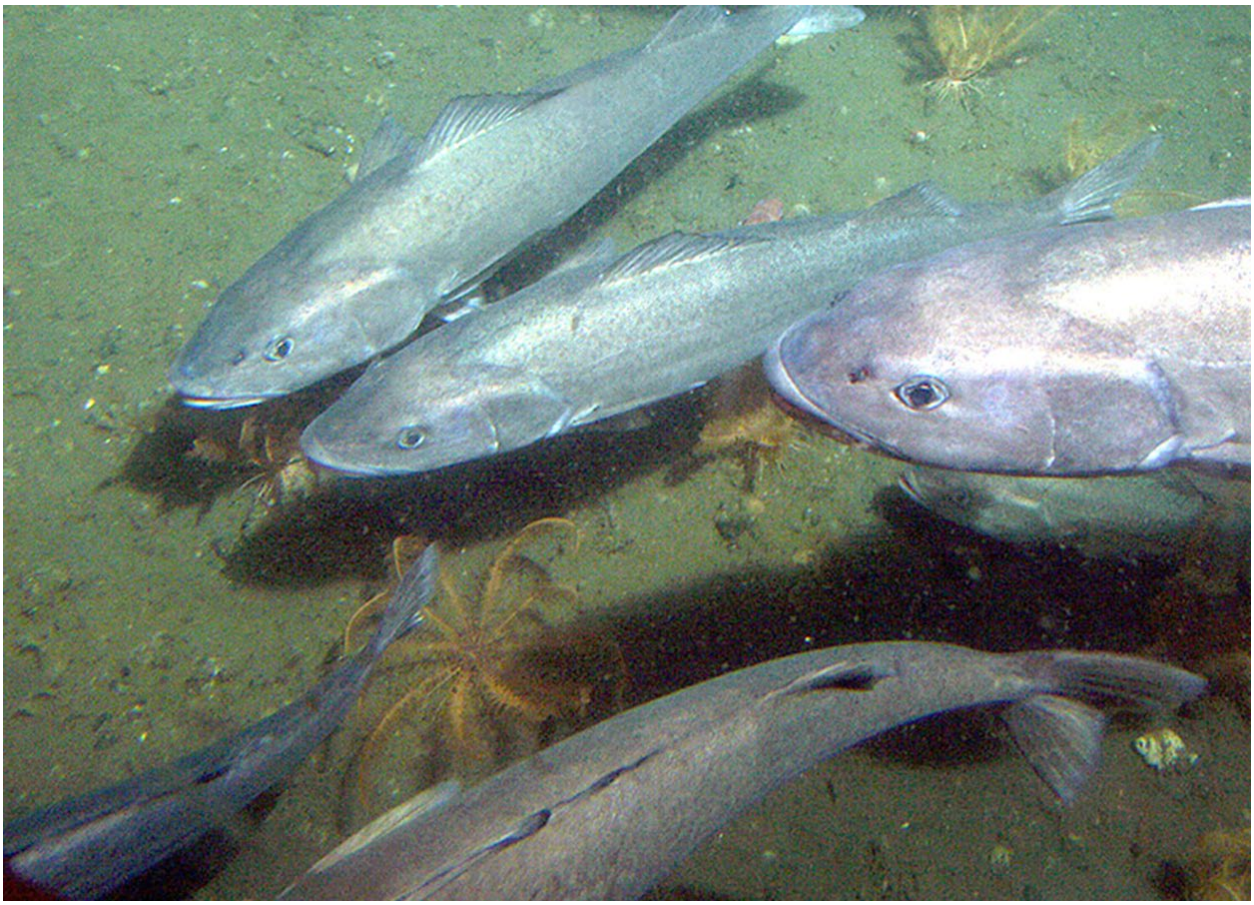
Science, economics, and culture are deeply connected and interwoven in this partnership. With an eye on the future, the project's goal is to increase the use of science-based aquaculture in the U.S. But the partnership also looks to the past through a heritage lens, recognizing and upholding the history and traditional cultural practices of Indigenous tribal communities. The partnership is made possible through a Cooperative Research and Development Agreement between the Jamestown S'Klallam Tribe and NOAA, which is administered by the NOAA Technology Partnerships Office.

On the science side of things, figuring out how to grow sablefish on land is crucial for ensuring a sustainable supply of fish for the future. Climate change, urban development, and water pollution have all impacted the availability, quality, and viability of commercially important fish species, and taking aquaculture innovation to the next level is of urgent importance.

Researchers harvest market-size sablefish from research net-pens at NOAA's Manchester Research Station. Credit: NOAA Fisheries

The research partners have traditionally focused on growing sablefish in what are called net-pens near the ocean shore, where fish can reach market size in a fraction of the time it would take in the wild. Exploring land-grown fish may help to further increase production and monitoring of growth rates and health. Land-grown fish also ensures a safety net for replenishing wild stocks. Beyond improving food availability and security, advancing the science of sablefish aquaculture also has the added benefit of encouraging local business development through direct sales and distribution to regional businesses and communities.

This research also encourages collaboration through its close connection to other public-private partnerships. For example, nutrient output resulting from this aquaculture project is used in research on the land-based production of seaweed as part of another NOAA partnership at the research station.

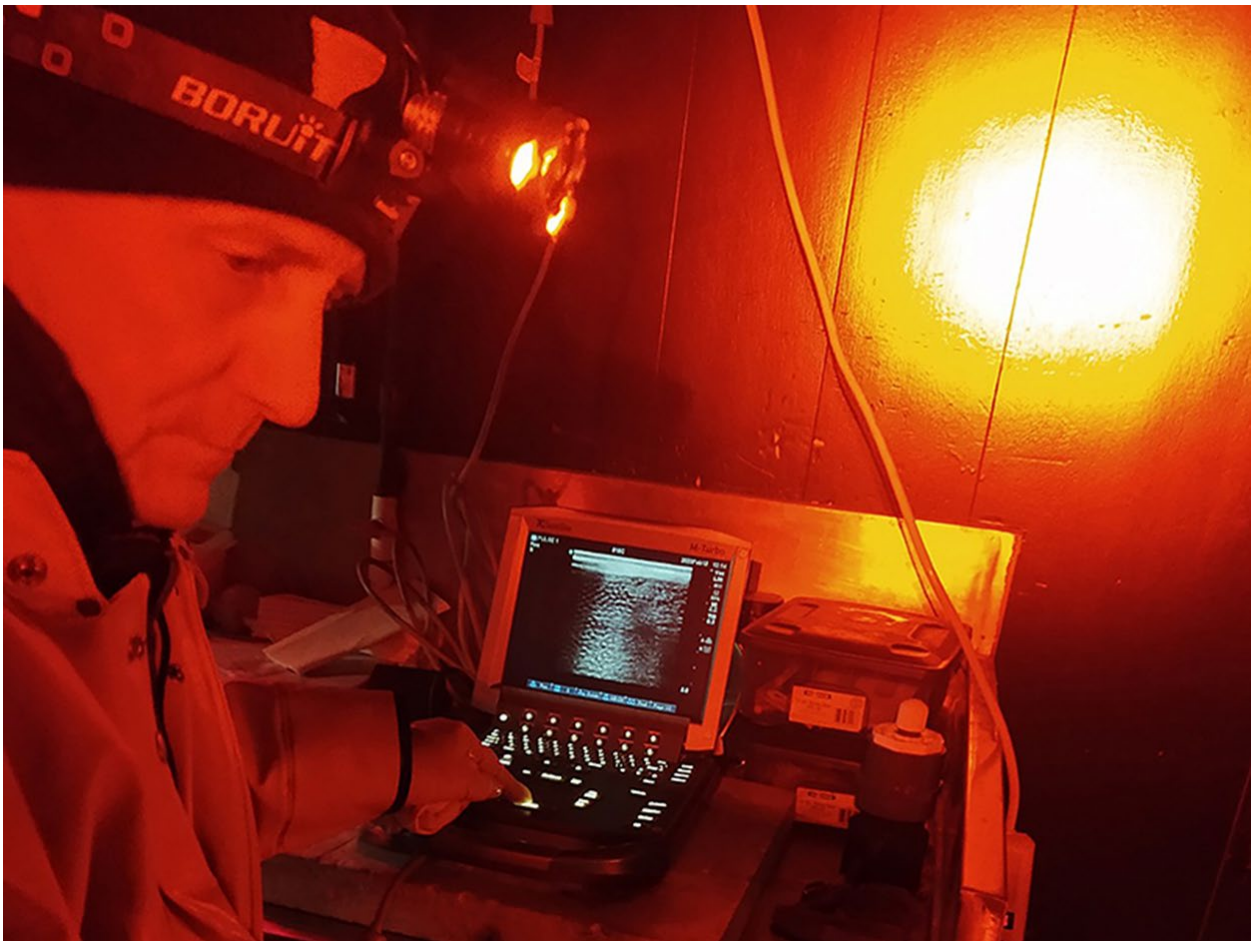


Sablefish, a deepwater species native to the Pacific Northwest and Alaska, are a high-value species that can be commercially farmed. Credit: NOAA Fisheries

“Collaboration has been the key all along,” said research partner Jim Parsons, Jamestown S’Klallam Tribe member and CEO of Jamestown Seafood, LLC. “You can’t do this work in a vacuum, and the scientific staff have been extremely helpful and have been good advocates to keep pushing things forward. And they have helped us connect to other collaborators such as the University of Washington and Sea Grant. It’s been a great partnership.”

The partnership has the potential to create economic benefits beyond the Pacific Northwest region. Up to 85 percent of all the seafood consumed by Americans is imported from other parts of the world, which makes the U.S. dependent on other countries to meet the demand for fish protein. Advancing aquaculture within the U.S. is enabling local economies to flourish and to become more self-sustaining.

“Over half of the seafood production worldwide is through aquaculture, but very little of that production comes from the U.S. and domestic production”, said researcher Ken Cain, Aquaculture Program Manager at the NOAA Northwest Fisheries Science Center. “There’s a huge need to increase seafood production domestically through aquaculture.”



Research staff using ultrasound technology to determine the stage of maturity of eggs within an adult female sablefish. Credit: NOAA Fisheries

Beyond the science and economy, there are social aspects at play which influence the advancement of this research. Key challenges include overcoming public misconceptions about aquaculture and their impacts on the environment, as well as addressing any resulting political resistance to advancing commercial aquaculture. As researchers continue to develop aquaculture science, they must simultaneously contend with social and political pushback that can hinder their work.

Importantly, this partnership also supports local Indigenous access to and preference for eating locally harvested fish. The relationship of local tribes, such as the Jamestown S'Klallam Tribe, to fishing is deeply interwoven into their history and identity. Local- and land-based commercial fish farming not only helps tribes achieve and maintain self-sufficiency, but the technique also has the potential to provide job opportunities for tribal community members and boost local economies.

Partnerships like this one are more successful when supported by a framework that allows the participants to be flexible, responsive, and free to experiment, while still maintaining protection

of their processes and intellectual property. Cooperative Research and Development Agreements, known as CRADAs, provide that framework. CRADAs are written agreements between a private U.S. company, university, or other entity and a NOAA Laboratory or Science Center. Both partners agree to work together on a collaborative research project and use their scientific results to develop commercially-viable products and services.

NOAA, U.S. Patent and Trademark Office create work-sharing program to advance green technology

The Department of Commerce's U.S. Patent and Trademark Office (USPTO) and the National Oceanic and Atmospheric Administration (NOAA) announced a collaboration to promote and advance further innovation in climate and "green" technology areas, a key focus of the Biden administration.

The cornerstone of the collaboration is a work-sharing program that focuses on the intersection of intellectual property and climate and environmental technologies. The program, featuring the exchange of employees over the course of up to a year, will enhance cooperation among the agencies and strengthen their respective work to incentivize greater innovation in these critical areas.

Under the new program, USPTO and NOAA employees will serve out a "detail" at the sister agency for several months, infusing new knowledge into both agencies. USPTO expertise will help NOAA provide intellectual property training for its scientific workforce and support the NOAA Technology Partnerships Office with other lab to market initiatives. The goal will be to help researchers understand the importance of protecting intellectual property so that NOAA's research and technology can better serve the public and inspire future innovation across NOAA's mission.

Conversely, NOAA experts will provide training to USPTO patent examiners reviewing patent applications related to climate and environmental technologies and will advise the agency on USPTO green initiatives to help foster innovations in these critical areas. USPTO patent examiners examine the applications of inventors seeking legal protection for their inventions in the United States in the form of patents. Examiners ensure that patented inventions meet a number of statutory requirements, including that they be new, novel, and not an obvious improvement over an existing invention.

"Fostering innovation to strengthen our nation's resilience against climate change is core to our mission at the USPTO," said Kathi Vidal, Under Secretary of Commerce for Intellectual Property and Director of the USPTO. "I am thrilled to be working hand-in-hand with NOAA, our sister agency, to promote intellectual property protection for the agency's climate innovations so these innovations can reach the market and solve problems."

“Innovation is in our DNA at NOAA,” said Rick W. Spinrad, Ph.D., Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator. “For decades, we have been launching life-saving satellites into orbit, exploring our ocean’s deepest secrets, and conducting and supporting vital research to shore up our nation’s economic and environmental resilience. We are excited to be working with the USPTO to better understand and advance intellectual property protection for innovations borne out of the brilliant workforce of our agency and our research partners, for the benefit of all.”

The program formally kicked off on Monday, February 13, 2023, after months of strategy sessions between the agencies. It will be evaluated at its conclusion to determine if an extension is warranted.

The collaboration will be formalized via an upcoming memorandum of understanding between the two agencies that will feature additional areas of work, including identifying new ways of streamlining, promoting, and celebrating innovation in key environmental technologies across the public and private sectors.

NOAA scientist’s patented design expands the limits of atmospheric research

Unsatisfied with the standard research-grade instrument used to measure one of the most significant sources of air pollution, nitrogen oxides, or “NOx”, NOAA scientist Andrew Rollins decided to build a better one.

In the last 20 years, a number of intensive field campaigns have investigated urban air pollution in several major cities, including NOx, which is generated by burning fossil fuels and other emissions. With research now turning to remote, less-polluted areas, a more sensitive instrument was needed, Rollins said.

“NOx continues to drive a lot of the chemistry we need to understand, especially in the remote background atmosphere, for example, over the oceans,” Rollins said. “But as we get farther from cities and our study areas get cleaner, what we want to measure is in lower and lower amounts.”

The new design invented by Rollins, a researcher with NOAA’s Chemical Sciences Laboratory, is small, light, easy to operate, and measures NOx at levels more than ten times lower than possible with the previous generation of research-grade instruments. Rollins was awarded a U.S. Patent for his innovative design in August 2022.

Before Rollins’ redesign, instruments used to measure NOx hadn’t changed much since the 1970s. The size of a washing machine, the standard, research-grade NOx instrument weighs several hundred pounds, and has electronics that have to be cooled to ultra-low temperatures. This made the old instrument difficult to load onto research aircraft, where every cubic inch and pound is at a premium. The standard instrument is also unable to measure NOx at levels

low enough to answer important scientific questions. Thousands are still in use around the globe.

Rollins' version is about the size of a microwave oven and weighs about 70 lbs. One of his custom-built instruments is currently flying aboard NASA's WB-57 research aircraft during CSL's ongoing SABRE field campaign. The previous instrument would barely fit in this special high-altitude plane at all.

Rollins' invention continues a rich tradition of NOAA scientists designing and building custom instruments for atmospheric research, said David Fahey, director of NOAA's Chemical Sciences Laboratory. "This invention enables the kind of high-risk, high-reward 'disruptive science' our lab strives for," he said. "By pushing the boundaries of what we are able to observe and measure in the atmosphere, we're shifting the paradigms of what we thought we knew."

A major technological advancement

The current research-grade instrument measures NOx indirectly by using a technique called chemiluminescence, which creates a chemical reaction between NOx and ozone inside a chamber in the instrument to generate photons (or light). This is converted into an electrical signal that is proportional to the amount of NOx in the sample. Since NOx is not being measured directly, other reactions involving ozone inside the chamber can reduce the accuracy of the measurement.

In contrast, Rollins' design measures NOx directly with a technique called laser- induced fluorescence, or LIF. It uses a fiber-optic laser to excite NOx molecules, causing them to produce photons in a narrow range of wavelengths that are specific to NOx. This technique is not subject to interference from other gasses and allows for a very precise detection of NOx at very low levels. Laboratory testing showed Rollins' instrument is capable of accurately measuring NOx in the atmosphere down to ~0.3 parts per trillion, a tremendous improvement necessary for research in relatively unpolluted air.

The new design requires much less servicing as well. The older instrument needs to have refrigerant added every 12 hours or so. "We did a study last summer where we left the new one at a site on Bermuda for a month, where it continuously measured NOx levels. at 5 parts per trillion" he said. "We wouldn't have been able to get measurements anywhere close to that with the old instrument, and we would have had to service it once or twice a day."

In 2018, Rollins' decided to adapt the LIF approach he'd used in an earlier instrument he'd invented for measuring sulfur dioxide. The key to the NOx instrument, he said, was the custom-built fiber-optic laser he had developed with the help of engineers from the Department of Commerce's National Institute of Standards and Technology, which has a major lab located next door to NOAA's David Skaggs Research Center in Boulder.

The first purpose-built NOx prototype was finished about a week before a massive 2019 NASA-NOAA aerial research mission to investigate wildfire smoke, called FIREX-AQ, launched.

The patenting process

NOAA patents and then licenses new technologies to move them from NOAA's labs into the hands of scientists and other users worldwide, where they can ultimately have broader impact.

"Patenting a technology protects the invention and gives NOAA the authority to decide the best approach for driving adoption of the technology," said Wayne MacKenzie, NOAA Technology Transfer Program Manager, whose office submitted the patent application. "Holding a patent can also allow NOAA scientists to work closely with commercial partners and ensure that technologies are manufactured to high standards."

NOAA scientists receive Technology Transfer award

A NOAA-led team of scientists will be recognized at this year's 2022 Governor's Awards for High Impact Research event on December 14 in Denver, Colorado. The event is sponsored by CO-LABS and will honor NOAA and CIRES award recipients for both the Pathfinder Partnership and Technology Transfer award categories.

The Technology Transfer Award recognizes research that resulted in a technological solution with widespread and measurable societal use, with related impact on a global challenge or issue. This year's recipients developed a first-of-a-kind Whole Atmosphere Model and Ionosphere Plasmasphere Electrodynamics Model (WAM-IPE), which allows forecasters to provide better information to the public about potential impacts from solar storms. Collaboration with CIRES, CU Boulder, NOAA's Space Weather Prediction Center, and NOAA's Environmental Modeling Center has brought this new model forward to provide crucial insight to various economic sectors—including communications, satellite and airline operations, human space flight, and navigation and surveying to mitigate damages.

ERDDAP server increases access to drifting buoy data

The Global Drifter Program at AOML has a new ERDDAP, or Environmental Research Division Data Access Program, server that is now publicly available and hosts both hourly and 6-hour quality-controlled interpolated drifter datasets. This new scientific data server uses free and open-source software created by the Environmental Research Division of NOAA's Southwest Fisheries Science Center.

ERDDAP provides a simple, consistent way to download drifter data in common file formats, resulting in easier access to data for the scientific community. It is currently used by approximately 100 organizations in more than 17 countries, and NOAA's Data Access Procedural Directive recommends ERDDAP as a data server for groups within NOAA.

The staff of the Global Drifter Program is excited to enhance its users' experience through the ERDDAP server. Distributing publicly-available data through ERDDAP provides many advantages, including compliance with NOAA's Findable, Accessible, Interoperable, and Reusable (FAIR) standards, the flexibility of offering numerous output file formats, and the minimal need to reformat data on the user's end. ERDDAP provides an additional benefit for data analysts, web application developers, and numerical modelers interested in retrieving drifter data through computer programs, rather than the ERDDAP webpage interface.

Specifically, the RESTful API (representational state transfer application programming interface) feature of ERDDAP, which provides an interface for two computer systems to securely exchange information over the internet, allows users to access drifter data through coding languages such as Matlab, R, Python, Javascript, HTML, Fortran, and Bash. As a result, the ERDDAP server helps increase drifter data accessibility and data sharing for weather model improvements, the validation of satellite temperature measurements, hurricane intensity forecasts, and scientific research.

Notably, the hourly drifter dataset now includes diurnal and non-diurnal sea surface temperature estimates, in addition to drifter positions and velocities. Users can quickly retrieve these datasets in their desired file format, as well as filter their query by constraining drifter variables such as time, location, drifter identification number, and/or World Meteorological Organization number.

Additionally, simplifying the data output format and providing an option for plotting drifter trajectories further supports the Global Drifter Program's involvement in NOAA's Adopt a Drifter and Teacher at Sea programs. These educational programs enable K–12 students to use drifter data to learn about ocean climate science.

Finally, the Global Drifter Program's database spans 40+ years, covers all ocean basins, and includes contributions from more than 25 countries. The ERDDAP product provides users with access to metadata that recognizes the considerable impacts of the Global Drifter Program's global partners and the immense efforts from agencies worldwide to sustain the global coverage of drifting buoys.

AOML begins tenth year of hurricane glider operations

This summer marks AOML's tenth consecutive year of gathering underwater glider observations during the Atlantic hurricane season. The project began in 2014 with two gliders deployed off Puerto Rico to study the ocean's role in tropical cyclone development and intensification. Since then, glider observations have become an integral part of the data gathered annually to improve tropical cyclone forecasts, as well as better understand how the ocean and atmosphere interact during the passage of tropical cyclones.

Gliders are autonomous, remotely piloted observing platforms. They monitor the thermal structure of the upper ocean along pre-programmed tracks in the Caribbean Sea and tropical

North Atlantic, regions where tropical cyclones typically pass. Advancing at speeds of up to 1.2 miles per hour, i.e., 1 knot, gliders dive to depths of 900 meters several times a day to measure temperature, salinity, and dissolved oxygen. Upon returning to the surface, their data are -transmitted to AOML for quality control and then added to tropical cyclone forecast models.

Gliders gather temperature, salinity, and dissolved oxygen observations for 4-5 months in regions where tropical cyclones typically travel and potentially intensify or weaken. Photo credit: NOAA AOML.

To date, AOML has conducted 61 glider missions, of which 12 were in partnership with the U.S. Navy. These missions have spent more than 4,900 combined days at sea; traveled more than 68,000 kilometers, approximately one and a half times the distance around the Earth; obtained more than 72,000 profiles of temperature, salinity, and dissolved oxygen; and surveyed ocean conditions under 21 tropical cyclones.

During the 2023 Atlantic hurricane season, AOML will work with numerous partners to implement and maintain a robust network of underwater gliders. One glider will operate east of the Bahamas; another will pursue the Caribbean Sea south of the Dominican Republic; four will monitor the waters off Puerto Rico, one to the north and three to the south; and one will observe the Gulf of Mexico. AOML will additionally lead and/or participate in operations for three U.S. Navy gliders off Puerto Rico and contribute to a mission led by staff from the Caribbean Coastal Ocean Observing System.

These gliders will be deployed in collaboration with the U.S. Integrated Ocean Observing System (IOOS), Dominican Republic Maritime Authority, the Cape Eleuthera Institute, Naval Oceanographic Office, Gulf of Mexico Coastal Ocean Observing System, NOAA's National Data

Buoy Center, the University of Southern Mississippi, and NOAA's Environmental Modeling Center.

Research derived from data collected by AOML gliders has advanced the understanding of the ocean's role in tropical cyclone intensity changes, leading to improved forecasts. Additionally, AOML scientists have participated in the publication of 18 peer-reviewed journal articles based on glider data.

The most relevant research results include studies of how areas of low salinity water of riverine origin, e.g., the Mississippi, Orinoco, and Amazon rivers, contribute to the intensification of tropical cyclones. Other studies have assessed the impact of glider observations in reducing intensity errors in NOAA's experimental and operational forecast models and the -impact of integrating glider observations with data from other observing -platforms.

More recently, AOML scientists have gathered collocated, simultaneous observations using gliders and saildrone uncrewed surface vehicles to improve estimates of heat fluxes between the ocean and atmosphere during tropical cyclone events. This summer the gliders will also collect collocated observations with NOAA drifting buoys in the Gulf of Mexico and Caribbean Sea.

AOML gliders are an integral component of NOAA's 2023 Hurricane Field Program. They are also part of the new NOAA-funded Coordinated Hurricane Atmosphere-Ocean Sampling, or CHAOS, field experiment. Glider operations at AOML are funded by U.S. Congress appropriation funds, NOAA, and IOOS.

Underwater robots significantly advance our ability to study Lake Erie's harmful algal blooms

Newly published research from the NOAA Great Lakes Environmental Research Laboratory (GLERL), the Cooperative Institute for Great Lakes Research (CIGLR), and partners reveals that using underwater robots could significantly advance scientists' ability to study the harmful algal blooms (HABs) that appear in the Great Lakes and oceans every summer. You may remember reading about NOAA's collaborative fieldwork in 2019 that used these robots to detect toxins in Lake Erie's harmful algal bloom. Three years later, the findings from this pioneering research come bearing good news!

This autonomous underwater vehicle (AUV), known as "Makai," visited the Great Lakes from the Monterey Bay Aquarium Research Institute (MBARI) to help scientists study Lake Erie's harmful algal bloom. Credit: Steve Ruberg, NOAA GLERL

What are HABs, and how do we study them?

HABs occur when colonies of algae grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds. Western Lake Erie in particular has been plagued by intensified HABs over the past decade. These blooms consist of cyanobacteria, or blue-green algae, which are capable of producing toxins that endanger human and animal health, compromise drinking water supplies, foul coastlines, and impact communities and businesses that depend on the lake.

Harmful algal bloom in western Lake Erie in October, 2011. Credit: NOAA Great Lakes CoastWatch

The underwater robot used in this research project is known as a long-range autonomous underwater vehicle, or LRAUV. As the name suggests, the LRAUV is built to travel long distances beneath the water's surface, collecting data for an extended period of time. LRAUVs are useful research tools, as they can collect high-quality data more efficiently and cost-effectively than scientists taking samples from a ship or along the shore. They can be deployed day and night in all weather conditions and can provide more detailed information to researchers and drinking water managers than other monitoring methods.

For this project, NOAA and CIGLR teamed up with the Monterey Bay Aquarium Research Institute and university partners to equip an LRAUV with a 3rd Generation (3G) Environmental Sample Processor (ESP) — a mobile version of what has previously been known as NOAA's "lab in a can." The 3G ESP's job is to measure microcystin, a potent liver toxin produced by the cyanobacteria that cause harmful algal blooms in the Great Lakes. In just a few hours, the 3G ESP can collect and analyze water samples from the bloom with the same methods that scientists use to analyze samples back at the lab. It does this with the use of 'omics, a collective suite of technologies used to analyze biological molecules such as DNA, RNA, proteins, or metabolites. These technologies can be used to identify the algal species that produce HABs, understand their behavior, and predict shifts in their population structure.

Did this robot step up to the challenge?

Before widely adopting the use of the LRAUV-3G ESP to study Lake Erie HABs, scientists had to ensure that the data these instruments collect is accurate and reliable. A main goal of the new publication was to assess how dependable the LRAUV-3G ESP's data is compared to data that was collected and analyzed by humans.

The authors used a variety of parameters to assess the vehicle's performance of 'omics tests on samples it collected from the HAB. They ultimately found that the LRAUV-3G ESP successfully

performed flexible, autonomous sampling across a wide range of HAB conditions, and the results indicated equivalency between autonomous and manual methods. In fact, no significant differences were found between LRAUV-3G ESP and manual sample collection and handling methods in the 12 parameters tested. In other words, this robot passed the test!

One of the most exciting aspects of this research is that it shows that scientists can use an autonomous sampling platform to replicate traditional ship-based sampling, and they can do so in a particularly challenging environment (Lake Erie's shallow western basin) where HABs are a serious health concern. Using this instrument in Lake Erie's shallow waters presented another challenge for the scientists involved. In response to the lake's challenges, researchers worked on the LRAUV's buoyancy to ensure that the instrument didn't drag across the ground. With this technology – sampling DNA and measuring toxins on an autonomous platform – NOAA and partners may be able to provide an early warning system for HABs in the future.

Partners on this research came from far and wide to conduct this important research:

National Oceanic and Atmospheric Administration (NOAA)
NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML), Ocean Chemistry and Ecosystems Division
NOAA Great Lakes Environmental Research Laboratory
NOAA National Centers for Coastal Ocean Science (NCCOS)
NOAA Southwest Fisheries Science Center
Cooperative Institute for Great Lakes Research (CIGLR), University of Michigan
Northern Gulf Institute, Mississippi State University
Monterey Bay Aquarium Research Institute (MBARI)
Department of Earth and Environmental Sciences, University of Michigan

How a NOAA partnership helped create a seaweed dream team

The power of partnership

When Diane Boratyn first decided to grow macroalgae – more commonly known as seaweed – on land to support her plant-based skincare company, she knew about the health benefits of seaweed but lacked the know-how to cultivate it consistently on a commercial scale. She quickly learned that it would take large-scale production of seaweed in order to be competitive in expanded markets. Boratyn has a mind for business innovation and was fully aware that in order to be successful, she needed to grow more, better, and faster.

Dr. John Colt is a recently retired research fish biologist at the National Oceanic and Atmospheric Administration (NOAA) Northwest Fisheries Science Center in Seattle, Washington. He is an expert on aquaculture, and since 2000 he has explored growing macroalgae in land-based systems. While he was well-versed in the science of growing seaweed in controlled environments at the time, he had yet to experiment with growing it at a scale and consistency that was marketable.

That's where a public-private partnership between Boratyn and NOAA came into play.

An example of seaweed grown in culturing tanks. Courtesy of SOLSEA, Ltd.

Having worked together in the past and realizing their similar needs, Boratyn and Colt formalized their partnership with a CRADA, or Cooperative Research & Development Agreement, in 2015. A CRADA is one of the easiest and most flexible ways for small businesses to work with NOAA.

CRADAs are written agreements between a private U.S. company, university, or other entity and a NOAA Laboratory or Science Center. Both partners agree to work together on a collaborative research project and use their scientific results to develop commercially-viable products and services.

When Boratyn and Colt started their research partnership, their main goals were to optimize the production of farm-raised seaweed and document how chemical compounds affected growth cycles. As a result of this collaboration, Boratyn's seaweed tanks at her company, SOLSEA Ltd., now work to their full potential and deliver sustainable, high-quality plants that can meet the demands of today's growing markets. At the same time, Colt's scientific research has demonstrated that land-based seaweed farming offers a productive alternative to traditional harvesting and ocean farming.

The CRADA partnership has been a win-win for Boratyn and NOAA.

Commercialized skincare products that resulted from the SOLSEA CRADA partnership. Courtesy of SOLSEA, Ltd.

Boratyn is a firm believer in the market potential of seaweed and seaweed products. Coming from an ocean and fisheries background, she began foraging for seaweed in the early 1990s to explore growth cycles and experiment with seaweed for cosmetic products. That activity turned into a skincare product line which integrated vitamins, lipids, minerals, and proteins originating from a species of seaweed indigenous to the Pacific Northwest. Today, her company is focused on aquaculture technology and commercializing a wider diversity of products for food, fertilizers, animal feeds, and plant-culturing operations.

Colt began working at NOAA in 1995 and has focused his research on aquaculture ever since. He argues that land-based seaweed farming offers a productive alternative to wild harvesting. This is especially true in the U.S., where open-ocean farming is restricted to a few areas and is subject to regulatory and permitting processes that limit its attractiveness to private companies.

Colt's research and Boratyn's market vision were meant for each other. Boratyn already had the cultivating tanks in place, and Colt's work at the Northwest Fisheries Science Center provided her with the analytical techniques to design the study. "We complemented each other on everything. It was a good mix," reflected Colt.

Boratyn echoes his sentiment. "We found there was a mutually beneficial relationship," she said. "We got to study seaweed growth rate, water quality, and other scientific parameters while being able to develop high-end commercial products with a predictable and steady supply. It was beneficial all the way around."

Left to right: Diane Boratyn and Dr. John Colt show off examples of seaweed produced in SOLSEA's 1200-gallon, land-based culturing tanks. Courtesy of SOLSEA, Ltd.

SOLSEA and NOAA's partnership journey has involved tackling research problems – such as addressing various seasonal culturing challenges – that are key to mastering continuous growth cycles. Boratyn stated, "The last few years have been very challenging due to global warming and COVID-19. My goal in the next few years is to better understand how climate change impacts algae growth, and to design better aquaculture systems to handle the inevitable changes that impact any farming system."

Boratyn noted that another important aspect of the CRADA is the teamwork involved in learning how to navigate environmental impacts and other external influences. As the business changed over time, the researchers learned how to grow high-value species of seaweed, build new databases to log their findings, and preserve native cultures of seaweed that became important for future genetic mapping and long-term stability of the business.

“The goal we had in mind was to grow our own seaweed, manufacture our products out of it, and then put them in the market,” explained Boratyn. “As a business, we needed to clearly define our goal, our output, and our final product.” She continued, “Most importantly, we realized that in order to build a good business model we needed reliable data from a good science base. That is why our collaboration with the Fisheries Science Center was fundamental.”

CRADA research has shown that the inclusion of red macroalgae known as Turkish Towel (indicated by the “TT” in this lab photo) in plant-based feeds for sablefish increases feed intake, fish growth, and fish health. Shown here is dried seaweed from SOLSEA culturing operations which has been converted into fish food pellets. Courtesy of Ronald Johnson.

The partnership between NOAA and SOLSEA has been economically successful and has substantially advanced scientific research.

SOLSEA has been able to expand its business from cosmetics to include fish food production and other potential revenue streams. Boratyn explained, “In the private sector, it is very important to not only have products on a weekly basis – which does not occur with a single annual harvest – but to come up with realistic economic models based on year-round production. This CRADA has allowed me to refine production and better forecast the company’s finances based on the species in new emerging markets.”

Colt noted that their CRADA provided fundamental proof of concept and helped the company get to the next level, while simultaneously allowing NOAA to conduct experimental research in large commercial systems. Colt added, “Our research shows that it is possible to grow macroalgae with good yields over the entire year. We are also exploring the feasibility of putting two different types of macroalgae together where they can help each other grow while also keeping the tanks clean.”

Results of this partnership have highlighted the potential of U.S. coastal communities to produce seaweed and have demonstrated that land-based systems are suitable for high-quality mass production. Through public presentations and publications, research findings from this CRADA have the potential to bolster the broader U.S. aquaculture economy.

Researchers measure and weigh seaweed cultures during the building of new research databases. Courtesy of SOLSEA, Ltd.

When asked to reflect on her CRADA experience, Boratyn stated, “From a company perspective—especially as a small business—it can be unaffordable to conduct the necessary foundational work and research. Our research partnership with NOAA helped us overcome the uncertainty of the question, ‘Can we do this?’ and gave our business a leg up on expanded species production for new markets.”

Boratyn is already looking to the future, as she plans to develop the technology needed to expand land-based seaweed farming beyond her Seattle location, and to integrate educational and community outreach elements into future sites of engagement.

Revolutionary NOAA high-altitude research tool passes key milestone

The quest by Global Monitoring Laboratory scientists to develop a reliable, cost-effective way to study Earth’s stratosphere passed a significant milestone on May 17 when a remotely controlled glider, carried to an elevation of 90,000 feet by a weather balloon, returned to its launch location on Colorado’s Pawnee National Grasslands with its scientific payload intact.

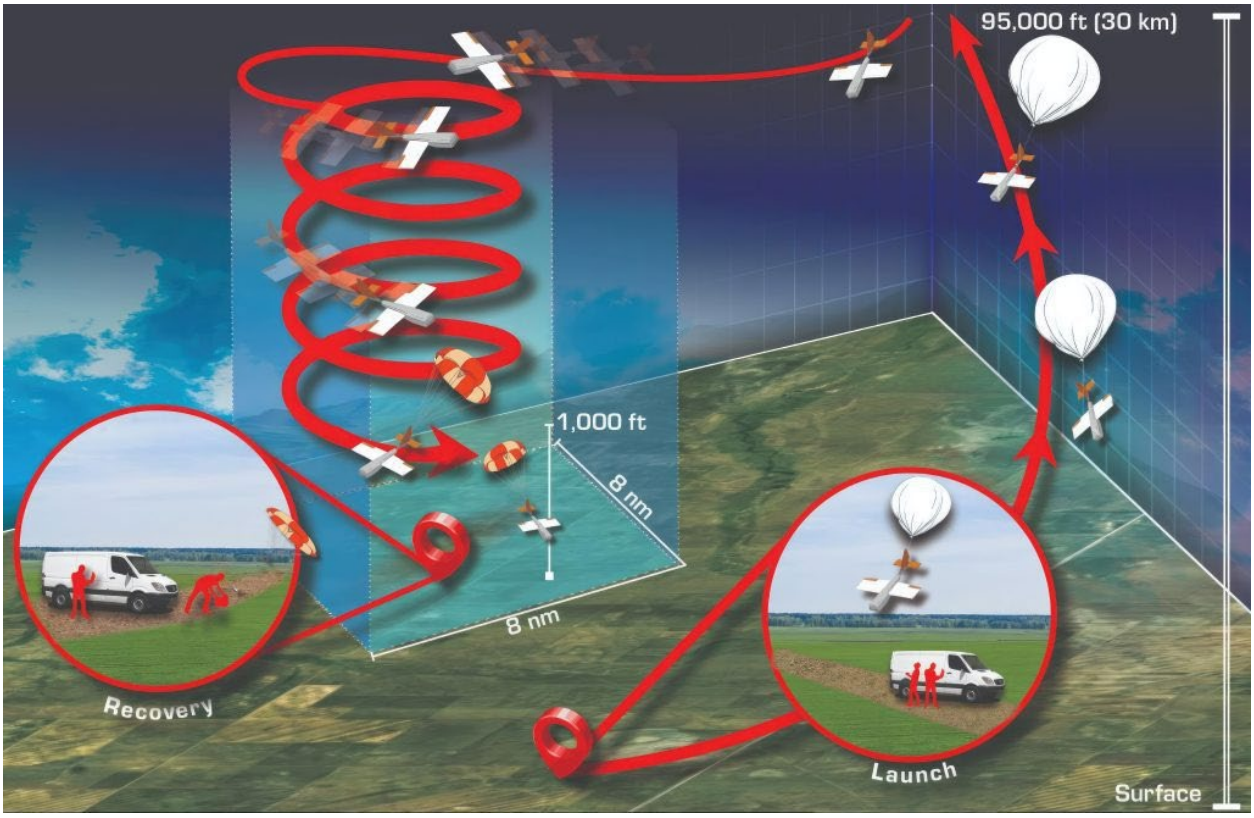
The successful mission marked the next step in a four-year effort to deploy and recover an atmospheric sampling and measurement system from that altitude in controlled airspace.

“To collect any highly accurate measurements from a balloon-borne platform in controlled airspace and have it return to where you launched is a first for the non-military research community,” said Colm Sweeney, the lab’s Associate Director of Science.

The HORUS glider and balloon prepared for a test flight on May 17, 2023 in Colorado’s Pawnee National Grasslands. (Credit: NOAA)

Balloons have long been essential tools for weather and climate research, but advancements in the measurement technologies they use have always been limited by the challenge of tracking and recovering their data and payloads. While balloons can easily surpass typical aircraft altitudes of 45,000 feet on the way up, they drift with the wind, resulting in instruments landing up to 100 miles from the launch point, or being lost. The lack of control often dictates the type and quality of instruments included in the payload.

GML scientists, with support from NOAA's Office of Research Transition and Application and Office of Marine and Aviation Operations have solved this problem by combining the tried-and-true weather balloon with modern uncrewed aerial vehicle (UAV) technology. The balloon lifts a remote-controlled glider with an instrument package installed in its belly to altitudes up to 90,000 feet. The glider is programmed to release from the balloon at a specific altitude and then navigate back to a loiter point above the landing spot, where it circles until the launch crew takes over controls and lands it.



This illustration depicts how the HORUS autonomous instrumented atmospheric sampling system collects high-altitude measurements and then returns to the launch site. (Credit: NOAA)

The project, called the High-altitude Operational Return Uncrewed System, represents a unique collaboration between NOAA and the Federal Aviation Administration (FAA), which are both seeking ways to allow UAVs to fly beyond the operator's sight. While UAVs offer increased opportunities for weather and climate research, the need to restrict flight paths to allow remote control has created a huge barrier to UAV research and operational use.

Developed by scientists from NOAA, CIRES, the University of Colorado, Arizona State University, Delta Zee Solutions, and Spektreworks, the system, dubbed HORUS after the falcon-headed Egyptian god of the sky, provides a predictable and trackable trajectory back to its launch location, making it easy for FAA air traffic control to ensure the safety of other aircraft.

With few trees, water hazards or topography, eastern Colorado grasslands offer an ideal opportunity to demonstrate the system's reliability. On the recent test flight, the glider for the first time successfully returned a payload consisting of two Global Monitoring Lab-designed AirCore autonomous atmospheric sampling instruments. The AirCore is a lightweight, whole-air sampler that provides a means for retrieving calibrated, vertical profiles of trace gases. Constructed around a long, coiled tube, the AirCore provides one of the only routine, accurate, low-cost pathways for sampling over 90% of the atmospheric column relative to other atmospheric sampling platforms available.

The lab's ultimate goal is to deploy the HORUS systems to locations where balloon retrieval would be nearly impossible or a payload would be lost or might come down in a populated area, said NOAA's Bianca Baier, a Global Monitoring Laboratory researcher.

"That means we may be able to conduct high-altitude sampling from an island, or a ship, or other places where a payload would be lost or create a potential hazard on descent," Baier said.

It also means scientists can improve the quality of balloon-borne atmospheric measurements. "If you can safely and reliably land a payload, you might buy more expensive instruments that provide better performance," she said.

RIPPLE EFFECT
A Public-Private Partnership Advances Ocean Science

New technologies allow us to explore uncharted territory, improve our understanding of the world, and make exciting discoveries that solve complex problems. The best technologies are born out of collaboration, when the right mix of people, resources, and skills come together around an innovative idea.

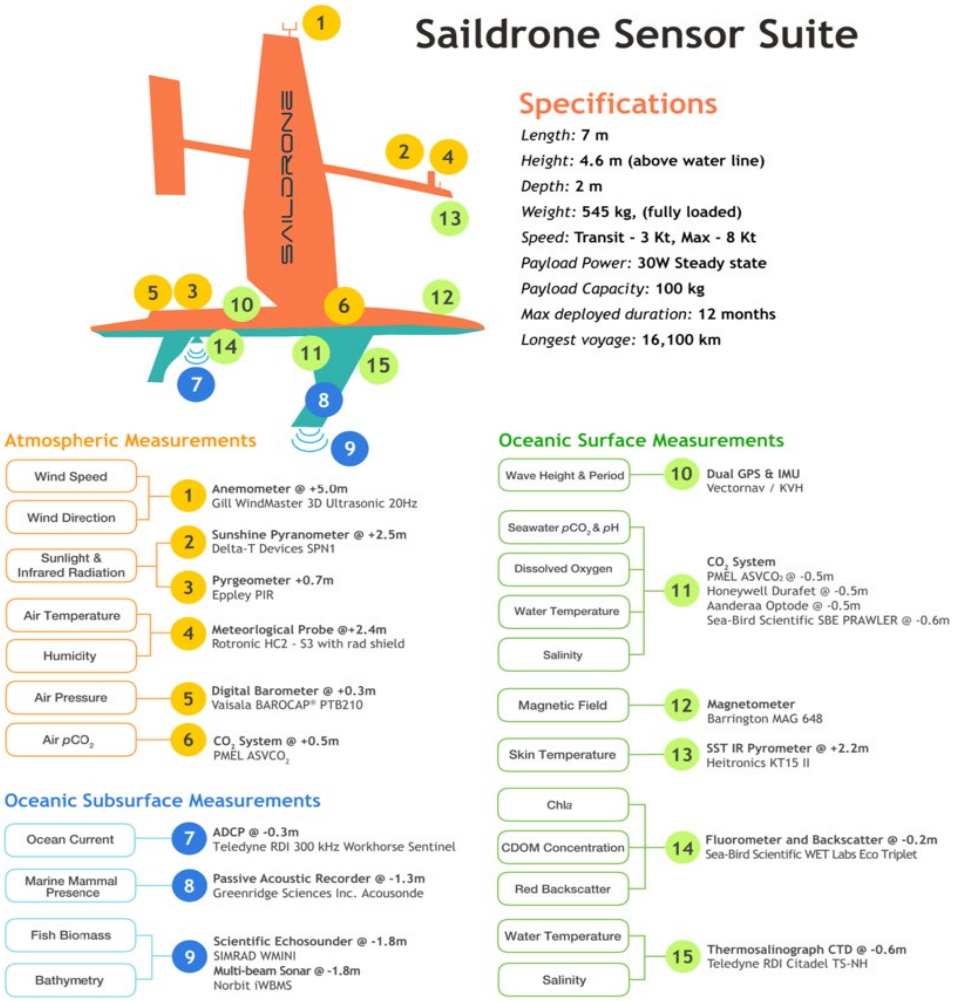
When NOAA collaborates with a company through a public-private partnership, the goal is to leverage each partners' unique skills and resources to accomplish something together that neither partner could have done on their own.

A partnership between the National Oceanic and Atmospheric Administration and Saildrone, Inc. did just that – the resulting collaboration has expanded to support research missions across NOAA, led to business growth and technological innovation, and contributed to the broader New Blue Economy.

PMEL engineers tried a new approach to technology development: Instead of NOAA purchasing a technology and then altering it to meet research needs, they continued to work with Saildrone as a data service provider. Saildrone provided wind-powered ocean drones, operated them remotely, and delivered the final data back to NOAA. This allowed Lawrence-Slavas and his team to focus on developing specialized instruments and figuring out ways to deploy the drones to meet NOAA's various needs.

An early challenge the partners faced was demonstrating that the Saildrone vehicles could travel long distances for extended durations, in sometimes incredibly harsh environments, and still send back accurate data without interruption. A second challenge was to increase the complexity of sensors that were installed on each vehicle.

"It's one thing to get instruments onto a vehicle, but quite another to get verified, climate-quality data back," Jenkins said. "We spent years chasing NOAA ships, or the ships chasing us, as we collaborated on comparing data and then figuring out how to filter and transfer that data via satellite in a reliable and timely manner."



A graphic from 2018 shows locations on a saildrone for 22 essential ocean and climate sensors. Exact instrument placement varies by mission. Credit: NOAA/Saildrone

NOAA Partners With USPTO on an Employee Exchange Program

Kristen Schepel from NOAA's Geophysical Fluid Dynamics Laboratory is participating in an employee exchange (known as a detail) with the USPTO in Washington, D.C. Her assignment:

Help patent examiners and others at the USPTO understand climate change and the need for innovations that can help predict and measure its impacts.

Schepel is one of a handful of people participating in the exchange. Three USPTO employees have also been assigned to work at NOAA as a part of this project.

NOAA's Kristen Schepel has given many presentations during her detail with the U.S. Patent and Trademark Office. Credit: NOAA

Parikha Mehta has spent four months focused on the intersection of intellectual property and climate and environmental technologies while on an employee exchange (known as a detail) at NOAA from the USPTO. Her goal: Help researchers understand the importance of protecting their inventions so that NOAA's research and technology can better serve the public and inspire future innovation.

The work overlaps with her usual job as a senior patent examination policy advisor at USPTO. "In my USPTO role, I focus on advising all types of stakeholders on our patent policy– soup to nuts of the whole patent process,"

Dr. Paul Johnston showing Parikha an engineering work-in-progress in his lab at NOAA's Physical Sciences Lab in April 2023. Credit: NOAA

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 a 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, 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.

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 2020	FY 2021	FY 2022	FY 2023
Invention Disclosures Received	0	0	0	0
Total Patent Applications Filed	0	0	0	0
U.S.	0	0	0	0
Foreign	0	0	0	0
Total Patent Cooperation Treaty (PCT) Applications Filed	0	0	0	0
Total Patents Issued	0	0	0	0
U.S.	0	0	0	0
Foreign	0	0	0	0

Table 32: NTIA ITS Licensing[25]

Metric	FY 2020	FY 2021	FY 2022	FY 2023
Invention Licenses, Total Active	0	0	0	0
New Invention Licenses	0	0	0	0
New Invention Licenses Granted to Small Businesses	n/a	n/a	n/a	n/a
Income Bearing Licenses, Total Active	0	0	0	0
New Income Bearing Licenses	0	0	0	0
Exclusive, Total Active	0	0	0	0
Partially Exclusive, Total Active	0	0	0	0
Non-Exclusive, Total Active	0	0	0	0
Other Licenses, Total Active	0	0	0	0
New Other Licenses	0	0	0	0
New Other Licenses Granted to Small Businesses	n/a	n/a	n/a	n/a
Elapsed Amount of Time for Granting Invention Licenses				
Average (months)	n/a	n/a	n/a	n/a
Minimum (months)	n/a	n/a	n/a	n/a
Maximum (months)	n/a	n/a	n/a	n/a
Licenses Terminated for Cause	n/a	n/a	n/a	n/a

[25] 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 2020	FY 2021	FY 2022	FY 2023
Invention License Income	n/a	n/a	n/a	n/a
Other License Income	n/a	n/a	n/a	n/a
Total Earned Royalty Income (ERI)	n/a	n/a	n/a	n/a
ERI from Top 1% of Licenses	n/a	n/a	n/a	n/a
ERI from Top 5% of Licenses	n/a	n/a	n/a	n/a
ERI from Top 20% of Licenses	n/a	n/a	n/a	n/a
Minimum ERI	n/a	n/a	n/a	n/a
Maximum ERI	n/a	n/a	n/a	n/a
Median ERI	n/a	n/a	n/a	n/a
Disposition of ERI				
Percentage Distributed to Inventors	n/a	n/a	n/a	n/a
Percentage Distributed to Lab/Agency	n/a	n/a	n/a	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 2023, 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 2020	FY 2021	FY 2022	FY 2023
Total Active CRADAs	0	6	8	5
New CRADAs	0	0	2	0
New CRADAs Involving Small Businesses	0	0	0	0
Other Collaborative Agreements	0	0	0	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 2023, 67% of manuscripts released through the ERB process were published in scientific journals or conference proceedings and 33% 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 2023, ITS technical publications of all kinds in all media were downloaded or viewed 12,357 times.

4.4.1.2 Multimodal Transfer of Technical Methods

High-precision radio frequency 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 electromagnetic compatibility analysis 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 best practices messaging and expand message penetration.

Workforce development to support the demands of the rapidly expanding telecommunications industry has been identified as a priority at all levels of the Administration and the Department. However, for the most part university curricula have been slow to adapt to the needs of industry. ITS is currently participating in curriculum development initiatives with the National Science Foundation to enable the development of a technical workforce that is aware of spectrum technology and policy issues and well prepared to support the industry. Beyond academic preparation, best practices in areas such as radio frequency emissions and spectrum measurements must be disseminated in order that data collected by multiple parties can be considered comparable and reliable.

In FY 2023 the various "chapters" of NTIA Special Publication SP-09-460 "Seminar Series on Spectrum Measurement Theory and Techniques" received a total of 14,733 views, more than double the previous year. ITS published this first series of video publications aimed at dissemination of measurement best practices in FY 2009. It was originally distributed on DVD, later hosted on the ITS website, and 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. ITS still receives requests for the DVDs for use in training events behind military firewalls.

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 as executable packages, and those downloads increased 46% between FY 2022 and FY 2023. ITS began moving from offering software tools as .zip files from the ITS public website to using the GitHub open source code hosting platform about a decade ago and now offers 35 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 paradigm to enable distributed, persistent, and automated monitoring with 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 (i.e., scos-sensor, scos-actions, scos-usrp, 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, allowing accurate speech quality and intelligibility estimates without access to the originally recorded signal, thus expanding the utility of the tool to include real-time endpoint monitoring in the field. Staff continue to enhance and extend the ITS no-reference tools and are presently focusing on ways to advantageously combine contradictory datasets to produce larger, more powerful datasets.

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 56 times and cloned 78 times from GitHub in FY 2023.

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 2023, ITS expanded the NRMetricFramework public GitHub repository that was released to the public domain in FY 2020 to support collaborative R&D into NR metrics for image and video quality and stimulate an open exchange of ideas, information, and research. This repository was published with the goal of accelerating development of the robust and trusted NR metrics industry needs to more efficiently use increasingly crowded bandwidth. It contains all the tools, information, and statistical methods needed to begin research on this difficult problem. This repository was cloned 90 times and downloaded 11 times.

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 available to industry, academic, and government researchers.

The CDVL website was re-architected in FY 2021 to comply with new security policies and improve download robustness to accommodate an increasing volume of data as the site has become ever more important to the wider research community. The updated website allows researchers to share entire experiments as open data and by the end of FY 2023 offered 13 TB of data to researchers worldwide. Included in the data are ANSI T1.801.01 and ITU-R Rec. BT.802 standard video sequences that are no longer available from ATIS or the ITU. In FY 2023, 460 unique records were downloaded from the new website, by a total of 151 users.

The total number of media files downloaded by each user is difficult to calculate, because 52% of the downloaded records were datasets with hundreds of images or videos, most of the which also contain subjective ratings and other metadata. Individual sequences that are frequently downloaded are those that pose particular problems for codecs, such a professionally produced sports sequence in UHD HDR that was donated to CDVL by Sky. Just as complete datasets have become more desirable to researchers, so have higher resolution clips. While standard definition video is still of limited interest, demand is rapidly growing for UHD clips and lower resolutions (e.g., CIF, QCIF) are no longer of interest.

Datasets that bundle clips with subjective ratings and metadata will become increasingly important as researchers attempt to apply machine learning to accelerate the development of open metrics. In FY 2023, ITS began preparing a repository for publication that is intended to advance development of commonly accepted processes to train a machine learning model to predict image and video quality as a part of the NRMetricFramework.

CDVL users must register for each download or upload session. Self-reported demographics indicate users were 70% academic, 27% industry, and 3% government. 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 2023
Technical Publications Released	15
Technical Publications Downloaded	12,357
Consumer Digital Video Library Users Downloading	151
Video Quality Metric Software Users Downloading	56
Propagation Modeling Software Downloads	551
Other Software/Data Downloads	404
Public GitHub Repositories	35

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.

Various offices of NTIA work collaboratively with the International Telecommunication Union (ITU), U.S. National Committee for the International Union of Radio Science (USNC-URSI), 3rd Generation Partnership Project (3GPP), Wireless Innovation Forum (WInnForum), Institute of Electrical and Electronics Engineers Standards Association (IEEE), ORAN ALLIANCE, Telecommunications Industry Association (TIA), Internet Engineering Task Force (IETF), and Inter-American Telecommunications Commission (CITEL) to develop, interpret, analyze, and implement standards, specifications, and regulations.

ITS in particular participates most intensely at the Working Group or Working Party level, both directly providing technical contributions and engaging in collaborative assessment and validation of others' technical contributions. For example, a plurality of the technical recommendations of the International Communication Union Radiocommunication Sector (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. This method of technology transfer directly addresses improvement and protection of U.S. competitiveness in telecommunications.

ITS also actively contributes to ITU efforts around best practices for video quality assessment. In FY 2023, 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 2023, staff from five separate offices of NTIA held 102 positions in 13 standards bodies, including 21 Chair/Co-Chair/Vice-Chair/Chair-Elect positions. NTIA staff filled key leadership positions in the ITU-R, ITU-T, USNC-URSI, and CITEL. This hard work during FY 2023 contributed to several spectrum policy accomplishments at the ITU World Radiocommunication Conference 2023 (WRC-23) in December 2023. The U.S. delegation advanced spectrum policy for critical federal missions like aviation safety, weather, climate monitoring, and—looking to the future—

lunar communication, and for the private sector in support of both licensed and unlicensed services, and in expanding space and satellite services.

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; objective audio and video Quality of Experience (QoE) metrics; and broadband air-interface and core network capabilities for Long Term Evolution (LTE) and 5G 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 Federal Advanced Communications Test Site (FACTS) within the quiet zone supports fundamental research, engineering studies, and experiments into the nature, interaction, and evaluation of telecommunication devices, systems, and services. These studies are critical to ensuring full utilization of the limited radio spectrum for new and emerging telecommunications technologies. They provide real world, over-the-air measurement data to validate models and simulations that support technical feasibility studies for spectrum sharing between and among disparate spectrum-dependent systems.

A unique feature of the FACTS is an automated system for performing emission measurements on 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 continues to pose a serious technical challenge to expanding 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 that 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 NOAA, NIST, other federal agencies, universities, private companies, and other organizations conduct research at the Table Mountain Radio Quiet Zone under IAAs and CRADAs. The work provides unique opportunities for cooperative learning and discovery, with the outcomes frequently becoming seeds of commercial and government successes.

- In FY 2023, ITS used the Table Mountain Radio Quiet Zone to perform additional comprehensive measurements to address technical concerns about possible interference between 5G base stations operating at 3.7 GHz and radars operating in adjacent and near-adjacent bands.
- In FY 2023, ITS continued to expand its support of NOAA's Radio Frequency Interference Monitoring System (RFIMS) program at the Table Mountain Radio Quiet Zone 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. Table Mountain 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.
- In FY 2023, several companies used the Table Mountain site 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.

4.5.2 Innovative Commercial Services

ITS research, development, testing, and evaluation (RDT&E) of the technologies that enabled successful commercial deployment of the Citizens Broadband Radio Service (CBRS) in the highly desirable 3.5 GHz spectrum band entered a new phase in FY 2023. The path to the 2020 $4.6 billion auction of CBRS licenses spanned a decade of ITS research, from initial technical

feasibility studies of sharing between high power radars and commercial services through initial conformance and compliance testing of the Environmental Sensing Capability (ESC) and Spectrum Access System (SAS) components of CBRS.

This work with the FCC (through interagency agreements), industry (through CRADAs), and the standards group WInnForum (through membership) to identify, address, and resolve technical issues of interference potentials, protection thresholds, and propagation predictions, widely published and freely transferred to Industry, laid the foundation for CBRS mid-band sharing. In FY 2023, having completed FCC Part 96 conformance testing on two waves of SAS candidate systems, ITS delivered the SAS certification test system harness to the FCC and conducted several trainings, supported by video tutorials, on the use of the certification test harness.

As part of the post-3.5 GHz Priority Access License (PAL) auction (FCC Auction 105) spectrum relocation fund programs approved by OMB and Congress, ITS is also 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 took a lead role in the Shared Spectrum Ecosystem Assessment (SEA) project by developing and deploying 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 was transferred to the public domain through GitHub and is freely available for use in other bands of interest for sharing. In FY 2023, NTIA Technical Report TR-23-567, "An Analysis of Aggregate CBRS SAS Data from April 2021 to January 2023" provided an analysis of aggregate CBRS SAS data reported quarterly from April 1, 2021, to January 1, 2023. The data provide valuable insights into the growth of CBRS, the impact of dynamic spectrum sharing, the role of General Authorized Access (GAA) spectrum usage, and CBRS's role in rural wireless connectivity.

In FY 2023, ITS executed a spectrum measurement campaign as part of a multi-year project with the DOD Chief Information Officer (CIO) to develop plans for improving propagation models for mid-band spectrum. The collected data is expected to be published in FY 2024, along with several articles and reports summarizing the data and describing the novel measurement system used to collect it. This critically important research will continue through FY 2027 with proceeds from the Spectrum Relocation Fund 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 includes significant inputs and information sharing with other federal agencies, academia, and the commercial sector through regular meetings of a multistakeholder group first convened in FY 2023. Open source sharing of measurements, modeling, and code is an integral part of this program. The improved propagation models in turn provide an opportunity to refine the

parameters used by the CBRS SASs to control on-demand spectrum access through dynamic channel sharing.

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 acts as Head of the U.S. Delegation to the international Study Group 3 meetings, convening the preparatory meetings of U.S. Study Group 3. At these meetings, U.S. Government agencies, academia, and private industry prepare U.S. contributions and positions to be discussed during upcoming plenary meetings. In addition to Head of Delegation, ITS holds three U.S. Working Party Chairs of Study Group 3, one International Working Party Chair, and chairs three correspondence groups. In FY 2023, arrangements were completed for ITS to host 2024 ITU-R Working Party meetings May/June 2024 in Denver, CO.

Correspondence Group CG-3L-3 focuses on updates to Recommendation ITU-R P.372, *Radio Noise*, a Recommendation which is also cited by the Radio Regulations. Information on the background levels of radio noise in frequencies 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 has become increasingly important for improving robustness of communication systems as the spectrum continues to get more crowded. Topics of interest in FY 2023 were the sharing of new datasets for propagation prediction inputs and agreeing on methods to reduce these sometimes voluminous datasets so that they can be ingested into the various models. Technical efforts in FY 2023 supported an ever-increasing focus on improving the accuracy of calculations, extending the frequency ranges to which ITU-R propagation models apply, and developing new modeling/prediction methods to address the increasingly complex radio environment.

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 2023, 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 2023, 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 vehicles, 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. ITS continues to participate in 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). A primary goal of the SEA program is 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. Building on prototypes deployed in FY 2022, data collection began in earnest in FY 2023 as well as analysis to prepare publicly available datasets for future publication.

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.

ITS continues to support industry discussions within VQEG that pursue new or improved ITU Recommendations. In FY 2023, ITS worked within VQEG and ITU-T Study Group 12 to merge ITU-T Recs. P.910, P.911, and P.912 into a single Recommendation. These three Recs. Each separately addressed subjective testing methods for video quality assessment techniques for reasons that are no longer relevant. ITS identified new techniques developed by VQEG attendees over the past decade and led discussions on the best way to incorporate those techniques into the updated ITU-T Rec. P.910. These new methods will help US industry and academia develop new technologies that rely on video streaming. The impact of the updated Recommendation is difficult to measure, since industry rarely publishes techniques used during their product development cycle, but intense participation by industry in this standardization effort testifies to the perceived value of the updated ITU-T Rec. P.910.

5 SUMMARY

This report details the results of the FY 2023 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.