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SCIENCE AND TECHNOLOGY

Overview of GAO's Enhanced Capabilities to Provide Oversight, Insight, and Foresight

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December 5, 2019

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Overview of GAO's Enhanced Capabilities to Provide Oversight, Insight, and Foresight

GAO Highlights

Highlights of GAO-20-306T, a testimony before the Committee on Science, Space, and Technology, House of Representatives

Background

Rapid developments in S&T are transforming multiple sectors of society, including medicine, transportation, communication, defense, and even culture. Like all technological change, each of these developments brings opportunities and potential unintended consequences. The ability of Congress to understand and evaluate such changes will be critical for the United States to remain safe, innovative, and globally competitive.

GAO's mission is to support Congress in meeting its constitutional responsibilities and to help improve the performance and ensure the accountability of the federal government for the benefit of the American people. The 2019 Legislative Branch Appropriations Bill Conference Report encouraged GAO to reorganize its S&T function by creating a new office. In January 2019, GAO created the STAA team to build on and expand its decades-long work providing Congress with science and technology analysis.

This statement discusses (1) GAO's S&T products and services for Congress; (2) how GAO is structured to provide S&T advice to the Congress; and (3) GAO's plan to continuously improve its S&T advising capabilities.

View GAO-20-306T. For more information, contact Timothy M. Persons, Ph.D., Chief Scientist, GAO, and Managing Director, Science, Technology Assessment, and Analytics, at (202) 512-6888 or personst@gao.gov.

GAO provides a variety of science and technology (S&T) products and services to Congress. Over the decades, GAO has grown its S&T portfolio by adding technology assessments, engineering/project controls best practices guides, and, most recently, the Science & Tech Spotlight series. Together, these products are designed to address key congressional interests on S&T issues by providing foresight on the consequences of advances in S&T, oversight of the federal S&T enterprise and S&T-centric programs and projects, and insight into emerging issues and topics of congressional interest.

GAO has the expertise, independence, and access to data to provide authoritative, nonpartisan advice to Congress in a manner that complements other sources of S&T advice.

- **Expertise:** GAO's new Science, Technology Assessment, and Analytics (STAA) team has 59 staff members with masters' degrees and/or doctorates, as of November 2019. Fifty-six staff members have at least one degree in a science, technology, engineering, and mathematics field. GAO's technology assessments are informed by appropriate S&T expertise, including external experts across academia, think tanks, and industry. GAO integrates subject and policy knowledge from across its 15 mission teams to develop rigorous methodological approaches to expertly analyze quantitative and qualitative data.
- **Independence:** GAO has a robust quality assurance framework to help ensure its independence and has congressional protocols to help ensure GAO is responsive to Congress in a nonpartisan manner.
- **Access to data:** GAO's legal authorities grant it unique access to an extensive range of agency information and data, including classified information and other information that is not available to the public.

GAO will continue to build its capacity to respond to congressional demand. STAA's current staff level is about one-half of what was outlined in the April 2019 plan submitted to Congress. GAO's key S&T activities are shown in the figure below.

Key Science and Technology Activities in GAO

Source: GAO. | GAO-20-306T

Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee:

Thank you for the opportunity to discuss GAO's science and technology (S&T) support to Congress. As you are aware, rapid developments in S&T are transforming multiple sectors of society, including medicine, transportation, communication, defense, commerce, and even culture itself. Like all technological change, each of these developments brings both opportunities—for economic growth and improved quality of life, for example—and the potential for unintended consequences. The ability of Congress to understand, evaluate, and prepare for such changes will be critical for the United States to remain safe, secure, innovative, and globally competitive.

We at GAO provide Members of Congress and their staffs with an array of professional services in the domains of oversight, insight, and foresight to help them carry out their Article I constitutional responsibilities as they relate to the nation's science and technology enterprise. Our expertise, research, and analyses help address a number of specific congressional needs, including:

- Evaluation of the impacts of science, technology, and innovation—including programmatic and/or policy implications
- Development of policy options concerning science, technology, and innovation issues in the context of actual or hypothesized congressional policy goals
- Proactive and/or on-demand, "just-in-time" scientific/technical assistance on science, technology, and innovation issues

The 2019 Legislative Branch Appropriations Bill Conference Report encouraged GAO to reorganize and enhance its S&T function by creating a new office. In January 2019, the Comptroller General directed the creation of the Science, Technology Assessment, and Analytics (STAA) team to build on and expand our decades-long work providing Congress with S&T analysis. GAO also enhanced its Information Technology and Cybersecurity team's existing capabilities with the hiring of 32 additional information technology (IT) and cybersecurity experts during fiscal year 2019. In addition, last year GAO inaugurated its Center for Strategic Foresight to identify and explore major emerging issues affecting government and society—including areas involving science and technology—such as personal identity and privacy, space policy, deepfake video, and other emerging technologies.

In my testimony today, I will discuss (1) our S&T products and services for Congress; (2) how we are structured to provide S&T advice to Congress; and (3) our plan to continuously improve our S&T advising capabilities.

GAO Provides Congress a Variety of S&T Products and Services

GAO has been successfully conducting science and technology-related work for close to 50 years—including technology assessments for almost two decades—providing Members of Congress and their staffs with a variety of products and services on S&T topics. This work addresses key congressional interests on S&T issues by providing foresight on the consequences of S&T advancement; oversight of the federal S&T enterprise; and insight into specific challenges and topics of congressional interest. Recent examples of these are included in table 1. Our products include traditional GAO reports such as S&T-related performance evaluations and testimonies. Over the decades, however, we have grown our portfolio of S&T products to include technology assessments (TAs), best practices guides, and most recently, our Science & Tech Spotlight series—the latter being designed to provide a brief overview of an emerging technology area and its possible implications for policy (see app. I for a list of technology assessments and related products, app. II for Spotlights, and app. III for a broader list of selected S&T products).

Table 1: Examples of GAO Products and Services that Provide Science and Technology Foresight, Oversight, or Insight

Category	Products and Services	Approx. Time frame	Examples
FORESIGHT 	Science & Tech Spotlights	4 to 6 weeks	*Science & Tech Spotlight: Hypersonic Weapons,* GAO-19-705SP *Science & Tech Spotlight: Opioid Vaccines*, GAO-19-706SP
	Evaluations and Testimonies	2 weeks to 2 years	*Biodefense: The Nation Faces Long-Standing Challenges Related to Defending Against Biological Threats*, GAO-19-635T *Science and Technology: Considerations for Maintaining U.S. Competitiveness in Quantum Computing, Synthetic Biology, and Other Potentially Transformational Research Areas.* GAO-18-656
	Technology Assessments	8 to 16 months	*Irrigated Agriculture: Technologies, Practices, and Implications for Water Scarcity,* GAO-20-128SP *Technology Assessment: Artificial Intelligence: Emerging Opportunities, Challenges, and Implications,* GAO-18-142SP
	S&T Horizon Scanning	Continuous	GAO's Center for Strategic Foresight, in partnership with STAA, is doing work on Deep Fakes, Deep Space, 5G and Cellular Agriculture.
OVERSIGHT 	Briefings and Technical Assistance	Days to weeks	In April 2019, we briefed congressional staff on National Institute of Standards and Technology's measurement services and standards development activities.
	Evaluations and Testimonies	2 weeks to 2 years	*Sexual Harassment in STEM Research: Preliminary Observations on Policies for University Grantees and Information Sharing among Selected Agencies.* GAO-19-583T
	Cross-cutting and Domain-specific Reporting	2 weeks to 2 years	*Critical Infrastructure Protection: Actions Needed to Address Significant Cybersecurity Risks Facing the Electric Grid.* GAO-19-332 *Nuclear Waste: Opportunities Exist to Reduce Risks and Costs by Evaluating Different Waste Treatment Approaches at Hanford.* GAO-17-306
INSIGHT 	Briefings and Technical Assistance	Days to weeks	In October 2019, our Chief Scientist participated as a subject matter expert in a Data Roundtable for the House Veterans' Affairs Committee to discuss data portability, use of electronic health records, and privacy and security concerns, among other things.
	Guides and Related Evaluations	5 months to 2 years	*GAO Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects, forthcoming. Exposure draft available at:* GAO-16-410G *Columbia Class Submarine: Overly Optimistic Cost Estimate Will Likely Lead to Budget Increases,* GAO-19-497
	S&T Issue Tracking	Continuous	Gene Editing; AI and Automation; Quantum Information Science; Brain/Augmented Reality; Cryptocurrencies

Source: GAO | GAO-20-306T

Note: Time needed is dependent on the scope and methodologies chosen. We are continuously working to decrease the amount of time taken to issue GAO reports and TAs.

In addition to written products, we provide S&T-related services to Members and their staffs, including briefings on our products or on our areas of expertise, and short-term analyses and reviews. Each product and service requires a different level of effort and time, tailored to the current and anticipated needs and interests of the requesters. Significant to STAA's long-term, sustainable service to the Congress is the shift in our strategic posture from a product-centered to an agile, content-centered operation in order to capitalize on newer information channels (e.g., podcasts, interactive/visualized data, mobile platforms) and in a manner that fits today's legislative operational tempo.

Foresight of Scientific and Technological Advancement

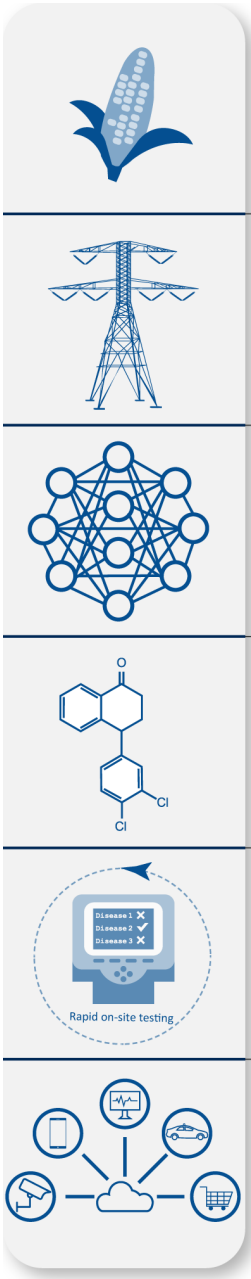
Members and their staffs need to understand how new technologies will shape our world. We provide foresight into technological opportunities and risks with thorough and balanced assessments of critical innovations that affect society, the environment, and the economy. GAO foresight products include TAs, Science & Tech Spotlights, and S&T-related evaluations and testimonies, while foresight services include S&T horizon-scanning and issue tracking in partnership with GAO's Center for Strategic Foresight. Having multiple product types and services allows us to respond in an appropriate time frame with the information Congress needs.

Technology assessments. Our TAs analyze the latest developments in science and technology, draw attention to implications of technological change, and make core concepts accessible to policymakers. The content of TAs varies. They may:

- Highlight potential short-, medium-, and long-term impacts of scientific advancement and/or technological development
- Elaborate on and communicate the risks and benefits associated with a technology, including early insights into the potential impacts of technology
- Highlight the status, viability, and relative maturity of a given technology—especially in the context of a complex acquisition program
- Describe federal investments in S&T
- Present policy options designed to inform decision makers on potential courses of action and the opportunities and challenges associated with each option.

TA time frames depend on their scope, but they can be completed within several months. Figure 1 highlights some recent TAs, and appendix I shows a full list of our TAs and related products.

Figure 1: Highlights of Selected GAO Technology Assessments



Irrigated Agriculture:
Technologies, Practices, and Implications for Water Scarcity
GAO-20-128SP

Provides an overview of irrigation technologies and practices that could reduce water usage. Also discusses factors that influence the adoption of efficient irrigation technology and how efficient irrigation technologies impact water conservation. Provides policy options in the area.

Critical Infrastructure Protection:
Protecting the Electric Grid from Geomagnetic Disturbances
GAO-19-98

Reports on the potential effects of geomagnetic disturbances on the U.S. electric grid, and technologies to prevent or mitigate a disturbance. Also discusses factors that could affect the development and implementation of these technologies.

Artificial Intelligence:
Emerging Opportunities, Challenges, and Implications
GAO-18-142SP

Discusses how artificial intelligence (AI) has evolved over time, the opportunities and future promise, as well as the principal challenges and risks. Report includes the policy implications and research priorities resulting from advances in AI.

Chemical Innovation:
Technologies to Make Processes and Products More Sustainable
GAO-18-307

Assesses selected technologies that are available or in development to make chemical processes and products more sustainable. Describes the contributions of the federal government, industry, and others to the development and use of such technologies.

Medical Devices:
Capabilities and Challenges of Technologies to Enable Rapid Diagnoses of Infectious Diseases
GAO-17-347

For multiplex point-of-care technologies, describes performance and costs. Discusses challenges and potential benefits of these technologies.

Internet of Things:
Status and Implications of an Increasingly Connected World
GAO-17-75

Describes the state of the Internet of Things, the purposes and uses of the technologies, along with potential implications.

Source: GAO. | GAO-20-306T

Science & Tech Spotlights. We also provide Congress with foresight through our Science & Tech Spotlights. Launched in 2019, Spotlights are two-page overviews for policymakers and the public. Each describes an emerging S&T development, the opportunities and challenges it brings, and the relevant policy context. Spotlights are designed to inform Congress of key developments in a timely and efficient manner, generally before congressional requests for deeper inquiries. Spotlights are completed in a few to several weeks. Our first four Spotlights, included in appendix II, address blockchain, hypersonic weapons, opioid vaccines, and probabilistic genotyping software—with the latter topic now requested as part of a full technology assessment project.

Evaluations and testimonies. Some GAO evaluations identify key technologies and their risks and opportunities, and provide policy options to decision makers. For example, in a series of reports from December 2009 through March 2019, we identified options for policy or structural changes that could help the Department of Homeland Security better fulfill its biosurveillance integration mission. More generally, since 2013, we have released 13 reports that included identification and assessment of policy options in a variety of technical and non-technical contexts. In addition, we addressed a range of S&T topics in testimonies before Congress. For example, in June 2019 we testified before the House Committee on Oversight and Reform on biological threats and biodefense efforts. In June 2019, we testified in front of the House Committee on Oversight and Reform on the privacy and accuracy of FBI's use of facial recognition. We also testified on a range of information technology and cybersecurity topics in fiscal year 2019, such as IT challenges at the Department of Veterans Affairs, systems development and cybersecurity efforts in preparation for the 2020 Census, and federal cybersecurity workforce issues.

S&T horizon scanning and issue tracking. In addition to working on specific foresight-related products, our staff continually perform horizon-scanning to support Congress. Further, awareness and evaluation of trends in S&T are part of our ongoing strategic planning efforts. In GAO's 2018-2023 Strategic Plan for Serving Congress and the Nation, we outline a number of technologies and scientific advances that will potentially transform society, among them genome editing, artificial intelligence and automation, quantum information science, brain-computer interfaces and augmented reality, and cryptocurrencies and

blockchain (see app. IV).[1] Our staff track advancements in these areas to inform our current and future products and services. The issues we focus on will change over time as our horizon-scanning identifies new priority issues.

Oversight of the Federal S&T Enterprise and S&T-centric Programs and Projects

Members and their staffs need trusted, nonpartisan information on the performance of federal programs and their outcomes for Americans. This work has increasingly focused on S&T as it has become more important to the efficient and effective performance of federal programs. GAO provides oversight through products, such as performance evaluations, and through technical assistance services, such as briefings on our prior work or short-term analysis of agency programs or activities.

Cross-cutting evaluations of S&T. We conduct cross-cutting work that evaluates the management and coordination of research and development across the federal government. This work addresses issues related to topics such as basic science, innovation, manufacturing, and S&T's role in economic competitiveness. For example, in fiscal year 2019 we issued products on advanced manufacturing, scientific integrity, and sexual harassment in Science, Technology, Engineering, and Mathematics (STEM) research.

Domain-specific performance evaluations. In addition, we evaluate a number of domains where S&T is critical, including defense, space, energy and the environment, nuclear, health care, and IT, as is shown in figure 2. The development of S&T-intensive systems, delivery of technology-dependent services, and development and application of technologies to solve problems are just some of the topics addressed in this work. Recent work in this area has examined topics such as synthetic biology, environmental cleanup technologies, critical infrastructure cybersecurity, and quantum computing. Time frames for this work, including testimonies and evaluations, typically average less than a year, but may range from 2 weeks to 2 years, depending on the scope of the work and congressional needs.

[1]GAO, *Strategic Plan 2018-2023: Trends Affecting Government and Society,* GAO-18-396SP (Washington, D.C.: Feb. 22, 2018).

Figure 2: GAO Examines Science and Technology in Many Domains

Defense and homeland security

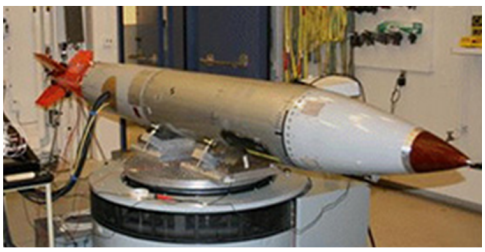
We evaluate technology readiness and risks for complex weapons and homeland security systems, such as missiles, radar, ships, and border security systems.

Space

We assess federal military and civilian space programs and efforts to support and oversee telecommunications in the public interest.

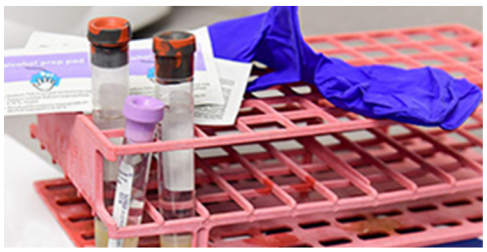
Energy and the environment

We evaluate developing and deployed technologies in a range of activities, including environmental monitoring, renewable energy, cleanup of hazardous sites, and civilian nuclear power.



Nuclear

We evaluate programs, infrastructure, technology readiness, and operations for the maintenance and management of nuclear weapons, as well as the aircraft and submarines designed to carry and deliver them.



Health care

We assess new technologies for emerging infectious diseases, such as technologies that can simultaneously test for multiple infectious diseases at or near the site of patient care, and the impacts of new technology on human health, disease prevention, and the delivery of health care.

Information technology and cybersecurity

We evaluate the management and operation of the government's substantial IT investments and assess efforts to protect federal systems, emerging technologies, critical infrastructure, and individual privacy from cyber threats.

Sources (top left to right): DoD, NASA/Kennedy, and GAO; (bottom left to right) GAO, GAO, and Social Security Administration. | GAO-20-306T

Series of performance evaluations. A third area in which we support congressional S&T oversight is long-term monitoring of agency operations and factors that could affect these operations. For example, GAO first designated federal information security as a government wide high risk area almost 22 years ago in 1997 and our cybersecurity work has been critical to informing and assisting Congress. Our work informed Congress as it considered major legislation on information security, such as the Federal Information Security Management Act of 2002 (FISMA), its successor, the Federal Information Security Modernization Act of 2014, and the Cybersecurity and Infrastructure Security Agency Act of 2018. We have also undertaken a series of reports evaluating the planning, design, and construction of large facilities sponsored by the National Science Foundation, such as telescopes and research vessels, and a series of reports on oversight of high-containment laboratories.

We also regularly provide services to Congress related to our oversight work, including briefings on past and ongoing work or technical assistance to provide additional data or context to our work. For example, informed by our bodies of work, we have provided overview briefings to committees, such as “Defense Space Systems 101” and “NIST 101.”

Insight into Priority Issues

Members and their staffs need partners to help ensure efficiency and accountability in government. We provide guidance to federal managers and employees to help S&T-intensive programs operate at their best. We developed a series of best practices guides that lay out proven and effective approaches and decision-making tools for federal managers. We developed these guides to respond to persistent challenges in managing the cost, schedule, and performance of the federal government’s significant investments in research and development and complex technical acquisition programs. Our guides currently cover cost, schedule, and technology readiness, with an additional guide planned for Agile software development. Our cost, schedule, and technology readiness assessment guides have improved project management practices across the federal government and spurred congressional action on technology risks. We have also used our expertise in these areas to review federal programs and identify targeted interventions to improve federal acquisitions, such as our December 2017 and April 2019 reports concerning, respectively, the technology readiness and cost estimate of the Navy’s Columbia class submarine. These guides are described in figure 3.

Figure 3: GAO Best Practice Guides

	Title	Summary
	**Cost Estimating and Assessment Guide** *Currently being updated* Best Practices for Developing and Managing Capital Program Costs GAO-09-3SP, Mar. 2, 2009	• Provides 12-step process to develop high-quality, reliable program cost estimates applicable across government and industry. • Provides a detailed link between cost estimating and earned value management (EVM).
	**Schedule Assessment Guide** Best Practices for Project Schedules GAO-16-89G, Dec. 22, 2015	• Provides 10 best practices to help managers and auditors ensure that a program schedule is reliable. • Develops standard criteria to determine the extent to which agency programs and projects meet industry scheduling standards.
	**Technology Readiness Assessment Guide** *Update forthcoming* Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects GAO-16-410G, Aug. 11, 2016	• Provides six-step outline of a reliable technology readiness assessment process and associated best practices to evaluate technology maturity across the federal government. • Provides a framework for better understanding technology maturity, conducting credible technology readiness assessments, and developing plans for technology maturation efforts.
	**Agile Guide** Upcoming June 2020	• Provides nine adoption best practices sorted into team activities, program processes, and agency environment. • Relates program control best practices established in the Cost Guide and Schedule Guide to Agile Software Guide processes and artifacts.

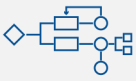
Source: GAO. | GAO-20-306T

We also provide Members and their staffs immediate access to a trusted source of nonpartisan information to gain insight into S&T topics and programs, ranging from answering technical questions by phone, to providing a comprehensive written and oral briefing on a complex issue. Depending on the need and topic, turnaround time can range from days to a few weeks. Some of our methods for providing technical assistance to Congress include:

- We frequently provide informal briefings and other assistance to Members of Congress and congressional staff on a very short time frame based on our expertise, prior work, and analysis. We have provided numerous technical briefings on request, such as on biodetection systems, big data, artificial intelligence, IT, and cybersecurity issues, among others. Our technical assistance also supports hearings. For example, we provided information on fentanyl and fentanyl analogs for a hearing on the opioid crisis. We developed a briefing on sustainable chemistry for a committee.
- We have briefed new committee staff on topics or agencies within their portfolios, highlighting our recent reporting and our understanding of the major issues involved.
- We also draw on our in-house expertise and prior reporting to provide context and issues to consider regarding draft legislation.

Our ongoing work develops S&T content across a mixture of product types, key topics, and for a variety of congressional committees. Figure 4 shows selected current work in S&T.

Figure 4: Selected Ongoing GAO Science and Technology (S&T) Work

	Topic (Product Type)	Congressional Clients
	CRISPR gene editing and surrounding policy context (Science & Tech Spotlight)	Biomedical, Agriculture, and National/Homeland security-related committees and caucuses
	Information on deepfake video technology (Science & Tech Spotlight)	Technology-related committees and caucuses
	Nuclear microreactors technology (Science & Tech Spotlight)	Energy-related committees and caucuses
	Artificial intelligence in drug development (Technology Assessment)	Senate Committee on Health, Education, Labor, and Pensions, and House Committee on Energy and Commerce
	Performance, usage, and challenges of 5G wireless networks (Science & Tech Spotlight and Technology Assessment)	House Committee on Armed Services, House Permanent Select Committee on Intelligence, House Committee on Science, Space, and Technology, and Senate Select Committee on Intelligence
	Artificial intelligence in the delivery of health care services (Technology Assessment)	Senate Committee on Health, Education, Labor, and Pensions, and House Committee on Energy and Commerce
	Algorithms used in forensics, including DNA fingerprints and facial recognition (Technology Assessment)	Security and technology-related committees and caucuses
	Infectious disease modeling as it relates to public health decisions (Performance Evaluation)	House Committee on Energy and Commerce
	Federal efforts to address antibiotic resistance (Performance Evaluation)	Senate Committee on Health, Education, Labor, and Pensions, and House Committee on Energy and Commerce
	The National Science Foundation's large facilities construction (Performance Evaluation)	House Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies
	The Department of Veterans Affairs research into veterans' health care needs (Performance Evaluation)	House Committee on Veterans' Affairs
	Intellectual property assistance for small businesses (Performance Evaluation)	House Committee on Small Business
	Department of Homeland Security's new biodetection technology system (Technology Assessment and/or Performance Evaluation)	Senate Committee on Homeland Security and Governmental Affairs, House Committee on Energy and Commerce, House Committee on Homeland Security, House Committee on Science, Space, and Technology
0100101001 1001010101	Identify and describe Agile software development best practices (Best Practice Guide)	Appropriations, Budget, and technology-related committees and caucuses
$	An update to GAO's 2009 Cost Estimating and Assessment Guide (Best Practice Guide)	Appropriations, Budget, and oversight-related committees and caucuses

Source: GAO. | GAO-20-306T

GAO Has the Expertise, Independence, and Access to Data to Provide Authoritative, Nonpartisan Advice to Congress

GAO is uniquely positioned to provide fact-based, non-ideological, nonpartisan and authoritative S&T advice to Congress in a manner that complements advice provided by the National Academies of Sciences, Engineering, and Medicine (National Academies) and the Congressional Research Service. Authoritative S&T advice requires distilling technical and policy expertise into clear, concise, and independent descriptions and recommendations. GAO has the in-house talent, access to external expertise, and employs the methodological rigor to do so, although we are not yet staffed up as intended in our April 2019 STAA plan. GAO has a strong reputation for independent, high-quality, nonpartisan analysis. In addition, we have unique access to expertise and information in the federal government, as well as significant access to external expertise, be it through our standing relationship with the National Academies or through our own convening and access to academic, nonprofit, and private-sector expertise.

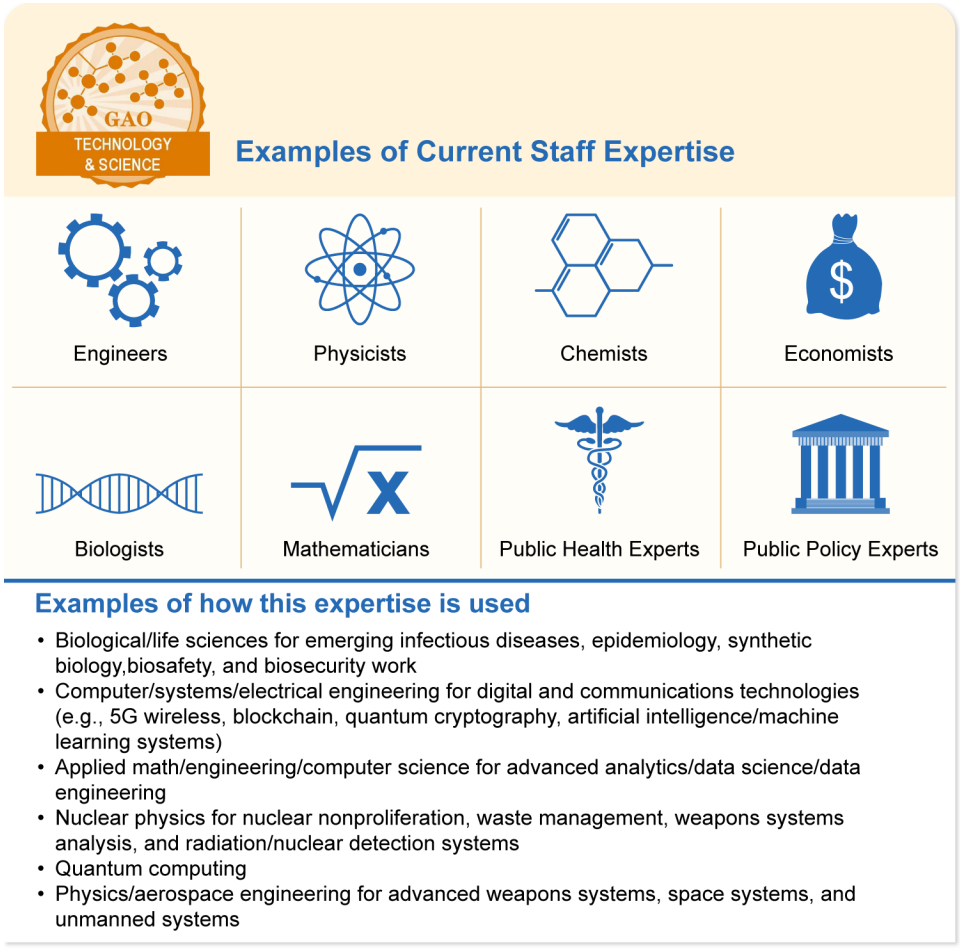
GAO Staff Are Well Qualified to Provide Congress a Variety of S&T Products and Services

Although we have expanded our technical expertise substantially over the past year, we have not yet fully staffed up as intended in our April 2019 STAA plan. Nevertheless, we have a well-trained and diverse talent pool. Our STAA team now has 59 staff members with masters' degrees and/or doctorates. Fifty-six staff members have at least one degree in a STEM field. The team currently includes engineers (e.g., biomedical, electrical and electronics, systems, petroleum, aerospace), chemists (e.g., analytical, environmental, inorganic, organic, theoretical), biologists, and physical scientists (e.g., nuclear physics, environmental science, geology), and others. STAA also has operations research analysts/project controls engineers who specialize in lifecycle cost estimating, scheduling, earned value management, technology readiness assessment, and Agile software development. In addition to these fields, STAA team members also hold advanced degrees in public policy, rounding out the team to expertly advise on the nexus of technology and policy. In October 2019, we hired our first Chief Data Scientist to lead innovative data analytics efforts for all of GAO. A team of attorneys within GAO's Office of the General Counsel provides support to STAA as well.

STAA staff also benefit from collaboration with GAO's broader workforce of subject-area policy analysts, economists, social scientists, methodologists, and attorneys across our 14 other mission teams. Some of the other mission teams that address S&T topics typically have their own dedicated, in-house S&T expertise on topics related to their missions. Examples include expertise in engineering, chemistry, biology,

physics and cybersecurity. Figure 5 shows a representation of S&T expertise within STAA and GAO more broadly.

Figure 5: GAO Has Extensive Science and Technology Expertise



Source: GAO. | GAO-20-306T

Our Information Technology and Cybersecurity (ITC) team, for example, has extensive knowledge of key IT domains, including IT and cybersecurity risk management, software development, system administration, and computer networking. Many ITC team members have one or more specialized certifications, such as Certified Information Systems Security Professional (CISSP), Certified Information Privacy Professional (CIPP), and Certified Ethical Hacker (CEH).

Furthermore, we have 11 field offices across the country, giving us deeper links throughout the federal community, access to talent from different regions, and connecting us with a diverse set of universities, research institutions, and industries. This access to a well-trained and diverse talent pool brings a powerful and sophisticated perspective to our work as we conduct TAs and analyze the policy implications of a range of technical and scientific topics for Members and their staffs.

GAO Work Is Fact-Based and Undergoes a Rigorous Technical Review Process

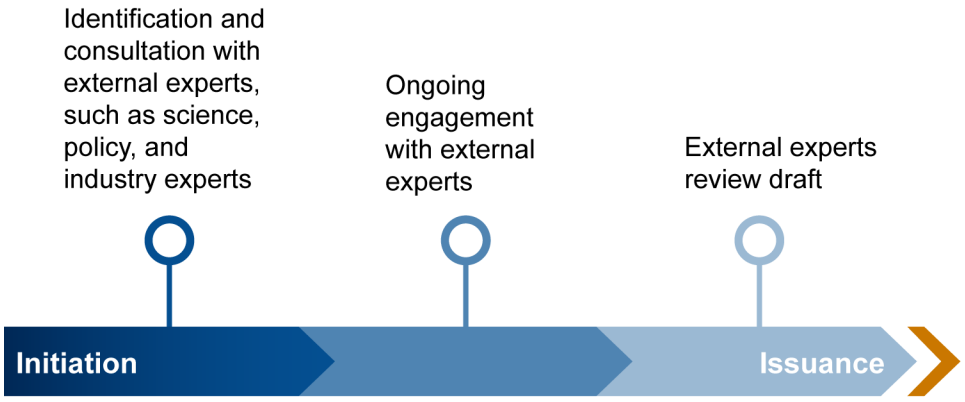
We employ rigorous methods to produce fact-based information, ensuring that all statements presented in our products are based on sufficient and credible evidence. Further, we integrate a wealth of knowledge from across GAO's 14 other mission teams to develop rigorous methodological approaches for expertly analyzing quantitative and qualitative data. We also tailor our methodologies to suit particular products and meet congressional needs.

We have designed our TA process to ensure that our work is informed by appropriate S&T expertise, including external experts across academia, think tanks, and industry.[2] We involve experts throughout our studies. To do so, we draw expertise from scientists, engineers, and physicians through routine engagement with the National Academies of Sciences, Engineering, and Medicine. Since 2001, we have maintained a standing contract that allows National Academies personnel to help GAO identify experts and assist with convening expert meetings for GAO. Once we have selected a group of experts that represents the needed cross-sector expertise (e.g., government, university, industry, and nonprofit), we traditionally convene a meeting of these experts to highlight and discuss the latest research in the field. We use an experienced moderator to encourage discussion that can result in new thoughts and ideas. We then contact the experts over the course of our work to gain additional input as needed. Once we have developed a draft report, the experts who participated in our meeting of experts then review our TAs for technical and scientific accuracy to ensure the assessments are of the highest quality. Involvement of these experts throughout the process is reflected in figure 6 and in more detail in appendix V. As described in our April 2019 STAA Plan, our TA portfolio is based on our well-established quality

[2]GAO, *Technology Assessment Design Handbook*. GAO-20-246G. (Washington, D.C.: Dec. 5, 2019).

assurance framework and is at times above and beyond how it is applied to our evaluation work.

Figure 6: GAO Involves Experts Throughout Its Technology Assessments



Source: GAO | GAO-20-306T

We collaborate with many other S&T entities as well. For example, we engage with federally funded research and development centers, such as the MITRE Corporation, the Institute for Defense Analyses, and the Carnegie-Mellon Software Engineering Institute. We are also building key academic partnerships with universities that have specialized programs in science, technology, and public policy, such as Arizona State University, Carnegie-Mellon University, the Georgia Institute of Technology, the Massachusetts Institute of Technology, and University of Maryland College Park, among others. By maintaining a diverse network, we are able to connect Members and their staffs with other relevant experts when needed.

GAO Responds to Congressional Priorities

Our work directly supports congressional interests. In fiscal year 2019, we devoted 96 percent of our engagement resources to work requested directly by Members and committees or required by Congress in statute. Prioritization of this work is guided by our congressional protocols, which we designed in consultation with Congress and which provide a sequence of internal controls that allows us to efficiently and effectively receive, prioritize, and respond to congressional requests. These protocols help ensure we work constructively with Congress and conduct our work in accordance with congressional priorities to meet the needs of both parties. These protocols also ensure that we are consistent in dealing with all committees and individual members. Although we prioritize

mandates and requests from Chairs and Ranking Members of congressional committees over individual member requests, we may also provide technical assistance and briefings in response to individual member requests.

In addition, we may undertake work that is not directly tied to requests.[3] This can be useful for topics that are of broad interest in Congress, generally longer-range, crosscutting, and transformational issues. The ability to conduct such work under "Comptroller General Authority," is also beneficial because it allows us to bring to Congress's attention important emerging S&T issues that may affect the nation's future. For example, we developed our Science & Tech Spotlights under this authority to quickly inform Congress of S&T topics of broad interest. Examples of some of our ongoing work—including requests and Comptroller General Authority work—were previously shown in figure 4.

Examples of our more recent S&T work to support Congress include our July 2019 testimony before the Subcommittee on Research and Technology on the technologies for making chemical products and processes more sustainable.[4] Also in July 2019, before the Subcommittee on Research and Technology and the Subcommittee on Investigations and Oversight, we testified on federal research, and strengthening scientific integrity policies. This hearing helped inform Members of the subcommittees as they considered the *Scientific Integrity Act.* In October 2019, our Chief Scientist participated as a subject matter expert in a Data Roundtable for the House Veterans' Affairs Committee to discuss data portability, use of electronic health records, and privacy and security concerns, among other things. Also, we provided a briefing of 5G technologies to Members and their staffs from the House Science, Space, and Technology Committee and staff from the House Armed Services Committee.

[3]31 U.S.C. § 717(b)(1) grants the authority to evaluate the "results of a program or activity" of the Government on the initiative of the Comptroller General. This work, conducted under "Comptroller General Authority," can be beneficial as we identify emerging S&T issues.

[4]*Chemical Innovation: Technologies for Making Products and Processes More Sustainable,* GAO-19-660T (Washington, D.C.: July 25, 2019)

GAO Work Is Independent and Nonpartisan by Design

We ensure our independence both in our work and as an independent agency that works for Congress. We are careful to ensure that our opinions, findings, conclusions, judgments, and recommendations will be impartial and will be viewed as such by third parties. GAO has a robust quality assurance framework and systems to help ensure our independence. For example, GAO employees must disclose their personal financial holdings and other interests annually. In addition, employees must certify every two weeks that they remain independent with respect to their work. If any conflict or concern arises, supervisors, in conjunction with our Office of Ethics, take immediate and appropriate action.

As an agency, we efficiently use available resources to maximize our ability to meet the Congress's needs and consistently exercise the independence necessary to ensure that our products and work conform to professional standards and our core values of accountability, integrity, and reliability. While we work closely with Congress to understand their needs and to conduct work that will address those needs, we do so in a manner that enables us to demonstrate our independence throughout all aspects of our work to ensure credibility. For example, we make the final determination of the specific questions our work will address, the scope of those questions, and the methods we will use to answer them.

GAO Has Unique Access to Federal Agency Data

We are also well-positioned to address Congress's S&T needs because our legal authorities grant us unique access to an extensive range of agency information and data, including classified information and other information that is not available to the public. This gives us a unique ability to provide well-informed, high-quality S&T advice. For example, in the technology assessment *Irrigated Agriculture: Technologies, Practices, and Implications for Water Scarcity,* we used nonpublic data from the U.S. Department of Agriculture to create an econometric model examining the effects irrigation technology had on how much water farms were using.[5] We found that use of efficient irrigation technologies alone may not conserve water, and provided two policy options designed to address that concern.

[5]*Irrigated Agriculture: Technologies, Practices, and Implications for Water Scarcity,* GAO-20-128SP (Washington, D.C.: Nov. 12, 2019)

GAO Plans to Continue to Expand Its S&T Capacity to Respond to Congressional Demand

In January 2019, we created the STAA team and since then have dramatically enhanced our ability to provide Congress with thorough and balanced analyses of technological and scientific developments that affect society, the environment, and the economy. Since that time, we have built significant capacity to produce S&T products and services, but more needs to be done. We will work to continuously enhance our products and services by exploring additional product types, and expanding our staff by attracting additional world-class talent.

Future Content-Centric Plans to Meet Congressional S&T Needs

Using a content-centric strategy, we are implementing a number of steps that take into account the unique requirements of TAs and related S&T work to meet the needs of Members of Congress and their staffs. As we build on our existing capabilities and grow the new STAA team, we will:

- Develop and refine content development and delivery formats designed to issue clear and concise communication on technical topics in accordance with the current and projected congressional operational tempo
- Develop additional methods and standards that are appropriate to TAs and separate from those covering our evaluation work
- Designate staff whose primary focus will be TAs and the provision of direct technical assistance to the Congress
- Continue engaging with external experts and advisory boards, as appropriate

We are exploring and anticipate making future changes. While still in the exploratory phase, these may include preparing an annual horizon scanning report and establishing an S&T advisory board.[6]

Future Staffing Plans to Enhance S&T Work

To ensure Members and their staffs continue to receive high-quality, independent, and nonpartisan advice and analysis on technological and scientific topics, we organized our S&T activities into four key groups, as is shown in Figure 7. We plan to continue to build capacity in those areas to respond to greater congressional demand.

[6]Though not finalized yet, the S&T advisory board may consist of external S&T policy experts from industry, academia, nonprofits, and former senior government officials.

Figure 7: Key Science and Technology Activities

Across our work we aim to augment our core products with a range of timely, high-value technical assistance services for our congressional clients.

Source: GAO. | GAO-20-306T

STAA's current staff level is about one-half of what was outlined in the plan submitted to Congress, so we will grow our current S&T workforce over the next few years. Depending on congressional priorities through the normal authorization and appropriations process, we aspirationally plan to grow STAA to 140 full-time equivalent total staff as we adapt to meet future congressional demand. We anticipate that at least half of STAA staff will have advanced degrees across the physical, life, and computational sciences as well as most variants of engineering. We will continually assess optimum staffing levels for the team based on congressional needs and product demand. As we continue to assess anticipated future work and S&T issues that will be of interest to the Congress, we have hired and plan to continue hiring to add expertise in areas such as:

- Biological/life sciences for emerging infectious diseases, epidemiology, synthetic biology, biosafety, and biosecurity work

- Computer/systems/electrical engineering for digital and communications technologies (e.g., 5G wireless, blockchain, quantum cryptography, artificial intelligence/machine learning systems)
- Applied math/engineering/computer science for advanced analytics/data science/data engineering
- Nuclear physics for nuclear nonproliferation, waste management, weapons systems analysis, and radiation/nuclear detection systems
- Quantum computing
- Physics/aerospace engineering for advanced weapons systems, space systems, and unmanned systems

In addition to permanent staff, we are exploring actively recruiting temporary or limited-term staff to meet project-specific needs, particularly around the latest S&T advances. Such staff could include experts from the National Academies or Intergovernmental Personnel Act detailees.[7] The exact number of such staff will vary based on our hiring authority, project needs, and congressional demand for our work. We will seek additional authorities if necessary to obtain needed expertise. As discussed during meetings with external stakeholders, there is a strong interest within the S&T community in opportunities to participate in and contribute to analysis of S&T issues on behalf of the Congress, and to enhance their own work on S&T issues through an understanding of the broader policy context.

Thank you, Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, this concludes my prepared statement. I would be pleased to answer any questions.

[7]The Intergovernmental Personnel Act Mobility Program provides for the temporary assignment of personnel between the federal government and state and local governments, colleges and universities, Indian tribal governments, federally funded research and development centers, and other eligible organizations. Assignment agreements can be made for up to two years, and may be intermittent, part-time, or full-time.

For further information on this testimony, please contact Timothy Persons, Chief Scientist, GAO, and Managing Director, Science, Technology Assessment, and Analytics who may be reached at (202) 512-6888. Contact points for our Congressional Relations and Public Affairs offices may be found on the last page of this statement. Other individuals making key contributions to this work include: Karen Howard (Director), Laura Holliday (Assistant Director), Jenn Beddor (Analyst-in-Charge), Will Bauder, Anika McMillon, Jon Menaster, Tind Shepper Ryen, and Ben Shouse.

Appendix I: List of GAO Technology Assessments and Science Forum Highlights

Irrigated Agriculture: Technologies, Practices, and Implications for Water Scarcity, GAO-20-128SP (Nov. 12, 2019)	*Highlights of a Forum: 3D Printing: Opportunities, Challenges, and Policy Implications of Additive Manufacturing,* GAO-15-505SP (June 24, 2015)
Critical Infrastructure Protection: Protecting the Electric Grid from Geomagnetic Disturbances, GAO-19-98 (Dec. 19, 2018)	*A Capsule Version of Nanomanufacturing—Emergence and Implications for U.S. Competitiveness, the Environment, and Human Health,* GAO-14-406SP (May 19, 2014)
Technology Assessment: Artificial Intelligence: Emerging Opportunities, Challenges, and Implications, GAO-18-142SP (Mar. 28, 2018)	*Nanomanufacturing: Emergence and Implications for U.S. Competitiveness, the Environment, and Human Health* GAO-14-181SP (Jan. 31, 2014)
Chemical Innovation: Technologies to Make Processes and Products More Sustainable, GAO-18-307 (Feb. 8, 2018)	*Technology Assessment: Neutron Detectors: Alternatives to Using Helium-3, GAO-11-753 (Sept. 29, 2011)*
Medical Devices: Capabilities and Challenges of Technologies to Enable Rapid Diagnoses of Infectious Diseases, GAO-17-347 (Aug. 14, 2017)	*Technology Assessment: Climate Engineering: Technical Status, Future Directions, and Potential Responses,* GAO-11-71 (July 28, 2011)
Internet of Things: Status and Implications of an Increasingly Connected World, GAO-17-75 (May 15, 2017)	*Technology Assessment: Explosives Detection Technologies to Protect Passenger Rail,* GAO-10-898 (July 28, 2010)
Highlights of a Forum: Data and Analytics Innovation—Emerging Opportunities and Challenges, GAO-16-659SP (Sept. 20, 2016)	*Securing the Transport of Cargo Containers,* GAO-06-68SU (Jan. 25, 2006)
Technology Assessment: Municipal Freshwater Scarcity: Using Technology to Improve Distribution System Efficiency and Tap Nontraditional Water Sources, GAO-16-474 (Apr. 29, 2016)	*Technology Assessment: Protecting Structures and Improving Communications during Wildland Fires,* GAO-05-380 (Apr. 26, 2005)
Technology Assessment: Municipal Freshwater Scarcity: Survey of Technology Adoption by Municipal Water Utilities (GAO-16-588SP, Apr. 29, 2016), an e-supplement to GAO-16-474	*Technology Assessment: Cybersecurity for Critical Infrastructure Protection,* GAO-04-321 (May 28, 2004)
Technology Assessment: Water in the Energy Sector: Reducing Freshwater Use in Hydraulic Fracturing and Thermoelectric Power Plant Cooling, GAO-15-545 (Aug. 7, 2015)	*Technology Assessment: Using Biometrics for Border Security,* GAO-03-174 (Nov. 15, 2002)
Technology Assessment: Nuclear Reactors: Status and Challenges in Development and Deployment of New Commercial Concepts, GAO-15-652 (July 28, 2015)	

Source: GAO | GAO-20-306T

Appendix II: Examples of GAO Science and Technology Spotlight Series

GAO | Science, Technology Assessment, and Analytics

SCIENCE & TECH SPOTLIGHT:

PROBABILISTIC GENOTYPING SOFTWARE

SEPTEMBER 2019

WHY THIS MATTERS

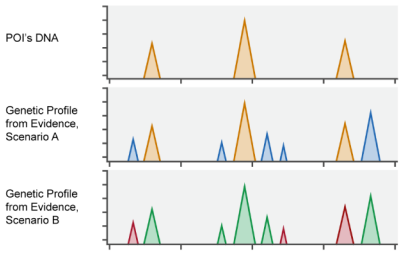
New developments in software to analyze contaminated or partly degraded DNA could greatly facilitate criminal investigations. However, the validity of the analysis and the implications for constitutional due process protections remain unsettled.

/// THE TECHNOLOGY

What is it? Probabilistic genotyping software (PGS) is used in criminal investigations to help link a genetic sample — such as a sample from crime-scene evidence — to a person of interest (POI). It facilitates genetic analysis in complicated situations, such as when a sample is partially degraded or contains DNA from more than one person.

How does it work? The usual first step is to gather genetic material from both the evidence and the POI. Both samples are then separately analyzed using a process that examines multiple regions of DNA whose length varies among individuals. Investigators can then create genetic profiles that allow them to distinguish among individuals using this variability.

Next, laboratories compare the genetic profile of the evidence with that of the POI. They often do this with a computer simulation of many different scenarios (fig. 1). PGS provides a probability that the evidence gathered would have led to the evidence profile that was obtained, if the POI were — or were not — a contributor to the sample. Investigators can use the relative values of these two probabilities to establish the strength of the evidence in favor of, or against, the POI.



Source: GAO. | GAO-19-707SP

Figure 1. Genetic profiles consist of "peaks." The peak heights represent the quantity of DNA fragments, and the peak's horizontal position corresponds to the length of the DNA fragments. The top graph shows the POI's DNA profile. Scenario A indicates the possibility that the DNA from the POI (orange) could have been mixed with DNA from one or more other contributors (blue) to generate this evidence sample. Scenario B indicates the possibility that DNA from other contributors (green and red) could have generated this sample, resulting in the same evidence profile.

How mature is it? PGS was available by the late 1990s, yet it is not fully mature. There are several software packages for PGS, some open source, some commercial. About 100 laboratories in the United States reportedly use PGS. PGS analyses are used by law enforcement offices, crime or forensics laboratories, defense attorneys, and law offices at the county, city, state, and federal levels. For example, according to a President's Council of Advisors on Science and Technology (PCAST), the FBI started using a PGS package called STRmix in 2015.

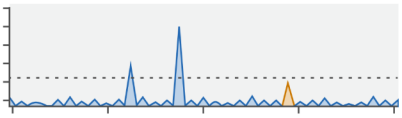
PCAST stated that, in order to establish the scientific validity of PGS, outside groups need to conduct scientific evaluation studies, in addition to the developers and affiliated laboratories that typically conduct such studies currently. PCAST also recommended publication of study results.

/// OPPORTUNITIES

- **Usable on a variety of samples.** PGS allows for interpretation of genetic material that is degraded, comes from multiple people, or is present at low concentrations, such as when a person only touched a piece of evidence (instead of leaving blood behind, for example).
- **Scenario analysis.** PGS also could facilitate analysis of a large number of scenarios and may help ensure consistency in laboratory methodology.

/// CHALLENGES

- **False negatives.** When a genetic marker is present but at a concentration too low to detect, it may produce a false negative result (fig. 2).



Source: GAO. | GAO-19-707SP

Figure 2. A peak (orange) is below the threshold (dotted line) for recognizing peaks, which may inadvertently exclude the POI during analysis. The rest of the peaks below threshold could represent background "noise" or minute quantities of DNA fragments.

- **False positives.** Conversely, when contamination or random "noise" gives the appearance of a marker that is not actually present, it can lead to a false match.

GAO-19-707SP Probabilistic Genotyping

Source: GAO. | GAO-20-306T

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- **Limited information content.** PGS cannot attribute a DNA sample to a particular event. For example, a high likelihood of matching the POI does not mean the POI handled the object at a particular time or during a particular incident.
- **Lack of clarity.** It can be challenging to present results in a way that is meaningful to a lay audience. For example, if the test shows that the POI match is 500,000 times more likely than a match to a random person, how a non-specialist would interpret this statistic is unclear.
- **Lack of consistency.** Different software packages may yield different results from the same sample. In some cases, even the same software package can yield varying results, although this may not invalidate the results. One of the causes for lack of consistency is the lack of standards for using and interpreting PGS results.
- **Lack of validation.** It is challenging to validate PGS for certain scenarios, such as when a sample contains DNA from more than three people, or if the amount or quality of DNA decreases. If outside parties cannot validate the methods or examine how validation was conducted, legal questions could arise. For example, one news report suggested that results from a single PGS were used as the sole physical evidence in a trial that ended in conviction. However, the defense argued that the software company did not make its source code available for examination. Additionally, without validation, one may not know specifically why different methods produce different results.

Source: GAO. | GAO-19-707SP

Figure 3. Lack of clarity, standards, and validation studies may raise legal concerns about the use of PGS results.

/// POLICY CONTEXT AND QUESTIONS

PGS use in forensic analyses is increasing, but PGS results reportedly can be used with only limited confidence under certain circumstances. Some key questions for consideration include:

- In what situations is PGS useful, and when should it be avoided or used with caution?
- What are the gaps in empirical evidence that need to be filled to increase confidence in PGS results for use in criminal or civil trials, and what is the cost and feasibility of addressing these gaps?
- How are federal agencies evaluating and using PGS, and what should the federal role be?
- What additional validation work is needed to expand use of PGS?

/// SELECTED GAO WORK

- DNA Evidence: DOJ Should Improve Performance Measurement and Properly Design Controls for Nationwide Grant Program, GAO-19-216
- DNA Evidence: Preliminary Observations on DOJ's DNA Capacity Enhancement and Backlog Reduction Grant Program, GAO-18-651T
- Technology Assessment: Artificial Intelligence: Emerging Opportunities, Challenges, and Implications, GAO-18-142SP

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Coble MD, Bright J "Probabilistic genotyping software: An overview." Forensic Science International: Genetics 38:219-224 (2019).

President's Council of Advisors on Science and Technology "Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods." (Washington, D.C., September 2016).

Department of Justice "Uniform Language for Testimony and Reports for Forensic Autosomal DNA Examinations Using Probabilistic Genotyping Systems." effective March 18, 2019.

Kwong K "The Algorithm Says You Did it: The Use of Black Box Algorithms to Analyze Complex DNA Evidence." Harvard J Law Tech 31(1):275-301 (2017).

GAO SUPPORT:

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Staff Acknowledgments: Sushil Sharma (Assistant Director), Hayden Huang (Analyst-in-Charge), Anika McMillon, Ben Shouse, and Jessica Smith.

Source: GAO. | GAO-20-306T Part 2 of 2

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SCIENCE & TECH SPOTLIGHT:

OPIOID VACCINES

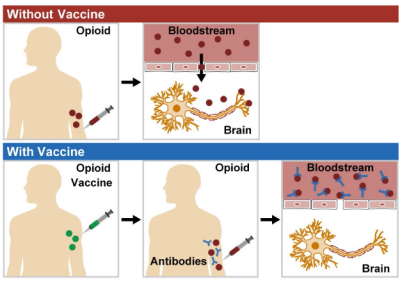
SEPTEMBER 2019

WHY THIS MATTERS

The ongoing opioid epidemic in the United States impacts lives on both a personal and national level. More than 10 million people abused opioids in 2017, with more than 47,000 opioid-related deaths — a nearly six-fold increase since 1999. Opioid vaccines could offer advantages over current treatment options.

/// THE TECHNOLOGY

What is it? Opioid vaccines are medical therapies designed to block opioids, such as heroin and fentanyl, from entering the brain or spinal cord, thus preventing addiction and other negative effects. While none are approved for use yet, they could be useful for at-risk individuals, patients in drug recovery programs, or first responders who might accidentally come into contact with deadly opioids that can be absorbed through the skin. This approach offers advantages over some current treatment methods, including requiring minimal medical supervision and no potential for abuse.



Source: GAO. | GAO-19-706SP

Figure 1. When an opioid enters the bloodstream (top), it crosses into the brain, where it can act on the target receptor to cause psychotropic effects, addiction, and overdose. Opioid vaccines (bottom) trigger the body to create antibodies that bind to opioid molecules and prevent them from entering the central nervous system, thus preventing negative effects.

How does it work? When opioid molecules bind to receptors in the central nervous system (the brain and spinal cord), they can cause psychotropic effects (e.g., hallucination, euphoria), addiction, and overdose. Opioid molecules have specific chemical structures. Opioid vaccines are designed to trigger an immune response to these structures when injected into a patient. Similar to vaccines for infectious diseases, such as polio or measles, when a patient is treated with an opioid vaccine, their immune system learns to identify the targeted opioid as a dangerous foreign substance so it can respond if that opioid enters the bloodstream in the future.

After the body has learned to target an opioid molecule, it naturally forms antibodies that can bind to it. These opioid-specific antibodies stick to opioid molecules in the bloodstream, forming a unit that is too large to enter the central nervous system.

Without entering the central nervous system, the molecule is not able to produce the negative effects associated with opioids. The antibody-bound opioid will eventually be excreted via urine without harming the exposed individual.

How mature is it? As of 2019, the Food and Drug Administration (FDA) has not approved any opioid vaccines for use. While opioid vaccine studies were initially proposed as early as the 1970s, clinical trials have thus far been unsuccessful. Currently, at least three early-stage clinical trials of potential opioid vaccines are underway, including one that the Walter Reed Army Institute of Research is conducting on a heroin vaccine.

Recently the National Institutes of Health and the National Institute of Allergy and Infectious Diseases released a broad agency announcement to fund the development of opioid vaccines against heroin and fentanyl. This funding is set to begin in August 2020. Other academic researchers continue to publish studies focusing on development and preclinical testing of opioid vaccines.

/// OPPORTUNITIES

- **Treat at-risk patients.** Unlike some current treatment options, opioid vaccines do not carry the risk of abuse. This could allow for more effective treatment of patients at high risk of abusing another medication, such as methadone.
- **Medical advantages.** The vaccines have a long duration (months to years) of action and require limited medical supervision.
- **Compatible with other therapies.** Vaccines currently in development are targeted to illicit use of opioids such as heroin and fentanyl, and therefore do not interfere with most drug treatment or pain management therapies.
- **Protection against accidental exposure.** Vaccines could be administered prophylactically to individuals at risk of accidental exposure to opioids, such as law enforcement, military, and first responders.

/// CHALLENGES

- **Lack of broad-based effect.** Current opioid vaccines are designed against the specific chemical structure of each opioid; therefore, multiple vaccines would be needed to provide broad-spectrum

GAO-19-706SP Opioid Vaccines

Source: GAO. | GAO-20-306T

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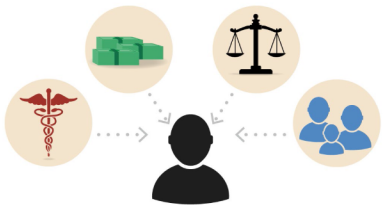
immunity. In addition, opioids such as fentanyl can be easily altered into a series of similar molecules called analogs, further complicating vaccine development.

- **Less effective in immune-compromised patients.** Patients with opioid use disorders often have other infections and altered immune responses that may limit the effectiveness of vaccines.
- **Mechanism not well understood.** The current biological mechanism of opioid vaccines is not as well understood as that of vaccines for infectious diseases.
- **Patient consent.** Consent issues could arise for people who might receive an opioid vaccine. For example, some might question a parent's right to compel their child to take a vaccine against a non-infectious agent, or an addicted person's ability to understand potential long-term effects of an opioid vaccine.
- **Interference with medical care.** If vaccines were developed against legal opioids that are used for pain management, vaccinated individuals would have a reduced risk of addiction but would also be unable to use those medications as effective treatments.
- **Insurance and payment.** Recent refusals to provide insurance to individuals who carry naloxone, used to counter opioid overdose, highlight the insurance issues surrounding opioid-related treatments. Would insurance cover an opioid vaccine? What might be the baseline costs?



Source: GAO. | GAO-19-706SP

Figure 2. Opioid vaccines will likely have a wide range of social and economic effects that could impact the individual.

/// POLICY CONTEXT AND QUESTIONS

- What means are available to facilitate the development of successful commercial opioid vaccines?
- What standards and validations should the FDA set for clinical trials of an opioid vaccine?
- When and to whom should an opioid vaccine be administered?
- What insurance coverage options are there for opioid vaccines?

/// SELECTED GAO WORK

- Drug Policy: Assessing Treatment Expansion Efforts and Drug Control Strategies and Programs, GAO-19-535T
- Opioid Crisis: Status of Public Health Emergency Authorities, GAO-18-685R
- Opioid Use Disorders: HHS Needs Measures to Assess the Effectiveness of Efforts to Expand Access to Medication-Assisted Treatment, GAO-18-44
- Opioid Addiction: Laws, Regulations, and Other Factors Can Affect Medication-Assisted Treatment Access, GAO-16-833

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Staff Acknowledgments: Karen Howard (Assistant Director), Eliot Fletcher (Analyst-in-Charge), Anika McMillon, Ben Shouse, and Jessica Smith.

GAO-19-706SP Opioid Vaccines

Source: GAO. | GAO-20-306T

Part 2 of 2

GAO | Science, Technology Assessment, and Analytics

SCIENCE & TECH SPOTLIGHT:

HYPERSONIC WEAPONS

SEPTEMBER 2019

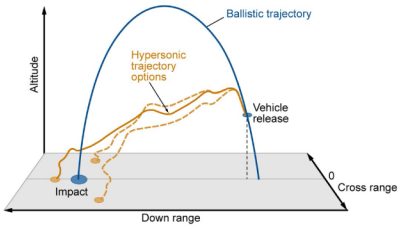
WHY THIS MATTERS

Hypersonic weapons, once developed, would fly faster than 3,800 mph and be extremely difficult to defend against. Advances in hypersonic technologies have significant implications for national security, as well as for transportation and space systems. Research and development of offensive and defensive capabilities in hypersonics is and will remain critically important.

/// THE TECHNOLOGY

What is it? Hypersonic weapons fly at least Mach 5 – five times the speed of sound, or approximately 3,800 mph. Unlike ballistic missiles, which can reach similar speeds but have a relatively fixed flight path, hypersonic weapons, once developed, would fly at lower altitudes, be highly maneuverable, and may be able to change targets during flight. This will make them extremely difficult to defend against.

How does it work? Most hypersonic weapons fall into two categories, hypersonic glide vehicles (HGVs) and hypersonic cruise missiles (HCMs).



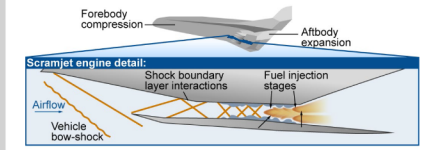
Source: GAO. | GAO-19-705SP

Figure 1. Ballistic Reentry Vehicle (RV) Versus HGV Trajectories. An RV follows a parabolic trajectory determined mainly by its launch characteristics, its target, and gravity. An HGV can take a variety of trajectories and leave its final destination ambiguous.

HGVs are unpowered and glide to their targets from a high altitude after initial launch by a rocket. They are expected to fly at altitudes between 25 and 60 miles.

HCMs are powered by high-speed engines during their entire flight. They are expected to fly at altitudes between 12 and 19 miles.

For most HCMs, a rocket would accelerate the missile to Mach 3 or 4, and then the HCM's own ramjet or supersonic combustion ramjet (scramjet) engine would take over. A ramjet uses the speed of the vehicle to "ram" and compress air with fuel, which is burned to produce thrust. A scramjet is similar, with air moving at supersonic speed.



Source: GAO. | GAO-19-705SP

Figure 2. Scramjet Engine. The air enters the inlet at a speed greater than Mach 1. It is then compressed by the engine geometry, and combustion occurs at supersonic speeds.

How mature is it? According to a U.S. Air Force Scientific Advisory Board report, domestically, the core technologies needed for the development of a tactical range HGV have reached Technology Readiness Level (TRL) 5 out of 9. The board expected the remaining subsystems for such a weapon to reach TRL 6 or higher by 2020. According to GAO best practices, TRL 7 is the level of technology maturity that constitutes a low risk for starting system development. It indicates that a technology has achieved form, fit, and function, and has been demonstrated in an operational environment.

/// OPPORTUNITIES

- **Penetrate defenses.** Hypersonic weapons would likely enable U.S. warfighters to penetrate existing adversary anti-aircraft and anti-missile systems because of their speed, maneuverability, and altitude (above typical anti-aircraft defenses and below interception points for ballistic reentry vehicles).
- **Strike fleeting targets.** The speed of hypersonic weapons would allow them to hit targets that are only vulnerable for a limited time, such as mobile, high-value military targets and adversary weapons systems.
- **Agile targeting.** A traditional missile needs to be launched with a target in mind, but a hypersonic weapon could be maneuvered later in flight. This could provide U.S. decision-makers more time and make it extremely difficult for adversaries to prepare.
- **High travel speeds.** Piloted hypersonic vehicles would allow for very short travel times and may have commercial applications. Such vehicles have essentially been limited to certain spacecraft reentering the atmosphere and experimental aircraft.

Source: GAO. | GAO-20-306T

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/// CHALLENGES

- **Heat-tolerant materials.** At hypersonic speeds, the exterior temperature of a hypersonic vehicle or weapon can exceed 2,000°F, necessitating advanced materials that will protect interior electronics. Such materials also need to be mechanically strong and efficient.
- **Propulsion technology.** Refinement of engine technology is needed for HCMs. This includes increasing the reliability and efficiency of scramjet engines. New types of engines that allow for propulsion from standstill to hypersonic speeds are also being developed, which would eliminate the need for rockets to provide the initial launch.
- **Weapon tracking.** Defense against a hypersonic weapon would involve tracking and intercepting it, but current radar and satellite systems are inadequate for this task.
- **Limited testing resources.** There are limited places to perform ground tests and flight tests of hypersonic weapons and vehicles in the United States. Currently, there are limited wind tunnel facilities in the country capable of running propulsion tests of hypersonic weapons and vehicles.
- **Safety and control.** Hypersonic velocities require additional improvements of aircraft control and guidance to help ensure the accuracy of hypersonic weapons and to avoid in-flight accidents or loss of control of hypersonic vehicles.

/// POLICY CONTEXT AND QUESTIONS

Within the Department of Defense (DOD), multiple programs by the Defense Advanced Research Projects Agency (DARPA), the Air Force, the Navy, and the Army are leading research or developing hypersonic weapons for a variety of applications and launch methods.

NASA also conducts work related to hypersonics for vehicles and spacecraft reentry into the atmosphere, both for NASA programs and in support of DOD. This includes research to safely control and guide hypersonic vehicles.

With U.S. investment in hypersonics increasing, and key technologies not yet mature, some questions for consideration include:

- What is the status of U.S. efforts to advance the science and technology needed to develop hypersonic weapons and vehicles?
- What measures are needed to ensure timely and efficient development?
- Are the development goals realistic given the current status of key technologies?
- Which federal agencies are investing in hypersonic weapons, vehicles, and related technologies, and how are these efforts coordinated?
- What are the implications of the proliferation of hypersonic weapons? What are the implications of the commercialization of hypersonic technologies and vehicles?

/// SELECTED GAO WORK

- DOD Acquisition Reform: Leadership Attention Needed to Effectively Implement Changes to Acquisition Oversight, GAO-19-439
- National Security: Long-Range Emerging Threats Facing the United States As Identified by Federal Agencies, GAO-19-204SP
- Technology Readiness Assessment Guide, GAO-16-410G

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Staff Acknowledgments: Laura Holliday (Assistant Director), Richard Horiuchi (Assistant Director), R. Scott Fletcher (Assistant Director), Anika McMillon, Ben Shouse, Jessica Smith, and Spencer Barnes.

GAO-19-705SP Hypersonic Weapons

Source: GAO. | GAO-20-306T

Part 2 of 2

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SCIENCE & TECH SPOTLIGHT:

BLOCKCHAIN & DISTRIBUTED LEDGER TECHNOLOGIES

SEPTEMBER 2019

WHY THIS MATTERS

Distributed ledger technology (e.g. blockchain) allows users to carry out digital transactions without the need for a centralized authority. It could fundamentally change the way government and industry conduct business, but questions remain about how to mitigate fraud, money laundering, and excessive energy use.

/// THE TECHNOLOGY

What is it? Distributed ledger technologies (DLT) like blockchain are a secure way of conducting and recording transfers of digital assets without the need for a central authority. DLT is "distributed" because multiple participants in a computer network (individuals, businesses, etc.), share and synchronize copies of the ledger. New transactions are added in a manner that is cryptographically secured, permanent, and visible to all participants in near real time.

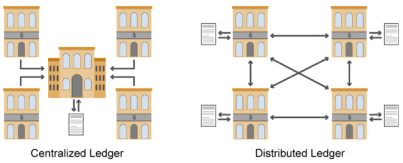

Figure 1. Difference between centralized and distributed ledgers.

How does it work? Distributed ledgers do not need a central, trusted authority because as transactions are added, they are verified using what is known as a consensus protocol. Blockchain, for example, ensures the ledger is valid because each "block" of transactions is cryptographically linked to the previous block so that any change would alert all other users. With an agreement on that history, users may then conduct a new transaction with a shared understanding of who has which resource.

Distributed ledgers can be either "permissioned" or "unpermissioned." With unpermissioned ledgers, which are generally public, any participant can conduct a transaction. Permissioned ledgers may or may not be public, but only trusted users can conduct transactions.

How mature is it? Businesses have been using ledgers to record transactions for thousands of years, and a defining characteristic of such ledgers was their reliance on central management. Furthermore, DLT is not a new technology, but an innovative way of using existing, mature technologies. In October 2008, an unknown author using the name Satoshi Nakamoto published a white paper called "Bitcoin – A Peer-to-Peer Electronic Cash System", which is credited as the first theoretical framework of a DLT. In January 2009 the service the paper described was launched.

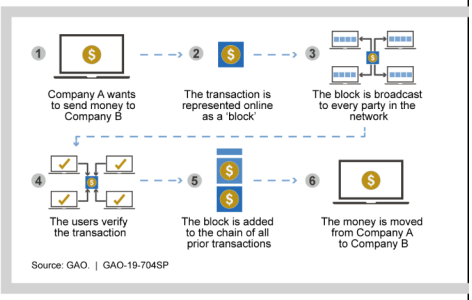

Figure 2. How blockchain, a form of distributed ledger technology, acts as a means of payment for cryptocurrencies.

Cryptocurrencies like Bitcoin are a digital representation of value and represent the best-known use case for DLT. The regulatory and legal frameworks surrounding cryptocurrencies remain fragmented across countries, with some implicitly or explicitly banning them, and others allowing them.

In addition to cryptocurrencies, there are a number of other efforts underway to make use of DLT. For example, Hyperledger Fabric is a permissioned and private blockchain framework created by the Hyperledger consortium to help develop DLT for a variety of business applications. The consortium is made up of companies such as Airbus, Cisco, American Express, IBM, and Intel.

/// OPPORTUNITIES

- **Transparency.** Because any user can view the ledger, DLT may result in benefits such as reduced corruption.
- **Reduced labor costs.** DLT reduces or eliminates the need for human workers to track data.
- **Data quality and reliability.** Transaction information is automatically generated by a computer, which may reduce errors.
- **Wide applicability.** DLT is being explored for use across many sectors, including supply chain and logistics, news, energy, healthcare, and government. For example, Target built a system now known as ConsenSource to verify products are sourced sustainably.

Source: GAO. | GAO-20-306T

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The New York Times created the News Provenance Project to explore a blockchain-based system for recording and sharing information published by news organizations.

/// CHALLENGES

- **Excessive energy usage.** Some uses of DLT can be costly to operate. For example, cryptocurrencies using "proof-of-work" consensus protocols (also known as "mining") require large amounts of computing power and energy to generate new units of currency.
- **Collusion.** Security of the network relies on the consensus protocol that maintains the ledger, and research has shown that users who collude could gain enough influence to manipulate the ledger to their benefit and gradually disrupt the protocol.
- **Security.** Entities using DLT will need to ensure data stored on a permissioned distributed ledger is not accessible to outside actors. Additionally, holders of cryptocurrency can have their digital wallets hacked and their currency stolen.
- **Permanence.** While the permanence of transactions may be a core strength of DLT, it can also be a weakness should an entity find that it needs to regularly correct errors in its ledger, as it would be unable to easily do so with DLT.
- **Lack of transparency.** Because DLT can be used without a central authority, governments may feel uncomfortable allowing cryptocurrencies (or other DLT) to be used as a method of exchange or contracting, since they cannot easily be tracked and could be used to facilitate illicit activity (such as tax evasion and money laundering).
- **Lack of regulation.** Businesses may express concern about making investments in DLT because of uncertainties surrounding how such technologies might be regulated. While there have been initial efforts to regulate cryptocurrencies such as Bitcoin, much less has been done around other DLT use cases.

Source: GAO. | GAO-19-704SP

Figure 3. Permanence and lack of transparency and regulation raise concerns about adoptability.

/// POLICY CONTEXT AND QUESTIONS

DLT use across many sectors is increasing, but challenges remain to widespread adoption. Some key questions for consideration include:

- In what situations is DLT useful, and when should it be avoided or used with caution?
- To what extent can DLT be used to facilitate illegal activities, and how might policymakers mitigate such use?
- How are federal agencies evaluating and using DLT.

/// SELECTED GAO WORK

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- Trends Affecting Government and Society: United States Government Accountability Office Strategic Plan 2018-2023, GAO-18-396SP
- Financial Technology: Information on Subsectors and Regulatory Oversight, GAO-17-351
- Virtual Currencies: Emerging Regulatory, Law Enforcement, and Consumer Protection Challenges, GAO-14-496

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Staff Acknowledgments: William Carrigg (Assistant Director), Jon Menaster (Analyst-in-Charge), Anika McMillon, Ben Shouse, and Jessica Smith.

Source: GAO. | GAO-20-306T Part 2 of 2

Appendix III: Selected GAO Science and Technology Products, Fiscal Years 2018 and 2019

Defense and Space

Army Modernization: Army Futures Command Should Take Steps to Improve Small Business Engagement for Research and Development. GAO-19-511. Washington, D.C.: Jul 17, 2019	*Defense Science and Technology: Actions Needed to Enhance Use of Laboratory Initiated Research Authority.* GAO-19-64. Washington, D.C.: Dec 20, 2018.
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Source: GAO. I GAO-20-306T

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Biological Select Agents and Toxins: Actions Needed to Improve Management of DOD's Biosafety and Biosecurity Program. GAO-18-422. Washington, D.C.: Sep. 20, 2018.	*Illicit Opioids: While Greater Attention Given to Synthetic Opioids, Agencies Need to Better Assess Their Efforts.* GAO-18-205. Washington, D.C.: Mar. 29, 2018.
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Source: GAO. I GAO-20-306T

Physical Sciences and Engineering

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Source: GAO. I GAO-20-306T

Environmental Science and Agriculture

Climate Change Adaptation: DOD Needs to Better Incorporate Adaptation into Planning and Collaboration At Overseas Installations. GAO-18-265C. Washington, D.C.: Apr. 02, 2018.	*Food Safety: USDA Should Take Further Action to Reduce Pathogens in Meat and Poultry Products.* GAO-18-272. Washington, D.C.: Mar. 19, 2018.
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Source: GAO. I GAO-20-306T

Cybersecurity

Critical Infrastructure Protection: Actions Needed to Address Significant Cybersecurity Risks Facing the Electric Grid. GAO-19-332. Washington, D.C.: Sep. 25, 2019.	*Future Warfare: Army Is Preparing for Cyber and Electronic Warfare Threats, but Needs to Fully Assess the Staffing, Equipping, and Training of New Organizations.* GAO-19-570. Washington, D.C.: Aug. 15, 2019.
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Source: GAO. I GAO-20-306T

Computer Science and Data

Face Recognition Technology: DOJ and FBI Have Taken Some Actions in Response to GAO Recommendations to Ensure Privacy and Accuracy, But Additional Work Remains. GAO-19-579T. Washington D.C.: Jun. 4, 2019.	*Workforce Automation: Better Data Needed to Assess and Plan for Effects of Advanced Technologies on Jobs.* GAO-19-257. Washington, D.C.: Mar. 7, 2019.
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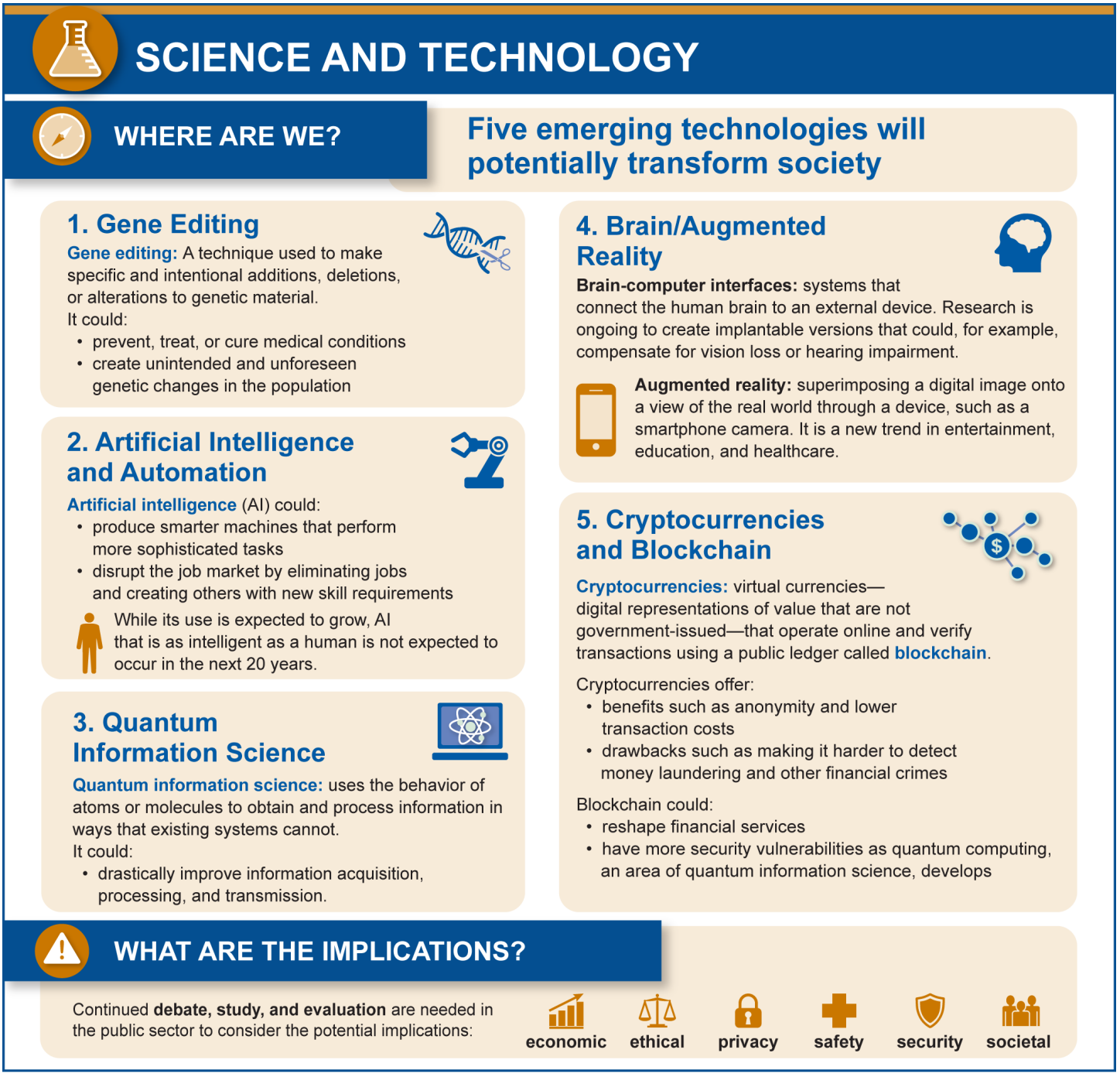
Source: GAO. I GAO-20-306T

Appendix IV: Science and Technology Trends from GAO's 2018-2023 Strategic Plan



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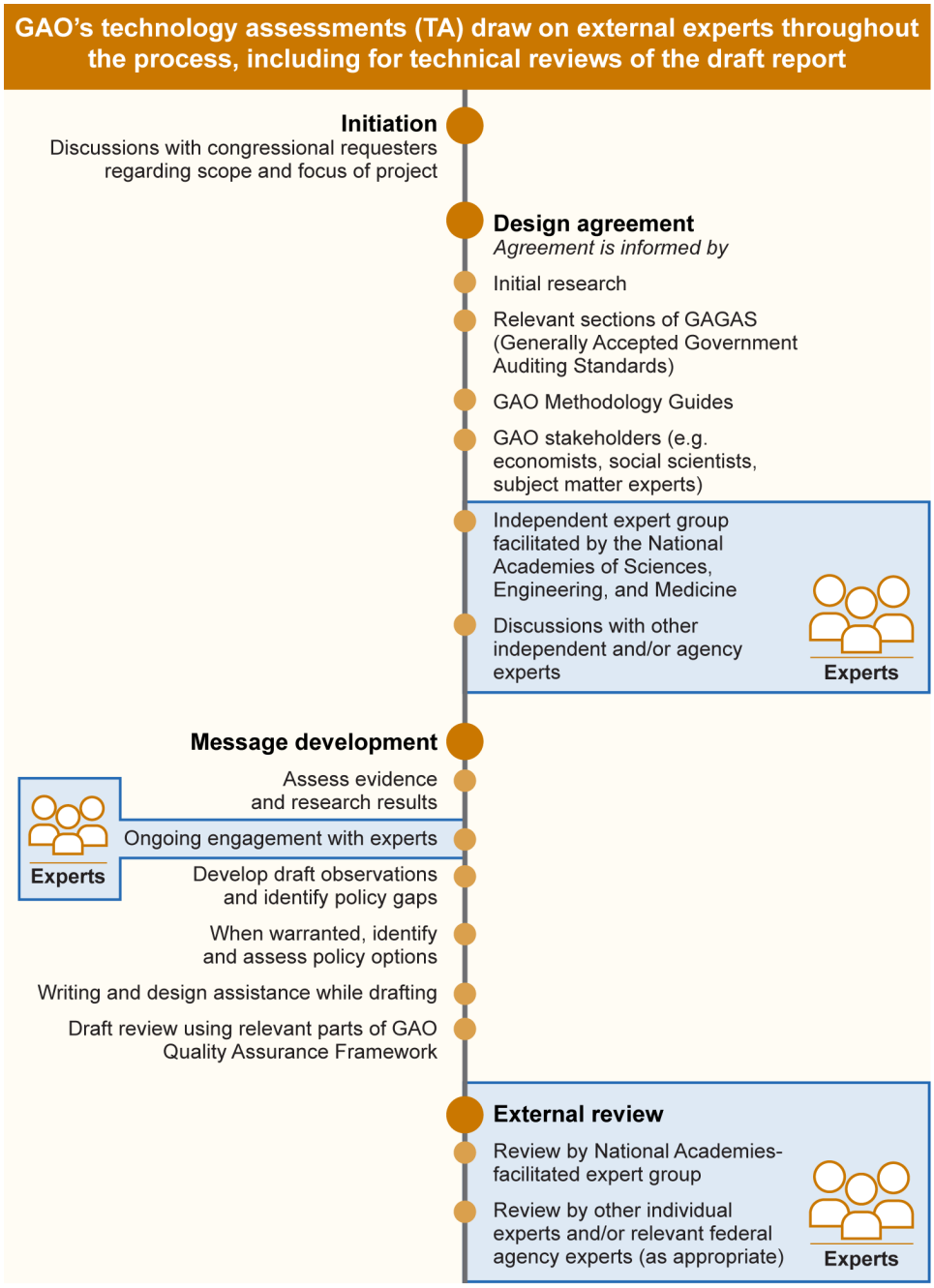
Appendix V: For Technical Reviews, GAO Involves External Experts Throughout the Engagement Process



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