



SCIENCE & TECHNOLOGY POLICY INSTITUTE

Early Stage Research and Technology at U.S. Federal Government Agencies

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Executive Summary

Federal early stage research and technology programs guide the transition between science-based inventions and usable technologies and applications. Understanding the strategies used to facilitate this transition is important to develop relevant research and development policies, programs, and projects. Federal agencies manage early stage research and technology portfolios using a variety of means, including centralized research offices or crosscutting research programs. At NASA, the early stage research and technology development portfolio is primarily managed by the Space Technology Mission Directorate (STMD). STMD crosscuts technologies and capabilities in the agency.

At the request of STMD's Early Stage Portfolio Executive, the IDA Science and Technology Policy Institute (STPI) examined the organization and management of early stage portfolios of other Federal agencies in order to inform the management of STMD's early stage research and technology development portfolio. We referred to early stage research and technology development at NASA as equivalent to research that explores basic principles (NASA Technology Readiness Level [TRL] 1), formulates a technology concept or application (TRL 2), includes analytical and experimental proof of concept (TRL 3), and includes component validation in a laboratory environment (TRL 4). Together, NASA TRLs 1–4 roughly correspond to basic and applied research at the Department of Defense and other agencies.

Using this equivalency, STPI researchers selected programs and offices across areas of national interest—defense, energy, intelligence, science, and health—that we believed to be similar to STMD's early stage programs (see the table on the next page). In addition, we examined three special topics—Innovation Corps, prizes, and evaluation of R&D programs (also shown in the table). We reviewed materials from each program, office, or area of interest, and conducted interviews to fill in aspects not available publicly. We addressed the following topics:

- Definition and Approach: How is early stage research and technology defined and organized?
- Budget: What is the early stage budget and does it vary over time?
- Personnel: What types of personnel (permanent or not) support early stage?
- Project Selection and Project Allocation: How are investments selected and allocated?

- Project Management: How is funding of projects managed once allocated?
- Transition: How do entities manage transition, if at all?
- Evaluation of Success: How do entities measure effectiveness and success?

Selected Federal Offices and Programs by Topic Area

| Topic Area | Federal Office/Program Name |
|----------------------------|---|
| Defense | Air Force Office of Scientific Research (AFOSR) |
| | Office of Naval Research (ONR) |
| | Defense Advanced Research Projects Agency (DARPA) Defense Science Office (DSO) |
| | U.S. Army Research Laboratory (ARL) Army Research Office (ARO) |
| | Multidisciplinary University Research Initiative (MURI) |
| Energy | Advanced Research Projects Agency-Energy (ARPA-E) |
| | Laboratory Directed Research and Development (LDRD) |
| Intelligence | Intelligence Advanced Research Projects Activity (IARPA) |
| | National Geospatial-Intelligence Agency Research and Development Directorate (NGA Research) |
| Science and Health | Emerging Frontiers in Research and Innovation (EFRI) at the National Science Foundation (NSF) |
| | Early Stage Technology Development at the National Institutes of Health (NIH) |
| Innovation Corps (I-Corps) | NSF |
| Use of Prizes | Various Federal agencies |
| Evaluation Metrics | R&D community |

Findings

Our findings demonstrated several common strategies across offices and programs related to the following topics of interest.

Definition and Approach

- Early stage of development meets relatively long-term needs. Definitions and philosophies differ, but, generally, early stage is thought of as research that addresses long-term future needs (at least 5 and as much as 20 years hence) and focuses on de-risking technology.
- Approach to early stage research drives organization structure. Whereas some agencies have adopted a timeline-oriented approach, others define their scope as de-risking, funding research from basic to a level where other parties, principally commercial ones, would consider investing. Further, organizations build varying levels of flexibility into their structure, where various divisions

are either limited or created and dissolved based on the changing needs of the agency.

Budget

- Funding levels vary across the Federal Government. Funding must be sufficient to draw research community interest; however, early stage funding for offices and programs typically represents a relatively small fraction of the overall research, development, and technology funding at an agency.

Personnel

- Mixed use of personnel. Offices and programs use permanent, temporary, and varying proportions of support staff; permanent staff allow for maintenance of institutional knowledge, while rotators provide a constant influx of new ideas.

Allocation and Management of Investment

- Topics are selected to support national priorities. Topics may be pulled from the general community (e.g., through broad agency announcements), from leadership within an agency, or through connections made through international offices.
- Formal connection to long-term missions. Use of topic selection and other review mechanisms allows offices and programs to solicit research in areas of principle interest to the agency; however, this strategy may be combined with an open solicitation for ideas.
- Internal and external experts are engaged for selecting topics and projects. Offices and programs engage experts to identify topics and review proposals that reflect agency priorities and emerging areas; some organizations solicit white papers from the academic community or hire rotating experts directly for their knowledge in an emerging field.
- Performers include a mix of intramural and extramural researchers. A mixture of projects are awarded from researchers from academia, industry, and government. Some programs rely entirely on academic researchers.
- Variety of funding mechanisms. Some agencies have embraced the use of prizes as an innovative way to induce breakthroughs; other organizations use particular mechanisms, such as Cooperative Research and development agreements (CRADAs), to formalize the collaborative nature of the research projects they fund.

- Flexibility in management. Certain organizations elect to provide autonomy to project managers, including allowing them to shape the early stage portfolio (e.g. number of awards, scope of research, funding amounts, research performers, and disciplines).

Transition

- Identification of transition partners. Program managers establish relationships with users both internal and external to the agency.
- Transition as an evaluative metric. Organizations track indicators of transition (e.g., memoranda of understanding and other agreements or follow-on funding from private and public actors) to evaluate the short-term success of their portfolios and projects.

Evaluation of Success

- Use of standard output measures of success or no metrics at all. Measures focus on near-term outputs (e.g. publications, patents, licenses), and some offices or programs do not use metrics at all, rather they focus on outliers to effectively communicate narratives of impact.
- Specific target “success” rates are uncommon. Only a handful formally define what success means on the organizational level. Some cautioned that if targets for success are too high, the research might not be sufficiently high risk.

In addition, we identified several notable practices that were less common. While they likely depend on the context of the agency or its mission, we felt they were worthwhile to mention. They include:

- Use of tournaments to encourage competition. IARPA uses tournaments to select multiple performers (teams) to solve the same challenge. Program managers continue funding research teams that perform better than others do, measuring all teams against project milestones and culling performers who are not meeting targets.
- Seeking international input. AFOSR maintains three foreign technology offices (located in London, England; Tokyo, Japan; and Santiago, Chile) to coordinate with the international scientific and engineering community to allow for better collaboration between the communities and U.S. Air Force personnel.
- Focus on program managers rather than project-level performance indicators. Epitomized by DARPA, but also adopted by other offices, such as ONR, offices hire visionary program managers and assess their performance based on the

overall research goals and management of their portfolio, rather than solely on project-level success metrics.

- Labor-intensive program management. A number of organizations engage in active and labor-intensive project management that involves continual and frequent evaluation against milestones. These programs are highly hands-on, with strong communication across the early stage program managers and leadership. Other organizations provide minimal management once projects have been awarded.
- Designating a transition role or responsibility. Offices and programs with goals to commercialize their products, such as ARPA-E, established a position or role within research teams to assist in transitioning the science-based inventions to application. NGA Research devotes resources, including both people and funds, to useful technologies, and relies on transitioning people to serve as the champions of those technologies in other locations at NGA.
- Funding investigator-initiated research. Both NGA Research and Department of Energy's LDRD support investigator-initiated research to bolster morale, recruitment, and retention. NGA Research provides up to 20 percent of staff time for independent research, while LDRD can make up the entirety of an employee's time.
- Mandating multidisciplinary teams. A number of programs prioritize interdisciplinary projects, cited as a proxy for potentially high-risk, high-reward research. The NSF's EFRI program, for example, mandates multidisciplinary in its proposals.

Finally, STPI developed the following series of questions related to these topics of interest to help spur dialogue across the community of early stage research and technology managers and stakeholders. The answers to these questions could support further understanding of dependencies across the topics of interest and their influence on the management of early stage research and technology development portfolios.

- *Definition and Approach: How do organizational context and differences in mission/objectives influence the core approach to early stage research and technology programs and portfolios?*
- *Budget: How do yearly budget profiles influence early stage research and technology program management and approach?*
- *Personnel: How does the use and management of the technical and support staff in your organization support the missions of the agency?*
- *Allocation and Management of Investment: What is unique about the program's selection process that enables early stage research? What are best practices for*

determining cutting-edge, early stage topics and selecting projects to move the field forward? What are effective funding mechanisms to spur early stage research and technology?

- *Transition: What role does transition play in the program, and how can goals for transition be integrated into program management and evaluation?*
- *Evaluation of Success: How are metrics and targets used to evaluate outcomes and provide guidance throughout the management of early stage programs and portfolios?*

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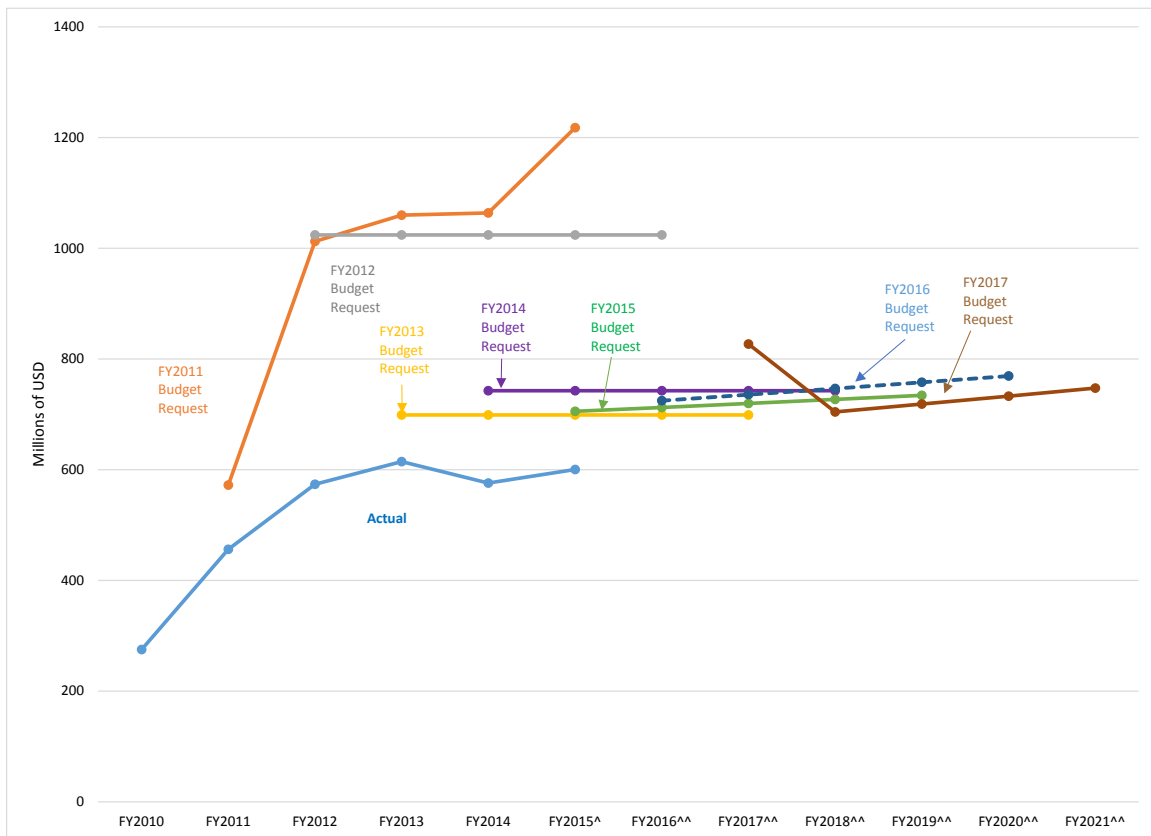
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1. Introduction

The Space Technology Mission Directorate (STMD) of the National Aeronautics and Space Administration (NASA) was formally created in 2013 to develop crosscutting and pioneering technologies and capabilities in the agency. Fiscal year (FY) 2015 technology funding for STMD was \$600.3 million (Figure 1).^{1, 2}



Source: NASA Budget Data

Note: STMD's precursor, which was established within the Office of the Chief Technologist in 2010, was renamed STMD in 2013.

Figure 1. Requested and Appropriated STMD Budget over Time

¹ More information on NASA's technology budget can be found in NASA Office of Inspector General (2015).

² NASA's technology budget is not the same as its research and development (R&D) budget, which is about \$12 billion. See American Association for the Advancement of Science (AAAS) 2016, 10, Table 1.

Three of STMD’s ten programs—the Space Technology Research Grants, Center Innovation Fund, and NASA Innovative Advanced Concepts—are devoted to research for NASA Technology Readiness Levels (TRLs) 1–4 and comprise most of STMD’s early stage portfolio. As Table 1 shows, the three programs together (shaded in the table) add up to about \$44 million, or less than 5 percent of NASA’s technology development portfolio and about 7 percent of the STMD technology portfolio (in FY 2015).

Table 1. Overview of NASA’s Space-Related Technology Development Programs (FY 2015)

| Program | FY 2015 Funding (\$ millions) |
|--|----------------------------------|
| Space Technology Mission Directorate (STMD) Total Funding for Technology Development | \$600.3 |
| Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) | \$190.7 |
| Technology Demonstration Missions (TDMs) | \$161.9 |
| Game Changing Development (GCD) | \$125.6 |
| Space Technology Research Grants (STRG) | \$23.7 |
| Office of Chief Technologist | \$31.3 |
| Small Spacecraft Technology | \$19.3 |
| Center Innovation Fund (CIF) | \$12.9 |
| Flight Opportunities | \$10.0 |
| NASA Innovative Advanced Concepts (NIAC) | \$7.0 |
| Centennial Challenges | \$4.2 |
| Human Exploration and Operations (HEO) Mission Directorate Total Funding for Technology Development | \$170.9 |
| Advanced Exploration Systems (AES) | \$170.9 |
| Science Mission Directorate (SMD) Total Funding for Technology Development | \$179.1 |
| Astrophysics | \$65.7 |
| Earth Science | \$59.7 |
| Planetary Science | \$49.0 |
| Heliophysics | \$4.7 |
| Total FY 2015 Funding for NASA’s Space-Related Technology Development Programs | \$950.3 |

Source: NASA Office of the Inspector General (2015, Table 7).

Note: the three STMD programs devoted to research for NASA TRLs 1–4 are shaded grey.

As part of an internal review, the STMD Early Stage Portfolio Executive requested that the IDA Science and Technology Policy Institute (STPI) examine the organization and management of early stage portfolios of other agencies in the Federal Government so that NASA can assess similarities and differences with its own portfolio, and possibly learn from other agencies’ experiences.

A. Space Technology Mission Directorate’s Early Stage Portfolio

NASA does not have a formal definition of early stage research and technology; however, the following three programs comprise the bulk of the STMD early stage portfolio:³

- ***Space Technology Research Grants (STRG) Program.*** The goal of the STRG program is to “accelerate the development of low-TRL space technologies to enable future systems capabilities and missions for NASA, other government agencies and the commercial space sector.”⁴ The STRG program focuses on “push” technologies.
- ***Center Innovation Fund (CIF).*** The goal of the CIF is to stimulate and encourage creativity and innovation *within the NASA Centers* in addressing the technology needs of both NASA and the United States. Projects are not required to be at a certain TRL; however, the vast majority (~95 percent) of the projects fall within TRL 1–4.⁵
- ***NASA Innovative Advanced Concepts (NIAC).*** The goal of the NIAC is to support early studies of visionary concepts that are revolutionary, yet technically substantiated, in very early development (TRLs 1, 2, or early 3; aiming for mission integration 10 or more years out) and to be analyzed in a mission context.^{6, 7}

B. Project Goals

The goal of this project was to investigate early stage research and technology development programs and portfolios in other organizations, such that STMD and its early stage portfolio leadership can assess similarities or differences with its own programs, and learn from their experiences. In particular, the following areas are of interest:

³ NASA (2017c) contains additional information about NASA’s STMD organization.

⁴ The TRLs of STRG projects were not available publicly, and STPI was unable to interview the STRG program manager. More information about STRG can be found at NASA, Space Technology Research Grants (STRG),” <https://www.nasa.gov/directorates/spacetech/strg/index.html>.

⁵ More information about the CIF can be found at NASA, “STMD: Center Innovation Fund,” https://www.nasa.gov/directorates/spacetech/innovation_fund/index.html.

⁶ NASA classifies its space technology development programs and projects into nine TRLs. For a project at TRL 1, “basic principles are observed and reported”; at TRL 2, “technology concept and/or application formulated”; and at TRL 3, “analytical and experimental critical function and/or characteristic proof of concept.”

⁷ More information about NIAC can be found at NASA, “STMD: NIAC,” <https://www.nasa.gov/content/niac-overview>.

- *Definition and Approach: How is research and technology development at various entities defined and organized? In practice, are these just different labels for the same activities? Alternatively, are there fundamentally different definitions, organization, or management approaches? Are there any stated rationales for the above categories or their funding profiles?*
- *Budget: Roughly what percentage of the entities' overall budgets are dedicated to research and technology development? Roughly what percentage of that is "early stage"? Do early stage investment profiles vary much over time? Do the total research and technology budgets fluctuate or stay relatively constant? Are the funding distributions within a given budget typically stable or volatile? Are there any notable trends, either global or for types of research and technology entities?*
- *Personnel: What types of personnel (permanent or not) support early stage? What are their roles and how do they help guide early stage portfolios, programs, and projects?*
- *Allocation and Management of Investment: How do funding entities choose their early stage investments? What influences "make-buy" (in-house vs. external) decisions for pursuing new technology developments? Are there categories that are typically outsourced or researched internally? If so, is this due to availability of expertise, facilities, data, sensitivity, or other factors?*
- *Transition: How do entities manage transition, if at all? Is transition a goal? How do programs and projects identify and collaborate with potential transition partners?*
- *Evaluation of Success: Do the entities state expectations about, or attempt to measure or estimate, the effectiveness, return on investment, throughput, or other indicators of success or productivity for their early stage programs or investments?⁸ Roughly what percentage of "early stage" activities are considered "successful" (i.e., produce a product or other tangible/intangible outcome that the entity considers positive)? Do any of the entities included have their own early stage management lessons learned that NASA should consider?*

⁸ The terms *metrics*, *measures*, and *indicators* are used interchangeably in this report. *Indicator* refers to a variable or attribute (quantitative or qualitative) that is intended to reflect progress toward certain goals. Indicators are meant to have predictive power, or to be able to reliably demonstrate some quality of the system. The use of the term *indicator* includes a sense of how or whether a system is progressing toward certain goals. Indicators are related to, but distinct from metrics, which are defined as any objectively measurable variable or attribute. Metrics are descriptive, but do not necessarily demonstrate changes in a system. Indicators can be based on metrics (e.g., increasing number of citations to an organization's funded research could be an indicator of quality, while publication rate alone would be a metric).

C. Definitions, Approach, and Report Organization

In order to identify lessons and best practices from across the Federal Government, our first challenge was to identify programs that could be considered similar enough to those as in STMD’s early stage portfolio. This was difficult in part because the rest of the government does not necessarily use the same terminology and definitions as NASA to identify its early stage portfolio.

The terms *research* and *development* have specific definitions in the R&D community.⁹ *Research*, defined as the “systematic study directed toward more complete scientific knowledge or understanding of the subject studied,” comprises early stage research and technology development, the target of this project.¹⁰ Different agencies, however, have different way of categorizing research. NASA tends to use the TRL scale (Table 2).

Table 2. NASA Definitions of Technology Readiness Levels (TRLs)

| TRL | Description |
|-----|---|
| 1 | Basic principles observed and reported |
| 2 | Technology concept and/or application formulated |
| 3 | Analytical and experimental critical function and/or characteristic |
| 4 | Component and/or breadboard validation in laboratory environment |
| 5 | Component and/or breadboard validation in relevant environment |
| 6 | System/subsystem model or prototype demonstration in a relevant environment (ground or space) |
| 7 | System prototype demonstration in a space environment |
| 8 | Actual system completed and “flight qualified” through test and demonstration (ground or space) |
| 9 | Actual system “flight proven” through successful mission operations |

Source: NASA (2012).

The Department of Defense (DOD), on the other hand, uses a numeric budget-driven continuum for its science and technology (S&T) efforts where basic research is labeled as

⁹ *Research* and *development* are defined by the Office of Management and Budget (OMB) Circular No. A–11 (OMB 2015, 8, Section 84).

¹⁰ The Federal Government classifies research as either basic or applied according to the objective of the sponsoring agency. In basic research the objective is to gain knowledge or understanding of phenomena without specific applications in mind. In applied research the objective is to gain knowledge or understanding necessary for meeting a specific need. More information can be found at AAAS. “R&D Budget and Policy Program: Definitions of Key Terms,” <http://www.aaas.org/page/definitions-key-terms>.

6.1, applied research as 6.2, technology development as 6.3, and so on.¹¹ The “DOD Financial Management Regulation” defines 6.1 and 6.2 research as follows (DOD 2011a, Vol. 6B, Chap. 11):

- **Basic (6.1):** Systematic study to gain knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications, processes, or products in mind. Basic research involves the gathering of a fuller knowledge or understanding of the subject under study. Major outputs are scientific studies and research papers.
- **Applied (6.2):** Systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met. It is the practical application of such knowledge or understanding for the purpose of meeting a recognized need. This research points to specific military needs with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters. Major outputs are scientific studies, investigations, and research papers, hardware components, software codes, and limited construction of, or part of, a weapon system to include non-system-specific development efforts.

The DOD schema does not directly translate on a one-to-one basis to NASA’s TRLs. However, the DOD has adopted TRL terminology in its “Technology Readiness Assessment (TRA) Guidance.” TRL 1 is listed as including observation and reporting of basic principles; TRL 2, as including formulation of technology concept and/or application; TRL 3, as including an analytical and experimental critical function and/or characteristic proof of concept; and TRL 4, as including component and/or breadboard validation in a laboratory environment (DOD 2011b).

In a 2010 report, the National Research Council (NRC) attempted to create the mapping between DOD and NASA scales (NRC 2010, Appendix D).

- **6.1: Basic research, typically associated with TRLs 1 and 2**, in which new scientific phenomena are sought in an effort to discover and advance fundamental knowledge in fields important to national defense. Such research is generally broad in nature, and because of its low TRL, can be considered inherently “high risk.”
- **6.2: Applied research (also called exploratory development), typically associated with TRLs 3 and 4**, in which technology is developed based on a

¹¹ “DOD defines basic research as systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and/or observable facts without specific applications toward processes or products in mind. With very few exceptions, the results of basic research will not be classified or restricted, and are reported in the open literature” (Murday 2016, 3).

newly discovered scientific phenomenon, or by the application of scientific phenomena in an entirely different manner than currently applied.

- **6.3: *Advanced technology development, typically associated with TRLs 5 and 6***, in which multiple technologies (often from cross disciplines) are integrated and demonstrated to enable the development of a new military capability to satisfy a military need.

Based on both DOD and NRC inputs, we have assumed that early stage research at NASA (TRLs 1–4) corresponds roughly to research at the 6.1–6.2 levels at the DOD and other agencies.

Using this equivalency, STPI researchers selected Federal programs and offices that we believe are similar enough to programs within the STMD early stage portfolio to provide insights for NASA (Table 3). The programs and offices fall into broad areas of national interest—defense, energy, intelligence, science, and health. In addition, we examined three special topics of interest: Innovation Corps, prizes, and program evaluation metrics. We reviewed materials from each program, office, or area of interest, and conducted interviews to fill in aspects not available publicly. It is important to note that most findings come from interviews. When a finding comes specifically from the literature or a public source, it is cited. Findings are summarized in case studies of each program in Chapters 2–5, which are organized by topic. Chapter 6 contains information about the three special topics of interest. In Chapter 7, we summarize overall findings in terms of the project’s six areas of interest explored and provide potential next steps. Appendix A contains graphics from various sources that together summarize Federal R&D data. Appendix B reproduces a summary of evaluation best practices from the American Evaluation Association, and Appendix C summarizes insights from a review of literature on the private sector, which should be considered a work in progress.

Table 3. Selected Federal Offices and Programs by Topic Area

| Topic Area | Federal Office/Program Name |
|----------------------------|---|
| Defense | Air Force Office of Scientific Research (AFOSR) |
| | Office of Naval Research (ONR) |
| | Defense Advanced Research Projects Agency (DARPA) Defense Science Office (DSO) |
| | U.S. Army Research Laboratory (ARL) Army Research Office (ARO) |
| | Multidisciplinary University Research Initiative (MURI) |
| Energy | Advanced Research Projects Agency-Energy (ARPA-E) |
| | Laboratory Directed Research and Development (LDRD) |
| Intelligence | Intelligence Advanced Research Projects Activity (IARPA) |
| | National Geospatial-Intelligence Agency Research and Development Directorate (NGA Research) |
| Science and Health | Emerging Frontiers in Research and Innovation (EFRI) at the National Science Foundation (NSF) |
| | Early Stage Technology Development at the National Institutes of Health (NIH) |
| Innovation Corps (I-Corps) | Various Federal agencies |
| Use of Prizes | Various Federal agencies |
| Evaluation Metrics | R&D community |

2. Early Stage Research at the Department of Defense

A. Introduction

The Department of Defense (DOD) is the largest Federal sponsor of research and development (R&D),¹² mostly through its Research, Development, Test, and Evaluation (RDT&E) budget accounts. The DOD divides its RDT&E budget using a scale from 6.1 to 6.7, where 6.1 comprises basic research, 6.2 applied research, 6.3 advanced technology development, and so on. The DOD refers to the 6.1, 6.2, and 6.3 research portfolios collectively as the science and technology (S&T) program; however, the majority of the RDT&E budget is devoted to weapon and vehicle technology development, or 6.4 to 6.7 funding. The mission of the DOD S&T program is to “invest in and develop capabilities that advance the technical superiority of the U.S. military to counter new and emerging threats” (Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer 2014).

DOD Financial Management Regulation defines basic research, applied research, and advanced technology development as follows (DOD 2011a, Vol. 2B, Chap. 5; NRC 2010):

6.1: Basic research: “Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and/or observable facts without specific applications toward processes or products in mind” (*TRLs 1 and 2*).

6.2: Applied research: “Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met” (*TRLs 3 and 4*).

6.3: Advanced technology development: “Includes all efforts that have moved into the development and integration of hardware for field experiments and tests” (*TRLs 5 and 6*).

The full list of definitions can be found in Table 4.

¹² Throughout the report, we use the term *R&D* to signify early stage research and technology developments that are appropriate to each agency.

Table 4. DOD RDT&E Funding Classification System

| | Classification | Description |
|--|---|--|
| Science and Technology Activities | Basic Research (6.1) | Scientific study for greater understanding of phenomena without specific applications in mind. Farsighted, high payoff research. |
| | Applied Research (6.2) | Expansion and application of knowledge to understand the means to meet a specific need. Development of useful materials, devices, systems, or methods. Official RDT&E estimates of 6.2 do not include Defense Health Research, though this program is included in overall AAAS estimates of the total DOD science and technology budget. |
| | Advanced Technology Development (6.3) | Development and integration of subsystems and components into model prototypes for field experiments and/or tests in a simulated environment. Proof-of-concept testing. |
| Weapons Development Activities | Advanced Component Development and Prototypes (6.4) | Evaluation of integrated technologies or prototypes in realistic operating environments. Technology transitions from laboratory to operational use. |
| | System Development and Demonstration (6.5) | Development of mature systems in preparation for actual production. Prototype performance established at or near planned operational system levels, including live fire testing. |
| | RDT&E Management Support (6.6) | Funds to sustain or modernize installations or operations for the performance of general RDT&E, including test ranges, military construction, and maintenance for laboratories and test vehicles. |
| | Operational System Development (6.7) | Scientific study for greater understanding of phenomena without specific applications in mind. Far-sighted, high-payoff research. |

Source: Adapted from Doom (2015).

In FY 2015, the total estimated funding for R&D (RDT&E plus Medical Research and other appropriations) at the DOD was \$66.09 billion (Table 5). Research funding (6.1–6.2) represents 10 percent of the total R&D budget with \$6.93 billion. From FY 2014 to FY 2016, basic research (6.1) remained relatively constant, while research (6.1–6.2) increased by almost 3 percent.

Table 5. DOD Research and Development (R&D) Budget (\$ millions)

| | FY 2014 Actual | FY 2015 Estimates | FY 2016 Budget | FY 2014– 16 Change (Percent) |
|---|-------------------|----------------------|-------------------|------------------------------------|
| Basic Research (6.1) | 2,096 | 2,278 | 2,089 | –0.34% |
| Applied Research (6.2) | 4,523 | 4,648 | 4,713 | 4.0% |
| Total Research (6.1–6.2) | 6,618 | 6,925 | 6,802 | 2.7% |
| Advanced Technology Development (6.3) | 5,102 | 5,326 | 5,464 | 6.6% |
| Total Science & Technology (6.1–6.3) | 11,721 | 12,252 | 12,266 | 4.4% |
| Advanced Component Development (6.4) | 11,655 | 12,491 | 14,404 | 19.1% |
| System Development and Demonstration (6.5) | 11,154 | 11,112 | 12,771 | 12.7% |
| Management Support (6.6) | 5,296 | 4,396 | 4,185 | –26.6% |
| Operational System Development (6.7) | 7,530 | 8,098 | 8,560 | 12.0% |
| Classified Programs (999) | 16,102 | 15,657 | 17,791 | 9.5% |
| <i>Budget Authority Adjustment*</i> | 25 | –184 | –191 | — |
| Total RDT&E (6.1–6.7 and classified) | 63,483 | 63,823 | 69,785 | 9.0% |
| Medical Research† | 1,226 | 1,194 | 940 | –30.4% |
| Other Appropriations‡ | 1,311 | 1,074 | 1,203 | –9.0% |
| Total DOD R&D | 66,020 | 66,091 | 71,928 | 8.2% |

Source: American Association for the Advancement of Science (AAAS 2016, Agency Budgets: Chapter 11, Department of Defense, Table 1).

Note: All figures are rounded to the nearest million dollars. Changes from FY 2015 to FY 2016 are calculated from unrounded figures and changes from FY 2014 to FY 2016 are calculated from rounded figures.

* Budget Authority Adjustment converts Total Obligation Authority (TOA) into budget authority.

† Medical research is appropriated in Defense Health Program, not RDT&E, and is included in total “DOD S&T” figures.

‡ R&D support in military personnel, construction, chemical agents, and munitions destruction, and other programs are included in the “Other Appropriations” figures.

The DOD’s research budget (6.1–6.2) is distributed across the three military Services and the other defense agencies,¹³ representing 66 percent and 33 percent of the research budget, respectively (Table 6). The three Services split the 66 percent more or less equally; Army represents 21 percent, Navy represents 22 percent, and Air Force represents 24 percent.

¹³ Defense agencies are established as DOD Components by law, the President, or the Secretary of Defense, is to provide for the performance, on a DOD-wide basis, of a supply or service activity that is common to more than one Service when it is determined to be more effective, economical, or efficient to do so, or when a responsibility or function is more appropriately assigned to a defense agency. Each defense agency operates under the authority, direction, and control of the Secretary of Defense, through a Principal Staff Assistant in the Office of the Secretary of Defense. Examples of defense agencies include the Defense Advanced Research Projects Agency (DARPA) and the Defense Intelligence Agency (DIA).

Table 6. DOD Science and Technology (S&T) Budget (\$ millions)

| | FY 2014 Actual | FY 2015 Estimates | FY 2016 Budget |
|---------------------------------------|---------------------------|------------------------------|---------------------------|
| Army | 2,401 | 2,555 | 2,201 |
| Basic Research (6.1) | 425 | 460 | 425 |
| Applied Research (6.2) | 931 | 981 | 880 |
| Advanced Technology Development (6.3) | 1,045 | 1,113 | 896 |
| Navy | 2,071 | 2,155 | 2,114 |
| Basic Research (6.1) | 604 | 650 | 587 |
| Applied Research (6.2) | 844 | 870 | 865 |
| Advanced Technology Development (6.3) | 623 | 635 | 663 |
| Air Force | 2,260 | 2,282 | 2,378 |
| Basic Research (6.1) | 511 | 551 | 485 |
| Applied Research (6.2) | 1,124 | 1,101 | 1,217 |
| Advanced Technology Development (6.3) | 624 | 630 | 676 |
| Defense Agencies | 4,989 | 5,260 | 5,573 |
| Basic Research (6.1) | 555 | 616 | 592 |
| Applied Research (6.2) | 1,623 | 1,696 | 1,752 |
| Advanced Technology Development (6.3) | 2,810 | 2,948 | 3,230 |
| Total 6.1–6.3 | 11,721 | 12,252 | 12,266 |
| Medical research* | 1,226 | 1,194 | 940 |
| Total DOD S&T | 12,947 | 13,446 | 13,206 |

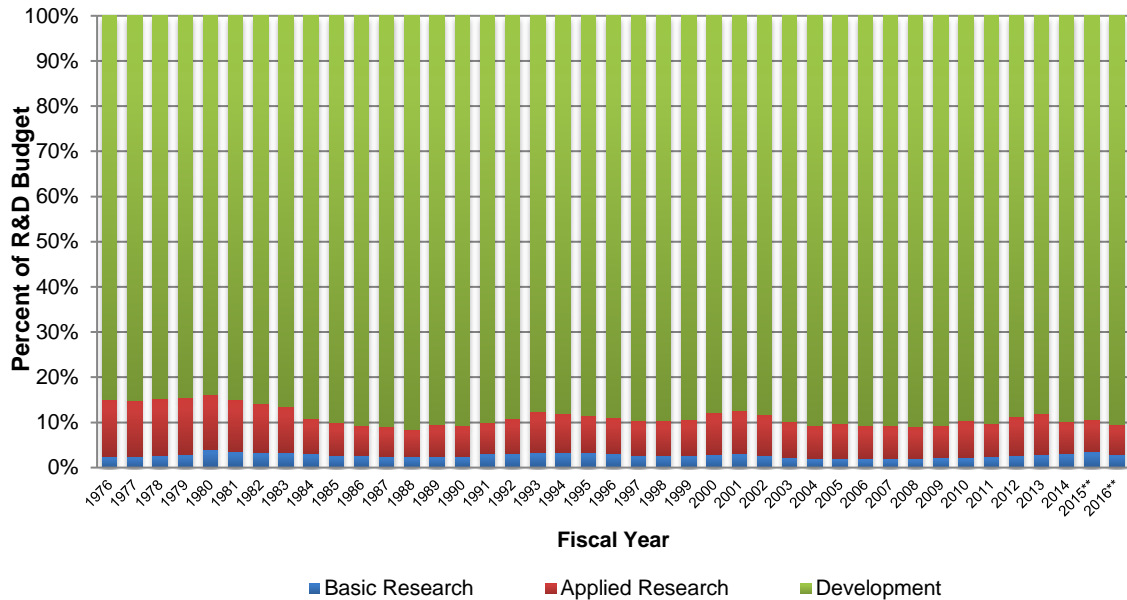
Source: American Association for the Advancement of Science (AAAS 2016, Agency Budgets: Chapter 11, Department of Defense, Table 2).

Note: All figures are rounded to the nearest million dollars.

* Medical research is appropriated in Defense Health Program, not RDT&E

The DOD’s basic research (6.1) budget increased 17.5 percent between FYs 2007 and 2017, while its applied research (6.2) budget decreased by 19.6 percent. Its S&T budget decreased by 16 percent and overall R&D budget decreased by 18 percent. Figure 2 shows a breakdown of the DOD’s R&D budget from FY 1976 to FY 2016 and Figure 3 and Table 7 show a breakdown of the DOD’s S&T budget from FY 1990 to FY 2017.

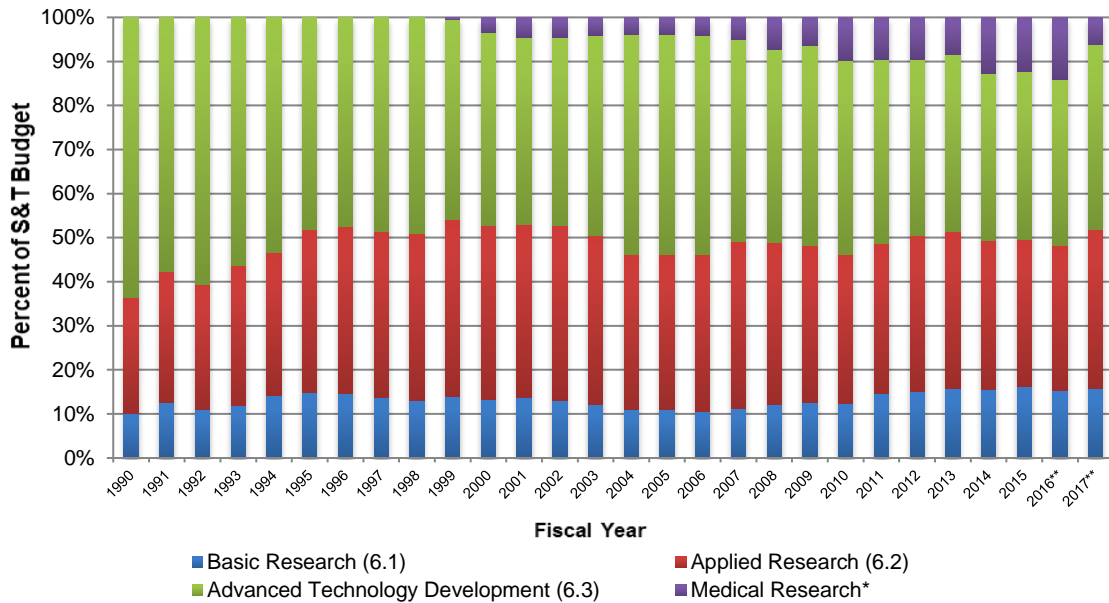
The percentage of the DOD’s S&T budget devoted to basic research (6.1) has increased from 10.2 percent to 15.8 percent since 1990. The applied research (6.2) percentage has also increased—from 26.2 percent to 36.1 percent. The DOD’s long-term goal is to ensure that 6.1 research be about 16 percent of the S&T (6.1–6.3) budget; in FY 2017, it is expected to be 15.8 percent.



Source: AAAS (2017), OMB and agency R&D budget data. Includes conduct of R&D and R&D facilities.

* Latest estimates. FY 2016 is the President's request.

Figure 2. Department of Defense R&D Budget, 1976–2016



Source: AAAS (2017) and agency budget data. Constant dollar conversions based on OMB's GDP deflators from the FY 2017 budget.

* Medical research is appropriated outside RDT&E; appropriated in 6.2 accounts before 1999.

** Latest estimates. FY 2017 is the President's request.

Figure 3. Department of Defense S&T Budget, 1990–2017

Table 7. DOD Science and Technology (S&T) Budget, 1990–2017 (\$ millions 2016)

| | Percent of S&T Budget by Fiscal Year | | | | | | | |
|---------------------------------------|--------------------------------------|------|------|------|------|------|-------|-------|
| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016* | 2017* |
| Basic Research (6.1) | 10.2 | 14.9 | 13.2 | 10.9 | 12.3 | 16.1 | 15.2 | 15.8 |
| Applied Research (6.2) | 26.2 | 37.1 | 39.6 | 35.3 | 33.8 | 33.4 | 33.0 | 36.1 |
| Advanced Technology Development (6.3) | 63.6 | 48.1 | 43.8 | 49.9 | 44.1 | 38.1 | 37.8 | 41.9 |
| Medical Research** | 0.0 | 0.0 | 3.4 | 3.9 | 9.8 | 12.4 | 14.0 | 6.2 |

Source: AAAS (2017) and agency budget data. Constant dollar conversions based on OMB's GDP deflators from the FY 2017 budget.

* Latest estimates. FY 2017 is the President's request.

** Medical research is appropriated outside RDT&E; appropriated in 6.2 accounts before 1999.

The DOD's research management is highly decentralized; it is spread across the three military Services and the Office of the Secretary of Defense with voluntary coordination.

The Air Force Research Laboratory (AFRL), headquartered at Wright-Patterson Air Force Base, manages Air Force S&T (6.1–6.3). The AFRL comprises ten subcomponents—the Air Force Office of Scientific Research (AFOSR) and nine Technology Directorates.¹⁴ The AFRL conducts intramural research and outsources about 75 percent of its S&T budget to academia, industry, and the international community. Air Force basic research is primarily managed by AFOSR.

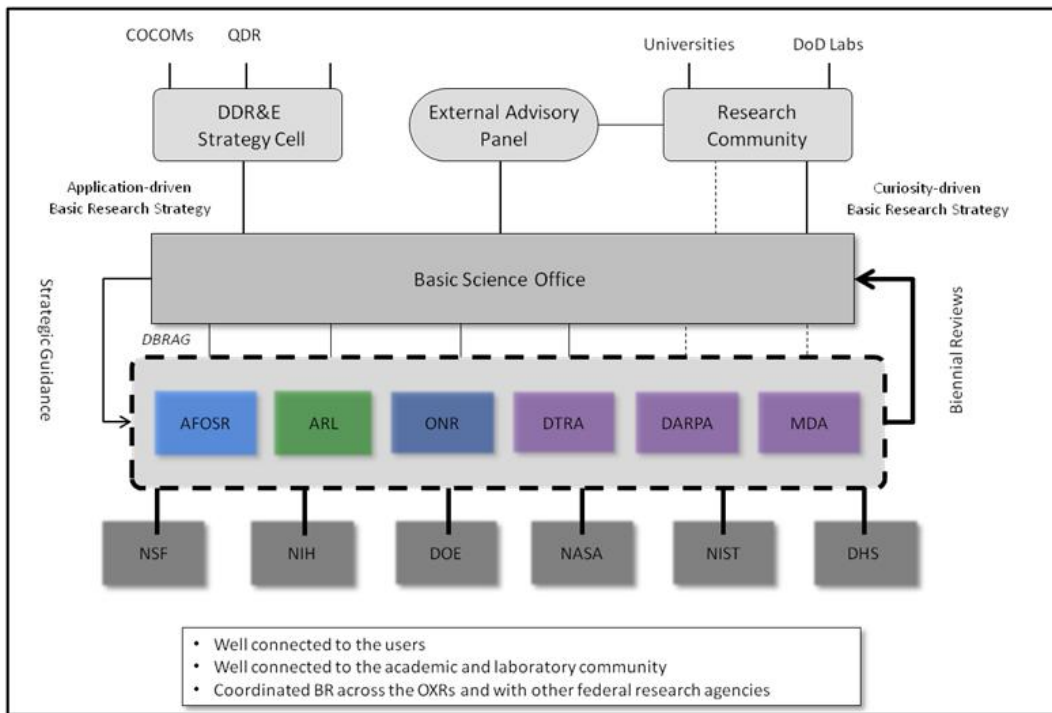
The Office of Naval Research (ONR) is responsible for all funding of Navy S&T (6.1–6.3). ONR is divided into two directorates—the Offices of Research and Technology—and six S&T departments. The S&T departments have access to all three phases of developmental funding (6.1–6.3). Intramural basic research is primarily performed by the Naval Research Laboratory (NRL).

High-level oversight for Army basic and applied research is provided by the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, but much of the program management is handled by other organizations, including the Research, Development, and Engineering Command (RDECOM). Under RDECOM, intramural funding is executed by the Army Research Laboratory (ARL) and extramural funding is executed by the Army Research Office (ARO). ARL is the Army's corporate basic and applied research laboratory. The ARL directorates, while having primary responsibility for ARL's in-house research programs, also manage select extramural basic research

¹⁴ The directorates are the 711th Human Performance Wing (711HPW) (WPAFB and Fort Sam Huston, TX), Aerospace Systems Directorate (WPAFB and Edwards AFB), Air Force Office of Scientific Research (AFOSR) (Arlington, VA), Directed Energy Directorate (Kirtland AFB, NM and Maui, HI), Information Directorate (Rome, NY), Materials and Manufacturing Directorate (WPAFB), Munitions Directorate (Eglin AFB, FL), Sensors Directorate (WPAFB), and Space Vehicles Directorate (Kirtland Air Force Base, NM). Wright-Patterson Air Force Base (2016).

programs. The Medical Research and Materiel Command (MRMC), Engineer Research and Development Center (ERDC), Army Research Institute (ARI) for the Behavioral and Social Sciences, and the Army Space and Missile Defense Technical Center manage the remainder of the Army basic research budget.

At the level of the Office of the Secretary of Defense, the Defense Advanced Research Projects Agency (DARPA) and the Defense Threat Reduction Agency (DTRA) manage basic and applied research, and advanced development programs. DARPA and DTRA fund both extramural researchers and researchers at the DOD laboratories. Figure 4 displays the DOD research enterprise.



Source: Gluck, Balakrishnan, Fisher, et al. (2011, Figure 8-2).

Note: See the list of abbreviations at the back of this paper for the meanings of abbreviations used here.

Figure 4. DOD Research Organization

The DOD supports research performed at its laboratory facilities, University Affiliated Research Centers (UARCs), and federally funded research and development centers. It uses a variety of funding mechanisms, including Broad Agency Announcements (BAAs), contracts, cooperative agreements, and grants.

In the following sections, we provide five case studies that are relevant to and may have lessons for programs in NASA’s early stage portfolio. They cover the range of DOD research organizations. It is important to note again that most findings come from

interviews, and may not represent the views of others within or outside the organization being discussed.

B. Case Study: Air Force Office of Scientific Research (AFOSR)

The Air Force Office of Scientific Research (AFOSR) is the Directorate within the Air Force Research Laboratory (AFRL) that manages the Air Force basic research programs.¹⁵ Its mission is to “discover, shape, and champion basic research that has the potential to produce revolutionary new capabilities for the Air Force” (Kaper 2015).

AFOSR is primarily a funding body for external research (70 percent extramural funding), while the other AFRL directorates perform research in-house or under contract to external entities. AFOSR has three strategic goals: identify breakthrough research opportunities in the United States and abroad; foster revolutionary basic research for Air Force needs; and transition technologies to the DOD and industry. AFOSR was included as a case study because of its focus on supporting early stage extramural university-based research, which may have similarities with the STRG program.

1. Definition and Approach

AFOSR funds exclusively basic research, specifically within the 6.1 envelope of the DOD. While it funds basic research, it sees itself as being different from other basic research organizations such as the National Science Foundation (NSF), focusing on what it considers “mission-focused...basic science that profoundly impacts the future Air Force.”¹⁶ AFOSR recognizes that the boundaries between 6.1 and 6.2 research are often blurred, and its charter allows spending of 6.2 funds as if they were 6.1.

As per our interviewees, AFOSR considers the “Air Force of the future” as its customer. However, since the customer does not exist *per se*, AFOSR’s research focus has oscillated between what is needed today versus what will be needed in the far future. Since 30 percent of the portfolio is intramural and there is personnel overlap, there is a built-in forcing function away from 6.1. As a result, management continually has to ensure that AFOSR is not pulled too far into 6.2 research.

¹⁵ The AFRL is composed of seven technical directorates, one wing, and the Air Force Office of Scientific Research. Each technical directorate emphasizes a particular area of research within the AFRL mission which it specializes in performing experiments in conjunction with universities and contractors.

¹⁶ A central purpose of the DURIP is to provide equipment and instrumentation to enhance research-related education in areas of interest and priority to the DOD (AFRL 2014).

AFOSR has roughly 34 investment portfolios managed by the same number of program officers that cover a wide range of science and engineering fields (Kaper 2015).¹⁷ AFOSR has no internal researchers, and funded research occurs via partnerships with universities, with industry through the Small Business Technology Transfer (STTR) Program,¹⁸ and with AFRL’s other directorates. At any given time, AFOSR has roughly 1,200 grants at over 200 academic institutions worldwide, 100 industry-based contracts, and more than 250 internal AFRL research efforts.

2. Budget

AFOSR’s enacted budget in FY 2015 was \$537 million,¹⁹ of which about 70 percent is extramural (going primarily to universities) and 30 percent is intramural (going to various AFRL technology directorates). Of this, about \$350 million is considered “core,” and the rest is dedicated to research initiatives, such as the Multidisciplinary University Research Initiative (MURI) and the Defense University Research Instrumentation Program (DURIP), and to other DOD organizations.

AFOSR’s enacted budget represents 24 percent of the Air Force’s S&T budget, or 2 percent of the overall RDT&E Air Force budget (Table 8).

Table 8. Air Force Research, Development, Technology, and Evaluation (RDT&E) Budget (FY 2015)

| Category | 2015 Base and Overseas Contingency Operations Budget | Percentage of Air Force S&T Budget | Percentage of Air Force RDT&E Budget |
|-----------------------|--|------------------------------------|--------------------------------------|
| 6.1 | 538,586 | 24.1% | 2.3% |
| 6.2 | 1,090,419 | 48.8% | 4.6% |
| 6.1 + 6.2 | 1,629,005 | 72.8% | 6.9% |
| 6.3 | 606,365 | 27.1% | 2.6% |
| S&T (6.1 + 6.2 + 6.3) | 2,235,370 | | 9.5% |
| Air Force RDT&E | 23,619,928 | | |

Source: U.S. Air Force (2016).

¹⁷ See Grants.gov, “BAA-AFRL-AFOSR-2016-0007, Research Interests of the Air Force Office of Scientific Research,” <http://www.grants.gov/web/grants/view-opportunity.html?oppId=285269>.

¹⁸ This program is similar to the Small Business Innovative Research (SBIR) program, but requires official collaboration with a U.S. university, federally funded research and development center, or nonprofit research institution.

¹⁹ Personal communication, AFOSR. Official DOD documents included the basic research budget of the Air Force. We have assumed 100 percent of that budget goes to AFOSR which may not be an accurate assumption. Basic research budget from U.S. Air Force (2016).

3. Personnel

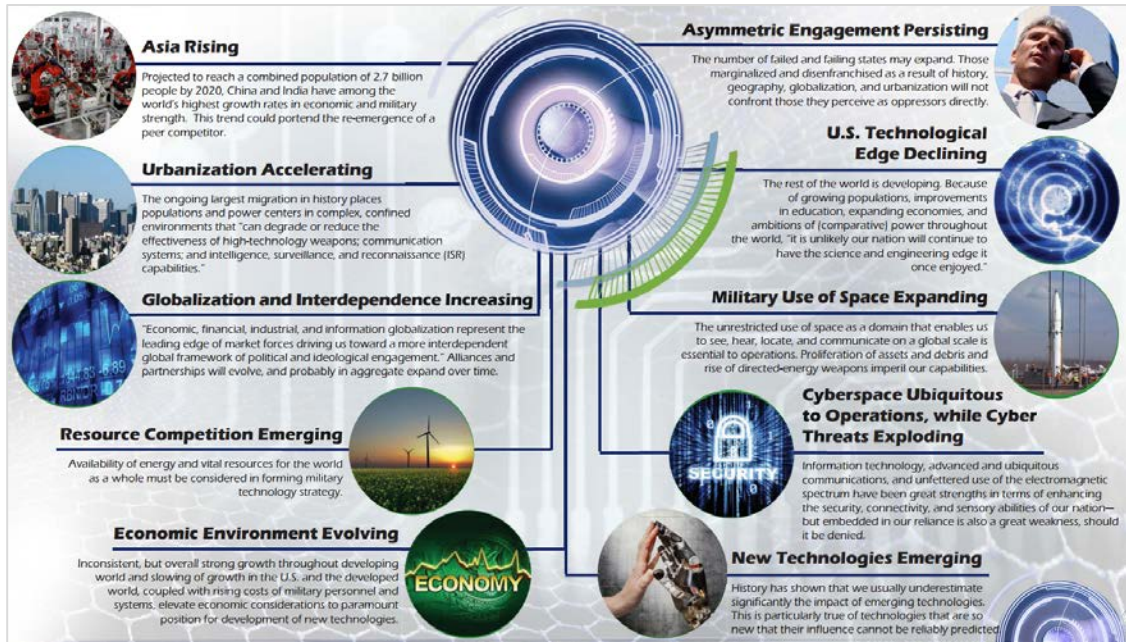
AFOSR is organized into four divisions, each of which has several program officers and is led by a chief who reports to a director. The directors and chiefs are responsible for integrating and executing the organization's technical strategy. As per the AFOSR strategic plan, the research divisions are a flexible construct that can evolve rapidly in response to significant shifts in the scientific environment. Divisions can close or consolidate, as needed, and new divisions can be created with "comparative ease" (AFRL 2014). Their chiefs serve for 2 years.

Over time, program officers have had to spend more time responding to increasing bureaucracy, related primarily to contracting, but during this time, program officers have also seen an increase in support. Previously, the ratio of support staff to program officer was 1:1. Now, that ratio is 4:1 (four support staff members for every one program officer).

With respect to tenure, AFOSR has only permanent hires, and no term appointments. There are about 34 program officers, one per portfolio. Their tenure distribution is bimodal—12 of the program officers have been at AFOSR over 15 years; and about 12 have been there fewer than 5 years. AFOSR used to be able to infuse Intergovernmental Personnel Act (IPA) detailees into its workforce, which was viewed as an excellent way to gain expertise in new subject areas, but it no longer uses this mechanism.

4. Allocation and Management of Investment

AFOSR attempts to be strategic in its portfolio design in that its leadership tries to understand from Air Force and other DOD leaders what capabilities will be needed 20–30 years down the road, and then seeks to attain that. An overview of trends that inform the topical scope of the AFOSR portfolio is provided in Figure 5. Up to 10 percent of AFOSR's core extramural funds each year are dedicated to new basic research initiatives; program officers develop proposals, which undergo internal and external review for relevance, excellence, and priority. New research areas are often identified via a BAA.



Source: AFRL (2014, Table 1).

Figure 5. Illustration of Identified Trends That Inform AFOSR Decisions

With respect to portfolio management, according to AFOSR’s technical strategy, the following questions are posed for every program; in reality, the approach is more ad hoc, and varies from one program officer to another (AFRL 2014).

1. What research to support? Major emphasis is placed on research where AFOSR can have a significant impact, where support from other sources is missing or inadequate.
2. Where to support it and why? Over 90 percent of AFOSR’s funds are spent within the United States. AFOSR supports foreign research when it is unique and it complements domestic research.
3. How much funding is needed and is leverage possible?
4. How long to fund the research?
5. How can success be determined?
6. If successful, what is required to ensure transition to the Air Force, the DOD, or industry?

While there are no targets for areas, leadership ensures at least qualitatively that investment balances across technology areas. They also look for duplication with other organizations, and choices are made as to where duplication makes sense and where it does not. AFOSR looks broadly for input and performers. As a result, in addition to its headquarters in Arlington, Virginia, AFOSR maintains three foreign technology offices

located in London, England; Tokyo, Japan; and Santiago, Chile. These offices coordinate with the international scientific and engineering community to allow for better collaboration between the community and Air Force personnel.

AFOSR program officers have an “enormous amount of freedom” in choosing topic areas of need and interest. The program officer also chooses the size of project, which can range from \$5–20 million. Even though AFOSR funds basic research, program officers are encouraged to manage their projects actively; they follow grantee progress, forcing collaborations (e.g., matching grantees with experimentation facilities) when needed.

Each proposal received by a program officer is also reviewed by a minimum of two external reviewers, and the manager has to provide a record of the final decision. Ultimately, the program officer decides which proposal is funded. AFOSR management also has the option to get the National Research Council (NRC) to judge proposals and portfolios. Unlike the three “ARPAs”,²⁰ leadership determines the subject areas of interest, and hires the appropriate program officer. Program officers maintain a great deal of autonomy once onboarded.

It is important to note that AFOSR funding is not restricted to U.S.-based grantees. Its international offices not only promote awareness, engagement, and relationships with the international S&T community, but they also issue grants at international universities, which is possible for all AFOSR program officers. The program officers search for transformational international opportunities while balancing informed “relevance” risk by leveraging the abilities of the international offices. This access allows the program officers to stay engaged in what is happening internationally and what other agencies are funding.

5. Transition

Transitioning basic research is “central to AFOSR’s strategy” (Wright-Patterson Air Force Base, 2016). AFOSR considers transition to begin when another party (a laboratory, the DOD, industry, the National Reconnaissance Office, DARPA, etc.) starts to invest. This may include a transition to: (1) industry, the supplier of Air Force acquisitions; (2) the academic community, which can lead to more research; or (3) other directorates of AFRL that carry the responsibility for applied and development research leading to acquisition. Recognizing that relationships are the “proximate cause” of transition, program officers work hard to develop them through talks at laboratories and idea exchange. Further, AFOSR works closely with SBIR and STTR partners to transition basic research into higher TRLs.

²⁰ The three ARPAs—discussed in other parts of this report—are the Defense Advanced Research Projects Agency (DARPA), the Intelligence Advanced Research Projects Activity (IARPA), and the Advanced Research Projects Agency–Energy (ARPA-E).

Obtaining funding for the mechanics of transition is feasible. Because its research is basic, and the transition pathway is sometimes not obvious, AFOSR is beginning to use science analytics to track results routinely and in real time.

6. Evaluation of Success

AFOSR leaders are aware that assessing success is essential but also that doing so effectively is difficult. They would like to know if they are doing productive research, the right research (not just counts of publications but publications that matter), and transitioning research to other organizations. They would also like to be able to capture other outputs, including student outcomes, development of relationships with other organizations, and exchange of samples.

AFOSR's primary desired outcome for research results is to transition the knowledge to the rest of AFRL for use, if appropriate, in applied research programs. Over the long term, the primary metric for success is the evidence of transformational impact on the Air Force. In the near term, traditional measures of research output apply, although these measures cannot supply definitive answers to questions of investment success. AFOSR tracks major awards garnered by its principal investigators, along with publications, presentations, and patents; graduation rates in U.S. universities; and in-house capabilities and productivity within AFRL. It focuses considerable attention on the research communities it affects. To the extent possible, AFOSR seeks to build and grow vibrant research communities, and eventually—in some cases and over periods that may vary widely—to wean the communities from AFOSR's funding.

Currently, management uses expert review techniques such as advisory boards to review and assess its portfolios. AFOSR also realizes that not every project can or should be successful especially in the near term because "hard things take time." Scientific Advisory Board (SAB) reviews are convened every two years to assess the distribution of investments and the progress made and promise offered by each portfolio under examination. SABs strongly influence evolutions of and distributions within portfolios. In addition, each program officer holds a yearly program review, which assures exchange of current vital information among the assembled researchers. The annual review also allows program officers to determine the courses of their investments, to make informed decisions on future funding, to change course (when appropriate), and to forge alliances and build teams of research groups.

At the core, success is measured in terms of AFOSR's program officers: are they aware of developments in their research areas, especially outside the United States, and are they being strategic and thinking long-term in the way they describe their portfolios to their colleagues, managers, and external advisors.

7. Lessons Learned

Table 9 provides a summary of the findings from which the following lessons were derived.

- AFOSR utilizes a flexible organizational structure where divisions can be created and dissolved based on the changing needs of the Air Force and developments in S&T. AFOSR's portfolios are a flexible construct that can evolve rapidly in response to significant shifts in the scientific environment.
- AFOSR attempts to be strategic in its portfolio design in that its leadership tries to understand from Air Force and DOD leaders what capabilities will be needed 20–30 years down the road, examines R&D across the world through its international offices, and then seeks or designs research that will aid that. Program managers are flexible in their topic selections.
- AFOSR uses SBIR and STTR to transition technology to higher TRLs.
- AFOSR uses bibliometrics, but not as the sole indicators of performance.

Table 9. Summary of Findings for Air Force Office of Scientific Research (AFOSR)

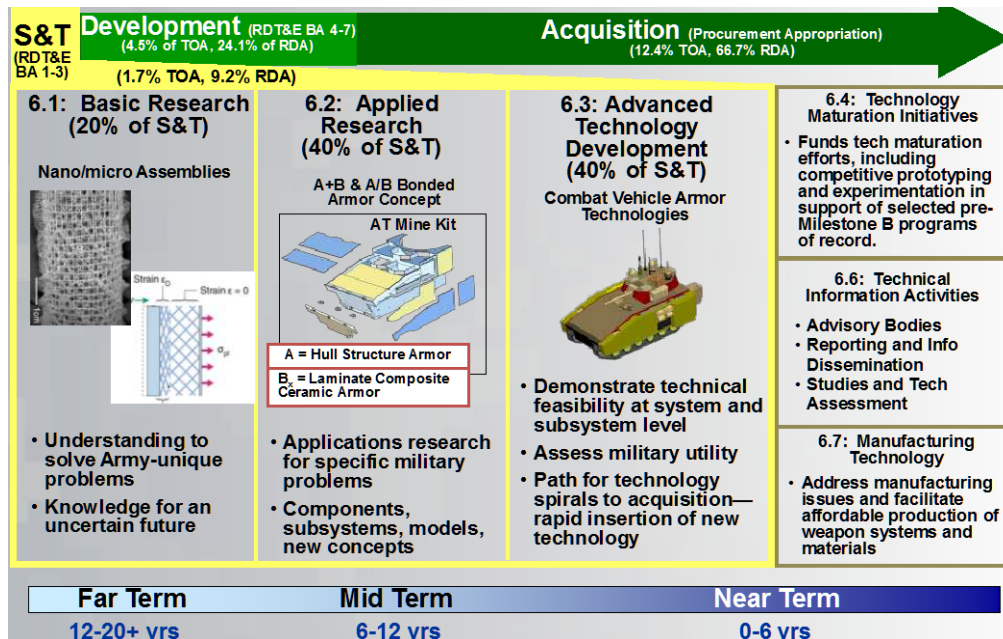
| | |
|--|--|
| Definition and Approach | <p>AFOSR, a Directorate within the Air Force Research Laboratory (AFRL), manages a portfolio of basic research programs (6.1)</p> <p>Projects are extramural and intramural</p> <p>Flexible organizational structure exists, in which research-oriented organizational units can be created and dissolved based on need</p> |
| Budget | <p>\$537 million (FY 2015), represents 24% of Air Force's S&T budget or 2% of Air Force's RDT&E budget</p> <p>Majority of funding is extramural (to universities), remaining goes to various ARFL projects (~30%)</p> <p>Up to 10% of core funds are allocated to new basic research initiatives yearly</p> |
| Personnel | <p>Uses only permanent hires, no term appointments</p> <p>Previously used Intergovernmental Personnel Act (IPA) detailees in the workforce, but the mechanism is no longer or rarely used</p> <p>Ratio of four support staff members for every one program officer</p> |
| Allocation and Management of Investment | <p>New research areas are identified through Broad Agency Announcements to solicit as many ideas as possible from various research communities</p> <p>Topics are connected to national priorities and selected to ensure projects focus on strategic areas</p> <p>Process includes international input via international offices</p> <p>Leadership determines the subject areas of interest and hires the appropriate program officer</p> <p>Size of projects are \$5–20 million</p> <p>Proposals are reviewed by at least two external reviewers</p> <p>Program officers are given authority to engage with international researchers</p> <p>Grants, cooperative agreements, Federal contracts, and Other Transaction Agreements are used</p> <p>Program officers are empowered and given autonomy to make decisions, including project selection and size of funding</p> <p>Program officers follow the grantee's progress and push for collaborations when needed</p> |
| Transition | <p>AFOSR uses Small Business Innovation Research (SBIR) and SBIR Small Business Technology Transfer (STTR) funding to transition technology to higher Technology Readiness Levels (TRLs)</p> <p>Program officers work to develop external relationships</p> |
| Evaluation of Success | <p>Qualitative reviews by external experts</p> <p>Bibliometrics used, but not as sole indicators of performance</p> <p>Duplication is evaluated and avoided</p> <p>No quantitative target specified</p> <p>Leadership ensures at least qualitatively that investment balances across technology areas</p> |

C. Case Study: Army Research Office (ARO) and Army Research Laboratory (ARL)

The Army Research Office (ARO) and the Army Research Laboratory (ARL) are collectively responsible for the majority of the Army’s basic research program. ARL is the corporate research laboratory of the Army, and houses both intramural and extramural programs. ARO, which sits within ARL, manages only extramural programs, which provides research funding to educational institutions, nonprofit organizations, and private industry.

1. Definition and Approach

The ARL performs 6.1 to 6.3 research, and ARO, like AFOSR, exclusively funds 6.1. Specific examples of each of these categories are shown in Figure 6. ARL/ARO conducts research on anything a soldier could touch; this spans life science, physical science, information technology, and engineering. The projects are split between opportunity-based research (what Army calls *blue-sky research*) and needs-based research, but all have an identified connection to an ultimate use for a soldier. The exact percentage of opportunity-based versus needs-based research is determined by the project manager and depends on the nature of the scientific field.



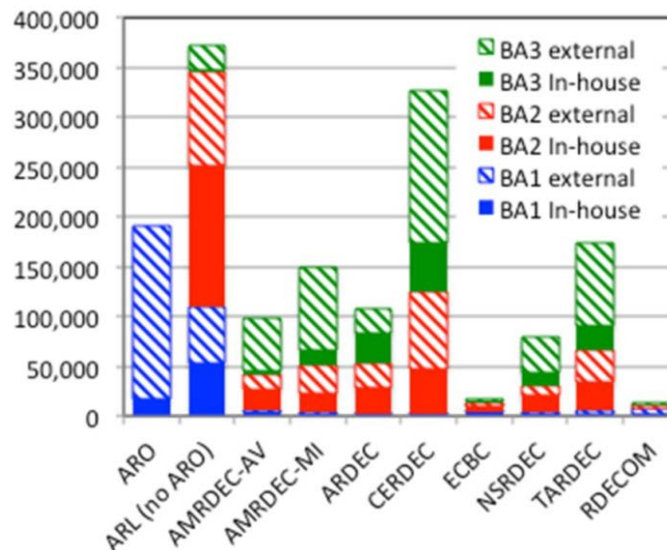
Source: M. J. Miller (2013).

Figure 6. Army S&T Funding Categories, Work Focus, and Time Frames

ARL has six directorates: Computational and Information Sciences, Human Research and Engineering, Sensors and Electron Devices, Survivability/Lethality Analysis, Vehicle

Technology, and Weapons and Materials Research. ARO has four divisions: Physical Sciences, Life Science, Information Sciences, and Engineering Sciences. ARO's divisions are not platform-focused, in order to avoid limiting the potential research areas each division funds.

Seventy to seventy-five percent of the Army's 6.1 funding goes to ARL/ARO. The remainder is housed in the medical and engineering commands (Figure 7). ARL and ARO coordinate with other early stage programs in the Army, other Services, and other Federal agencies. Individual program managers work closely with their counterparts elsewhere in the Federal Government. For example, program reviews are populated by program managers from other Services; program managers interact at technical meetings, and they collaborate and combine funding on certain projects with their counterparts.



Source: Army Science Board (2013).

Notes: While these figures are from FY 2011, we have confirmation from Army personnel that the breakdown is similar today. For this report, 6.1, 6.2, and 6.3 funding levels are interchanged with BA1, BA2, and BA3 levels.

Figure 7. Army S&T Budget for FY 2011

2. Budget

ARO and ARL together had a budget of approximately \$300 million for 6.1, \$250 million for 6.2, and \$25 million for 6.3, for a total of \$575 million. In FY 2011, this represented 25 percent of the Army's S&T budget (\$2.2 billion), and 0.2 percent of its total budget (\$245 billion). Recently, the Army has been increasing its 6.1 budget, while winding down its 6.4 programs because its combat mission is decreasing. Table 10 summarizes the 2015 Army RDT&E budget.

Table 10. Army Research, Development, Test, and Evaluation (RDT&E) Budget (FY 2015)

| Category | 2015 Base and Overseas Contingency Operations Budget | Percent S&T | Percent RDT&E |
|-----------------------|---|------------------------|--------------------------|
| 6.1 | 447,868 | 17.91% | 6.64% |
| 6.2 | 964,085 | | |
| 6.1 + 6.2 | 1,411,953 | 56.45% | 20.94% |
| 6.3 | 1,089,087 | | |
| S&T (6.1 + 6.2 + 6.3) | 2,501,040 | | |
| RDT&E | 6,744,134 | | |

Source: U.S. Army (2016).

3. Personnel

ARO program managers are primarily permanent staff; though between 15 to 25 percent of ARO program managers are rotators. While they appreciate the infusion of outside perspectives rotation brings, ARO leaders have chosen to favor permanent staff because they value the corporate memory permanent staff can provide. However, all of the current program managers of the international research programs are rotators.

4. Allocation and Management of Investment

For 6.1 research, ARL allocates 55 percent of its funding to intramural performers and 45 percent to extramural performers based on this set percentage. This split tends to favor intramural performers more than Navy and Air Force. The extramural/intramural division of 6.2 research is not automatic and is a science-based decision made by the program managers.

ARO solicits proposals through BAAs and prefers proposals to cover a 3-year period; awards may be negotiated for an entire 3-year program or individual 1-year increments of the total program. Proposals may be submitted at any time.

When looking for new research areas, individual program managers release solicitations, hold workshops, and network with researchers in academia or the military Services. Choices are made as to which topics are especially relevant to the Army (e.g., rotorcraft). The proposal process involves multiple levels of review, including external peer review. Each program manager’s portfolio is reviewed every 2 years by external experts. These reviewers include military Service laboratory scientists, researchers from other government agencies, and academics that are not funded by the DOD. In addition to technical quality, program managers must demonstrate how each project matches the goal of the program. The portfolio reviews also provide valuable information on where each

research program should be headed, and result in the turnover of approximately one-third of projects.

ARL/ARO leadership has found it important to create rigorous review processes for programs and then empower the program managers to run the program. Micromanaging ultimately damages the research portfolio. If instead, management creates a process that supports the project manager, the research program will be able to meet the mission goals successfully.

5. Transition

Project managers are responsible for creating and implementing a transition plan for each project. Transition is part of their employee evaluation. The transition flow plan typically involves moving the project outside of ARL, often to another Army laboratory, such as one of the engineering or medical centers. The more applied Army laboratories are the natural transition partners, but ARL/ARO also leverage other funding sources like SBIR and Multidisciplinary University Research Initiative (MURI).

6. Evaluation of Success

ARL/ARO's goal for success—meaning the research project accomplished its goals—is 70 percent. The remaining 30 percent do not necessarily constitute true failure because knowledge gained is valuable in its own right. Approximately 40 to 70 percent of the projects successfully transition to the next phase; the exact percentage depends on the scientific area. Transition is measured via follow-on funding.

ARL/ARO also tracks publications, patents, popular press citations, students, and degrees awarded. They have found, however, good performance on quantitative metrics does not necessarily mean the research has high impact for the military.

7. Lessons Learned

Table 11 provides a summary of the findings from which the following lessons were derived.

- Program managers engage external experts to identify new research areas and review proposals.
- ARL/ARO leaders find it important to create rigorous review processes for programs and then empower the program managers to run the program.
- ARL/ARO indicated that success of transition is a formal part of each program manager's employee evaluation.
- ARL/ARO's goal for success—meaning the research project accomplished its goals—is 70 percent.

**Table 11. Summary of Findings for Army Research Office (ARO)/
Army Research Laboratory (ARL)**

| | |
|--|--|
| Definition and Approach | <p>ARL, a corporate research laboratory of the Army, performs and manages intramural and extramural research</p> <p>ARO, situated within ARL, manages a portfolio of extramural programs for academia, nonprofits, and industry (6.1, 6.2)</p> <p>Projects are split between needs-based (Army/mission oriented) and opportunity-based (outward looking) research</p> <p>ARO's divisions are focused on discipline, not platforms or technology, which is intended to broaden the possible research areas in which ARO works</p> |
| Budget | <p>\$575 million, represents 23% of Army's current S&T budget, or 9% of Army's RDT&E budget</p> <p>Funding is split between intramural (55%) and extramural (45%)</p> |
| Personnel | <p>Leaderships prefers use of permanent staff to maintain institutional memory</p> <p>15–25% of program managers are rotators (all international research programs are staffed by rotators)</p> |
| Allocation and Management of Investment | <p>New research areas are identified through Broad Agency Announcements to solicit as many ideas as possible from various research communities</p> <p>Topics are connected to national priorities and selected to ensure projects focus on strategic areas</p> <p>Program managers engage with internal and external scientific community (through site visits, formal interfaces, and other methods) to identify priorities and emerging areas and to learn about user needs</p> <p>Program managers employ reviewers from inside and outside the organization</p> <p>Reviewers are Service laboratory scientists, researchers from other government agencies, and academics that are not funded by DOD</p> <p>Grants, cooperative agreements, Federal contracts, and Other Transaction Agreements are used</p> <p>Program managers are empowered and given autonomy to make decisions</p> <p>Portfolio reviews provide input on where each research program should be headed, and they result in the turnover of approximately one-third of projects</p> |
| Transition | <p>Program managers are responsible for transition</p> <p>Transition is part of employees' performance evaluations</p> <p>Transition often involves movement to another Army laboratory or leveraging Small Business Innovation Research (SBIR), and Small Business Technology Transfer (STTR), and Multidisciplinary University Research Initiative (MURI) program funding</p> |
| Evaluation of Success | <p>ARO/ARL tracks publications, patents, popular press citations, students, and degrees awarded</p> <p>Metrics do not necessarily indicate research has affected the military</p> <p>ARO/ARL aims for 70% success rate</p> |

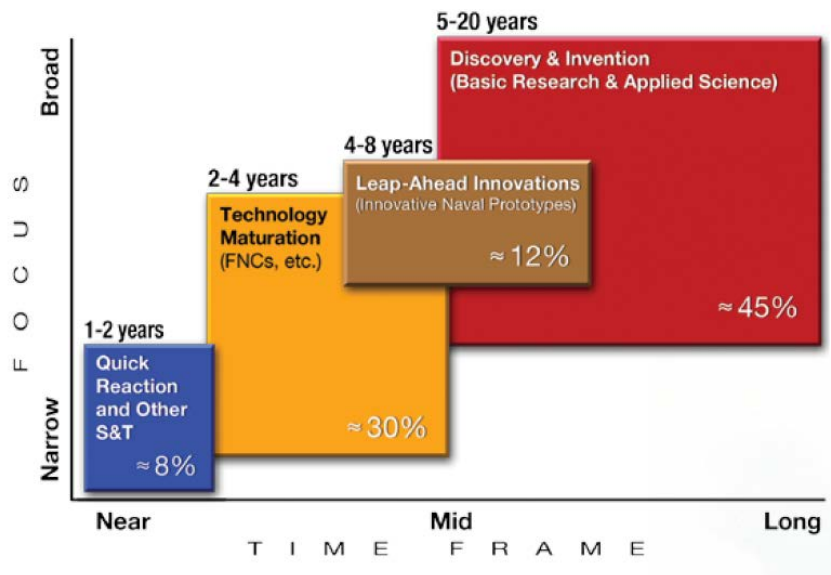
D. Case Study: Office of Naval Research’s Discovery and Invention Portfolio

The Office of Naval Research (ONR) manages the Navy’s basic, applied, and advanced research. ONR has three goals: (1) align S&T with naval mission and future capability needs, (2) balance and manage the S&T investment portfolio, and (3) communicate the S&T vision and approach to senior decision makers, key stakeholders, partners, customers, and performers (ONR 2015, 8). ONR is directed by the Chief of Naval Research who reports to the Secretary of the Navy via the Assistant Secretary of the Navy for Research, Development, and Acquisition (ONR 2017a). ONR is composed of two directorates (research and technology) and six departments (ONR 2017b).

1. Definition and Approach

ONR manages its research portfolio through four programs that reflect a range of time frames (from near-term to long-term) and encompass a breadth in research scope. These programs represent 6.1 through 6.3 research and cut across ONR’s six S&T departments.

ONR’s early research portfolio includes basic and early applied research programs (namely, 6.1 through early 6.2). The discovery and invention (D&I) portfolio of research represents ONR’s early stage research, while leap-ahead innovation, technology maturation, and quick-reaction portfolios represent later 6.2 and 6.3 advanced technology research portfolios (Figure 8). The D&I portfolio spans broad research that requires between 5 and 20 years to mature.



Source: ONR (2015, 18).

Figure 8. ONR S&T Investment Strategy

2. Budget

Early stage research and technology development through the D&I portfolio represents about \$1 billion or 45 percent of ONR's 6.1–6.3 funding (total ~\$2 billion). The D&I portfolio is about 6 percent of the Navy's overall appropriation of about \$16 billion for RDT&E (6.1 through 6.7 research). ONR's budget (and the D&I portion of it) has stayed consistent over time.

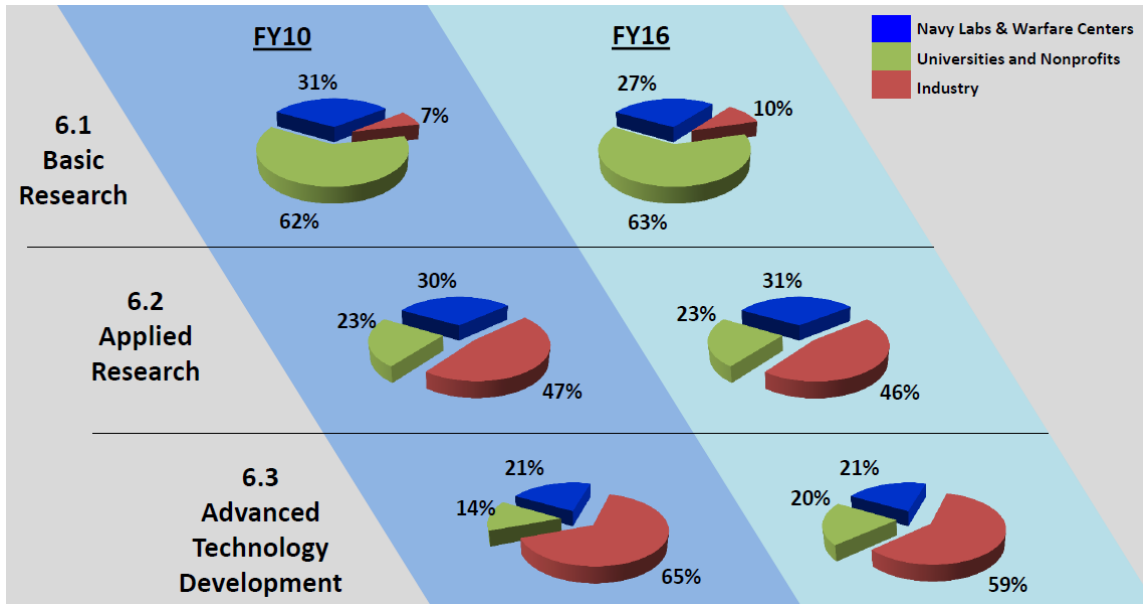
3. Personnel

The D&I portfolio is managed by about 120 program officers, who develop solicitations, review proposals, and award grants. Support staff number about two to three times more than the number of program officers. ONR depends on the expertise of its program officers to identify cutting-edge science topics. A program officer may come to ONR from a career as a Navy researcher, as a researcher from another defense laboratory, or from a research position in industry or academia. ONR uses temporarily employed detailees. In the past, ONR was the largest user of IPA details to bring on program officers external to the DOD into the organization. Currently, program officers are typically permanent staff equivalent to a General Schedule (GS) level of GS-14 or equivalent. However, they come from diverse backgrounds, including laboratory staff across the military Services and IPA detailees that decided to stay in government.

4. Allocation and Management of Investment

ONR issues both long-range annual BAAs and focused BAAs (or Funding Opportunity Announcements [FOAs] if they are for grants) to solicit proposals to the D&I program. Program officers use separate BAAs for unique topics that they may pursue. In particular, ONR has an internal basic research challenge to stimulate new D&I topics. These are brought forward to the Director of Research and Executive Director for final approval and selection. D&I program officers provide the topics and participate in the selection. In 2015, ONR funded 8 new topics after initially receiving 41 initial topics and 15 topic proposals.

D&I awards can range from about \$2 to \$5 million over 1 to 3 years. The bulk of the D&I portfolio is awarded to academic researchers with a smaller percentage awarded to industry or Federal laboratories. Performers vary depending on the category of research (Figure 9). ONR does not fix a target for the proportion of performers selected for awards by category of research; however, interestingly, the proportions across sectors has been reasonably stable over time. As of 2015, roughly 2,000 active 6.1 and 6.2 awards were granted.



Source: ONR (2015).

Figure 9. Performers by Research Type (6.1 to 6.3)

The project proposal review consists of two phases—a white paper and full proposal (ONR 2016). The white paper provides an opportunity for program officers to comment on and strengthen proposal ideas. It also provides an opportunity for program officers to externally engage with the broader scientific community to foster interest in ONR’s topical priorities. Program officers manage a peer review process to select awardees from full proposals. Program officers will establish a peer review panel with members based on their scientific or technical expertise, absence of conflict of interest, and other criteria (ONR 2013). The panel members can be internal and external to ONR. Final approval of the panels is made by the division director and department head with final selections forwarded to the Director of Research. Criteria used to evaluate awards are significance and originality, scientific merit, risk and potential impact, and principal investigator qualifications. Panel members submit individual written reviews to the program officers, who then review the materials and make a decision on awards.

Funding within each department’s research and topic portfolios can be redirected by Department Heads and by the Chief of Naval Research for funding across all of ONR.

5. Transition

As per our interviewee, ONR leaders views themselves as a venture capital arm of the Navy, meaning they place many bets on research to reap higher rewards. Since Navy research is funded through working capital—the organization is reimbursed for the services performed—there is no guarantee for future funding of specific research areas. This culture makes program officers highly motivated to lead the successful transition of D&I research.

Program officers continually engage and foster relationships with acquisition customers and program funders across the Navy to understand their requirements and how the D&I research can best meet their needs. Transition is formally established through a technology transition agreement, which describes the commitments by acquisition and program elements in the Navy to transition the research.

The working capital model also offers organizational flexibility in that the workforce can be quickly shaped to respond to rapid growth, redirection, or decline in interest of a particular research area.

6. Evaluation of Success

The D&I portfolio is reviewed every one to two years. The review typically involves an assessment of how successfully program officers manage the research in their portfolios. The review includes a review of the technical quality and technical progress of a program officer's portfolio.

ONR tracks scientific publications that are generated from their projects. However, our interviewee at ONR noted that scientific impact is difficult to measure and publications may be only one of the means by which impact can be measured, saying that one "should be very reluctant to use a simple gate count of paper production as that will drive behavior to more papers, with potentially less impact."

A primary goal of D&I research is its transition and technology acquisition by the Navy. Transition is not formally tracked; however, according to our interviewee, the D&I portfolio of awards has been highly successful. Some successes highlighted in *The Naval S&T Strategy*, published in 2015, include the advancement of an electromagnetic railgun using "high-power electricity instead of chemical propellants to launch low-cost guided projectiles greater than 100 miles at hypervelocity speeds" (ONR 2015, 7).

7. Lessons Learned

Table 12 provides a summary of case study findings, from which the following lessons were derived.

- A strength of ONR's S&T investment portfolio is that it manages the transition of basic and applied research to technology development (6.1–6.3) in its entirety.
- The responsibility for managing the research program and transition lies with one individual (the program officer) who identifies potential customers and guides successful research in the D&I portfolio through other technology maturation programs managed by ONR.

- Research portfolio reviews are focused on program officers and their role in successfully transitioning D&I research into mature technologies and Navy acquisitions.
- ONR's culture and working capital funding model complement one another in encouraging high-risk, high-reward research and flexibility in research direction.
- Being transition driven has the downside that research is sometimes not as far-term as it should be.

Table 12. Summary of Findings for Office of Naval Research (ONR)

| | |
|--|---|
| Definition and Approach | <p>ONR manages the Navy's portfolio of basic and applied research programs (6.1–6.3)</p> <p>Projects are extramural and intramural</p> <p>A timeline-oriented approach is used to manage programs—far term (10–20 years) versus Near term(1–5 years)—rather than distinguishing programs as basic and applied</p> <p>The culture and working capital funding model complement one another to encourage high-risk, high-reward research and flexibility in research direction</p> |
| Budget | <p>~\$1 billion allocated to discovery and invention (D&I), which is approximately 45% of ONR's budget for 6.1–6.3 research, 45% of Navy's S&T budget, or 6% of Navy's RDT&E budget</p> <p>Early stage is a significant part of ONR's R&D portfolio; bulk of portfolio is awarded to academic researchers</p> |
| Personnel | <p>Use of permanent staff and temporarily employed detailees</p> <p>Program officers may come to ONR from a career as a researcher for the Navy, from another defense laboratory, or from a research position in industry or academia (typically equivalent to GS-14)</p> <p>120 program officers manage the portfolio and are relied upon to identify cutting-edge research</p> <p>Ratio of two to three support staff members for every one program officer</p> |
| Allocation and Management of Investment | <p>New research areas are identified through Broad Agency Announcements and Funding Opportunity Announcements, to solicit as many ideas as possible</p> <p>Program officers develop solicitations for topical areas and typically lead more than one technical program</p> <p>Use of a two-phase white paper/full-proposal process leads to stronger and more relevant proposals</p> <p>Program officers encourage reviewers to embrace high-risk projects</p> <p>Program officers employ reviewers from inside and outside organization</p> <p>Grants, cooperative agreements, Federal contracts, and Other Transaction Agreements are used</p> <p>Program officers are empowered and given autonomy to make decisions</p> <p>Technical, evaluation, and administrative/budget support (protection from excessive requests from within and outside organization) for program officers</p> <p>Funding can be withdrawn if targets are not met</p> |
| Transition | <p>Program officers are responsible for transition (and the same program officers span programs to enable that transition)</p> <p>Transition plans created, presented, and evaluated at time of program creation</p> <p>Program officers engage with acquisition personnel, customers, laboratories, and other transition partners to understand how to meet needs</p> |
| Evaluation of Success | <p>Evaluation based on program officer's performance in managing a research portfolio rather than the success of a single project</p> <p>Program officer portfolio of programs and projects are reviewed every 1–2 years</p> <p>No quantitative target specified</p> <p>A primary goal is technology acquisition by the Navy, although transition is not formally tracked and thus the target is not quantitative</p> |

E. Case Study: Defense Advanced Research Projects Agency (DARPA) Defense Sciences Office (DSO)

The Defense Advanced Research Projects Agency (DARPA) has six technical offices that manage its research portfolio, including the Defense Sciences Office (DSO) that houses most of DARPA's early stage research (DARPA 2017a). The office dates back to DARPA's inception in 1958, when it focused on high-risk, high-reward materials research as the Material Science Office.²¹ Over time, DSO evolved, developing new programs and spinning out new DARPA technical offices from programs funded by the office. DARPA's creation in the 1960s of interdisciplinary science centers brought together disparate fields, such as metallurgy, chemistry, and mining, which led to the creation of the field of materials science. Twenty years ago, the Microsystems Technology Office was created, leading to the development of areas like microelectromechanical systems. Most recently, in April 2014, the new Biological Technologies Office (BTO) was established as another technical office to consolidate life and biological sciences programs across DARPA (Servick 2014), and to reduce "crowding out" investment in physical sciences. This move clarified DARPA's commitment to biological technologies as priority. DSO's life science programs were transitioned into BTO and current programs funded through DSO focus on physical sciences, mathematics, modeling and design, and human-machine systems (DARPA 2017a). DSO is still conducting biological research but focusing on foundational areas.

1. Definition and Approach

DSO funds research that aligns with the DOD's definitions for basic and applied research, and associates (roughly) basic research (6.1) with TRLs 1 and 2, and applied research (6.2) with TRLs 3 and 4.²² DSO leadership does not use any numeric scales to describe its research portfolios other than to formalize budget requests and to communicate the research portfolio across the DOD and the public. DSO argues that its research programs, being highly risky and not well-defined by design, are not easily categorized into the DOD's budgeting frameworks, and may fall in between these categories, particularly as the research and technologies rapidly evolve.

2. Budget

DARPA's offices, including DSO, do not disclose their annual budget. However, DSO is closest to, but does not comprise all of, basic research at DARPA. Total basic

²¹ DSO's inception is detailed in Public Law 85-325, February 12, 1958 [H.R. 9739].

²² According to the Assistant Secretary of Defense for Research and Engineering's "Technology Readiness Assessment (TRA) Guidance," TRL 1 includes observation and reporting of basic principles, TRL 2 includes formulation of technology concept and/or application, TRL 3 includes an analytical and experimental critical function and/or characteristic proof of concept, and TRL 4 includes component and/or breadboard validation in a laboratory environment (DOD 2011b).

research at DARPA is \$390 million (FY 2016), which is approximately 14 percent of DARPA’s overall \$2.87 billion annual budget. The total 6.1–6.2 budget is \$1.55 billion, the latter being 54 percent of the DARPA 2016 enacted budget (DARPA 2016a). Approximately half of DSO’s budget is associated with basic research, while the other half is applied (DARPA 2016a). However, this total does not represent DSO’s budget.

3. Personnel

DARPA appoints program managers as Federal employees (generally at higher salaries than provided by GS pay scales) for a fixed term of no more than 4 years. The fixed term helps with generating an influx of new ideas. The ratio of support staff to technical program staff is 2:1 (two support staff members for every technical staff member). Support staff protect technical managers from administrative workload—handle administrative functions, rigorously review and respond to external requests, and engage in other activities such as responding to new DOD policies.

4. Allocation and Management of Investment

DSO can typically support areas that need large investment to make measurable progress. For example, it may devote tens of millions of dollars to answer a math question for which other organizations might only be able to afford a fraction of that (e.g., an average AFOSR grant is \$120,000). DSO program managers can also award “seedling” (small project) grants in the million-dollar range, again much larger than those of other S&T funding organizations in the DOD. In selecting the research to fund, DSO leadership and program managers consider the impact of the research and the likelihood that it can improve or meet one or two specific national security needs. However, DSO does not use a formalized framework to allocate its investments in research programs or to select which programs to prioritize. Instead, DSO relies on the ingenuity, creativity, and technical expertise of their program managers as their business model. DSO currently has 12 program managers.²³

DSO program managers are appointed as Federal employees under a special hiring authority provided to DARPA under the National Defense Authorization Act of FY 1999, Section 1101.²⁴ The authority allows DARPA to appoint scientists and engineers non-competitively for a fixed term not to exceed 4 years. This flexibility allows for expeditiously recruiting and hiring of highly qualified program managers. DSO provides its program managers autonomy to set the direction of their research programs and to

²³ As of May 2016, DSO had 12 staff members with the position “program manager” (DARPA 2016b).

²⁴ National Defense Authorization Act for Fiscal Year 1999, Public Law 105-261, October 17, 1998 [H. R. 3616] 105th Congress, codified under Note 5 U.S.C. § 3104, Employment of specially qualified scientific and professional personnel.

develop relevant milestones. The program managers bring ideas before they are hired, which drives DSO investment. Once hired, a program manager uses seedling funds to flesh out an idea, and ultimately the DARPA Director makes the final decision (with input from the DARPA Technology Council). DSO's goal is to consider ideas that would take 3–5 years to establish. If a capability takes longer than 5 years to come to fruition, there is a good chance that DARPA was the wrong source of investment in that area in the first place. But the office is flexible on the 5-year rule. Although DSO's research programs typically aim for ideas to come to fruition in about 5 years, program managers may not manage a program from start to finish. Instead, new program managers take over where another left off and may steer the program in a new direction.

DSO program managers do not typically engage with users and customers from the DOD throughout the management of their program. There may be a set of users envisioned early in the program, but DOD representatives external to DARPA do not typically participate or contribute to the direction of the research. Engagement with users largely depends on the research program.

DSO leadership places a high value on facilitating funding and minimizing undue administrative burdens on the program managers given their relatively short-term tenure (compared with those in other parts of the Federal Government). About two-thirds of the staff at DSO are support staff that handle administrative functions and engage in other activities that could be distracting for program managers such as justifying exceptions to new DOD policies.

DSO continually reviews research proposals throughout the year. DSO staff also maintain awareness of state-of-the-art technology through site visits to universities and meetings with research communities across the United States. DSO began these site visits in 2014 with goals to clarify what DARPA does and how it funds programs and projects and to facilitate its access to potentially innovative ideas. DSO measures its success by tracking changes in the number and type of proposals submitted. Sometimes universities need to be convinced to work with DARPA because university researchers may not fully understand DARPA high-risk culture and the nature of funded projects.

5. Transition

Although the DOD missions to which DSO research could be applied are identified as part of the project-selection criteria, DSO staff typically do not participate in transition to users. Transition would depend on the nature of the research project.

6. Evaluation of Success

DSO does not use and actually resists creating metrics to assess the success of their investments. Return on investment and other metrics are not tracked in a statistical way.

The rationale is that technologies may not present impacts to the DOD or to society for a long time. The analysis of success may mean analyzing research and technologies funded through DSO over a relatively large time span. Success is typically measured through anecdotes and specific examples on what projects made a difference. Examples include the creation of gallium nitride, which is currently a core technology in all military electronic systems. Impact from technology like this cannot be measured easily or quickly after the initial project's completion.

The program managers do assess their research programs and projects as a whole through the use of milestones (to the extent they apply to DSO research). These milestones are flexible, and can change as new information from the research develops. For instance, when a researcher manufactured a working technology months before it was expected, the program managers revised the milestones and immediately began purchasing and fielding the technology in pilots across the United States. DSO leadership and program managers work closely and conduct detailed 2- to 3-hour program reviews twice per year to gauge the progress of the programs. The office director meets with program managers informally on a regular basis.

7. Lessons Learned

Table 13 provides a summary of the findings from which the following lessons were derived.

- DSO's business model is to hire good people, remove obstacles from their way so they can do what is needed, not worry about making mistakes or taking chances, and kick them out when they start to get risk averse (after about 5 years). It is sometimes less costly to repeat a mistake than to do due diligence that may take 6 months. The office motto is "Just do it!"
- Encourage and commit to autonomy of program managers. DSO has high tolerance for risk, which is unique in the culture of the Federal Government, and DSO leadership is highly committed to maintaining the integrity of its high-risk culture. Program managers are provided substantial autonomy in the development of their ideas and overall direction of their research programs.
- Allow mistakes and resist documenting or institutionalizing lessons learned. In the spirit of reducing administrative burdens that create organizational bureaucracy, DSO does not collect lessons learned to inform the development of new policies. DSO leadership has a high tolerance for risks to assess the value of new policies and regulations. For instance, DSO may view the costs of repeating a mistake as minimal when compared with the impacts of a new administrative policy and processes that would be needed to prevent that mistake.

- Provide program managers with the leadership and support necessary to minimize bureaucracy. A large number of DSO staff are responsible for assisting program managers with the management and administration of research programs and minimizing bureaucracy and unnecessary oversight. The DOD establishes an abundance of memoranda and directives that would otherwise be applied across the entire DOD, including DARPA. DSO leadership and DARPA support staff continuously advocate for more organizational autonomy and serve as a buffer between program managers and the headquarters. This better allows program managers to concentrate on the implementation of their research programs.

Table 13. Summary of Findings for Defense Advanced Research Projects Agency (DARPA)/ Defense Sciences Office (DSO)

| | |
|--|---|
| Definition and Approach | <p>DSO houses most of DARPA’s portfolio of basic research programs (6.1)</p> <p>Projects are extramural and intramural</p> <p>Leadership prioritizes programs and projects that are high risk and not necessarily well-defined, seeking to maintain the integrity of the organization’s high-risk culture</p> |
| Budget | <p>DSO budget is not disclosed</p> <p>DSO is closest to (but does not comprise all) basic research at DARPA</p> <p>DARPA basic research was \$389.7 million in FY 2016, which represents 14% of DARPA’s total budget</p> |
| Personnel | <p>DARPA non-competitively appoints program managers for a fixed term (as Federal employees) not to exceed 4 years, intended to allow for a constant refresh of ideas</p> <p>DARPA uses authority to hire at higher salaries than government scales</p> <p>Ratio of about two support staff members for every one technical program staff member</p> <p>Protection of technical managers from administrative workload—support staff handle administrative functions, rigorously review and respond to external requests, and engage in other activities, such as responding to new Department of Defense policies</p> |
| Allocation and Management of Investment | <p>Program managers engage with internal and external scientific community (through site visits, formal interfaces, and other methods) to identify priorities and emerging areas, and to learn about user needs</p> <p>Program managers lead the development of topics and overall direction for the research programs with relative autonomy</p> <p>Program managers encourage reviewers to embrace high-risk projects</p> <p>Award sizes are large to ensure projects address big problems</p> <p>Grants, cooperative agreements, Federal contracts, and Other Transaction Agreements are used</p> <p>Program managers are empowered and given autonomy to make decisions</p> <p>Relatively strong reliance on expertise of program managers to push state of the art</p> <p>Funding can be withdrawn if targets are not met, culling and cutting back performers who are not meeting targets</p> |
| Transition | <p>Application of research to one or more DOD missions is part of the project-selection criteria</p> <p>DARPA does not typically engage with end-use customers, although may engage for some projects; engagement with end-use customers depends on nature of the research project</p> |
| Evaluation of Success | <p>Active resistance to measuring success at the project level because of the long timeline before impact</p> <p>No quantitative target specified</p> <p>Goal is to consider ideas that would take 3–5 years to establish</p> |

F. Case Study: Multidisciplinary University Research Initiative (MURI)

The Multidisciplinary University Research Initiative (MURI) program was established by Congress in 1986 in the Department of Defense (DOD) Office of the Secretary of Defense (OSD). MURI supports multidisciplinary teams from institutions of higher education to conduct high-payoff basic science or engineering research of critical concern to the DOD. The purpose is to promote large-scale academic research efforts that combine expertise from multiple disciplines, ultimately with the goal of addressing specific DOD challenges. In 2004, the program funding, execution, and program management devolved to the Air Force, Army, and Navy through each of their respective research offices, the Air Force Office of Scientific Research (AFOSR), Army Research Office (ARO), and Office of Naval Research (ONR). OSD retained oversight responsibility of the program across the Services. The MURI program complements the other basic research programs in the Services, which have a strong focus on single investigator research.

1. Definition and Approach

MURI awards are all 6.1 basic research. Topics are specified by each of the Services with new topics selected each year. Awards are typically for 3 years with an additional 2 years as renewal options. The majority of awards receive renewal to 5 years. Funding levels for awards can range from \$1 to \$2.5 million per year, depending on the topic, goals, and funding availability. The majority of awards are about \$1.5 million per year for a total 5-year funding of about \$7.5 million.

2. Budget

In 2016, the DOD granted 23 awards totaling \$162 million over a 5-year period to fund MURI teams, including 54 academic institutions (DOD 2016). In 2015, the DOD programmed \$149 million to MURI. MURI funding represents about 8 percent of the DOD's 6.1 budget of \$2.1 billion. The total available funds vary across the Services; in 2016, Air Force, Army, and Navy were at \$47, \$56, and \$53 million, respectively. These figures represent about 10 percent, 13 percent, and 9 percent, of total funding for 6.1 in the Air Force, Army, and Navy, respectively.

3. Personnel

Program managers or officers at research offices at AFOSR, ARO, and ONR manage MURI projects.

4. Allocation and Management of Investment

The MURI topic selection process begins with the Director for Basic Research in the Office of the Assistant Secretary of Defense for Research and Engineering (ASD[R&E])

providing general guidance on broad research topic areas to the Director of ARO, the Director of Research at ONR, and the Director of AFOSR. The general guidance is provided by the Director of Basic Research in the Office of the ASD(R&E) in order to encourage forward-looking, innovative topics. In general, topics are expected to be high-risk with the potential for major scientific advances or breakthroughs. Topics for the MURI program are proposed by technical research managers at AFOSR, ARO, and ONR, and finalized by the senior management of each of the Services. As previously described, program managers and officers at each of the Service research offices are typically permanent staff. The selection of topics allows DOD leadership in the military Services to guide research into areas of importance to the DOD.

Program managers and officers submit topics, which are evaluated by management at each of the DOD research offices. The research organizations depend on their program managers and officers to maintain awareness of the latest research and technology and the cutting-edge research in their communities. Some program managers and officers host workshops with the research community to help develop MURI topic proposals. Program managers and officers consult widely to develop topics, including interacting with the DOD laboratories and attending conferences. There is informal collaboration on topics across program managers and officers as well.

Topics are reviewed on the following criteria: it is basic research, is multidisciplinary, is timely, provides the prospect of anticipated scientific advances, is of high scientific quality, and is of interest to the DOD. OSD encourages highly innovative topics that may lead to paradigm shifts.

In general the Services have different specific processes for the development of topics, but all have similar characteristics. The Service program managers and officers maintain scientific awareness of the developments and new ideas in their fields from contacts with the academic and industrial communities, Service laboratories, other program managers and officers, the scientific literature, conferences, workshops, and informational meetings. Formulated topics or topic ideas are informally coordinated within and between the Services. For instance, in the Air Force, topics are internally reviewed by an Internal Research Council (IRC) made up of its four technical branch officers, the Chief Scientist, and others. The IRC provides feedback to strengthen proposed topics and to avoid overlap among technical offices. On occasion, the IRC may recommend that program managers and officers work together on a topic proposal if proposals are complementary. The topics are ranked by the senior leaders of each Directorate and their Branch Chiefs. In the Army, the topic proposals are presented across the organization in a forum called “MURI Day,” which brings program managers and officers together with leadership to provide feedback on topic ideas. Formal review processes in each Service research office provide leadership oversight, with final topic candidates being recommended to the OSD Director for Basic Research.

Candidate topics are reviewed by an OSD oversight panel and the Director of Basic Research, who down-selects the final approved list. The number of topics recommended by each Service research office has varied between 5 and 12, generally averaging around 8 per Service, depending on various budgetary and programmatic factors.

After topics are selected, a Funding Opportunity Announcement (FOA) is issued requesting white papers be submitted by university research teams to the respective research topic chief. University teams must be interdisciplinary and may consist of researchers from multiple departments within a single university or from more than one university. White papers are reviewed within each Service, with feedback provided on whether or not the university team should submit a full proposal. However, teams not recommended can still submit a full proposal for evaluation by a full proposal review panel. White papers are generally reviewed for the scientific and technical merits of the proposed research and relevance and potential contributions of the proposed research to the topical research area and to DOD missions. The white paper is an important aspect of the selection process in that the initial white paper review helps program managers and officers determine whether or not to encourage researchers to submit their full proposals.

A single topic typically receives about 4–12 proposals, with a much larger number of white papers preceding them. In 2016, the MURI programs received 270 white papers and 88 full proposals (DOD 2016). To review full proposals, the topic chief forms a review panel composed of subject matter experts from inside and outside the DOD, with a separate review panel for each topic. The number of reviewers varies between about 4 to as many as 12. Particular emphasis is placed on reviewers from outside the DOD when evaluating proposals from defense-related institutions (e.g., the Naval Post-Graduate School and the Naval Academy). Non-government subject matter experts are employed as technical advisors for each panel. They provide technical advice to the evaluation process, but do not contribute to the decision for final award recommendation. The panel sends recommendations to the deciding official in AFOSR, ARO, or ONR, who endorses the recommendations and sends it to the Director of Research. An OSD oversight panel reviews the proposal evaluation process and the Director of Research makes the final award approval.

Full proposals are evaluated based on the following criteria: scientific and technical merits, potential for the research to significantly advance fundamental understanding in the topic area, potential DOD interest, qualifications and availability of the investigators, adequacy of facilities and equipment, impact of interactions with other R&D organizations, (particularly those related to defense R&D), and realism and reasonableness of cost. The first three are considered more important and usually weighted higher. White papers are usually rated based on the first three criteria, but others may be used.

There seems to be some limitation in the flexibility to redirect funding once an award has been made. Program managers and officers can propose incremental changes in research direction and most awardees continue to receive funding renewals for years 4 and 5.

Throughout the award, the awardees periodically update program managers and officers and submit annual reports for approval. Program managers and officers work with research teams to guide research direction, to identify project-based milestones and to manage the execution of funding.

5. Transition

For technology transition, program managers and officers may connect MURI awardees with researchers at the DOD laboratories to carry the research into application. Annual program reviews are presented to the program manager and an assessment panel that is composed of government and sometimes external experts with an interest in the project. The program manager, with the advice of his assessment panel, will make the decision to continue the 2 option years. OSD conducts an early program review roughly at the end of the second year, with participation of and feedback to the military Service program managers and officers.

Since 2015, OSD has been increasing its efforts to emphasize transition of MURI awards. OSD has adopted an Innovation Corps (I-Corps) modeled after those of NIH and NSF²⁵, with a first course being set up this year for its university awardees. OSD has also extended an invitation for participation in its reviews of MURI programs to the DOD laboratories as well as small businesses and industry. As the MURI university awardees discuss their progress, OSD strives to provide an opportunity for the laboratories and businesses to make further connections to spur technology transition.

6. Evaluation of Success

Program managers and officers formally review their awards on a yearly basis. This process involves participation from potential end users to review research progress. They also review annual progress reports and often conduct interim visits and teleconferences. They review all publications being generated as a result of the research (journal articles, conference abstracts or proceedings, books or book chapters, theses, manuscripts, etc.) in order to evaluate the scientific progress in the project. The MURI progress is also a part of the formal reviews of the overall Service research programs by external Boards of Visitors. OSD conducts a yearly program review of selected MURI projects, as described above. OSD conducted an in-depth review of the impact of the first 25 years of the MURI program, which was important because most of the impact of a MURI program occurs well after the program ends.

Some metrics that are collected to gauge the success of the awards include number of publications and citations to publications (compared with citations to published work from

²⁵ For more information about I-Corps, see Section B in Chapter 6.

others in similar scientific community). For example, a 2014 study found that MURI awards are productive, yielding on average 40 papers published in peer-review journals (Belanich et al. 2014). The same study noted that about a quarter of MURI awards produced patents, with an average of about four patents produced by those awards. In the Army, program managers and officers track how many graduate students are supported by the MURI award.

In addition, program managers and officers may informally track the transition of research from basic to applied, but they do not track amounts of follow-on funding. However, this measure does not fully capture the value of the research given the long time frames (10–20 years) for basic research to develop. Overall, the MURI program does not force researchers to develop an application and prefers to encourage exploratory research.

7. Lessons Learned

Table 14 provides a summary of the findings from this case study, which are highlighted in the following lessons learned:

- OSD emphasizes discovery and surprise as basic tenets of the MURI program.
- Program officers, the Services, and OSD do not over-specify the problem and outcomes, and they are flexible in the management of MURI awards to allow new developments in research to occur..
- Program managers and officers are relied upon for their domains of expertise, requiring strong engagement with their respective scientific communities as well as industry or other end users and customers if there is an opportunity for technology transition
- The design of the MURI program is highly visible across the DOD. Program managers and officers are motivated to participate because their leadership encourages them and gives them the opportunity to influence future military capabilities and the state of the art in their fields of science.
- The two-stage white paper/full-proposal process allows for immediate feedback from program managers and officers to research teams on the relevance and strength of their proposal and makes for a better portfolio of projects meeting topic goals
- The MURI program provides an opportunity for program managers and officers across Services to engage with one another, circulating topics across the other Services, and possibly working together toward complementary research goals
- The MURI program provides opportunity for program managers and officers and research organizations to work across disciplines to solve research challenges for the DOD and to make scientific advances and breakthroughs that

lead to new military capabilities. Requirements for multidisciplinary research and research teams is not typical in the DOD.

- Topic selection and high funding levels of \$7.5 million over 5 years (atypically large project funding) allows the DOD to better shape a particular research area of interest. The key has been to prevent MURI awards from becoming too large; otherwise teams, communication, and synergy would be more difficult to manage and could diminish the quality of the proposals and research, while maintaining a level of funding that makes possible the right combination of expertise to make progress in science that could not have been made by funding individual disciplines.

Table 14. Summary of Findings for Multidisciplinary University Research Initiative (MURI)

| | |
|--|---|
| Definition and Approach | <p>MURI is a cross-DOD Service program that supports a portfolio of projects for academic institutions to conduct high-payoff basic science or engineering (6.1)</p> <p>Funded research projects are in areas of critical concern to DOD</p> <p>Projects are relatively large-scale academic research efforts that require a combination of expertise from multiple disciplines</p> |
| Budget | <p>\$149 million (FY 2015), represents 10%, 13% and 9% of total 6.1 funding for the Air Force, Army and Navy respectively</p> <p>Early stage research is funded at levels that are less than one percent of the agency's RDT&E budget</p> |
| Personnel | <p>Permanent program managers and officers at Service research offices (AFOSR, ARO, and ONR) support MURI</p> |
| Allocation and Management of Investment | <p>Technical research managers and officers at AFOSR, ARO, and ONR propose topics (and are evaluated by senior management at each office)</p> <p>An Office of the Secretary of Defense oversight panel and the Director of Basic Research select a final list of topics</p> <p>Panel engages with internal and external scientific community (through site visits, formal interfaces, and other methods) to identify priorities, emerging areas, and learn about user needs</p> <p>Use of a two-phase white paper/full-proposal process leads to stronger and more relevant proposals</p> <p>Panel encourages reviewers to embrace high-risk projects</p> <p>Award sizes are large to ensure projects address big problems</p> <p>Mandate or encourage multidisciplinary teams</p> <p>Panel employs reviewers from inside and outside organization</p> <p>Grants are used.</p> <p>Minimal management once awards are given.</p> |
| Transition | <p>Program officers are responsible for transition</p> <p>Engage with acquisition/customers/laboratories and other transition partners to understand how to meet needs</p> |
| Evaluation of Success | <p>Bibliometrics used to get a big picture view of outputs and identify outliers, but not as sole indicators of project performance</p> <p>Awards are reviewed yearly by program managers and officers</p> <p>No quantitative target specified</p> |

3. Early Stage Research at the Department of Energy

A. Introduction

The Department of Energy (DOE) is a prominent sponsor of Federal research and development (R&D), with a broad portfolio spanning basic and applied research to development. The 2014–2018 DOE Strategic Plan classifies the mission of DOE into three areas: science and energy, nuclear security, and management and cleanup of DOE’s nuclear legacy. All three mission areas include an R&D component, with at least some of it early stage.

No single office at DOE supervises all R&D funding. Instead, eight different offices and subagencies within DOE administer R&D-focused programs tailored to meet specific missions and needs. These offices are—by descending order of total R&D funding in FY 2015 (Table 15)—the National Nuclear Security Administration (NNSA), Office of Science, Energy Efficiency and Renewable Energy (EERE), Nuclear Energy, Fossil Energy, Advanced Research Projects Agency–Energy (ARPA-E), Electricity Delivery and Energy Reliability, and Environmental Management. R&D is sometimes funded jointly by multiple programs.

DOE does not have a formal or uniform definition of early stage research and technology. Instead, elements of early stage research at DOE appear across an R&D continuum as captured in Table 16, as interpreted and presented in the 2014 *Basic Energy Sciences Summary Report* (DOE Office of Science 2014). While other DOE offices and subagencies may have slightly different definitions and interpretations of R&D, this continuum captures the science and energy programs at DOE.

In FY 2015, funding to R&D comprised \$13.6 billion of DOE’s \$27.4 billion budget (Table 15). Of this \$13.6 billion, 33 percent went to basic research, 41 percent to applied research, and 24 percent to development.

Using the TRL definition of early stage research as basic and applied research, DOE expends 36 percent of its total budget (or 74 percent of its R&D budget) on early stage research. The amount individual offices and subagencies expend across these R&D areas varies considerably. Seven of DOE’s eight R&D-funding offices spend less than 10 percent their total R&D budget on basic research, and five of these seven expend less than 1 percent. The outlier, Office of Science, spends 100 percent of its R&D funding on basic research efforts.

Table 15. Department of Energy Funding to R&D, FY 2015 (\$ millions)

| | Enacted Budget | Budget to R&D | Basic | Applied | Development |
|--|-----------------------|--------------------------|--------------|----------------|--------------------|
| <i>NNSA</i> | 11,399 | 6,184 | 91 | 3,887 | 1,932 |
| <i>Office of Science</i> | 5,068 | 4,310 | 4,310 | — | — |
| <i>EERE</i> | 1,914 | 1,360 | — | 594 | 763 |
| <i>Nuclear Energy</i> | 833 | 826 | 35 | 679 | 112 |
| <i>Fossil Energy</i> | 791 | 551 | 5 | 198 | 332 |
| <i>ARPA-E</i> | 280 | 280 | — | 140 | 140 |
| <i>Electricity Delivery and Energy Reliability</i> | 147 | 115 | 8 | 67 | 40 |
| <i>Environmental Management</i> | 5,861 | 14 | — | 5 | 9 |
| <i>Non-R&D Offices</i> | 1,109 | — | — | — | — |
| <i>Total (R&D Performing)</i> | 27,402 | 13,641 | 4,450 | 5,570 | 3,328 |

Note: All figures are rounded to the nearest million dollars. Data from enacted FY 2015 budget as reported in FY 2017 Department of Energy Budget Request to Congress. While DOE distinguishes between basic research, applied research, and development in its budget requests, these differentiations are not absolute. Within the Office of Science, for instance, the Basic Energy Sciences Program Office supports Energy Frontier Research Centers that have both basic and applied research components.

Table 16. DOE Research, Development, and Deployment Continuum

| | Basic Research | Applied Research | Technology Maturation and Deployment |
|------------------------------------|--|--|--|
| <i>Goal and Metrics</i> | New Knowledge and Understanding | Practical Targets and Milestone Achievement | Practical Targets and Milestone Achievement |
| <i>Characteristics</i> | <ul style="list-style-type: none"> Addresses fundamental limitations of current theories and descriptions of matter in the energy range important to most energy technologies Seeks fundamental new understanding of materials or processes that may revolutionize or transform energy future energy technologies Pursues fundamental new understanding, usually focused on scientific showstoppers, to advance energy technologies | <ul style="list-style-type: none"> Establishes proof of new, higher-risk concepts Prototypes new technology concepts Explores the feasibility of scaling up demonstrated technology concepts in a “quick hit” fashion | <ul style="list-style-type: none"> Conducts research to meet technical milestones, emphasizing development, performance, cost reduction, and durability of materials and components or the efficiency of processes Scales up research Demonstrates small-scale and at-scale technology Reduces costs Involves manufacturing R&D Includes deployment and support activities leading to market adoption Shares cost with industry partners |
| <i>Major Performers within DOE</i> | <ul style="list-style-type: none"> Office of Science (core research and Energy Frontier Research Centers) | <ul style="list-style-type: none"> ARPA-E, applied energy offices, Office of Science Energy Innovation Hubs | <ul style="list-style-type: none"> Applied energy offices |

Note: Adapted from DOE Office of Science (2014). This continuum applies primarily to DOE’s science and energy portfolio and less to its nuclear security and environmental management efforts.

Both complementary to and overlaid with DOE's funding to R&D are its investments in its 17 National Laboratories, which conduct R&D for DOE's various offices and other Federal sponsors. In FY 2015, funding to the National Laboratories comprised \$13.1 billion of DOE's total budget, covering both R&D and associated costs of laboratory operation, facilities, and administration. These National Laboratories are major R&D performers for the DOE, especially for certain types of R&D efforts, such as fundamental research that rely on scientific user facilities at the Laboratories, or classified nuclear weapons R&D. Furthermore, notable early stage R&D efforts are funded through the Laboratory Directed Research and Development (LDRD) program, which are managed by the National Laboratories.

Laboratories are important in the broader context of how offices and subagencies of DOE fund R&D. In addition to laboratory programs, DOE offices also run open solicitations to universities for individual research projects, support large integrated research centers, and partner with industry, university, and laboratory consortia to execute major technology demonstrations. Basic Energy Sciences (BES), a program office within the Office of Science, describes a number of these mechanisms in the 2014 *Basic Energy Sciences Summary Report*, as recaptured in Table 17. To the extent appropriate for any given R&D program, DOE offices deploy extensive processes to review and select proposals from universities, industry, and laboratory researchers on a competitive, merit basis.

Table 17. R&D Mechanisms at the Department of Energy

| Research | Investigators and Their Institutions | Period of Award and Management | Typical Annual Award Amount | Core Motivation and Research Focus |
|----------------------------------|---|---|---|---|
| Core BES Research | <ul style="list-style-type: none"> • Single investigators, small and large research groups • Led by universities, DOE laboratories, or nonprofits | <ul style="list-style-type: none"> • Usually 3-year renewable awards • Managed by BES • Early Career awards, managed separately as 5-year, nonrenewable awards with set budgets | <ul style="list-style-type: none"> • \$150K to \$2M | <ul style="list-style-type: none"> • Fundamental research in the grand challenge and use-inspired areas • BES determines research focus for each core area, with community guidance on new basic research needs |
| Energy Frontier Research Centers | <ul style="list-style-type: none"> • Self-assembled groups of about 12 to 20 senior investigators • Led by universities, DOE laboratories, nonprofits, and industry, often with teaming across institutions | <ul style="list-style-type: none"> • 5 years with possible 5-year renewal (pending appropriations) • Managed by BES | <ul style="list-style-type: none"> • \$2M to \$5M | <ul style="list-style-type: none"> • Fundamental research requiring multiple investigators from several disciplines, often with clear link to new energy technologies • Research focused among large set of basic research needs developed with community input |
| Energy Innovation Hubs | <ul style="list-style-type: none"> • Large group spanning basic and applied R&D • Led by universities, DOE laboratories, industry, or nonprofits, with extensive teaming across institutions | <ul style="list-style-type: none"> • 5 years with possible 5-year renewal • Managed by single DOE office but with broad coordination across DOE • BES manages two Energy Innovation Hubs: Fuels from Sunlight and Batteries and Energy Storage | <ul style="list-style-type: none"> • About \$22M in year 1 (with up to \$10M for infrastructure but no new construction) • Up to \$25M in years 2–5 | <ul style="list-style-type: none"> • Purpose-driven research, integrating across basic and applied research toward commercialization • Generally, DOE determines topical areas addressed by the Hubs, and Funding Opportunity Announcements (FOAs) are specific |
| ARPA-E | <ul style="list-style-type: none"> • Single investigator to small teams. Led by universities, nonprofits, industry, or consortia of these institutions | <ul style="list-style-type: none"> • 1–3 years • Managed by ARPA-E, which reports to the Secretary of Energy | <ul style="list-style-type: none"> • \$500K to \$10M | <ul style="list-style-type: none"> • High-risk research driven by potential for significant commercial impact. Generally, DOE determines area of interest, and FOAs are specific |
| DOE Technology Offices | <ul style="list-style-type: none"> • R&D teams of varying size • Led by universities, DOE laboratories, industry, or consortia of these institutions | <ul style="list-style-type: none"> • 1–3 years • Managed by specific DOE technology offices | <ul style="list-style-type: none"> • Small teams (~\$300K) to large technology demonstrations (>\$1M) | <ul style="list-style-type: none"> • Developmental research and technology demonstration projects with specific deliverables and clear milestones • Generally, DOE determines area of interest, and FOAs are specific |

Source: DOE Office of Science (2014).

Note: DOE Technology Offices include EERE, the Office of Fossil Energy, the Office of Nuclear Energy, and others.

B. Case Study: Advanced Research Projects Agency–Energy (ARPA-E)

The Advanced Research Projects Agency–Energy (ARPA-E) was established in 2009 in order to fund R&D projects that are too early for private-sector investment but are identified for their high potential to advance energy technologies and lead to entirely new ways to generate, store, and use energy. In the continuum of DOE R&D, they occupy the space between the domains inhabited by the Basic Energy Sciences—and the Office of Science writ large—and by the applied energy offices.

STPI chose ARPA-E as a case study because it seeks to fund high-risk, high-potential research, focuses on transition of funded research to application, and is situated at the transition between applied research and early development. In these ways, ARPA-E has notable similarities with NASA’s NIAC program.

1. Definition and Approach

ARPA-E defines early stage research as research in high-potential energy technologies that are too early for private sector investment. The goal of ARPA-E is to develop and advance those technologies to the point at which the private sector is able to adopt and pick up those technologies for further, later-stage development. As such, ARPA-E projects range from TRL 1.5 to TRL 4. The distribution can be represented by a bell curve with the mean at TRL 2 or TRL 3.

ARPA-E leadership is proposing to expand its focus beyond simply getting the first product to market to accelerate the impact of the technology. Given the entrenched nature of energy industries, further transformations are needed before they will adopt new technology. Follow on funding is needed to demonstrate adoption to the energy industry and solve scaling barriers.

2. Budget

ARPA-E’s enacted budget in FY 2015 was roughly \$280 million, accounting for approximately 1 percent of DOE’s total budget. Since its establishment in 2009, ARPA-E’s budget has steadily increased. Created with an initial investment via the 2009 American Recovery and Reinvestment Act (ARRA), ARPA-E funding has increased from \$180 million in FY 2011 to \$280 million in FY 2015. The agency has further requested \$500 million in its FY 2017 Budget Request and aims to ramp up to a \$1 billion budget in FY 2021.

3. Personnel

ARPA-E staff consists of approximately 50 Federal employees and 50 contractors. The Federal staff includes the program directors, technology-to-market advisors, technology fellows, and operations staff (in-house legal, procurement, and contracting).

Contractor staff includes Systems Engineering and Technical Assistance (SETA), communications, administrative, and IT support.

Program directors are rotators from academia, industry, and other government agencies that serve 3- to 5-year terms. Agency leadership has found that 3 years can be too short, but sometimes the individuals must return to their home institutions because of the nature of their personnel agreement. At times program directors are able to continue part-time at ARPA-E after they return to their home institutions.

ARPA-E has special hiring authority but still cannot overcome all issues related to Federal employment, such as the perceived onerous civil service travel rules, which include regulations on paying for travel. It makes recruitment challenging, especially for industry personnel, who must also sever all ties with their company.

Of particular note is that ARPA-E identifies its ultimate customer as the energy industry, not the Department of Energy. This is an important difference from either NASA or the DOD, whose S&T organizations are primarily chartered to serve their own agencies. This distinction can also complicate the ARPA-E transition process.

4. Allocation and Management of Investment

The focus areas of ARPA-E's portfolio are defined by statute—technologies that improve efficiency, reduce emissions, reduce imports, or result in some combination of these. The agency strives to maintain an even distribution across the energy sector (electricity generation, electrical grid and storage, efficiency and emissions, and transportation and storage), but specific topics have changed significantly over time. Hiring program directors with expertise across the spectrum of topics helps balance the portfolio.

When developing a program, program directors conduct extensive outreach to determine the appropriate niche for ARPA-E involvement (i.e., where the gap is in funding). Program directors hold discussions with other DOE offices and other Federal agencies, conduct site visits at academia and industry, attend conferences and webinars, hold workshops, fund external studies, and issue requests for information. Each proposed program is assessed against ARPA-E strategic goals and subject to community input and a detailed technical and economic analysis.

ARPA-E funds two broad types of R&D: open solicitations and focused technical programs. Whether open or focused, programs last 3 years and fund multiple projects for between 1 to 3 years. Since ARPA-E was established, open solicitation programs have distributed \$125–175 million in funding to between 41 and 67 projects per solicitation. The median size of technical programs in FY 2014 was \$37.6 million, and the median number of projects was 14.

Project proposals are vetted by both external reviewers and internal Merit Review Boards (MRB). An MRB consists of the Deputy Director of Technology, the program

director for the topic, and two to three other program directors. After an extensive review process, the program director submits recommendations for funding to the ARPA-E director who makes the final decision. The director typically follows the recommendations of the program director with minor modification.

ARPA-E encourages team projects—75 percent of its projects are a collaboration between personnel from universities, industry, and/or government laboratories. As per our interviewee, multi-sector teams can take advantage of strengths found across organizations—small businesses in commercialization and Federal laboratories in project management.

Drawing from the DARPA model, ARPA-E program directors work closely with awardees and provide substantial guidance and direction over the course of a project. This includes both technical assistance from project directors, market awareness from technology-to-market advisors (also known as commercialization managers), and other support from an in-house legal, procurement, and contracting staff. ARPA-E uses cooperative agreements as its funding vehicle to formalize the collaborative nature of its projects.

Technology-to-market guidance, the formal role of a commercialization manager, and milestones are key elements of ARPA-E. When ARPA-E grantees receive the first phone call, it is not, “Congratulations, you have been selected for funding,” but, “Congratulations, you have been selected to negotiate milestones.” Awardees of ARPA-E grants are provided practical training and business information to help guide products to market, and awardees require a technology-to-market plan prior to receipt of award.

Managers monitor project milestones, and continually evaluate both whether the project is meeting its technical goals and whether the techno-economic assessment results are favorable. While managers provide extensive support and guidance to awardees, they will also stop funding programs if milestones are not met because the technology is either technically infeasible or not economically viable.

5. Transition

As described in the subsection above, transition is a critical component to ARPA-E program management. A commercialization manager provides specialized assistance for transition, and project teams may include transition partners from academia and private sector organizations.

6. Evaluation of Success

ARPA-E’s mission is largely to accelerate the economic impact of U.S. investments in energy R&D, and the major measure of ARPA-E success is therefore market impact. While ARPA-E does track the meeting of project/program milestones as well as early intellectual property metrics (patents, publication, inventions, and industry awards), the

key metrics for ARPA-E’s mission are the number of projects that receive follow-on funding from the private sector or government programs, as well as the number of new companies established through supported projects.

The FY 2017 ARPA-E Budget Request emphasized that these metrics do not fully capture the value produced by the agency. The types of high-potential research projects that ARPA-E supports are inherently high-risk or early stage enough that extended funding will be needed to “de-risk” and bring a given technology to a level that private industry is able to adopt it. As such, evaluating the success of ARPA-E projects—either individually or in aggregate—based on these metrics alone risks undercutting ARPA-E’s ability to find and support the most high-risk but high-potential research, since these projects are less likely to produce follow-on funding or new companies in the short term. Note that this is quite similar to research in parts of NASA; for example, the Aeronautics Research Mission Directorate is supporting high-risk, high-payoff projects that are too risky for private investment, but that may ultimately be transitioned to industry.

7. Lessons Learned

Table 18 provides a summary of findings from this case study. STPI observed the following lessons.

- ARPA-E’s use of rotators as program directors helps the agency stay up to date on the current state of energy research and industry needs. University professors provide the academic perspective and industry personnel provide the market perspective. The agency purposely targets active, engaged members of the research community to serve as a source of new ideas.
- Labor-intensive hands-on program management ensures significant progress toward commercialization. The role of the commercialization manager or technology-to-market advisor is key in this process. Many energy researchers are not market experts, but market awareness is important to ensure that technologies have the best chance of making an eventual impact on the industry.
- Small businesses seem to be the most successful project leaders based on available data on follow-on funding, which is a proxy for commercialization. According to our interviewee, projects led by small businesses performed five times as well, in terms of producing follow-on funding, as projects led by universities and laboratories. The agency also encourages collaborations between academia, industry, and government laboratories to take advantage of each of their strengths.

Table 18. Summary of Findings for Advanced Research Project Agency–Energy (ARPA-E)

| | |
|--|--|
| Definition and Approach | ARPA-E funds a portfolio of programs that are too early for private-sector investment and have high potential to advance energy technologies (6.2, 6.3) Projects are extramural and some involve FFRDCs Projects de-risk technology to attract commercial investments Flat organizational structure has a limited number of permanent departments or offices Unlike NASA and DOD offices, ARPA-E identifies its customer as the energy industry, not DOE |
| Budget | \$280 million (FY 2015), represents 2% of DOE's R&D budget, or 1% of DOE's total budget |
| Personnel | ARPA-E uses rotators as program directors that are hired through special hiring authorities to serve terms of 3–5 years to allow for a constant refresh of ideas ARPA-E uses authority to hire at higher salaries than government scales Staff is split into roughly 50 Federal employees and 50 contractors Project management teams include technical project managers; commercialization managers; and in-house legal, procurement, and contracting staff |
| Allocation and Management of Investment | Program ideas are sourced from the market and other external organizations, typically proposed by a program manager Program managers engage with internal and external scientific community (through site visits, formal interfaces, and other methods) to identify priorities and emerging areas, and to learn about user needs Award sizes are large to ensure projects address big problems Program managers require or encourage multidisciplinary and multi-sector teams Cooperative agreements are generally used to enable a stronger government role Funding agreements with FFRDCs or Government-Owned, Government-Operated laboratories may be used Other Transaction Agreements may be used Relatively strong reliance on expertise of program managers to push the state of the art Funding can be withdrawn if targets not met Active involvement of program management with continual evaluation against milestones |
| Transition | Commercialization manager provides specialized assistance for transition Project teams can include transition partners, including academia and private sector |
| Evaluation of Success | Follow-on funding from private sector or government programs Number of new companies established No quantitative target specified |

C. Case Study: Laboratory Directed Research and Development (LDRD)

Laboratory Directed Research and Development (LDRD) is a discretionary program that authorizes the leadership at 16 of the 17 National Laboratories to fund researcher-initiated R&D projects within their own laboratories.²⁶ These projects can serve as proofs of concept in emerging fields, address significant technical challenges facing laboratory programs, or explore innovative concepts to address DOE missions. For some laboratories, LDRD also plays a major role in the recruitment and retention of talented staff.

The precursor program to LDRD was first authorized in the Atomic Energy Act of 1954. The LDRD program was institutionalized as an official program in the FY 1991 National Defense Authorization Act.

STPI chose LDRD as a case study because of its similarity with NASA's Center Innovation Fund (CIF) program.

1. Definition and Approach

LDRD research must meet the following objectives, as articulated by DOE Order 413.2B, "Laboratory Directed Research and Development":

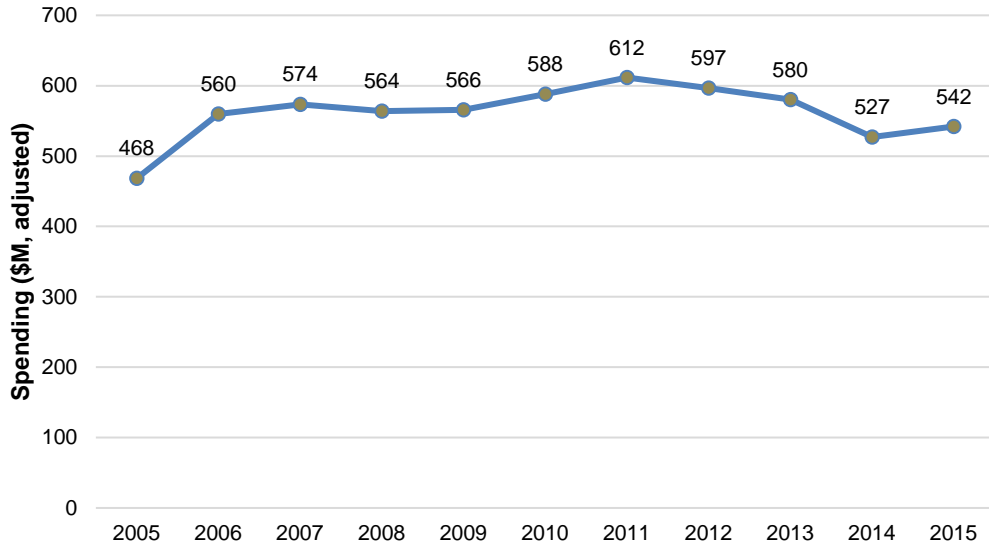
- Maintain the scientific and technical vitality of the laboratories;
- Enhance the laboratories' ability to address current and future DOE/NNSA missions;
- Foster creativity and stimulate exploration at the forefront of science and technology;
- Serve as a proving ground for new concepts in research and development; and
- Support high-risk, potentially high-value research and development.

The LDRD program does not explicitly define early stage research. As a proving ground for new, investigator-driven R&D concepts within an institution, it mirrors CIF.

2. Budget

Laboratories fund LDRD by charging a percentage fee on work performed at the laboratory. Currently, maximum LDRD funding is capped at 6 percent of total laboratory budget, though many laboratories elect to collect and expend less. In constant dollars, LDRD spending has remained relatively flat between FY 2005 and FY 2015 (Figure 10).

²⁶ The National Energy Technology Laboratory (NETL) is not a federally funded research and development center (FFRDC), and only FFRDCs are eligible for LDRD.



Note: Data from DOE's LDRD Annual Reports to Congress, FY 2005–2015. Spending is adjusted to constant 2015 dollars.

Figure 10. LDRD Spending in Constant 2015 Dollars, FY 2005–2015

Funding amount differs considerably between different laboratories, as shown in Table 19. The three laboratories of the NNSA (indicated in Table 19) spend the largest amount on LDRD, in terms of both total costs and a percent of their total budgets. This is due largely to the elevated importance of LDRD as a recruitment and retention tool at these laboratories compared to others. The flexibility for a laboratory to adjust the amount it expends on LDRD funding in response to mission and institutional needs is a noteworthy attribute of the LDRD program.

Table 19. Spending on LDRD by National Laboratories in FY 2015

| Laboratory | Number of Projects | LDRD Costs (\$ million) | Total Laboratory Costs (\$ million) | LDRD as a Percentage of Total |
|--|---------------------------|--------------------------------|--|--------------------------------------|
| Ames National Laboratory | 11 | 11 | 57 | 1.4% |
| Argonne National Laboratory | 125 | 31 | 748 | 4.1% |
| Brookhaven National Laboratory | 43 | 10 | 587 | 1.6% |
| Fermi National Accelerator Laboratory | 12 | \$2 | 342 | 0.6% |
| Idaho National Laboratory | 81 | 18 | 898 | 2.0% |
| Lawrence Berkeley National Laboratory | 86 | 25 | 751 | 3.3% |
| Lawrence Livermore National Laboratory | 158 | 83 | 1524 | 5.4% |
| Los Alamos National Laboratory | 279 | 116 | 2130 | 5.4% |
| National Renewable Energy Laboratory | 63 | 12 | 375 | 3.1% |
| Oak Ridge National Laboratory | 187 | 41 | 1258 | 3.3% |
| Pacific Northwest National Laboratory | 203 | 42 | 930 | 4.5% |
| Princeton Plasma Physics Laboratory | 25 | 2 | 90 | 2.5% |
| Sandia National Laboratories | 380 | 145 | 2813 | 5.2% |
| Savannah River National Laboratory | 54 | 8 | 185 | 4.2% |
| SLAC National Accelerator Laboratory | 28 | 6 | 256 | 2.5% |
| Thomas Jefferson National Accelerator Facility | 6 | 1 | 126 | 0.6% |

Source: All costs are rounded to the nearest million dollars. Data from DOE's FY 2015 LDRD Annual Report to Congress.

Note: Number of projects reflects both funding to both new and continuing projects. The NNSA laboratories are shaded grey.

3. Personnel

The LDRD program has no personnel per se. LDRD program awards fund external researchers working on the LDRD projects, which are managed internally by the director and staff of the sponsoring laboratory.

4. Allocation and Management of Investment

All DOE laboratories use some form of competitive solicitation to select a limited number of proposals in research areas of specific interest and relevance to work at the specific laboratory. These proposals are chosen through a merit-based peer review process that draws upon both internal research staff and external reviewers from industry and universities.

As an example of how one laboratory governs its program, STPI reviewed Sandia National Laboratories, which controls the largest LDRD budget among the National Laboratories, at \$145.3 million in FY 2015. At Sandia National Laboratories, the LDRD

application form consists of a one-page idea, or pre-proposal, of about 500 words that asks for a statement of the problem and potential research solution (200 words), a more detailed description of proposed research activity (200 words), and a brief description of the tie to DOE's mission (100 words). The LDRD program receives approximately 1,000 proposals, and ideas are reviewed by an internal management team for each investment area. The LDRD program invites 200 to 230 research ideas for submission as full proposals for which a template and guidance are provided. Principal investigators may discuss their ideas with peers or management to help researchers clearly articulate their research ideas and write good proposals. The chief technical officer reviews the LDRD portfolio, evaluating whether or not the research is at the forefront of science and engineering, has the potential to benefit missions of the laboratory, and is likely to advance the state of the art or create innovative technologies. Approximately 110 to 120 proposals are chosen each year for a funding period of up to 3 years.

5. Transition

There are notable examples of LDRD projects evolving into laboratory programs, such as the Joint Bioenergy Institute at Lawrence Berkeley National Laboratory, which have, in turn, enabled the creation and transfer of many inventions to the private energy industry (Commission to Review the Effectiveness of the National Energy Laboratories 2015, Volume 2). However, the primary objectives of the LDRD program are to foster the capabilities and development of a culture of innovation and support high-risk, potentially high-reward research. As such, transition is not an integral part of LDRD project design.

6. Evaluation of Success

Each fiscal year, the DOE Chief Financial Officer submits an LDRD report to Congress that details LDRD expenditures and metrics of LDRD impact. These metrics include number and percentage of post-doctoral researchers at National Laboratories partially or fully supported by LDRD, number of peer-reviewed publications derived from LDRD projects, and intellectual property generated by LDRD in terms of patents and invention disclosures.

While these metrics help to illustrate LDRD's output in clear terms, they fail to completely capture the fullness of the program's impact. No formal metrics are collected at the aggregate Federal level to trace and capture whether ideas from LDRD research become integrated into core research programs through received follow-on funding, or whether findings from LDRD guide the trajectory of mainline research programs. Ultimately, however, many notable contributions of the LDRD projects can only be captured by anecdote, some of which were described in the Commission to Review the Effectiveness and Efficiency of the National Laboratories (2015).

7. Lessons Learned

Table 20 provides a summary of the findings from which the following lessons were derived.

- Funding to LDRD at a given laboratory is capped to a percentage of the laboratory's total budget and is funded through an overhead fee placed on sponsored work. This creates two phenomena. First, because laboratories compete with other R&D performers, including other National Laboratories, for work, leadership must balance the need for LDRD funding with the burden it places on potential clients. Second, the laboratory had the flexibility to ramp up and ramp down LDRD investments as needed in order to meet mission needs.
- The decentralization of the LDRD program allows leaders of individual laboratories to create LDRD projects to suit the specific needs and strengths of their laboratories, thus increasing the likelihood that projects reflect the energies and potential of their staffs.

**Table 20. Summary of Findings for
Laboratory Directed Research and Development (LDRD)**

| | |
|--|---|
| Definition and Approach | LDRD supports a portfolio of laboratory researcher-led projects (6.1, 6.2) Funds researcher-initiated projects at 16 of the 17 DOE National Laboratories Support of investigator-initiated research (or set-aside time) for the purpose of recruitment and internal retention LDRD program is decentralized and discretionary, with funding based upon each laboratory director's approval |
| Budget | \$542 million (FY 2015), represents 4% of total DOE laboratory costs Funds come from a fee charged on work performed at the laboratories, capped at a maximum of 6% of each laboratory's budget |
| Personnel | Managed internally by National Laboratory director and staff |
| Allocation and Management of Investment | Decentralization allows leaders at individual laboratories to craft LDRD programs to suit the specific needs and strengths of their laboratories, increasing the likelihood that projects reflect the energies and potential of their staff Proposals are chosen through a merit-based peer review process, including internal research staff and external reviewers (from industry and academia) Two-phase white paper/full-proposal process leads to stronger and more relevant proposals In total, 110 to 120 project proposals are chosen for a 3-year funding period each year Laboratory funding via Federal contract (as FFRDC management and operating contract) is used Flexibility to ramp up and ramp down LDRD investments allows the laboratory to meet mission needs |
| Transition | Projects are to maintain laboratory capabilities and foster creativity; transition is not central to the program |
| Evaluation of Success | Yearly report tracks number of post-doctoral researchers funded, peer-reviewed publications, and intellectual property generated (patents and invention disclosures) No quantitative target specified |

4. Early Stage Research in the Intelligence Community

A. Introduction

The total Intelligence Community (IC) budget is about \$70 billion, but its R&D budget is classified.²⁷ Nonetheless, STPI conducted case studies on two IC R&D organizations. The Intelligence Advanced Research Projects Activity (IARPA) was chosen as a case study because of its use of a unique tournament approach to managing projects, its use of quantitative metrics and milestones, and its structured approach to transition. National Geospatial-Intelligence Agency (NGA)–Research was selected for its focus on developing in-house expertise within government organizations.

B. Case Study: Intelligence Advanced Research Projects Activity (IARPA)

Congress created IARPA in 2007 to “envision and lead high-risk, high-payoff research that delivers innovative technology for future overwhelming intelligence advantage.” The organization funds extramural research. Because it does not have an operational mission and does not deploy technologies directly to the field, IARPA can focus on a longer time horizon. The organization resides within the Office of the Director for National Intelligence.

1. Definition and Approach

IARPA does not set aside a portfolio of research in any particular category, and considers most of its research applied (6.2, TRLs 3–4, with one or two programs at 6.1, TRLs 1–2). Examples of work at IARPA that could be considered closer to 6.1 than 6.2 include the Multi-Qubit Coherent Operations (MQCO) program, which is looking at fundamental operations that can be performed with a quantum system, and the neuroscience program, which is studying how the human brain computes. However, goals for even a fundamental program like MQCO aim to become more applied eventually.

²⁷ In FY 2017, \$16.8 billion was requested for military intelligence programs and \$53.5 billion for national intelligence programs. See Office of the Director of National Intelligence (ODNI 2017).

2. Budget

IARPA's entire budget is classified and cannot be reported here. At any given time, 35 or so unclassified programs are underway. Unclassified programs fall in the range of \$10–20 million annually, so an annual budget of \$350–700 million for unclassified programs can be assumed. Funding for programs including quantum computing and neuroscience (the most basic of IARPA's programs) has been relatively level over the last 8 years.

3. Personnel

In the last year, IARPA's former three-office structure, each with three to five program managers, has been dissolved, and all program managers now report directly to the IARPA Director. In addition, three positions—a chief scientist, a chief of testing and evaluation (T&E), and a chief of transition—were added to support the core missions of IARPA.

IARPA program managers come from academia, industry, or government (ratio is about 20-40-40), and all have a research background. In some areas such as machine learning, IARPA competes fiercely with industry and often takes advantage of specialized hiring authorities²⁸), which allows IARPA to exceed traditional government salary caps for those personnel. Even so, IARPA is unable to meet the seven-figure salaries offered by industry, and has to appeal to a candidate's sense of patriotism or tout the organization's ability to affect the direction of an emerging field of research.

An IARPA program manager can serve a maximum of 5 years, which is shorter than the lifetime of many research projects, so about half of all research topics are taken over by other program managers who may change the project's direction. A program manager typically runs two programs. Since a given unclassified program is in the range of \$10–20 million per year, a program manager is responsible for about \$20–40 million per year plus or minus some for running small seedling projects and other programs.

IARPA program managers have substantial support from the organization. Each is supported directly by one full-time technical Systems Engineering and Technical Assistant (SETA) and one half-time programmatic SETA leading to about two full-time equivalent (FTE) staff members per program team, not counting contracting officers, whose effort is spread across the organization.²⁹ The total FTE count at IARPA divided over the total number of programs comes to about four FTEs per program (including the program manager).

²⁸ See Intelligence Community Directive (ICD) 623 (2008).

²⁹ SETA support refers to the use of civilian employees or government contractors to assist the DOD and other government personnel for analysis and engineering services.

4. Allocation and Management of Investment

Most IARPA programs run 3–5 years and start with a Broad Agency Announcement (BAA) that solicits research proposals, usually from teams made up of several academic and industry organizations. IARPA typically selects several proposals for funding and manages the teams in parallel. Each is working toward the same set of technical goals, and progress is measured regularly using third-party evaluators (typically a federally funded research and development center [FFRDC]).

With respect to topic selection (or what is essentially creation of a new program), a program manager has to prepare an in-depth briefing (100 slides or so) for what IARPA calls a “new start pitch,” an extended (3+ hour) meeting with the IARPA Director, external advisors from FFRDCs, government advisors, and consultants to justify the details of the program. The session is staged as a dissertation defense with cross-examination and grilling. After the meeting itself, the program manager typically has homework to do or follow-up questions to answer.

IARPA uses a modification of the Heilmeier catechism to help with selection decisions.³⁰ Additional questions include: Where is the market failure? Why should IARPA invest over others? Why isn’t the commercial sector or another part of government investing in the proposed topic area? The IARPA Director also often asks advisors to do a “pre-mortem” as part of the decision process:

Imagine 5 years from now, whence the program has failed. Why? Imagine the various failure modes: key assumption was wrong, high-quality data to train models didn’t exist, state-of-the-art equipment wasn’t precise enough.

Questions about security and appropriate level of classification are also addressed at this stage. Another consideration is whether IARPA researchers would regret inventing a technology in the event it is later stolen: “Will we wish we had never invented it?”

The program manager proposes the size of a program based on the size of the team required, number of teams likely to submit ideas, probabilities of failures (assume 50 percent failure rate at the program levels). Working with the IARPA Deputy Director, the IARPA Director decides how much money to assign to a new program. Typically, a program is allocated \$10–20 million annually with approximately \$5 million annually for each team. The decision includes trade-offs where one program may be ended to make

³⁰ Heilmeier’s catechism was originally developed at DARPA. It requires each program manager to be able to address the following questions: (1) What are you trying to do? Articulate your objectives using absolutely no jargon. (2) How is it done today, and what are the limits of current practice? (3) What’s new in your approach and why do you think it will be successful? (4) Who cares? (5) If you’re successful, what difference will it make? (6) What are the risks and the payoffs? (7) How much will it cost? (8) How long will it take? (9) What are the midterm and final “exams” to check for success? (DARPA 2017b).

funding available for another. About half of IARPA funds are expended outside the United States—IARPA goes where it must to get the best research possible.

Based on all inputs, the IARPA Director makes the decision as to whether to proceed. While other people can provide advice, the Director has final approval for all programs. The interactivity of the process differentiates it from topic selection in other organizations such as NSF's EFRI or NASA's NIAC.

5. Transition

Transition is a core part of an IARPA program from its inception, and there are formal mechanisms of engagement. Before a program begins, the program manager is required to identify potential transition partners, even if the partners are unwilling or critical. If an identified partner is critical, IARPA tries to understand whether it is because of resistance to change or because the capability being pursued is not useful to the potential partner. If the former, IARPA may keep pushing, and if the latter, the money may be better spent elsewhere.

Even unwilling future partners may be persuaded to serve as technology advisors. Transition partners identified before launch are brought in to offer feedback on new start pitches and BAAs. They are invited to attend “proposer days” (dates when companies and universities visit the agency and can form teams) and program kickoffs, and to join site visits and program reviews every 6 months. The engagement is continual. Even if the community does not see value upfront, IARPA may still proceed with a program while attempting to understand needs and institutional impediments to implementing technology.

It is expected that if research is successful, at some point there will be a memorandum of understanding or agreement (MOU or MOA) that formalizes a transitional plan; this plan may be a paper, equipment, software code, or a process, depending on research. In some cases, a transition agreement involves transfer of funds. An agreement may be finalized beforehand if a funding commitment needs to be made years in advance due to budgetary reasons. Sometimes the agreement needs to be planned well in advance, especially if infrastructure will be built or modified. Details of the agreement thus depends greatly on what kind of research is being delivered. MOUs also clarify roles and responsibilities; security, privacy, civil liberties, and other requirements (how will technology or subjects be protected); and issues related to protecting intellectual property.

IARPA has used two approaches to building support in potential transition partners. Approximately half of IARPA programs have been built by providing prototypes to individuals at the working level who then convince their leadership to adopt the idea. To do this, IARPA makes the tool freely available to potential users and invites them to experiment with the prototype. Once a community of users forms, the early users are encouraged to convince their management to adopt the tool. This method has proven

helpful in introducing tools that are particularly disruptive to the culture of an organization. Much of IARPA's success to date has depended upon this model, building a core set of diehard users as a means to transition. IARPA also uses the more traditional approach of starting at the top of an organization and convincing potential users that the product would be useful to them.

Another mechanism by which IARPA becomes aware of user needs is that program managers are themselves well integrated with the user community, not just the research community. Many program managers serve as technical advisors on intelligence assessments of science and technology because they are domain experts in specialized areas. While serving as advisors can distract managers from their core work, doing so is viewed by IARPA management as an important service to the community; volunteering makes program managers wiser as they learn about user needs firsthand.

6. Evaluation of Success

As mentioned previously, IARPA has a program structure that designs research as tournaments wherein teams submit ideas to solve the same problem; the research is run in parallel with the teams effectively competing against each other on the same quantitative metrics ("horse race" model). Each team is working toward the same set of technical goals, and progress is measured regularly using third-party evaluators.

Each program manager typically spends 20–25 percent of the program budget on test and evaluation (T&E) to measure which team is best meeting the metrics. At a minimum, measurement occurs every 6 months, but the actual interval varies depending on topic; in some programs, the measurement actually occur daily. This process is highly competitive from start to finish. IARPA leadership decides every 6 months whether to continue funding each team, and whether to continue funding the program as a whole. Overall, IARPA has discontinued funding for approximately 20 percent of its programs, and more than half of all project teams. This tournament approach and focus on T&E is another area where IARPA may be most different from other ARPA's.

Ultimately, program success is measured by looking at things that are considered to matter—for example, did results deliver a breakthrough in national decision making that led to, or could lead to, preventing a catastrophe. Such determinations are not always possible, so IARPA also collects data on traditional measures, such as the number of publications per program (one program generated 500 publications, including 50 in *Science* and *Nature*) and number of research contracts, but given the focus in the organization on transition, IARPA also counts the number of MOUs and MOAs with user organizations as a measure of success.

Over 70 percent of IARPA products move up the research pipeline, leading to a concern that the success rate may actually be too high. The IARPA Director believes it should be closer to 50 percent to ensure research is truly high risk.

7. Lessons Learned

In contrast to NASA with its early stage portfolio, IARPA has full authority over its programs, and no programs have been launched due to pressure from the Office of the Director of National Intelligence (ODNI), Congress, or other stakeholders. Each project receives tens of millions of dollars for potentially multiple years. This autonomy and the size of the programs makes IARPA a poor role model for NASA. However, two features of IARPA's management, focusing on transition planning and engagement, and measuring T&E against quantitative metrics to terminate unproductive research, are ideas that NASA ESP managers could adopt. Table 21 provides a summary of the findings from the IARPA case study.

**Table 21. Summary of Findings for
Intelligence Advanced Research Projects Activity (IARPA)**

| | |
|--|--|
| Definition and Approach | <p>IARPA supports a portfolio of programs and envisions and leads “high-risk, high-payoff research that delivers innovative technology for future overwhelming intelligence advantage” (6.1, 6.2)</p> <p>Projects are extramural</p> <p>IARPA does not have an operational mission and does not deploy technologies directly to the field, enabling the program to focus on a longer time horizon</p> <p>IARPA has a flat organizational structure with a limited number of permanent departments or offices</p> |
| Budget | <p>Budget is classified</p> <p>An estimated \$350–700 million is awarded to unclassified projects</p> |
| Personnel | <p>The program uses rotators through special hiring authorities to allow a constant refresh of ideas</p> <p>Ability to hire at higher salaries than government scales allows IARPA to compete with industry for recruitment</p> <p>Program managers come from academia, industry, or government (ratio is 20-40-40) for a maximum of 5 years; all have a research background</p> <p>Protection of technical managers from administrative workload</p> <p>Ratio of three support staff members to one program manager</p> |
| Allocation and Management of Investment | <p>Autonomy given for program topic selection</p> <p>Relatively strong reliance on expertise of program managers to push state of the art</p> <p>Autonomy given for project selection</p> <p>Program managers use modified Heilmeier catechism, incorporating additional questions regarding market gaps, national security, and vulnerabilities</p> <p>Program managers use a tournament approach, which selects multiple performers instead of one to solve the same challenge</p> <p>Program managers use a hands-on approach to program management</p> <p>Program managers are given authority to engage with international researchers</p> <p>Procurement contract, grant, cooperative agreement, or Other Transaction Agreements are used</p> <p>Program managers are empowered and given autonomy to make decisions</p> <p>Projects are required to have built-in metrics</p> <p>Funding can be withdrawn if targets are not met, culling and cutting back performers who are not meeting targets</p> |
| Transition | <p>Measures of transition are a program success metric</p> <p>Transition plans created, presented, and evaluated at time of program creation</p> <p>Engages with acquisition personnel, customers, laboratories, and other transition partners to understand how to meet needs</p> <p>Program managers are responsible for transition</p> |
| Evaluation of Success | <p>Transition metrics include number of MOUs signed with user organizations</p> <p>25% of project and program funds used for evaluation</p> <p>Evaluation results are used to redesign programs</p> <p>IARPA ensures its success rate is not too high</p> <p>Currently achieves a 70% success rate (defined as products moving up the pipeline)</p> |

C. Case Study: National Geospatial-Intelligence Agency (NGA) Research and Development Directorate

The Research and Development Directorate of the National Geospatial-Intelligence Agency (NGA) is referred to as NGA Research.³¹ The directorate was recently reorganized to “champion and drive research across the entire geospatial community,” but specifically from National Laboratories, universities, and commercial businesses (NGA 2016c). It does so by: eliminating technology risk sufficiently enough that someone in the private sector could convert an idea into product that the Federal Government can subsequently purchase; creating a cadre of people who understand the state of the art in relevant technology areas; and (more recently) fostering a culture of acquisition rather than building everything in-house.

Previously known as InnoVision, the NGA Research program concentrates in seven “strategic” research areas depicted in Figure 11: Radar, Automation, Geophysics, Spectral, Environment and Culture, Geospatial Cyber and Anticipatory Analytics. These focus areas were named “pods” to ensure there are no preconceived notions as to what they are; NGA leadership wanted to move away from any specific meanings already associated with terms such as *office*, *section*, and so forth. The chosen topics resulted from a culling through over 80 topic areas solicited from internal NGA sources, reports of the National Academies of Sciences, Engineering, and Mathematics, and other sources.



Source: NGA (2016b).

Figure 11. NGA’s Seven Research Pods

³¹ NGA’s 2015 strategy (available at <https://www.nga.mil/About/NGAStrategy/Pages/default.aspx>) does not use the terms *research*, *science*, *R&D* or *S&T*. The terms *analysis* and *technology* appear once each.

According to the NGA Research Director, the work is less about science and technology than it is about the intelligence mission (“we are scientists second,” he said). In its new incarnation, the directorate intends to move the agency away from conducting research internally, instead concentrating on the activation of external research and moving people with the research rather than just throwing research “over the transom.” In addition to transferring personnel in and out, there is also an effort to develop formal interfaces with outside bodies. For example (NGA 2016b):

- **NGA’s In-Q-Tel Interface Center (NGA QIC)** partners with In-Q-Tel to identify, adapt, and deliver technology from the commercial sector.
- **Geospatial Intelligence (GEOINT) Pathfinder** is “paving the way to succeed in the open by delivering remarkable results to intelligence questions with only unclassified data and commercial information technology” or using commercial imagery and technologies.
- **NGA Outpost Valley (NOV)** is a “dynamic lab presence” in Silicon Valley to investigate emerging research challenges, operate permanent analyst cells, and leverage emergent capabilities to deliver results to the National Security Enterprise across all security domains.

From a pipeline perspective, the organization may be thought of as being at the other end from the ARPA’s where instead of developing technologies independent of an operational mission, researchers are absorbing research from anywhere to explore what will help address real mission needs. While NGA Research follows some ARPA-like practices (e.g., the Heilmeyer catechism is used to select projects, portfolios, and activities), the AFRL or the National Security Agency (NSA) research program would be better comparisons in that NGA is developing career personnel who can move within and across organizations as needed to ensure insertion of appropriate technologies. In contrast, ARPA personnel are by design transitory. Given that the directorate has a strong mission support orientation, its goal is to bring in more junior scientists and grow them, give them a career (even as they move in and out of organizations bringing and taking new ideas), and expose them to the Heilmeyer way of thinking. The idea of a “pod” is similarly an attempt to nucleate culture change—that is, to get people to think differently.

In our interview, the NGA Research Director stated that he recognizes that cultural change at NGA would be difficult, and the organization is, as of this writing, only at the beginning of that change. He spoke about shaping the state of the art, not following it, using the metaphor of “sticks flowing down river” to describe their portfolio, the implication being to move with the prevailing current as opposed to getting stuck.

A unique feature of NGA Research—one that we did not discern for any other organization examined for this project—is that 20 percent of staff time can be spent on research in areas the staff members themselves deem important.

1. Definition and Approach

As with IARPA, the leader of NGA Research does not think in terms of TRLs or even 6.1 or 6.2 research categories. The organization is mission-driven and emphasizes whatever level of research is needed to achieve its goals, including leveraging fundamental research if needed. However, most work is from TRL 1 to TRLs 2–4.

The Director of NGA Research emphasized that the organization is not an ARPA: “We at NGA are on the other end of that—I don’t care where it comes from. I shouldn’t care where it comes from. If it will give us a war-winning capability, I should be interested in it and we should take advantage of it.”

The directorate has roughly 225 employees, and reaches out to 400 contractors (compared with DARPA, which has 140 program leaders and touches 10,000 researchers inside and outside government). This number is changing as the directorate evolves under new leadership.

The Director of NGA Research reports to the NGA Director of Plans and Programs but has strong support from the Director of NGA who brought him onboard (NGA 2016a). This gives the Director flexibility to make the changes he deems fit.

As discussed above, the directorate is divided into seven pods, each of which represents a “cluster of different types of things.” Pods are led by senior mentors whose job it is to mentor teams in a pod, and help get resources. Senior mentors are charged to “be the skill—get out there and make the connections to make things happen.”

2. Budget

The directorate’s budget is classified so details are not reported here. The predecessor organization was on a downward trend, and it lost about 75 percent of its budget between 2010 and 2015. Part of what the current NGA Research Director is doing is seeking to restore confidence among the staff and stabilization of the budget.

3. Allocation and Management of Investment

Having served previously at DARPA and IARPA, NGA Research’s current Director stated that he is attempting to bring an ARPA-like culture to the directorate, which has included using the Heilmeier catechism to select projects, portfolios, and activities.

The directorate relies primarily on Cooperative Research and Development Agreements (CRADAs) to collaborate with others. As an Intelligence Community entity, NGA Research has considerable flexibility with respect to means of contracting (Federal Acquisition Regulation [FAR], Other Transactional Authority [OTA] etc.)

4. Transition

Given its relatively small budget, NGA Research plans to leverage external organizations (for example, by allowing people to move in and out easily). There is also a plan to devote resources, including both people and funds, to useful technologies and to rely on transitioning people to serve as the champions of those technologies in other locations at NGA. Technologies will be taken to practice at other locations within NGA, not inside the pods. As the Director said in a recent interview:

The only way I've seen technology transition to practice reliably, repeatedly, is *where you move people with the technology* [emphasis added]. So we're going to be giving resources—people, funds—to technologies and having those people move to be the champions of that technology somewhere else at NGA and to take it into practice. We're not going to do development work inside the pods. We have so many places at NGA that are good at development (Corrin 2016).

5. Evaluation of Success

Current metrics are process-based metrics of transition. They include number of people (especially the Director of National Intelligence and others in positions of leadership) that attended briefings, number of new organizations that worked with staff, etc. Eventually, there will be steady state metrics, such as number of transition partner agreements; number of staff members coming in and going out (e.g., tours as program managers at DARPA or IARPA; as IPA detailees; or in term-limited assignments); number of staff members involved in source selection boards or flight tests at other agencies; amount of money or technology crossing borders; organizational influence; and the perception that NGA Research is a trusted partner that inspires user confidence. The Director of NGA Research does not see published papers as a core metric for his organization; instead, he focuses on those metrics that support combat missions.

6. Lessons Learned

Table 22 provides a summary of the findings from which the following lessons were derived.

- NGA Research focuses on developing a cadre of competent civil career officers
- Twenty percent of staff time can be spent on research in areas the staff members themselves deem important.
- Staff is encouraged to move with the technology, acting the champions of that technology somewhere else at NGA and to take it into practice.

**Table 22. Summary of Findings for
National Geospatial-Intelligence Agency (NGA) Research**

| | |
|--|--|
| Definition and Approach | <p>NGA Research, the R&D directorate of the NGA, funds a portfolio of projects that seek to de-risk technology so that the private sector can convert an idea into a product that subsequently can be purchased by the NGA (6.1, 6.2, 6.3)</p> <p>Projects are extramural and intramural</p> <p>NGA Research relies on experts with knowledge of the state of the art in relevant technology areas</p> <p>Previously developed technologies in-house, the office recently shifted towards fostering an acquisition culture</p> |
| Budget | <p>Budget is classified</p> <p>Investment is divided into seven pods, each of which represents a “cluster of different types of things”</p> |
| Personnel | <p>Focused on developing a cadre of competent civil career officers</p> <p>Pods are led by senior mentors who mentor members within the teams, and help secure external or additional resources</p> <p>Support investigator-initiated research (or set aside time) for the purpose of recruitment and retention</p> <p>225 staff and 400 contractors</p> |
| Allocation and Management of Investment | <p>Ideas are sourced from the market and other external organizations</p> <p>Program leaders engage with internal and external scientific community (through site visits, formal interfaces and other methods) to identify priorities and emerging areas, and to learn about user needs</p> <p>Cooperative Research and Development Agreements (CRADAs) are used</p> <p>Program leaders follow ARPA-like practices (e.g., the Heilmeier catechism to select portfolio of activities)</p> <p>Program leaders use cooperative agreements to enable a stronger government role</p> <p>Program leaders operate in a way similar to AFRL or NGA Research rather than the ARPAs by developing career personnel who can move within and across organizations as needed, to ensure insertion of appropriate technologies</p> |
| Transition | <p>Leverages external organizations, moves technology champion out to develop it fully elsewhere within the organization</p> |
| Evaluation of Success | <p>Number of invited people attending briefings, number of new organizations, number of transition partner agreements, number of staff coming in and going out</p> <p>Staff involved in source selection boards, flight tests; amount of money and technology crossing borders</p> <p>Organizational influence and user confidence</p> <p>Published papers not used as a success metric</p> <p>No quantitative target specified</p> |

5. Early Stage Research and Technology Development at the National Science Foundation and the National Institutes of Health

A. Introduction

The National Science Foundation (NSF) defines its mission in the context of its enabling legislation, the NSF Act of 1950, which states that the purpose of the agency is to “promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes” (NSF 2016a). NSF, in its current strategic planning processes, takes its legislative mandate as setting two core goals: “Transform the Frontiers of Science and Engineering” and “Stimulate Innovation and Address Societal Needs through Research and Education (NSF 2016b).

NSF is organized in seven directorates: (1) Directorate for Biological Sciences; (2) Directorate for Computer and Information Sciences & Engineering; (3) Directorate for Education and Human Resources; (4) Directorate for Engineering; (5) Directorate for Geosciences; (6) Directorate for Mathematics and Physical Sciences; and, (7) Directorate for Social, Behavioral and Economics Sciences. Inside the Office of the Director, research is funded through the Office of Integrative Activities and the Office of International Science and Engineering.

Almost all NSF research is basic and thus may not appear to be obviously relevant to NASA programs. However, NSF does run technology development programs that offer some lessons for NASA. A number of the NSF technology development-related program solicitations, as identified by STPI, are housed inside the Directorate for Engineering, especially in the Division of Engineering Education and Centers (EEC) and Division of Industrial Innovation and Partnerships (IIP). Funding for IIP in fiscal year 2015 was \$227 million (of which \$177 million was allocated to the NSF Small Business Innovation Research [SBIR] and Small Business Technology Transfer [STTR] programs), and funding for EEC was \$92 million (of which \$60 million was allocated to EEC technology development programs) (NSF 2016c).

In addition to the SBIR and STTR programs common to all Federal research agencies, major NSF technology development programs, as identified by STPI, are:

- Generation-3 Engineering Research Centers (ERCs). The ERCs are funded for up to \$4.25 million per year for up to 10 years, “in an emerging and potentially transformative engineered system(s) that has potential to significantly impact the

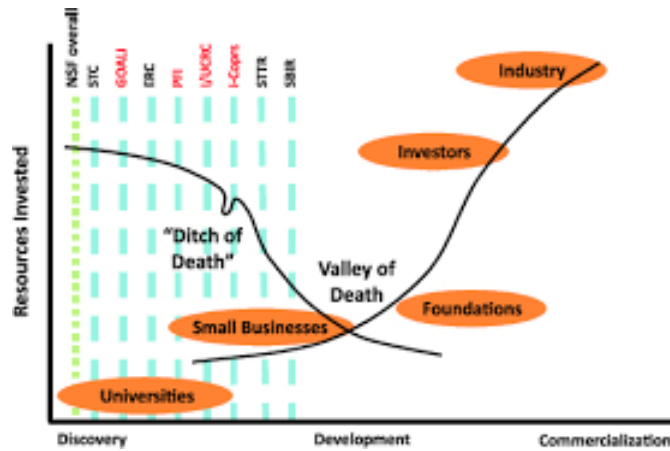
selected research area, establish new industries, or transform public sector services or infrastructure.” (NSF 2015a)

- Partnerships for Innovation (PFI). PFI has two tracks, an Accelerating Innovation Research track that is intended to commercialize the results of research conducted under other NSF research awards and a Building Innovation Capacity track that supports industry-academia partnerships in order to “carry out research to advance, adapt, and integrate technology(ies) into a specified, human-centered smart service system” (NSF 2015b).
- Industry/University Cooperative Research Centers (I/UCRC). I/UCRCs are funded by NSF for up to 15 years for the purpose of supporting joint industry-academia research.
- Innovation Corps (I-Corps). I-Corps offers entrepreneurship training to graduate students and postdoctoral researchers, with the goal of commercializing technologies developed through NSF research funding.

NSF uses a standard schematic that shows where these programs fit along the discovery-to-commercialization spectrum (Figure 12 and Figure 13). While these programs are assigned a particular location on the spectrum that appear to be independent, it should be noted that there are programmatic linkages:

- Both PFI and I-Corps are expected to develop innovations (though not necessarily technologies from NSF-funded fundamental research) that can be commercialized
- NSF has a supplemental solicitation intended to link SBIR Phase II awardees with relevant ERCs (NSF 2009).

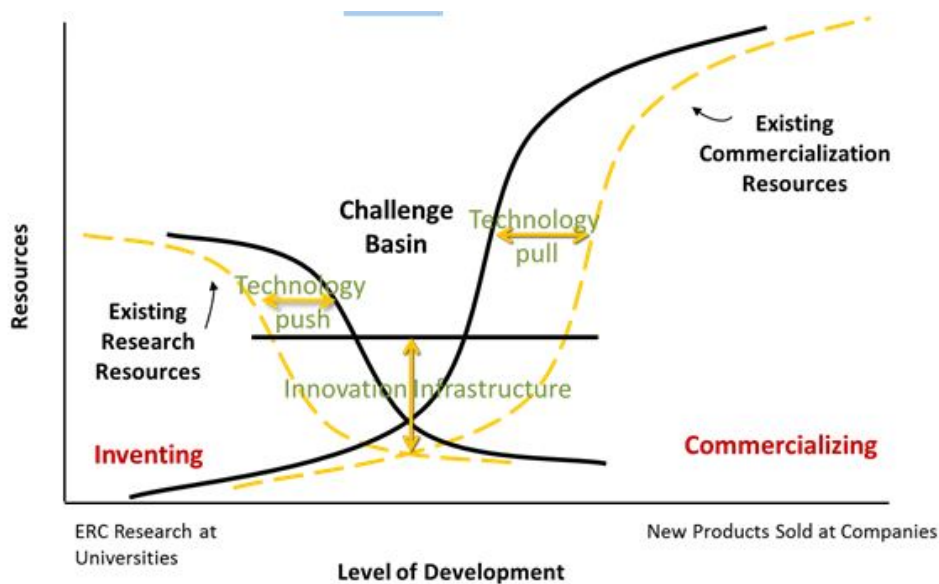
In the section that follows, we provide a case study on early research through NSF’s Emerging Frontiers in Research and Innovation program. In addition, we recap information from a recent STPI evaluation of technology development at the National Institutes of Health (NIH), which may also hold relevant lessons for early stage research at NASA.



Source: National Academies of Sciences, Engineering, and Medicine (2016).

Note: The term “ditch of death” refers to the gap between when NSF research funding runs out and when a team is credible enough (with enough customer and market knowledge) to raise private capital or license/partner with existing companies (<https://steveblank.com/2012/03/26/the-national-science-foundation-innovation-corps-what-america-does-best/>).

Figure 12. NSF Engineering Programs along Innovation Continuum



Source: Beck (2014).

Figure 13. Addressing the Gap between Invention and Commercialization

B. Case Study: Emerging Frontiers in Research and Innovation (EFRI)

The National Science Foundation (NSF) established the Emerging Frontiers in Research and Innovation (EFRI) program in 2006 to fund high-risk research that both addresses a national need or grand challenge and will lead to new research areas for the NSF, its Directorate for Engineering (ENG), and other agencies; new industries or capabilities that result in a leadership position for the country; or significant progress on a recognized national need or grand challenge. To attain these goals, the EFRI program funds interdisciplinary teams to conduct potentially transformative research for emerging fields.

The EFRI program awards funds to portfolios for emerging high-risk fields that have passed the phase of exploratory research, which are funded by smaller, short-term grants through NSF's Early-concept Grants for Exploratory Research (EAGER) program. The EFRI program differs from other programs within NSF in that it provides funding for portfolios based upon designated topics. Each fiscal year, the program awards 12–16 projects (up to \$2 million over 4 years) that are divided into designated topic areas. These grants are larger than the average NSF grant and are envisioned to, in the long term, mobilize a new field of research.

1. Definition and Approach

EFRI funds a portfolio of extramural high-risk, high-reward research 6.1 and 6.2 projects with the intention of developing new research areas, industries, or capabilities or making progress on national needs or grand challenges. In an effort to develop transformative research in new and emerging fields, EFRI projects are conducted by interdisciplinary teams of researchers. Managers of EFRI project teams define new research frontiers based on engagement with external experts on national priorities and interests.

2. Budget

EFRI is allocated roughly \$30 million annually to fund projects in the program. In FY 2016, EFRI received an estimated \$31 million to invest in two new topic areas—Advanced Communication Quantum Information Research in Engineering (ACQUIRE) and New Light and Acoustic Wave Propagation (NewLAW). In FY 2017, NSF seeks to increase appropriations by \$500,000 to support 16 interdisciplinary team projects through MURI.

The EFRI program is the largest activity in the Office of Emerging Frontiers and Multidisciplinary Activities (EFMA), representing about 58 percent of EFMA's approximate \$58 million FY 2017 budget request and 0.4 percent of NSF's budget. EFMA pursues and funds research in emerging fields for ENG. Other funding activities in EFMA include support for engineering research centers, multidisciplinary education programs, and annual operations support of the Cornell High Energy Synchrotron Source (CHESS)

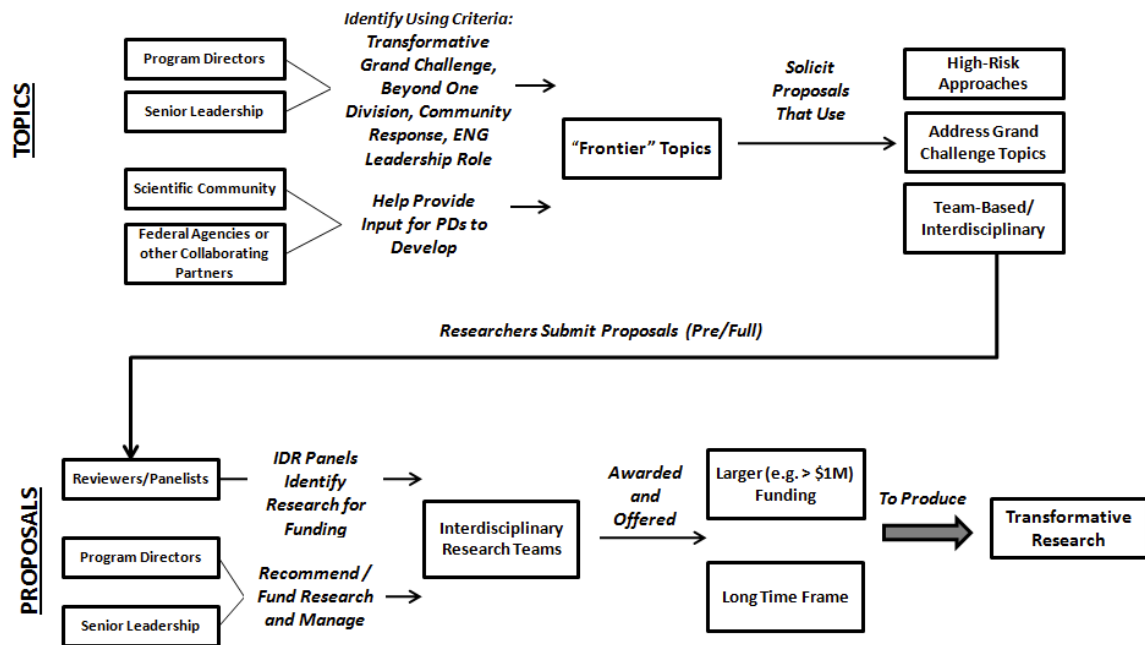
facility. Funding for ENG in FY 2016 reached \$916.19 million. EFRI represents about 3 percent of ENG’s budget and 12 percent of NSF’s budget.³²

3. Personnel

EFRI program awards are managed by program directors from other programs, which include permanent staff of core NSF divisions and crosscutting divisions as well as rotators that serve for 2–3 years. About half of NSF’s 40–50 program directors are permanent staff.

4. Allocation and Management of Investment

The EFRI office follows a two-stage process for allocating its funds yearly, as illustrated in Figure 14.



Source: Author representation of EFRI program topic and proposal selection processes.

Figure 14. EFRI Program Topic and Proposal Selection Process

Since the first RFP in FY 2007, the EFRI office has selected 16 frontier topics.³³ The process begins with the open solicitation of single-page white papers from the research community. The community submissions are reviewed by the EFRI program staff and

³² All budget estimates come from the Directorate for Engineering (ENG)’s FY 2017 Budget Request to Congress. ENG houses EFMA, which operates the EFRI program (NSF 2016c).

³³ Two topics are normally chosen per year; however, in FY 2013 and 2014, the same three topics were used, and in FY 2014 and 2015 the same single topic was used.

provided to the program directors to help guide their frontier idea proposals. Program directors form teams and submit frontier ideas to the EFRI office. At the program director retreat, program directors have the opportunity to revise the frontier idea based on input from others. All frontier idea proposals are ranked at the retreat based on votes by program directors, and the EFRI office selects 2 to 4 top-ranked frontier idea proposals to present at the Engineering Leadership Team (ELT) retreat. The ELT, which is composed of division directors, the ENG Assistant Director, and other technical staff, discuss the frontier idea proposals and select two ideas to develop as EFRI topics. Frontier ideas that emerge as topics are intended to be potentially transformative, interdisciplinary, and address a national need or grand challenge.

During the early years of the EFRI program, topics were internally discussed and selected by the NSF program directors and the ELT. Discussions at the April 2008 ENG Advisory Committee Meeting encouraged a wider and more direct opportunity for the research community to provide input on the selection of the EFRI program's topic ideas. In response, the EFRI office created a formal process to solicit ideas for topics from the community through a Dear Colleague letter. In the first year, the letter was not widely circulated, and 24 one-page white papers were received. In FY 2015, an aggressive outreach process extended the request to every individual who had previously submitted a grant (regardless of acceptance or rejection), leading to a collection of 300 white papers. The updated outreach process led to the selection of a topic focused on quantum computing proposed by a previously denied grantee.

Prior to the proposal deadline, complete descriptions of the selected topics and contact information for associated project coordinators are publicly available on the EFRI website for interested applicants. A webcast workshop is hosted by EFRI to support applicants prior to submission deadlines.

The EFRI program proposal review and selection process consists of two phases: the preliminary proposal (pre-proposal) review and the full proposal review. Pre-proposal project descriptions are limited to 5 pages and provide an overview of the research that allows the assessment of the main project ideas and approaches. Full proposal project descriptions are limited to 15 pages.

Each EFRI topic team, consisting of program directors involved in leading the topics, selects and invites experts to serve as reviewers on a pre-proposal, a full proposal panel, or both. One to three program directors lead a panel. Proposals are reviewed by at least three reviewers, with each reviewer assigned to evaluate 8 to 15 proposals. The EFRI office requests reviewers to submit an individual evaluation via FastLane, NSF's proposal data management system, prior to the panel. During the panel, the lead reviewer for each proposal leads the discussion, a secondary reviewer takes notes and prepares a panel summary, and the program directors make the final approval of the summaries. After the panel, reviewers are given the option to modify their individual evaluation. Additionally,

the panel, as a group, ranks the proposals rated within the top two rating categories (Invite/Invite If Possible/Do Not Invite for pre-proposals, and Highly Recommended/Recommended/Not Recommended for full proposals). These joint rankings take precedence over the individual evaluations when reviewed by the EFRI office.

The EFRI office reviews the pre-proposal panel recommendations, and invites principal investigators to submit full proposals. The full proposal review process is similar to the pre-proposal review. During the selection of proposals, panelists are encouraged by the EFRI office to embrace high-risk projects. In the competitive selection process, reviewers are asked not to provide reasons to pass on a proposal but rather reasons to keep and defend proposals. Funds are eventually allocated by the EFRI office once the portfolio is considered and all projects are reviewed. To provide greater flexibility to the review panels in selecting a portfolio, funds are not set aside for topics prior to the review process.

5. Transition

Although NSF does not typically engage with potential users, EFRI projects may transition when given follow-on Federal funding, including from SBIR, STTR, or other NSF programs.

6. Evaluation of Success

EFRI's portfolios are designed to encompass a variety of projects that differ in risk and development timelines. However, no aggressive management plan is in place for establishing or evaluating a time horizon for specific projects or portfolios. A single external process evaluation of the EFRI program was done by STPI in 2011; however, no internal office is in place to monitor EFRI investments consistently.

Currently, the EFRI program office does not systematically track follow-on funding; however, the EFRI program director is aware of multiple instances in which EFRI projects have received grants from NSF's Engineering Research Centers and Science and Technology Research Centers programs, which are large awards on the order of \$3–5 million per year over 5–10 years.

The EFRI program also requires annual reports from its awardees. Annual reports provide outputs, such as scientific publications, collaborations, and other outcomes of funding, that are collected and reviewed by program staff.

7. Lessons Learned

The findings from the EFRI case study, which are summarized in Table 23, provided the following lessons:

- EFRI requires interdisciplinary research proposals and aims to encourage researchers to transcend disciplinary limitations and assumptions. Principal investigators in the portfolio are encouraged to pursue “transformative” engineering research that extends well beyond defined disciplines.
- An intentional bottom-up approach for soliciting research topics from prior grant applicants (both successful and unsuccessful at obtaining grants) provides a direct and active route for the research community to influence topic selection.
- The selection process defines new research frontiers that are of national priority and interest through the active engagement of external experts and internal project managers (the latter having access to Congress, the White House, and other Federal agencies).
- By clearly defining and guiding reviewers toward what the EFRI office sought in proposals (e.g., high risk, transformative, and interdisciplinary projects), conservative reviewers and bias against high-risk proposals (albeit with potentially high impact) are well-managed.
- Grant applicants understand the rules that govern the selection process, motivating directed proposals, due to an intentionally transparent EFRI selection process. With close connection with other funding mechanisms within NSF, proposals that do not meet all the EFRI criteria for “emerging” fields are forwarded to alternative grants (such as the EAGER grant that funds exploratory research).
- Relatively large awards for relatively large interdisciplinary teams provides possibility of growth in emerging research areas.

Table 23. Summary of Findings for Emerging Frontiers in Research and Innovation (EFRI)

| | |
|--|---|
| Definition and Approach | <p>EFRI funds a portfolio of high-risk, high-reward research projects that address a national need or grand challenge (6.1, 6.2)</p> <p>Projects are extramural</p> <p>EFRI aims to develop new research areas, industries, or capabilities, or to progress on a recognized national need or grand challenge</p> <p>Projects require interdisciplinary teams to conduct potentially transformative research in emerging fields</p> |
| Budget | <p>\$31 million (FY 2016 enacted), represents a majority (53%) of the Emerging Frontiers and Multidisciplinary Activities (EFMA) office or 3% of the Directorate for Engineering's budget</p> <p>The budget is less than 1% of the NSF budget</p> |
| Personnel | <p>Depends on program directors from other programs (within core divisions and other crosscutting divisions) to manage awards</p> <p>Program directors include permanent NSF staff and rotators (temporary staff) that serve 2–3 years</p> <p>Slightly more than half of the estimated 40–50 program directors across NSF are permanent</p> |
| Allocation and Management of Investment | <p>Topics are connected to national priorities and selected to ensure focus on strategic areas</p> <p>Topics are from recently solicited white papers from the community; some ideas were selected as topics and managed by program directors</p> <p>Program directors engage with internal and external scientific community (through site visits, formal interfaces, and other methods) to identify priorities and emerging areas, and to learn about user needs</p> <p>Two-phase white paper/full-proposal process leads to stronger and more relevant proposals</p> <p>Topics reviewed internally by EFRI program director and other NSF program directors</p> <p>Topics led by NSF program directors</p> <p>Grants are used</p> <p>Program directors encourage reviewers to embrace high-risk projects</p> <p>Program directors employ reviewers from inside and outside organization through peer-review process</p> <p>Award sizes are large to ensure projects address big problems</p> <p>Requires multidisciplinary teams</p> |
| Transition | <p>Projects may transition with follow-on SBIR/STTR funding</p> <p>Does not typically engage with end-use customers, although may engage for some projects</p> |
| Evaluation of Success | <p>Annual reports are required from awardees</p> <p>Reports provide outputs, such as scientific publications, collaborations, researchers/graduate students supported, and other outputs or outcomes of funding that are collected and reviewed by program staff</p> <p>EFRI program director views success of topics as seeing topics in future solicitations (across NSF, Federal agencies, or research funding organizations—nationally and internationally)</p> <p>EFRI program director views success of projects as receiving follow-on funding from other NSF, Federal agency, or research funding organization's program</p> <p>No quantitative target specified</p> |

C. Case Study: Technology Development at the National Institutes of Health

The National Institutes of Health (NIH) supports innovative technology development as one aspect of fulfilling its mission to “seek fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to enhance health, lengthen life, and reduce illness and disability” (NIH 2017). The NIH extramural program supports technology development through a range of approaches, including: (1) unsolicited investigator-initiated grant applications; (2) broad Funding Opportunity Announcements (FOAs) for technology development proposals; (3) FOAs that solicit a mix of technology development and non-technology development proposals; and (4) FOAs requesting proposals for development of technologies aimed at a specific goal.

In this section, we use technology development as a proxy for early stage research, using information from a recent STPI evaluation for NIH on technology development (Zuckerman, Hautala, and Nek 2015). Given that the information derives from the previous STPI study, it does not constitute a case study in the sense of other case studies done for the present report. However, we frame the information as closely as possible to the topics of interest in other case studies to help with assessing the information’s relevance in the current context.

1. Definition and Approach

Although NIH does not have a formal definition of *technology development*, Zuckerman, Hautala, and Nek (2015) developed the following candidate definition for *technology*: a physical entity (e.g., a piece of equipment, a device, a new material, or a piece of hardware) or a virtual entity (e.g., software or methodology) used for a biomedical purpose, which could either be a clinical and diagnostic purpose or a research purpose. Although NIH has not officially accepted this definition, it suggests that a new microscope, an assay in kit form, and a software platform would all be considered technologies. For the same study, *development* was defined as the movement of a technology during the period of the award toward the point where it can be brought into clinical or research use (Zuckerman, Hautala, and Nek, 2015). The technology developed could be either wholly novel, the substantial improvement of an existing technology or the refinement or adaptation of an existing technology for a new purpose. Technology development FOAs include those that ask investigators to develop candidate technologies and concepts to a pilot stage, to validate the performance of technologies, or to refine technologies in the expectation of their dissemination and use.

A more refined definition was required for *information technology (IT) development*. *Technology* in an IT context includes: (1) *in silico*³⁴ methods, algorithms, and software only to the extent they are included in the functioning of a device (e.g., software that pre-processes raw data before it is analyzed by the user or software that automatically applies annotation to a sample as it passes through the device); (2) *in silico* methods, algorithms, and software implemented by the user to complete processing of data, perform quality control, etc. (e.g., for laboratory information management systems); or (3) *in silico* methods, algorithms, software, and models designed for use by others in data analysis, storage, etc. (e.g., compression algorithms, statistical packages, and computational models).

Given this overall definition, the NIH technology development analysis team excluded FOAs for drug or biologic development, for development of new research methods and tools (e.g., mouse models) unless they were exclusively for a technology development purpose, for basic research that might eventually lead to the development of a technology, and for new uses of existing technologies without any refinement or adaptation of the technology itself.

2. Budget

NIH does not have a budget categorization specific to technology development. The STPI evaluation, which focused solely on FOAs requesting proposals for development of technologies aimed at a specific goal (one of the four approaches used by NIH to support technology development), identified \$1.83 billion in total NIH spending and \$1.36 billion in direct costs over 10 years (Zuckerman, Hautala, and Nek 2015). Because this figure excludes spending under general technology development FOAs (e.g., generic SBIR FOAs) and FOAs encompassing a mix of technology development and non-technology development proposals as well as investigator-initiated technology development awards, it is certainly an underestimate of total NIH spending on technology development.

3. Allocation and Management of Investment

NIH funds research through 27 Institutes and Centers. The STPI evaluation identified technology development awards administered by 24 of them, though the largest number of FOAs were supported by the National Institute of Biomedical Imaging and Bioengineering (NIBIB) and the National Cancer Institute (NCI).

NIH does not allocate or manage its technology development investments centrally. As described by the program officers interviewed as part of the STPI evaluation for NIH, there were two primary rationales for technology development FOAs. The first was to meet a particular technology development need or objective identified by NIH program staff that

³⁴ Latin for “in silicon,” which here refers to computer-based or computer simulation techniques.

was not being adequately addressed by projects submitted to the general investigator-initiated pool or by FOAs from other parts of NIH. The second, which often was a companion rationale to the first, was to stimulate overall research activity in a particular technology domain that was viewed as underrepresented in the overall NIH portfolio.

FOAs come in the form of Program Announcements (PAs), Requests for Applications (RFAs), and PAs with special receipt or review considerations (PARs). PAs were often described by program officers as being used when the goal was to allow a field to grow organically, without requiring NIH to fund applications that did not score strongly in review. PAs were also used when the technology area was so broad that there would not be any value in convening special emphasis panels. PARs and RFAs were most often used when it was deemed valuable to convene special emphasis panels for review. RFAs tended to be chosen over PARs when it was deemed necessary to have designated funding in order to be able to make a reasonable number of awards or when projects were being solicited in a narrowly defined area.

Several reasons were cited by program officers for selecting particular funding mechanisms for their FOAs. Cooperative agreements were used when NIH viewed collaboration among awardees as being a critical success factor. R01s (larger single-investigator or small-team awards) and P01s (multi-project awards) were used when large independent projects were viewed as the best route to achieving the technology development objective. R21s (small single-investigator or team awards) were used when it was deemed necessary to stimulate early stage, potentially high-risk technology development projects. Both R01s and R21s were described as being employed when NIH specifically wanted to involve academic investigators in a technology development area. In contrast, SBIR and STTR awards were used when NIH concluded that involvement of commercial entities was the optimal route to rapid development of a particular technology. Occasionally, both SBIR/STTR and R21/R01 mechanisms were used simultaneously when involving both academic and industry investigators was important.

4. Evaluation of Success

No common set of success measures is used across NIH today for technology development, although the STPI evaluation proposed a candidate set of measures for potential future use. Of the program officers interviewed for the evaluation, the large majority considered use of the developed technologies for either research or clinical purposes as the ultimate objective of their technology development programs. *Use* was broadly defined, and could include continuing use in the principal investigator's own research, dissemination of the technology informally to other researchers, or licensing of the technology to a company that would make the technology available to the entire research community or for use in the clinic. Nearly half of the program officers interviewed indicated that increased research activity in the technology development domain (e.g.,

additional grant applications in the technology development domain of the FOA) was another ultimate objective of their FOA applications.

For many clinically focused programs, dissemination and use are expected to occur after the awards under the technology development programs completed. Therefore, several program officers mentioned intermediate measures of success primarily involving steps toward Food and Drug Administration (FDA) approval or clearance.

5. Lessons Learned

The most important lesson learned from the STPI evaluation is that the program officers considered focused technology development efforts to advance NIH's mission a worthwhile use of funds. Additional lessons learned were of two types:

- Program Management Best Practices
 - *Technology development benefits from award flexibility.* Because technology development projects often require higher levels of funding or longer periods of time than comparable discovery-oriented projects, it is important to take advantage of opportunities for longer award periods and larger award sizes. The flexibility of multiple acceptance dates is also valuable.
 - *Tailored review is necessary.* Because many technology development efforts involve engineering and physical sciences disciplines and have more applied goals, tailored review processes are essential.
 - *Milestones are valuable.* Because technology development projects are intended to result in a defined physical (or virtual) entity for use in research or the clinic, milestones are valuable for charting progress. Because “milestone” refers to a quantitative, measurable indicator of technical progress, one or more of a grant's specific aims may functionally be equivalent to a “milestone.”
 - *Grantee meetings with potential users and funders are valuable.* Grantee meetings open to potential investors and other commercial stakeholders as well as non-awardee researchers are valuable for sharing information among awardees, facilitating collaborations, and exploring potential commercial relationships.
 - *Program officer expertise in technology development is critical.* Technology development program officers require three critical characteristics: (1) clear understanding of requirements for commercializing or otherwise disseminating technologies; (2) expertise in the technology field; and (3) familiarity with the relevant investigator community.

- Ongoing Challenges
 - *Commercialization is a hurdle, especially for clinical technologies.* Technologies for clinical use almost uniformly require more funding than available through standard award mechanisms. As a result, clinical technologies often languish even if early-stage clinical testing has been completed.
 - *Funding “blue-sky” technology development is difficult.* Only the R21 mechanism was viewed as being tailored to fund truly high-risk projects and additional approaches for encouraging such projects need to be developed.
 - *Greater coordination of technology development efforts is needed.* Program officers were generally aware of other ongoing technology development initiatives, but indicated that a forum where they could share lessons learned and best practices would be beneficial.

6. Special Topics in Early Stage Research

A. Introduction

In this chapter, we look at three special topics with bearing on early stage research at NASA. The first topic, Innovation Corps (I-Corps) programs, centers on NSF's I-Corps program, but similar programs are used in other Federal agencies. Prizes, the second topic, are used by several Federal agencies to recognize early stage research accomplishments. The third topic explores evaluation metrics across the R&D community, not just in the Federal Government.

B. Innovation Corps (I-Corps) Programs

The purpose of the NSF Innovation Corps (I-Corps), which began in 2011, is twofold: (1) to catalyze the commercialization of technology deriving from NSF-funded research; and (2) to foster entrepreneurship by academic faculty, postdoctoral researchers, and students. I-Corps is therefore intended as a bridge between NSF's core research programs and SBIR and STTR technology development support. The program consists of three components.

- I-Corps Nodes operate regionally, providing entrepreneurship training (using a standard approach) to the I-Corps Teams selected in their areas, identifying best practices for entrepreneurship training and fostering innovation, and assessing the success of I-Corps to date (Murday 2016).
- I-Corps Sites are universities that are funded to foster entrepreneurship at the campus level, by providing support for nucleating potential I-Corps Teams and for potential entrepreneurs more generally.³⁵
- I-Corps Teams consist of a principal investigator, a faculty mentor, and an entrepreneurial lead who apply for support to commercialize a technology deriving from NSF-funded research. Teams are selected to receive entrepreneurship training from their regional nodes and are awarded 6 months' worth of funding to explore the customer base, market, and partnerships required to bring the teams' technology to the marketplace. Teams are also expected to complete a commercial prototype or proof of principle by the end of that period.³⁶

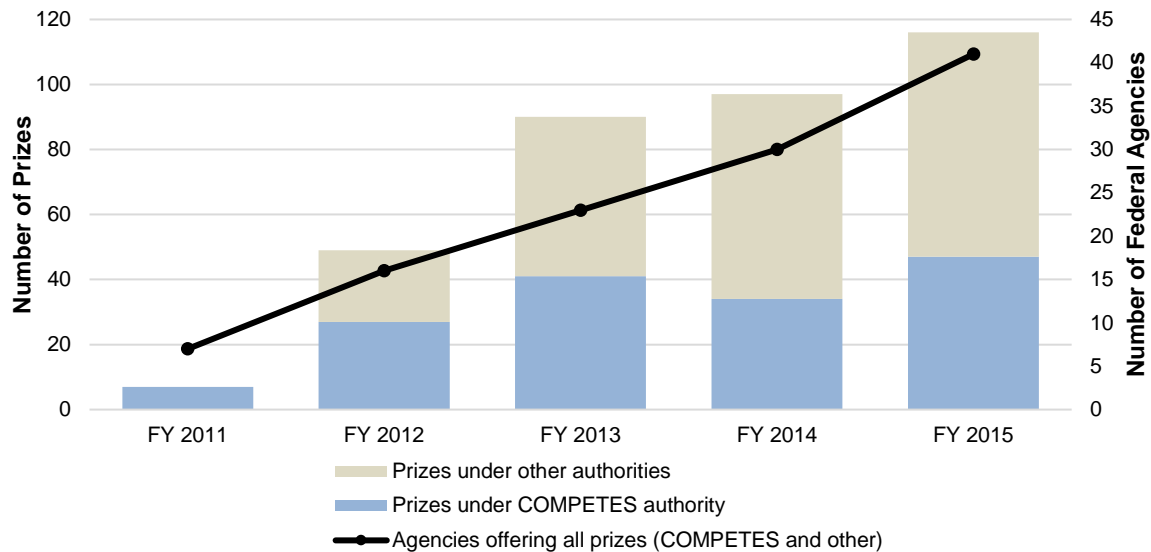
³⁵ See the Department of Health and Human Services (HHS) Funding Opportunity Announcement for I-Corps SBIR and STTR Grants, PA-16-019, <https://grants.nih.gov/grants/guide/pa-files/PA-16-019.html>.

³⁶ See the NSF Program Solicitation for the I-Corps Teams Program, NSF 12-602, <http://www.nsf.gov/pubs/2012/nsf12602/nsf12602.pdf>.

Variations on the I-Corps program have been piloted at NIH (focusing on the SBIR/STTR community),³⁷ at the DOD (focusing on the university researcher receiving awards), and at the DOE (focusing on National Laboratory personnel) (Energy.gov 2017).

C. Prizes for Promoting Early Stage Research

Prizes have been offered for centuries to solicit innovative solutions from problem solvers around the world. In 1714, the British Government set the Longitude Prize that eventually led to the world’s first practical method to determine a ship’s longitude; similarly, the 1919 Orteig Prize, set up by the First World War Allied Powers, inspired Charles Lindbergh to fly nonstop from New York to Paris. From these ambitious beginnings, incentive prizes have evolved, as one source put it, from “an exotic open innovation tool to a proven innovation strategy” (Mitchell et al. 2014). The reauthorization of the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act in 2010 established a prize authority that provided Federal agencies with more flexibility to conduct incentive prizes.³⁸ Since the establishment of the America COMPETES prize authority, there has been an eightfold increase in the number of Federal agencies that offer prizes and a sixfold increase in the number of prizes (Figure 15). In this section, we discuss how Federal agencies other than NASA have used prizes to promote early stage research.



Source: Data from Office of Science and Technology Policy (OSTP 2016, 8, Figure 1).

Figure 15. Number of Prize Programs in Federal Agencies, FY 2011–FY 2015

³⁷ See HHS PA-16-019, <https://grants.nih.gov/grants/guide/pa-files/PA-16-019>.

³⁸ America COMPETES Reauthorization Act of 2010, Public Law 111-358, January 4, 2011 [H.R. 5116], 111th Congress.

1. Definition and Approach

Federal agencies offered a total of 116 incentive prizes in FY 2015 with NASA offering 24 of these prizes (OSTP 2016). For the purpose of this analysis, each non-NASA prize from FY 2015 was categorized by Technology Readiness Level (TRL) to determine the number that promoted early stage research (TRLs 1–3). A prize is considered to be for early stage research if it advanced basic research, asked solvers to submit new research and technology ideas, or developed a technology from concept design to execution. Thus, the products of the challenges may lie beyond TRLs 1–3 and early stage research, but some part of the challenge leveraged early stage research, consistent with the definition put forth in the rest of this document. The success or failure of each challenge selected was not included in this assessment.³⁹

2. Descriptive Statistics

Of 92 non-NASA incentive prizes, we assessed 25 percent (23 incentive prizes) to have promoted early stage research at one stage or more (Table 24) (OSTP 2016).⁴⁰ The early stage prizes span an array of research topics from food safety to energy innovation to marine science (Table 24).

³⁹ Two prizes are highlighted in sidebars as examples of successful early stage research prizes.

⁴⁰ The total number of prizes include 24 prize competitions conducted by NASA, which were excluded from the early stage research categorization.

Table 24. FY 2015 Prizes Identified as Early Stage Research

| Name | Agency | Subagency |
|---|---------------|------------------|
| Head Health Challenge III: Advanced Materials for Impact Mitigation | DOC | NIST |
| Right Whale Recognition Challenge | DOC | NOAA |
| Forecasting Chikungunya (CHIKV) Challenge | DOD | DARPA |
| Novel Ballistic Coverage | DOD | USSOCOM |
| Improve Water Heater Performance with Phase Change Materials | DOE | EERE |
| Low-Temperature Intrinsically Safe Defrost System | DOE | EERE |
| Buildings Crowdsourcing Campaign | DOE | EERE |
| Dengue Fever Project | HHS | CDC |
| Food Safety Challenge | HHS | FDA |
| Design by Biomedical Undergraduate Teams (DEBUT) 2015 | HHS | NIH |
| Follow that Cell Challenge | HHS | NIH |
| Harnessing Insights from Other Disciplines to Advance Drug Abuse and Addiction Research | HHS | NIH |
| Innovations in Measuring and Managing Addiction Treatment Quality | HHS | NIH |
| Up for a Challenge (U4C)—Stimulating Innovation in Breast Cancer | HHS | NIH |
| Wearable Alcohol Sensor Challenge | HHS | NIH |
| “Where Am I, Where Is My Team?” Indoor Tracking of the Next Generation First Responder | DHS | — |
| New Concepts for Remote Fish Detection | DOI | USBR |
| Data Visualization Challenge: Using Data to Improve Justice | DOJ | NIJ |
| Randomized Controlled Trial Challenge in Criminal Justice Agencies | DOJ | NIJ |
| Automatic Speech Recognition in Reverberant Environment (ASpIRE) | IARPA | ODNI |
| Beyond the Box Digitization Competition | NSF | — |
| Fighting Ebola Open Ideation Challenge | USAID | — |
| Technology to Support Education in Crisis and Conflict Settings Ideation Challenge | USAID | — |

Notes: This list includes the 24 prizes awarded in FY 2015 that STPI determined to be for early stage research. In all, 41 prizes were awarded in FY 2015. See the list of abbreviations at the back of this report for meanings of agency and subagency abbreviations.

Early stage prizes offered a total of \$5.6 million with a median of \$25,500 per prize, and the prizes solicited over 4,500 solutions in total, with a median of 40 entrants per prize (Figure 16).⁴¹ Most of the challenge organizers (74 percent) entered into formal partnerships with other Federal agencies or private companies to conduct the prize, for either financial support, topic expertise, facility use, or marketing assistance.

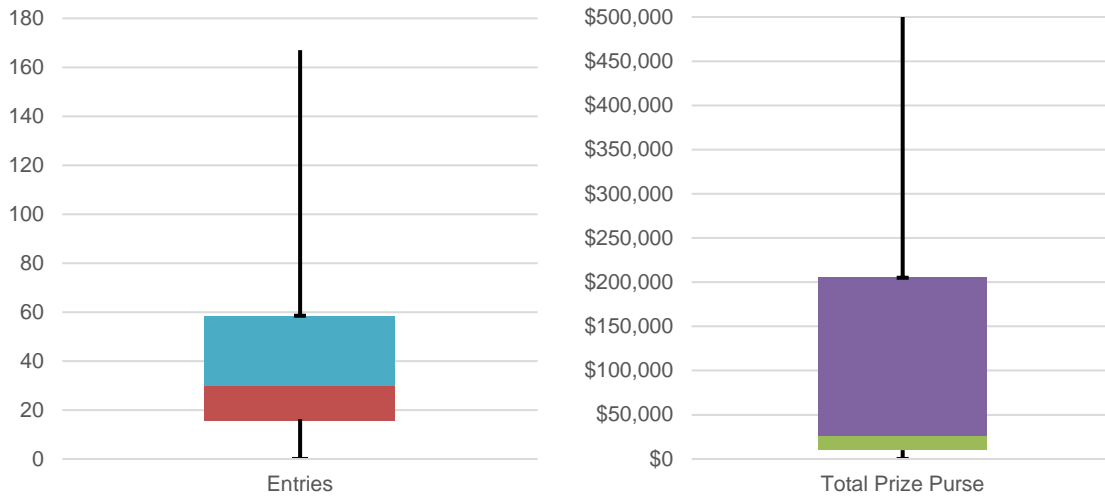
For the set of all prizes in FY 2015 and the subset of early stage research prizes, the most common type of solution was ideas, which is a broad category that encompasses short exploratory white papers to fully fledged research proposals (Figure 17).⁴² The subset of early stage research prizes solicited ideas at a much higher rate than the full set of prizes, 78 percent of the subset over 41 percent of the full set. Early stage research prizes also solicited scientific solutions at a much higher rate, 26 percent compared to the full set's 10 percent scientific solutions. The high rate of both of these types of solutions corresponds well with the goals of early stage research, to solicit novel concepts rather than finished software and hardware and to advance basic science. The early stage research prizes had a similar rate as the full set in terms of technology demonstration, hardware, analytics, visualizations, and algorithms, and a much lower rate for the remaining types of solutions.

New Concepts for Remote Fish Detection

This early stage research prize competition at the U.S. Bureau of Reclamation (USBR) tasked solvers with submitting ideas and solutions for new or better ways to reliably track fish throughout their life-cycle. Current methods to track fish rely on the capture and handling of fish to implant or attach tags that can be short-lived, costly, and limit data analysis. Many solvers were technical experts in their respective domains, but had not applied their skills to fish tracking. The top solutions leveraged the concept of piezoelectric energy harvesting to power the tagging technology with the swimming movement of the tagged fish. USBR plans to create a plan to test, develop, and demonstrate the top ideas.

⁴¹ These total figures include data for all early stage research prizes, but the medians were calculated with the outliers removed (Figure 16).

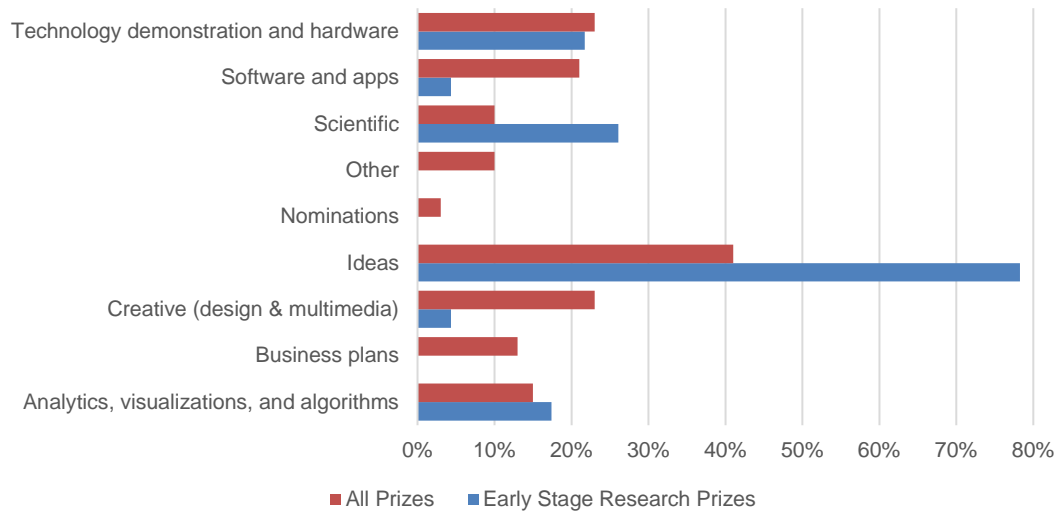
⁴² The categories for solution types were analytics, visualizations, and algorithms; business plans, creative (design and multimedia); ideas; nominations; other; scientific; software and apps; and, technology demonstration and hardware. Categorization of prizes derives from the FY 2015 COMPETES prizes report.



Source: Data from OSTP (2016).

Note: All outliers that were more than 3 standard deviations from the median were removed. For the left box plot, three outliers, 2,644, 606, and 404 entrants, were removed. For the box plot on the right, two outliers, \$1 million and \$2 million, were removed.

Figure 16. Range of Number of Entrants (Left) and Range of Prize Money Awarded (Right) for Early Stage Research Prizes



Source: Data for all prizes from OSTP (2016).

Note: Each prize may have multiple types of solution.

Figure 17. Percentage of Prizes with Each Type of Solution in FY 2015

Automatic Speech Recognition in Reverberant Environment (ASpIRE)

The ASpIRE challenge initiated by the Intelligence Advanced Research Projects Activity (IARPA) had an ambitious goal of building accurate transcription systems for speech recorded in noisy and reverberant environments without any further information about the location or the devices used. The current speech-recognition systems test in similar conditions to the final environment in order to train for an accurate transcription. Even though IARPA set out this ambitious goal for solvers, the four ASpIRE challenge winners developed systems that delivered at least a 50 percent reduction in error compared to the IARPA baseline system. IARPA considers these results to be quite successful for the cost of the challenge.

Organizers measured success of these challenges based on improvements upon the baseline technology, prestige of the final competition, engagement with non-traditional problem solvers, diversity of ideas, and total number of participants. These success measures were similar to the full set of prizes, but the early stage research subset had a higher incidence of improving upon baseline technology or accuracy of the final solution.

This initial analysis of FY 2015 prizes demonstrates that many Federal agencies utilize the incentive prizes mechanism to promote early stage research across varied research topics. A full quarter of all prizes promote early stage research and over 4500 competitors participated in early stage research prizes. Prizes ask solvers for different types of solutions, but for early stage research prizes, mostly idea solutions are solicited and to a lesser extent scientific solutions. Both of these solutions are consistent with the goals of early stage research.

To develop more detailed insights into how prizes may not only promote early stage research but also produce innovative and successful solutions to early stage research problems, further research needs to be completed on factors that make a prize successful for early stage research. Additionally, since a number of Federal agencies—even those with missions supported predominately by later stage research—utilize the prize format in this way, more evidence could be gathered about what motivates Federal agencies to conduct these prizes as well as an evaluation of lessons learned about prizes as one mechanism in an innovation and research portfolio.

D. Evaluation Metrics in the R&D Community

Rigorous evaluation of R&D programs can be complicated. As a report of the American Evaluation Association (AEA) notes: “One challenge, as compared to other evaluation domains, relates to the *nature and timing of RTD⁴³ progress as it is usually unpredictable and the translation of research into societal outcomes occurs through complex processes that involve many actors downstream of the RTD program*” [italics added] (AEA 2015). Fortunately, the R&D evaluation community-of-practice has existed

⁴³ AEA uses the terms *research, technology, and development* or *RTD* rather than *R&D*.

for many decades, and many best practices have been documented over the years.⁴⁴ Appendix B provides a summary of AEA findings related to improving evaluation practice. Here we summarize three areas emphasized by the AEA RTD topical interest group that would be relevant to STMD's early stage portfolio.

1. Use of Appropriate Methods and Metrics

In our experience in evaluating Federal programs, we have found that program managers sometimes struggle to identify metrics of success. Before metrics can be identified, the goals of the evaluation need to be clarified. AEA identified four purposes of an evaluation (AEA 2015, 15):

- **Accountability:** to show that money and other resources have been used efficiently and effectively, and to hold researchers to account;
- **Advocacy:** to demonstrate the benefits of supporting research, enhance understanding of research and its processes among policymakers and the public, and make the case for policy and practice change;
- **Allocation:** to determine where best to allocate funds in the future, making the best use possible of a limited pool of funding; and
- **Analysis (program improvement and learning):** to understand how and why research is effective and how it can be better supported (or allocated), feeding into research strategy and decision making by providing a stronger evidence base.

Once the goals of the evaluation can be clearly articulated, metrics are relatively easy to identify. Table 25 depicts an illustrative set of evaluation metrics for RTD programs from the AEA RTD white paper.

⁴⁴ There also exist many *ad hoc* evaluations of individual basic and applied research programs. An example is STPI's evaluation of the NIH Director's Pioneer Award (NDPA) program (Lal et al. 2012).

Table 25. Examples of Indicators and Outcomes for Research, Technology, and Development Programs

Program Design, Implementation:

- Efficiency, effectiveness of planning, implementing, evaluating; Stakeholder involvement
- Robustness of program partnerships, other delivery infrastructure
- Progress in required areas (e.g., e-government)

Contextual Influences:

- Characteristics of researchers (team size, diversity)
- Nature of RTD problem (type, scope, radicalness)
- Characteristics of interactions (continuity, diversity, etc.)
- Nature of research application (breadth, depth, timing, radicalness of change; sector absorptive capacity)
- Characteristics of macro environment (availability of capital, capabilities; ease of coordination)

Inputs and Resources for Research:

- Expenditures on research
- Expenditures on research support activities, such as database development, research planning and priority setting
- Depth, breadth of knowledge base and skill set of researchers and technologists, teams, organizations
- Capabilities of research equipment, facilities, methods that are available
- Vitality of the research environment (management, organizational rules, etc.)

Activities (the Research Process) and Outputs:

- Plan, select, fund, researchers, research projects, programs
- Quality, relevance, novelty, of selected researchers, projects, programs
- New knowledge advances (publications, patents, technical challenges overcome)
- Quality and volume of other outputs (grants made, projects completed, number of reports, people trained, etc.)

Interactions (includes Transfer and Use):

- Research collaborations, partnerships formed; preparation for transition to application
- Dissemination, exchange of research outputs (publications, inclusion in curricula, etc.)
- Industry engagement, co-funding, follow on funding for the research
- Public engagement, awareness of outputs (participation, media mentions)

Science Near-Term Outcomes:

- Publication citations; patent applications, patents
- Awards, recognition, professional positions
- Expansion of Knowledge base in terms of technical leadership and absorptive capacity
- Advances in research/technical infrastructure (new research tools, scientific user facilities, testing facilities)
- People educated in RTD area and research methods
- Linkages/communities of practice/networks
- Technical base (technology standards, research tools, databases, models, generic technologies)
- Commercialization/utilization support base (manufacturing extension programs, supportive codes, etc.)

More RTD or RTD Diffusion Activities, Outputs, and Interactions:

- Public funds expended for these RTD or Diffusion programs
- Leveraged investments by private sector
- Translational or cross-functional teams; Presence of intermediary organizations
- Technical milestones achieved, prototypes built/scaled up, additions technical knowledge and infrastructure
- Dissemination, exchange of knowledge; consultation; citation
- Additions to diffusion/adoption infrastructure (capabilities, delivery, etc.)

Application of Research, Progress toward Outcomes:

- New technology development advances (movement through stages, functionality)
- Product commercialized; policy /practice implemented; attitude or behavior changed
- New “technology” commercialization/diffusion advances (supply chain develops, adoption of new process technology)

For each of the above:

- Utilization/influence, sustainability of influence on decisions, behavior, physical or financial factors

Sector, Social and Economic Outcomes and Impacts:

| | | |
|------------------------------|-------------------------|-------------------------|
| • Modeled monetized benefits | • Income levels | • Environmental quality |
| • Health status | • Jobs | • Production levels |
| • Security, safety measure | • Benefit to cost ratio | • Cost savings |
| • Sustainability measure | • Quality of life | • Competitiveness |

Related Programs and Major Influencers:

- Date of formal handoffs to or take up from partners, others
- Chronological account of who else did what, when

Source: AEA (2015, Table 2).

2. Use of a Mix of Qualitative and Quantitative Methods

There is no perfect method that can address all the questions in an evaluation; each method has its own limitations, and a mix of methods is likely the best way to move forward. Multiple methods can also allow questions to be answered from different perspectives.

Table 26 summarizes both quantitative and qualitative methods that can be used in an evaluation.

Table 26. Evaluation Methods of RTD Programs

| Quantitative Methods | Qualitative Methods |
|------------------------------------|---------------------------------|
| Statistical analysis | Peer review and expert judgment |
| Econometric analysis | Site visit reports |
| Benefit-cost analysis | Descriptions of behavior |
| Impact assessment methods | Focus groups |
| Bibliometrics and patent analysis | Case studies |
| Benchmarking | |
| Social network analysis | |
| Cost-index methods | |
| Monitoring using indicator metrics | |
| Various scoring and rating systems | |

Source: AEA (2015).

On the quantitative metrics front, it has become easier to use bibliometric indicators such as h-indices, journal impact factors, citation indices, and other quantitative measures related to publications to measure scientific performance (Pendlebury 2008). Some universities are beginning to use them for basing promotion decisions, and (in parts of Europe), there has even been interest to using them for allocating funding to universities. These indicators have many challenges. For example, the older the researcher, the higher the h-index, even if the researcher stops publishing new papers (Hirsch 2005). H-indices also depend on the source used; according to one report, “there are researchers in computer science who have an h-index of around 10 in the Web of Science but of 20–30 in Google Scholar” (Bar-Ilan 2008.) To avert the misuse of metrics, experts have come up with heuristics or principles on the use of specific kinds of data for evaluating research (Hicks et al. 2015).

3. Integration of Evaluation Results into Program Planning

Evaluation should be an important management tool relevant to each stage in the life of a program, and not a one-off exercise driven simply by short-term needs to justify a program

(or address any of the four goals discussed above). Any evaluation conducted should feed into one or more of these stages—planning, implementation, or redesign (Table 27).⁴⁵

Table 27. Examples of RTD Program Evaluation Questions Posed by Government Leaders

| Stage in the Program Life Cycle | General Questions | Evaluation “Criteria” |
|--|---|--|
| Planning | What will the program do, when, and why? Are we doing the right thing? | Program implementation design Evaluation plan exists Relevance |
| Early to Middle of Implementation | Are we doing it the right way? | Economy Efficiency Quality Performance |
| Middle to End of Implementation | What has been the outcome/impact? | Effectiveness Performance Value for money |
| Learning and Redesign | What do we do next? | Use of evaluation findings |

Source: AEA (2015, 10, Table 1).

⁴⁵ Further detail on evaluation of RTD programs is available from AEA (2015). The conclusion section of the paper, which includes relevant recommendations, is reproduced in Appendix B.

7. Summary and Next Steps

In this report, STPI describes programs and offices of the Federal Government in areas that we believe are similar enough to programs within the STMD early stage portfolio to provide insights for NASA. In describing these similarities, we focus on the following areas of interest: (1) Definition and Approach (2) Budget (3) Personnel (4) Allocation and Management of Investment (5) Transition, and (6) Evaluation of Success. In this chapter, we first summarize our insights from findings in these areas before discussing two follow-on steps that could be worth considering.

A. Summary of Findings

Our findings demonstrated several common strategies across offices and programs related to topics of interest.

1. Definition and Approach

- Early stage of development meets relatively long-term needs: Definitions and approaches differ, but, generally, early stage is thought of as research that addresses long-term future needs (at least 5 and as much as 20 years hence) and focuses on de-risking technology.
- Approach to early stage research drives organization structure: Whereas some agencies have adopted a timeline-oriented approach, others define their scope as de-risking, funding research from basic to a level where other parties, principally commercial ones, would consider investing. Further, organizations build varying levels of flexibility into their structure, where various divisions are either limited or created and dissolved based on the changing needs of the agency.

2. Budget

- Funding levels vary across the Federal Government: Funding must be sufficient to draw research community interest; however, early stage funding for offices and programs typically represents a relatively small fraction of the overall research, development, and technology funding at an agency.

3. Personnel

- Mixed use of personnel: Offices and programs use permanent, temporary, and varying proportions of support staff; permanent staff allow for maintenance of institutional knowledge, while rotators provide a constant influx of new ideas.

4. Allocation and Management of Investment

- Topics are selected to support national priorities: Topics may be pulled from the general community (e.g., through broad agency announcements), from leadership within an agency, or through connections made through international offices.
- Formal connection to long-term missions: Use of topic selection and other review mechanisms allows offices and programs to solicit research in areas of principle interest to the agency; however, this strategy may be combined with an open solicitation for ideas.
- Internal and external experts are engaged for selecting topics and projects: Offices and programs engage experts to identify topics and review proposals that reflect agency priorities and emerging areas; some organizations solicit white papers from the academic community or hire rotating experts directly for their knowledge in an emerging field.
- Performers include a mix of intramural and extramural researchers: A mixture of projects are awarded from researchers from academia, industry, and government. Some programs rely entirely on academic researchers.
- Variety of funding mechanisms: Some agencies have embraced the use of prizes as an innovative way to induce breakthroughs; other organizations use particular mechanisms, such as Cooperative Research and Development Agreements (CRADAs), to formalize the collaborative nature of the research projects they fund.
- Flexibility in management: Certain organizations elect to provide autonomy to project managers, including allowing them to shape the early stage portfolio (e.g., number of awards, scope of research, funding amounts, research performers, and disciplines).

5. Transition

- Identification of transition partners: Program managers establish relationships with users both internal and external to the agency.
- Transition as an evaluative metric: Organizations track indicators of transition (e.g., memoranda of understanding and other agreements or follow-on funding

from private and public actors) to evaluate the short-term success of their portfolios and projects.

6. Evaluation of Success

- Use of standard output measures of success or no metrics at all: Measures focus on near-term outputs (e.g., publications, patents, licenses), and some offices or programs do not use metrics at all, rather they focus on outliers to effectively communicate narratives of impact.
- Specific target “success” rates are uncommon: Only a handful formally define what success means on the organizational level. Some cautioned that if targets for success are too high, the research may not be sufficiently high risk.

7. Less Common Practices

In addition, we identified several notable practices that were less common. While they may depend on the context of the agency or its mission, we felt they were worthwhile to mention. They include:

- Use of a tournament approach to encourage competition: IARPA uses tournaments to select multiple performers (teams) to solve the same challenge. Program managers continue funding research teams that perform better than others do, measuring all teams against project milestones and culling performers who are not meeting targets.
- Seeking international input: AFOSR maintains three foreign technology offices (located in London, Tokyo, and Santiago) to coordinate with the international scientific and engineering community to allow for better collaboration between the communities and U.S. Air Force personnel.
- Focus on program managers rather than project-level performance indicators: Epitomized by DARPA, but also adopted by other offices, such as the Office of Naval Research, offices hire visionary program managers and assess their performance based on the overall research goals and management of their portfolio, rather than solely on project-level success metrics.
- Labor-intensive program management: A number of organizations engage in active and labor-intensive project management that involves continual and frequent evaluation against milestones. These programs are highly hands-on, with strong communication across the early stage program managers and leadership. Other organizations provide minimal management once projects have been awarded.

- Designating a transition role or responsibility: Offices and programs with goals to commercialize their products, such as ARPA-E, established a position or role within research teams to assist in transitioning the science-based inventions to application. NGA Research devotes resources, including both people and funds, to useful technologies, and relies on transitioning people to serve as the champions of those technologies in other locations at NGA.
- Funding investigator-initiated research: Both NGA Research and DOE's LDRD support investigator-initiated research to bolster morale, recruitment, and retention. NGA Research provides up to 20 percent of staff time for independent research, while LDRD can make up the entirety of an employee's time.
- Mandating multidisciplinary teams: A number of programs prioritize interdisciplinary projects, cited as a proxy for potentially high-risk, high-reward research. The National Science Foundation's EFRI program, for example, mandates multidisciplinary in its proposals.

B. Next Steps

Throughout this work, STPI engaged with program managers across the DOD, the DOE, the Intelligence Community, and the NSF. Generally, program managers were eager to discuss their programs and share practices that have led to the success of their early stage research programs. Program managers were interested to hear about the findings of this report. They were seemingly interested in continuing dialogue and curious about the challenges and solutions employed by other programs. As a next step, it could be useful to engage other STPI-identified early stage research portfolio managers through a roundtable discussion or workshop.

STPI developed a series of questions to help spur dialogue across the community of early stage research and technology managers and stakeholders (Table 28). These questions could support further understanding of dependencies across the topics of interest and their influence on the management of early stage research and technology development portfolios.

In addition, engagement of early stage research portfolio managers across the Federal Government could strengthen collaboration and better leverage resources, for example, through joint-solicitations. Improved engagement with Federal counterparts could help managers identify common research areas and perhaps expand opportunities for transition across a larger pool of Federal and non-Federal communities. A natural next step would be to bring together all interviewees contacted for this project for a half-day or day-long workshop to discuss which of the insights apply best within the NASA context.

Table 28. Potential Roundtable Discussion Questions

| | |
|--|--|
| Definition and Approach | How does organizational context and differences in mission/objectives influence the core approach to early stage research and technology programs and portfolios? |
| Budget | How do yearly budget profiles influence early stage research and technology program management and approach? |
| Personnel | How does the use and management of the technical and support staff in your organization support the missions of the agency? |
| Allocation and Management of Investment | <p>What is unique about the program’s selection process that enables early stage research?</p> <p>What are best practices for determining early stage, cutting-edge topics and selecting projects to move the field forward?</p> <p>What are effective funding mechanisms to spur early stage research and technology?</p> |
| Transition | What role does transition play in the program, and how can goals for transition be integrated into program management and evaluation? |
| Evaluation of Success | How are metrics and targets used to evaluate outcomes and provide guidance throughout the management of early stage programs and portfolios? |

Second, STPI identified the use of prizes as a unique opportunity to apply the previously discussed considerations: (1) balance with transition-oriented research, (2) connection to mission, (3) engagement, and (4) flexibility. Prizes may provide early stage portfolio managers flexibility (duration, frequency, funding, etc.) to engage with non-Federal experts in research that is transition-oriented and solves challenges directly related to an agency’s mission. However, careful design and management of prizes is warranted given the mechanism’s diverse and burgeoning use across the Federal Government. As part of a related project, STPI developed a database of every prize offered by the U.S. Government in the last 15 years. Mining the database for insights as to if, when, and how prizes nurture early stage research would be a useful endeavor. We therefore propose a deeper look at the use of prizes as a mechanism for nurturing early stage research and technology development.

Appendix A. Figures Related to Federal R&D

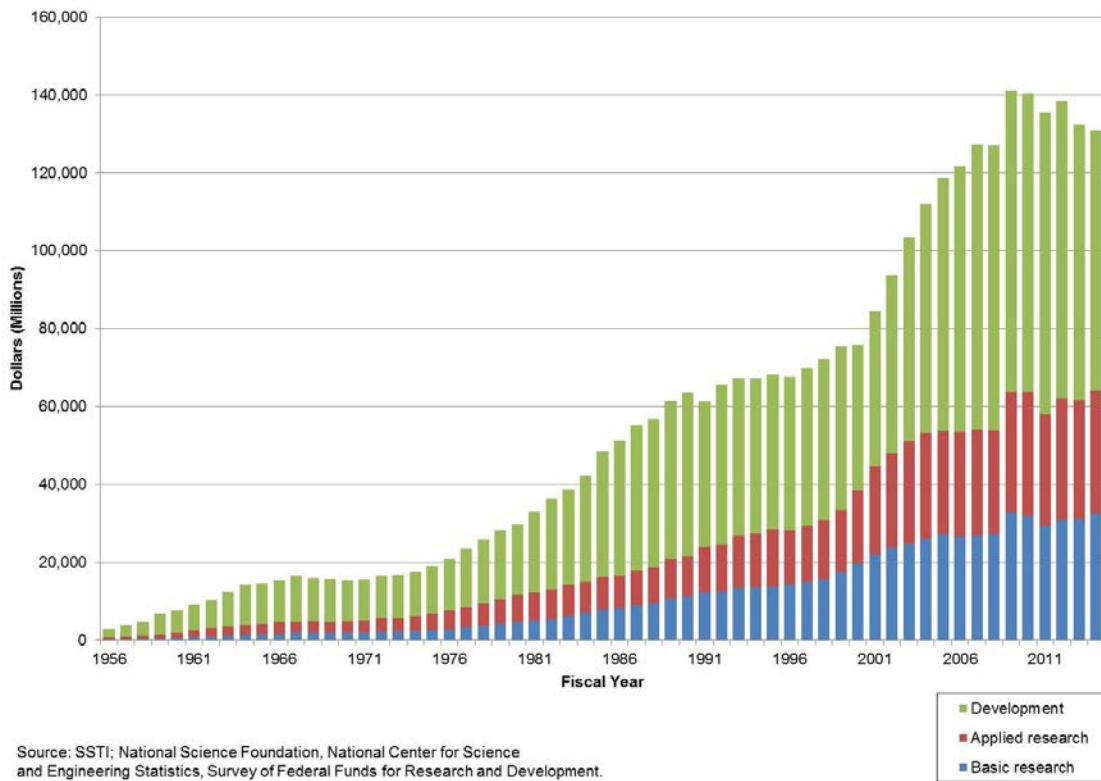
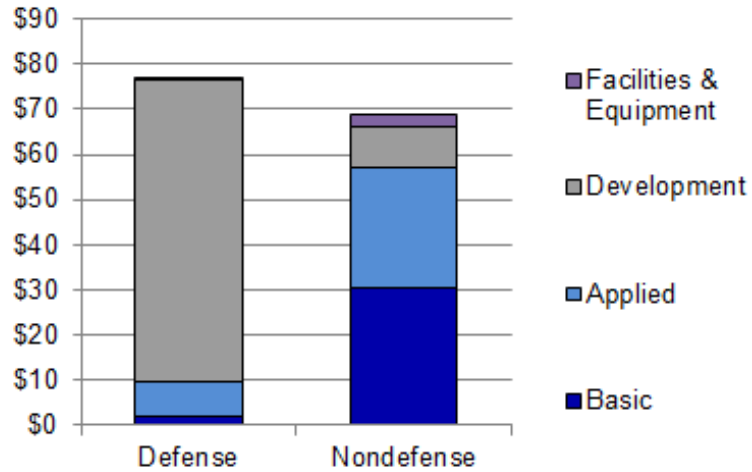
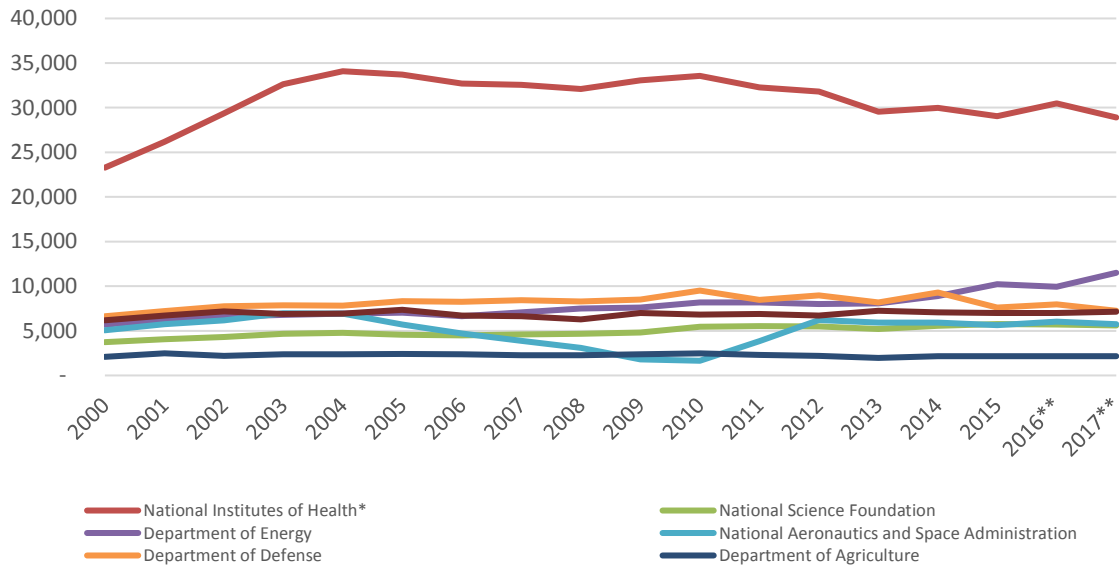


Figure A-1. Trends in Federal R&D by Character of Work



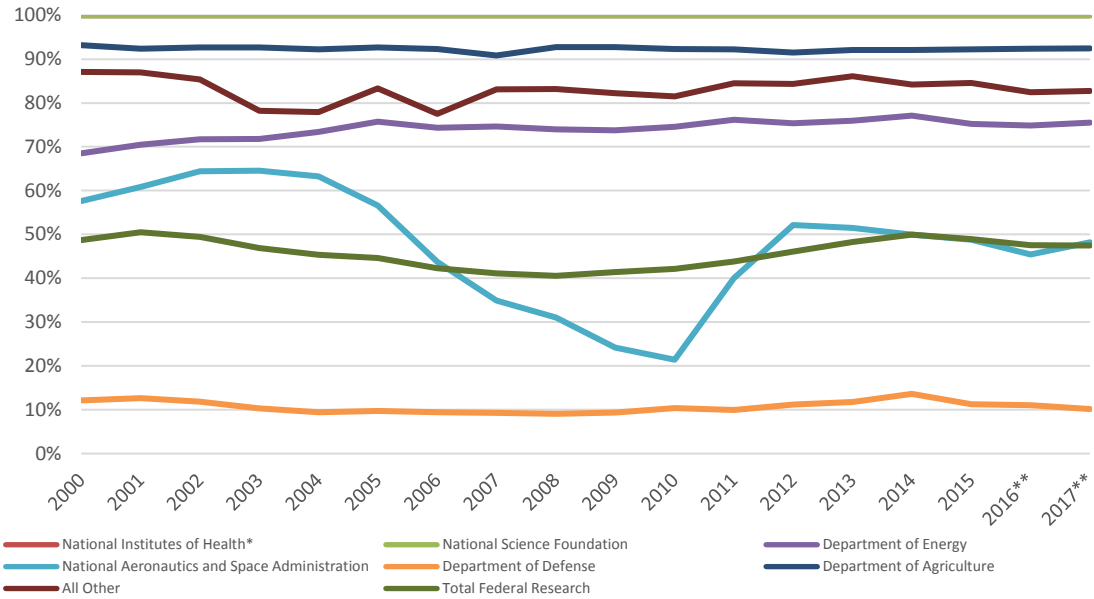
Source: OMB R&D data, agency budget justifications, and other agency documents. © 2015 AAAS

Figure A-2. R&D Budget Authority (in billion USD) by Character, FY 2016



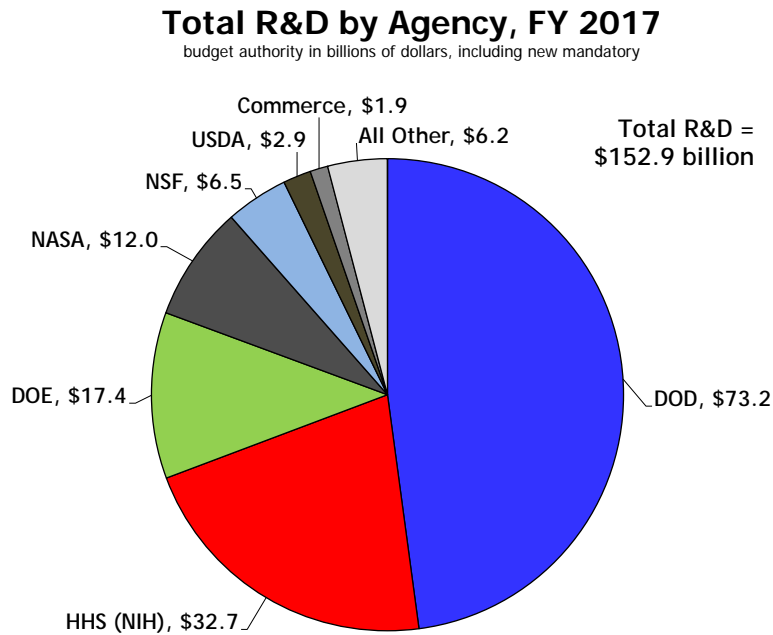
Source: AAAS (2017), OMB and agency R&D budget data.

Figure A-3. Basic and Applied Research in the Federal Government



Source: AAAS (2017), OMB and agency R&D budget data.

Figure A-4. Basic and Applied Research as a Percent of Total R&D

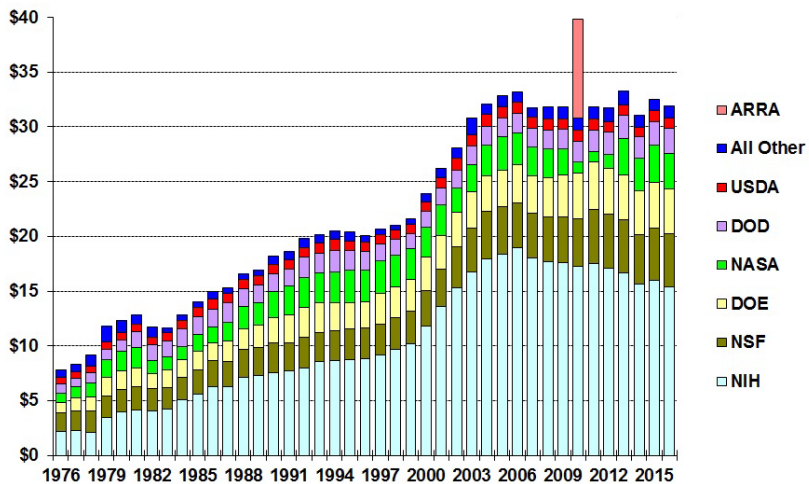


Source: OMB R&D data, agency budget justifications, and other agency documents and data. R&D includes conduct of R&D and R&D facilities. © 2016 AAAS

Figure A-5. Total R&D by Agency, FY 2017

Trends in Basic Research by Agency, FY 1976-2016

in billions of constant FY 2015 dollars

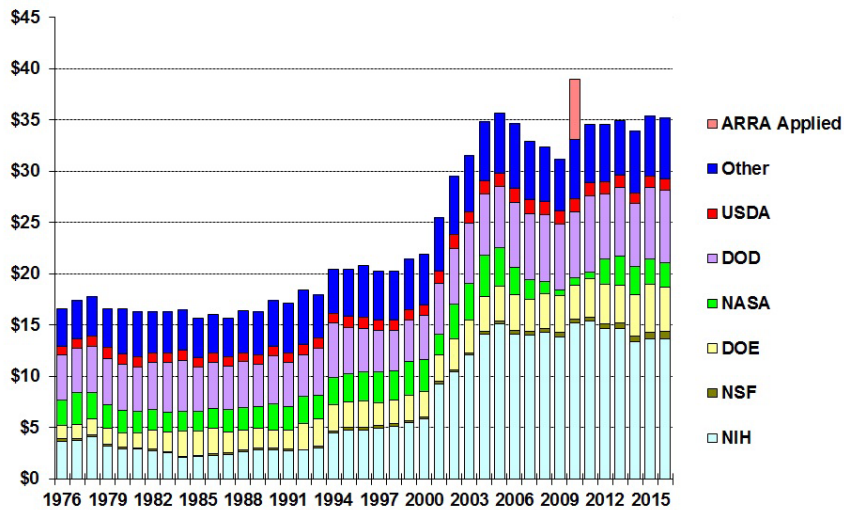


Source: AAASReport: Research & Development series. FY 2015 figures are latest estimates, FY 2016 is the President's request. © 2015 AAAS

Figure A-6. Trends in Basic Research by Agency

Trends in Applied Research by Agency, FY 1976-2016

in billions of constant FY 2015 dollars

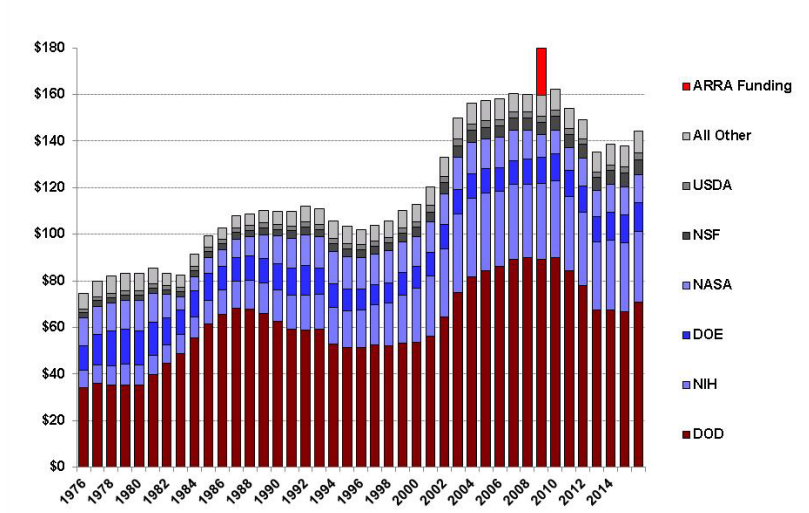


Source: AAASReport: Research & Development series. FY 2015 figures are latest estimates, FY 2016 is the President's request. © 2015 AAAS

Figure A-7. Trends in Applied Research by Agency

Trends in R&D by Agency

in billions of constant FY 2015 dollars

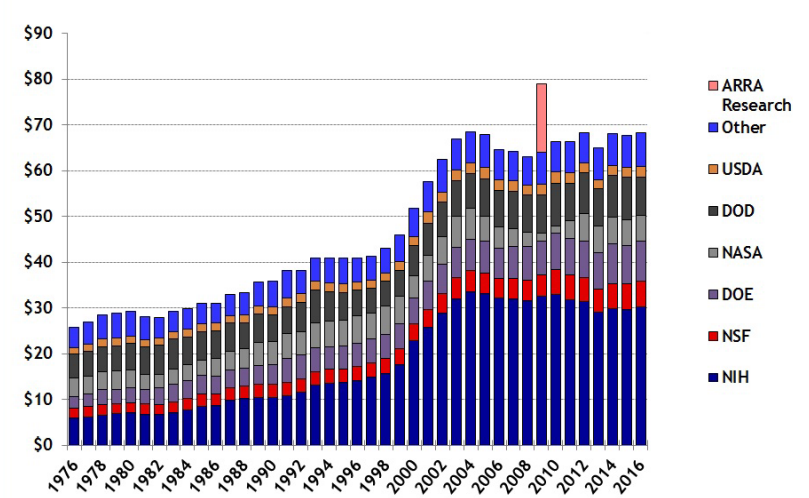


Source: AAAS Report: Research & Development series and analyses of FY 2016 budget request. 1976-1994 figures are NSF data on obligations in the Federal Funds survey. © 2015 AAAS

Figure A-8. Trends in R&D by Agency

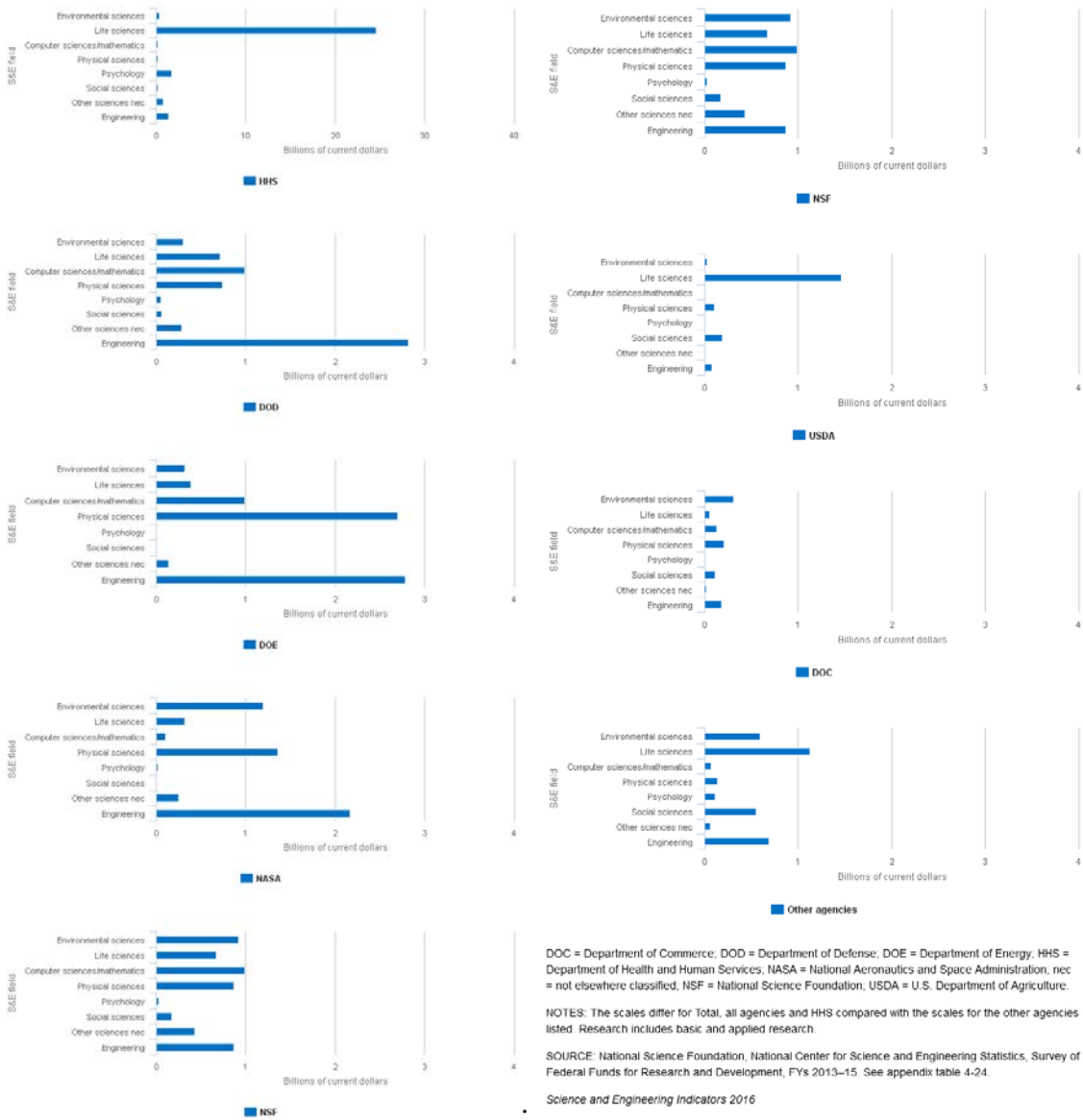
Trends in Research by Agency, FY 1976-2016

Billions of constant FY 2015 Dollars



Source: 1976-1994 figures are from the NSF federal funds survey; remainder is from AAAS R&D reports. FY 2015 are estimates, FY 2016 is the President's request. © 2015 AAAS

Figure A-9. Trends in R&D and Research (Basic and Applied Research) by Agency

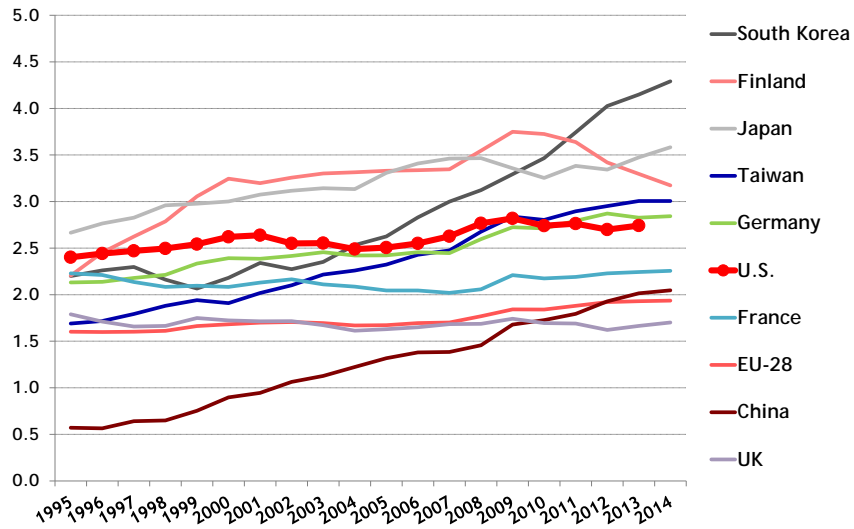


Source: National Science Board (NSB 2016).

Figure A-10. Federal Obligations for Research, by Agency and Major S&E Field: FY 2013

National R&D Intensity

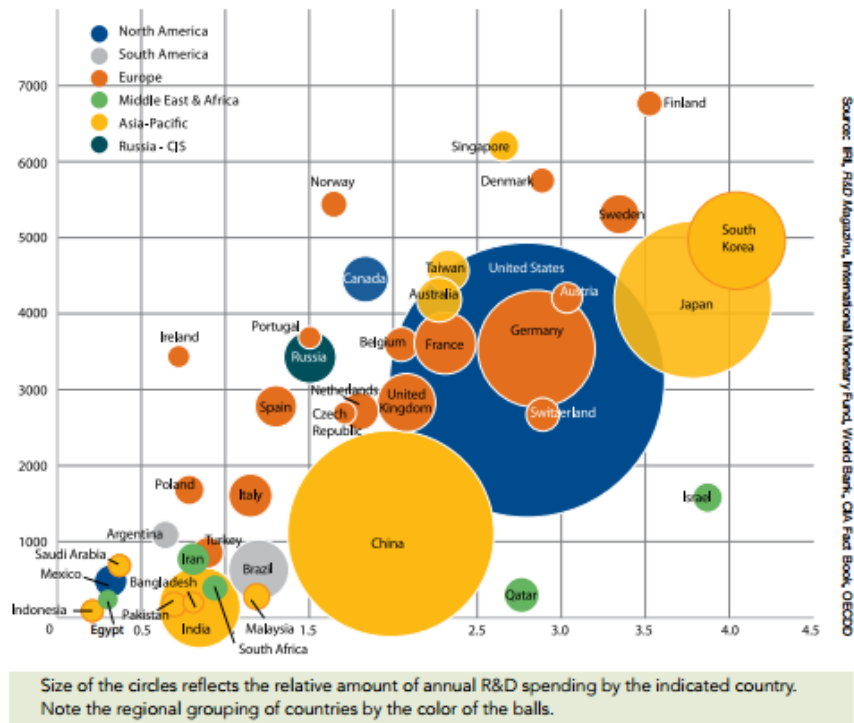
Gross R&D investment as a percent of GDP



Source: OECD, Main Science and Technology Indicators, January 2016. © 2016 AAAS

Source: <https://www.aaas.org/page/historical-trends-federal-rd>.

Figure A-11. International Comparisons



Source: IRI, R&D Magazine, International Monetary Fund, World Bank, CIA Fact Book, OECD

Size of the circles reflects the relative amount of annual R&D spending by the indicated country. Note the regional grouping of countries by the color of the balls.

Source: https://www.iriweb.org/sites/default/files/2016GlobalR%26DFundingForecast_2.pdf.

Note: Size of circle reflects annual R&D funding.

Figure A-12. GDP Per Capita versus Percent GDP Investment in R&D

Appendix B.

Evaluating Outcomes of Publicly Funded Research, Technology and Development Programs: Recommendations for Improving Current Practice

The following is an excerpt from a paper published by the American Evaluation Association (AEA 2015, 42–43).

This paper was developed to engage the audience in a dialogue about current RTD evaluation practice, how it has progressed, and how these practices might be further improved. The ultimate goal is to contribute to a consensus and broader implementation of a common evaluation language and practice within and across publicly-funded RTD programs. To achieve this, we have provided the larger context and guidance on RTD evaluation planning and implementation based on extensive review of the literature, practical experience, and the advice of expert reviewers. This context and guidance includes a newly developed generic high-level RTD logic model with accompanying output and outcome indicators; guidance on designing, monitoring, and evaluating outputs and outcomes of publicly-funded RTD programs; and a variety of examples from different types of RTD programs at different stages of implementation.

The discussion and examples contained in this paper support the following key recommendations:

Recommendation #1: Build into each new program and major policy initiative an appropriate evaluation framework to guide the program or initiative throughout its life.

- Evaluation should be undertaken because evaluation is a valuable management tool at all stages of the program life cycle;
- Evaluations should be planned using a logical framework that reflects the nature of RTD in a meaningful way; and
- Decision makers' questions may call for both retrospective and prospective evaluation, and for evaluation of outputs and early outcomes that are linked to longer-term outcomes.

Recommendation #2: More needs to be done to develop appropriate methods for designing programs and policies, improving programs, and assessing program effectiveness.

- More can be done to use or insist on the use of the robust set of methods that exists for evaluating RTD outcomes;
- Evaluation methods for demonstrating program outcomes should be chosen based upon the evaluation purpose and specific questions being answered and the context;
- Mixed methods are usually best, especially when outcomes of interest go beyond advancing knowledge to include social or economic; and
- There are options for assessing attribution, although it is recognized that experimental design is seldom an option and contribution to a causal package is more useful.

Recommendation #3: The RTD community should move toward the utilization of agreed upon evaluation frameworks tailored to the context in order to learn from synthesis of findings.

- There needs to be continued movement toward a common language and common evaluation frameworks by type of RTD program and context, with common questions, outcomes, indicators, and characterization of context; and
- Methods need to be further developed and used in relation to evaluation synthesis and the research designs, data collection, and analysis that support it.

Appendix C.

Public Sector Literature Review

Lessons related to managing early stage portfolios reside not just in Federal agencies but also in the private sector. Note that we use the terms *private sector* and *industry* interchangeably. In this appendix, we present a limited analysis of lessons from the private sector derived from a review of the literature.

Definition of Early State Research in the Literature

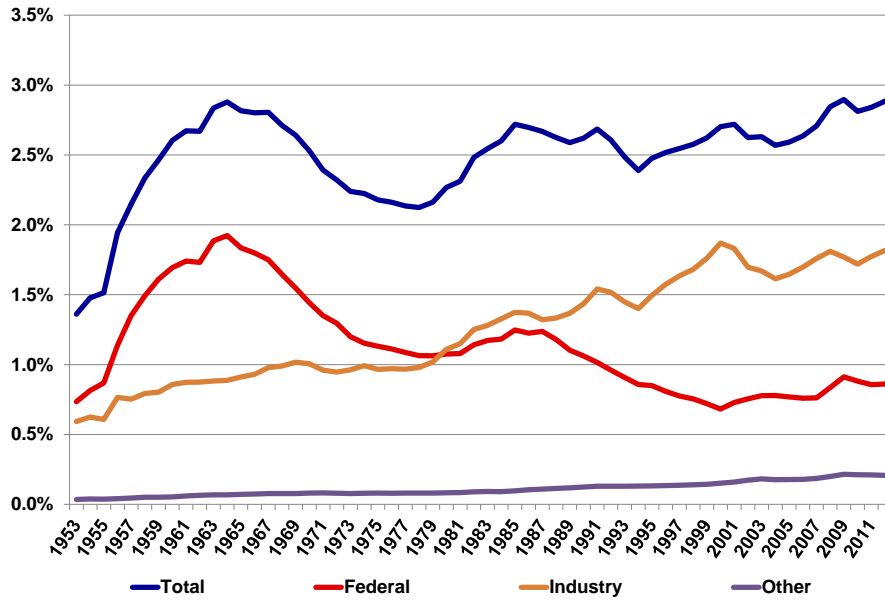
Early stage research and technology development can have different definitions depending on the context—both the performer of the research (academia, government, industry, or a combination of these) and the ultimate customer for the technology (government, industry, or some combination). Branscomb and Auerswald defined early-stage technology development (ESTD) as “the technical and business activities that transform a commercially promising invention into a business plan that can attract enough investment to enter a market successfully, and through that investment become a successful innovation.” Under their definition, “government directly supports the innovation process through grants and contracts to both scientific and engineering research as well as project-level support of early-stage commercial technology development” (Branscomb and Auerswald 2002).

Other common terms used in industry to distinguish between research projects are short-term, medium-term, and long-term. Short-term projects are focused on either product or process maintenance (impact felt within one year) or short-term development projects (products to market in less than 3 years) (Roberts 2001). Short-term research may also comprise business-oriented development versus long-term research, which is the development of theoretical research that may or may not have future applications (Varma 2000).

Budget Allocations and Trends

Taken together, Figure C-1 and C-2 show industry as an important and growing funder of both R&D and research. Industry spent \$341 billion on research and development (R&D) performed in the United States in 2014, a 5.6 percent increase over the previous year (Wolfe 2016). Six percent of this total (\$22 billion) went toward basic research, and 16 percent (\$53 billion) toward applied research (Table C-1). This total amount of basic and applied research exceeds the Federal Government spending on research (Appendix A). Research alone in the private sector exceeds the total R&D budget of the Department of Defense.

R&D as a Share of GDP by Funder

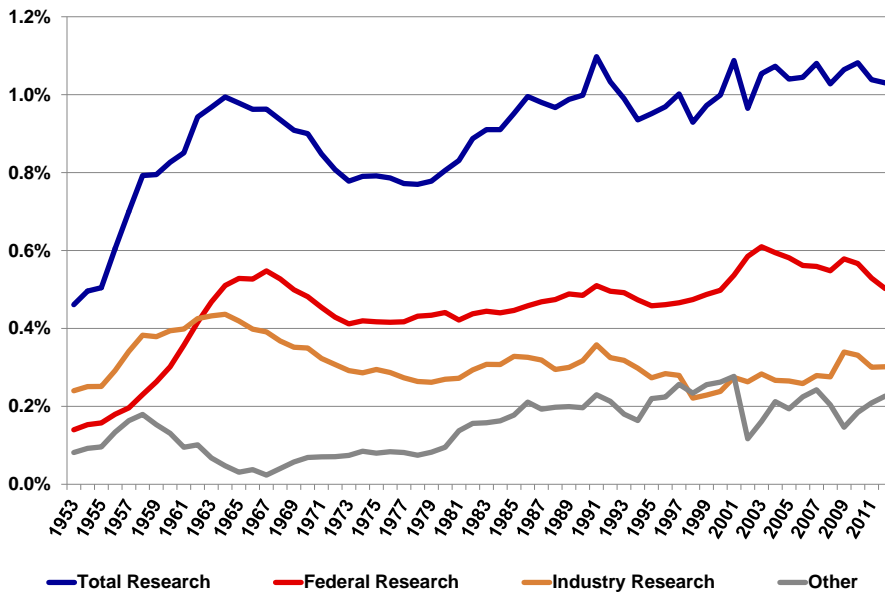


Source: National Science Foundation, *National Patterns of R&D Resources* series. © 2015 AAAS

Source: Hourihan (2015, slide 2).

Figure C-1. Ratio of U.S. R&D to GDP by Funder (1953–2013)

Research as a Share of GDP by Funder



Source: National Science Foundation, *National Patterns of R&D Resources* series. © 2015 AAAS

Source: Hourihan (2015, slide 3).

Figure C-2. Ratio of U.S. Research (Basic and Applied) to GDP by Funder (1953–2013)

Table C-1. Funds Spent for Business R&D Performed in the United States, by Type of R&D and Source of Funds (Millions of U.S. dollars)

| Selected Characteristic and Company Size | 2014 |
|---|---------------|
| Domestic R&D performance | 340,728 |
| Type of R&D | |
| Basic research | 21,936 |
| Applied research | 53,415 |
| Development | 265,377 |
| Paid for by the company | 282,570 |
| Basic research | 16,107 |
| Applied research | 39,012 |
| Development | 227,451 |
| Paid for by others | 58,158 |
| Basic research | 5,829 |
| Applied research | 14,403 |
| Development | 37,927 |
| Source of funds | |
| Federal | 26,554 |
| Other | 31,604 |

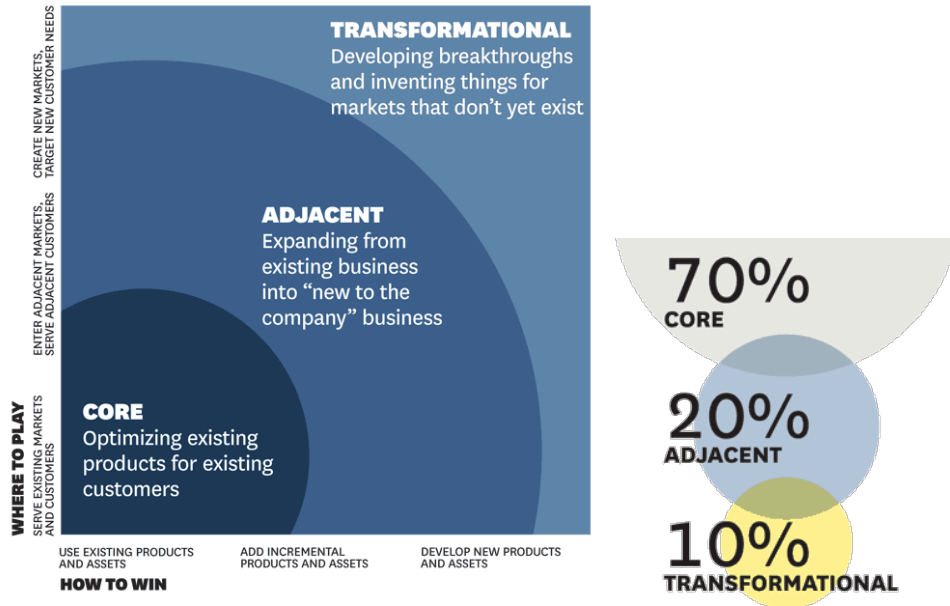
Source: Wolfe (2016, Table 1).

From a macro perspective, U.S. industrial R&D expenditures slowed in constant dollars beginning in the mid-1980s, but then began to increase in the mid-1990s, though the focus was on applied R&D. In the mid-1980s, corporate R&D laboratories also began terminating most risky and long-term research projects (Varma 2000).

From a firm-level perspective, a late-1990s survey of 209 European, American, and Japanese companies that performed R&D, found that the companies devoted close to two-thirds of their R&D budgets to short-term projects and long-term spending percentiles were in the low teens (Roberts 2001). Overall R&D represented 4.7, 5.3, and 7.9 percent of annual sales volume for companies in Europe, Japan, and North America, respectively (Roberts 2001).

With respect to proportion, Google and other companies rely on the 70-20-10 rule—70 percent of time on the core business, 20 percent on related projects, and 10 percent on unrelated new businesses (Figure C-3) (Nagji and Tuff 2012). Google CEO Eric Schmidt explains, “We spend 70 percent of our time on core search and ads. We spend 20 percent on adjacent businesses, ones related to the core businesses in some interesting way. Examples of that would be Google News, Google Earth, and Google Local. Then 10 percent of our time should be on things that are truly new. An example there would be the Wi-Fi initiative—which I haven’t kept up with myself” (Battelle 2005). The exact breakdown is dependent on the industry involved—for example, a technology company

may have greater emphasis on transformational business than a consumer goods company—a company’s competitive position, and the company’s stage of development (Nagji and Tuff 2012).



Source: Nagji and Tuff (2012).

Figure C-3. Percent of Industry Time Dedicated to Research Types

Table C-2 lists a set of industry-based innovation laboratories, and not all focus on R&D.

Table C-2. Innovation Laboratories in Industry

| Section Name | Name of Company | Innovation Laboratory Name | Summary | Year Founded |
|---------------------|------------------------|--|---|---------------------|
| Technology | Hewlett-Packard | HP Labs | HP Labs is an award-winning research facility focusing on technologies like natural language detection, audio/video analytics, immersive experiences, 3D printing, and more. | 1966 |
| | Google | X | Google's X research center is where some of Google's biggest projects happen. These teams work on research that is not directly tied to a product and encompasses challenging fields like speech processing, machine intelligence, quantum AI, and more. | 2010 |
| | Xerox | Xerox Palo Alto Research Center (PARC) | The PARC's professed approach is "open innovation." Founded in 1970, PARC has worked on world-changing innovations like Ethernet, laser printing, and GUIs. | 1970 |
| | Microsoft | Microsoft Research Lab | Microsoft has numerous laboratories, each with its own flavor, aimed at applying research independent of product development cycles. Projects include Skype translation, talk-to-text transcription, real-time hand tracking for single-depth cameras, and more. | 1991 |
| | Google | The Garage | While X may be better known, there is a lot of work and play happening at The Garage. Originally opened in 2008 by a group of Googlers who wanted somewhere a bit more free form to do their "20% work." (The phrase "20% work" itself is a form of constant innovation: it refers to the 20% of the workweek during which Google employees get to work on projects not directly connected to their core tasks.) It is open to all Googlers and boasts 3D printers, tons of tools, a CNC machine, and plenty of collaborative workspace to encourage out-of-the-box thinking. | 2008 |
| | TCS | TCS Innovation Labs | TCS's world-spanning network of Technology, Domain, and Academic Alliance Labs let IT experts of all stripes create new systems. Products from these laboratories include HeartSense and AkTrac ("wellness apps for activity detection and physiological sensing using mobile phones and wearables"), a mobile phone digital stethoscope, and RehabBox, a "Kinect-based telerehab system for post stroke patients." | 1981 |

| Section Name | Name of Company | Innovation Laboratory Name | Summary | Year Founded |
|--------------|-----------------|---------------------------------|--|-------------------|
| | Oracle | Oracle Labs | Originally founded as Sun Microsystems Laboratories, the name was changed to Oracle Labs after their acquisition in 2010. Oracle Labs' research philosophies are exploratory research, directed research, consulting, and product incubation. Past projects that have grown out of Oracle Labs research include chip multithreading and the Java programming language. | Unknown |
| | IBM | IBM Mobile Innovation Lab | The Mobile Innovation Lab brings together cloud and mobile experts to try to develop new technologies and applications for the IBM Cloud, clients, and more. | Unknown |
| | Avaya | Avaya Labs Research | Avaya Labs Research center focuses on WebRTC, mobility, cloud, and video solutions. Innovations include an ecommerce delivery mechanism for embedding open, mobile digital communication. | Unknown |
| | Autodesk | Autodesk Labs | Autodesk, makers of AutoCAD, Revit, and a wide array of design and engineering software, has its own innovation laboratory, called "Autodesk Labs." This innovation center focuses on "technology previews," public releases of new technologies in development which have set start and end dates and are focused on garnering user feedback. | Unknown |
| Telecom | AT&T | AT&T Labs Advanced Technologies | AT&T Labs Advanced Technologies focuses on data analytics, cloud services, networking, and much more; this venerable laboratory has won eight Nobel prizes. | Unknown |
| | Nokia | Nokia Bell Labs | Nokia's innovation laboratory was founded in 1925 under AT&T and its researchers have worked on inventions like lasers, the C programming language, UNIX, speech recognition, and more. It boasts awards including Nobel Prizes, U.S. National Medal of Science, Turing Awards, Kyoto Prizes, and many others. | 1925 (under AT&T) |
| | Vodafone | Vodafone Innovation Park Labs | Vodafone's Labs are focused on creating the next generation of telecommunications breakthroughs. The laboratories perform over 1,000 test projects every year on a network powerful enough to provide mobile coverage for a country the size of Switzerland. Past innovations they have worked on include LTE networks, IPv6, and remote file access. | Unknown |
| Finance | Visa | One Market Center | Visa's innovation laboratory within One Market Center is designed to offer increased collaboration for teams working on their latest technology solutions. | 2013 |

| Section Name | Name of Company | Innovation Laboratory Name | Summary | Year Founded |
|--------------|-----------------|---|--|--------------|
| | | | Projects include tokenization, payment apps, mobile location confirmation, and more. | |
| | Fidelity | Fidelity Center for Applied Technology (FCAT) | Fidelity's in-house innovation laboratory focuses on customer needs and advanced technologies to create new solutions that can range from incremental upgrades to disruptive ideas. | 1999 |
| | Wells Fargo | Wells Fargo Labs | Wells Fargo's internal laboratories bring together product strategists, developers, and project managers to build innovative new products, relying on a lean startup mindset. | 2015 |
| | JP Morgan Chase | FinLab | JP Morgan's FinLab is a 5-year program, managed by the Center for Financial Services Innovation, designed to spur innovations that help Americans save more and improve their credit. Teams work in collaborative groups to develop new financial apps and tools. The program also includes strategic partnerships with groups like Ideo.org and Ideas42. | 2015 |
| | Citi | Citi Innovation Labs | Citi's globe-spanning network of innovation laboratories is designed to speed up work on disruptive products and technologies like IoT and blockchain. They also manage an internal accelerator program (independent of Citi Ventures) and develop strategic partnerships with other companies, startups, and even universities like Stanford, MIT, Columbia, and UC Berkeley. | 2011 |
| | Capital One | Capital One Labs | Capital One Labs aims to streamline the new-product-creation process and is fueled by Design Thinking and a customer-first attitude. | 2012 |
| Retail | Staples | Staples Labs: Velocity, Innovation, Development | In 2012, the long-lived office superstore opened three laboratories in separate locations, each with its own mandate. "Velocity Lab" in Cambridge, MA and "Innovation Lab" in San Mateo, CA both handle mobile apps, digital platforms, and in-store technologies. The "Development Lab" in Seattle works on e-commerce platforms and data engineering. | 2012 |
| | CVS | Digital Innovation Lab | The CVS innovation center is focused on creating new digital health solutions. Operating like a startup and adhering to concepts like an accelerated idea-to-market schedule and a fast-paced testing and implementation process, the center's projects include simple things like mobile phone pharmacy reminders and complex ones like apps that turn those phones into remote diagnostic tools. | 2015 |

| Section Name | Name of Company | Innovation Laboratory Name | Summary | Year Founded |
|---------------------|------------------------|--|--|------------------------------------|
| | Lululemon | Lululemon Lab | Lululemon's solution to the constant need for new fashions was to open two in-house laboratories, one in Vancouver (where the corporate offices are) and one in NYC (a worldwide fashion hub). Designers work collaboratively in a setting that encourages forward thinking and creativity. | 2009 (Vancouver), 2016 (NYC) |
| | The Home Depot | Home Depot Innovation Lab (BlackLocus) | The Home Depot's solution to startup-style innovation was quite ingenious: the company acquired startup Black Locus and let it operate as an in-house innovation laboratory. Black Locus reports that even without a sales organization to support it and competing objectives to focus on, it can bring efforts to bear solving big problems for the Home Depot. | 2012 |
| | Walmart | Walmart Labs | Walmart's innovation laboratory is designed to help Walmart stay competitive in the increasingly online and mobile world. One notable accomplishment was a large-scale search engine overhaul for its online site that drove a 20% increase in sales. Workers are even organized into "mini-startups," each with their own projects. | 2005 |
| | Sephora | Sephora Innovation Labs | Sephora's innovation laboratory is in a converted warehouse near San Francisco's Mission Bay district. The facility's first use was to build and test in-store displays, but in 2015, its focus expanded to include digital, reflecting the increasingly online nature of any kind of shopping experience. Innovation team members work on solutions for web, mobile, and brick-and-mortar applications. The laboratory even includes a model Sephora store. | 2015 |
| | Kohl's | Kohl's Digital Center | Kohl's Digital Center opened in 2011. The center's 200-person technology team is housed in a 50,000-square-foot facility and has developed the Kohl's Pay app and other innovations to help customers pick up in-store deliveries faster, and more. | 2011 |
| | Target | Target Technology Innovation Center | In 2012, Target opened its San Francisco laboratory staffed with commerce technologists, data scientists, and product managers to work on projects like augmented reality, wearable computing, and gamification. | 2012 |
| | Lowe's | Lowe's Innovation Lab | Lowe's Innovation Lab's is all about disruptive technologies, including shipping a 3D printer to the International Space Station to help astronauts print parts and | Unknown |

| Section Name | Name of Company | Innovation Laboratory Name | Summary | Year Founded |
|--------------------|--------------------|---|--|--------------|
| | | | tools on demand. The laboratory also developed the Holoroom, a VR headset to help shoppers visualize bathroom and kitchen improvements. | |
| | Sears | iR Labs | Sears' iR Labs (short for "integrated retail") center was created to find ways to deliver modern shoppers the multi-channel shopping experience they demand. From within their startup-style offices, Sears workers from all disciplines (design, development, product management, etc.) work together to improve online and mobile shopping, create new in-store promotions, and more. | Unknown |
| | Tesco | Tesco Labs | Tesco's in-house technology innovation team dreams up, develops, and tests an array of solutions for things like online search and also built an Android app to help customers take control of their health and choices. One notable "startup" trait: Tesco even holds hackathons. | 2014 |
| | DuPont | DuPont Innovation Centers | DuPont has numerous innovation centers around the country and world. The Johnston Innovation Center at the DuPont global agriculture headquarters in Iowa (their largest R&D facility) boasts nearly 3,000 professionals in disciplines like food, agriculture, and biotechnology. DuPont customers work with these in-house experts to develop new solutions to needs that DuPont might be able to anticipate on their own. | 2010 |
| Auto/ Aerospace | Lockheed Martin | Skunk Works | While the term "skunkworks" or "skunk works" has come to refer to any secretive research facility or department, the originator of the term was Lockheed Martin's off-limits R&D team at its Burbank, CA facility. Origin stories conflict slightly, but their first recognized feat was the design of the Lockheed P-80 Shooting Star in just 143 days, in a contained setup away from other engineers. Development of the fighter actually began four months before formal contracts were delivered, a hallmark of the division's "off the books" modus operandi and part of the rogue culture that continues to define it to this day. Culture is king for innovation and 70+ years later, teams still strive to produce next-gen aircraft innovations that adhere to founder Kelly Johnson's mantra of "quick, quiet and quality." | 1943 |
| | Volkswagen | Volkswagen Automotive Innovation Lab (VAIL) | The Volkswagen Automotive Innovation Lab (VAIL) brings together interdisciplinary teams to work on industry-changing projects. Located on the Stanford University campus, VAIL partners with the school on projects like drive- | 2010 |

| Section Name | Name of Company | Innovation Laboratory Name | Summary | Year Founded |
|--------------|------------------------------|---|---|--------------|
| | | | by-wire and driver assistance systems, the Stanford Solar Car Project, and more. | |
| | Panasonic | Panasonic Automotive Innovation Center | The Panasonic Automotive Innovation Center, located inside the Centergy One building, is built for collaboration between software, electrical, systems, and mechanical experts working on the next generation of human-machine interfaces for cars. | 2013 |
| | Ford | Ford Research & Innovation Center | Ford's innovation center boasts open spaces to encourage collaboration and works on projects ranging from autonomous car research with the likes of MIT, Stanford, and the University of Michigan, to Big Data and analytics initiatives. | 2012 |
| Health | McKesson and the Mayo Clinic | Center for Innovation | The Mayo Clinic and McKesson gathered up a team of 60 innovators for their center and gave the team a simple mandate: to think differently about healthcare. The unit's approach/mantra is to "always be there for me [the patient]" as it tackles tough problems like redesign of care models, keeping patients connected to care in their homes and communities, and creating services to optimize health and wellness. | 2008 |
| | Cardinal Health | Fuse | Cardinal's Fuse Innovation Center is patient-focused and operates on a startup mentality geared toward creating innovations on an accelerated timescale, then rigorously testing them. | |
| | Johnson & Johnson | Johnson & Johnson Innovation Centers | Johnson & Johnson's innovation program is pretty much as old as the company itself, but in recent years has taken on a broader approach, combining in-house R&D efforts, partnerships with innovative startups, innovation hubs and incubators around the world, and strategic investments through its venture arm (JJDC). | |
| Media | IPG | IPG Media Lab | IPG's Media Lab has a team of marketers, engineers, and creatives who work directly with clients, partner with other agencies, deliver custom content to publishers, and more. | Unknown |
| | <i>The New York Times</i> | The New York Times Research & Development | The New York Times Research & Development group aims to create new products that will change how people interact with media. Projects include systems to visualize reader habits in real time, different interfaces for consuming | Unknown |

| Section Name | Name of Company | Innovation Laboratory Name | Summary | Year Founded |
|------------------------|-----------------|----------------------------|--|--------------|
| | | | news and other media, and crowdsourced programs looking to glean new insights from and about the Times' considerable photo and ad archives. | |
| Consulting/Advertising | Deloitte | Deloitte Analytics | Deloitte's innovation laboratory takes the established science of analysis into the modern era with a focus on how its analytics teams and technology can deliver real value for customers in new and unexpected ways. The laboratory allows clients to present their unique needs to highly efficient teams and quickly learn key takeaways that might have otherwise taken months to do through old methods. | Unknown |
| | McKinsey | Digital Labs | McKinsey Digital Labs uses modern fast-paced, startup-style methodologies like Design Thinking, concept sprints, DevOps, and more to deliver innovative results to clients based on their specific needs. The team of 850 designers, data scientists, software specialists, and other experts allows McKinsey Digital Labs to scale up its clients' digital capabilities at high speeds. | Unknown |

Source: CB Insights (2016).

Selections

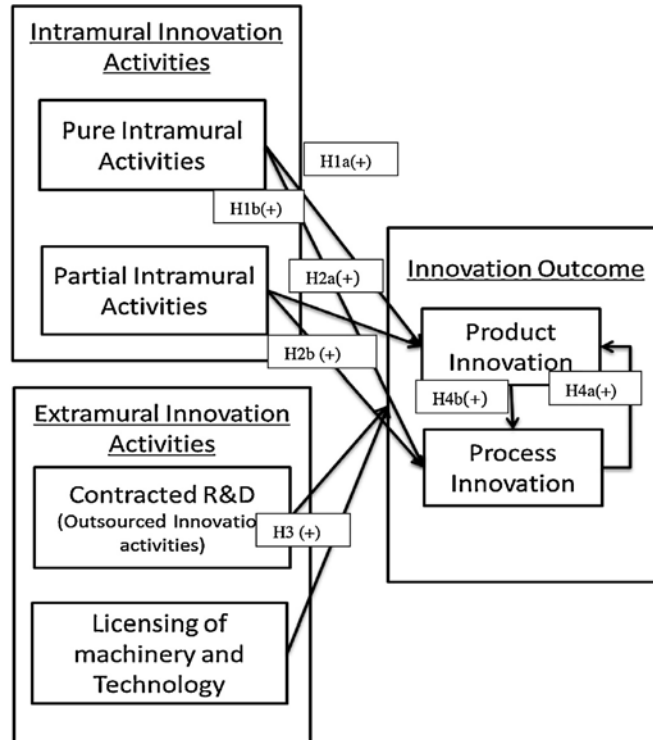
Internal vs. External

Over the past several decades, industry R&D performers have largely transitioned away from the centralized corporate laboratory model to one of either multiple decentralized laboratories, or a focus on harvesting innovations from external sources, or a combination thereof. Corning is one of the few companies that still have a centralized R&D laboratory (Pisano 2015). Roberts (2001) determined that in the late-1990s companies worldwide were shifting toward “acquiring more key technology from outside, relying increasingly upon universities for research and on joint ventures and alliances for development” (Roberts 2001).

Procter & Gamble adopted the *connect and develop* innovation model in 2000 with the goal of acquiring 50 percent of its innovations outside the company’s laboratories. As of 2006, more than 35 percent of its new products had elements that originated external to Procter & Gamble, as opposed to 15 percent in 2000 (Huston and Sakkab 2006).

Chesbrough and Crowther (2006) concluded that companies in industries beyond high technology (e.g., Lucent, IBM, and Intel), such as chemicals and aerospace, were adopting open innovation practices. Companies do not exclusively rely on external innovation, however. Jha and Bose (2015) illustrate how internal and external innovation activities can both produce positive innovation outcomes (Figure C-4).

The authors determined from their data on European and Chinese firms that intramural activities have a profound positive impact on process innovation, but only a positive impact on product innovation for large firms (Jha and Bose 2015).



Source: Jha and Bose (2015).

Figure C-4. Innovation Ecosystem

Selection Process

There is extensive academic literature on R&D resource allocation and portfolio selection that dates back to the 1950s. The methods can be roughly divided between qualitative and quantitative approaches. Qualitative techniques utilize subjective scoring models and product development maps. Quantitative approaches have evolved from static optimization models to the Real Options approach, which focuses on the identification and valuation of flexibilities available to R&D project managers, and multi-stage decision models (Santiago and Vakili 2005). Others recommend using a combination of subjective and objective methods (Linton, Walsh, and Morabito 2002).

In the “real world”, companies have been experimenting with new models for identifying and selecting promising new technology. For example, Procter & Gamble employ 70 global technology entrepreneurs. “These senior P&G people lead the development of our needs lists, create adjacency maps and technology game boards, and write the technology briefs that define the problems we are trying to solve. They create external connections by, for example, meeting with university and industry researchers and forming supplier networks, and they actively promote these connections to decision makers in P&G’s business units. The technology entrepreneurs combine aggressive mining of the scientific literature, patent databases, and other data sources with physical prospecting for

ideas—say, surveying the shelves of a store in Rome or combing product and technology fairs” (Huston and Sakkab 2006).

Assessment

Literature suggests evaluating R&D projects using financial measures like Net Present Value or risk (likelihood of success), but until a product is established, return on investment projections are speculative. Qualitative metrics like market familiarity, market life cycles, time to market, and patents have also been proposed instead (Linton, Walsh, and Morabito 2002).

Others recommend using a combination of noneconomic and internal metrics to assess early transformational efforts because “this can enhance the team’s ability to learn and explore. For example, what if the only hurdle an initiative must clear to receive continued investment is that the company is likely to learn (not earn) from it?” (Nagji and Tuff 2012).

The inverse of the 70-20-10 rule referenced above can be used to describe the average return on investment. “Core innovation efforts typically contribute 10 percent of the long-term, cumulative return on innovation investment; adjacent initiatives contribute 20 percent; and transformational efforts contribute 70 percent” (Nagji and Tuff 2012).

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Abbreviations

| | |
|----------|---|
| AAAS | American Association for the Advancement of Science |
| ACQUIRE | Advanced Communication Quantum Information Research in Engineering |
| AEA | American Evaluation Association |
| AES | Advanced Exploration Systems |
| AFRL | Air Force Research Laboratory |
| AFOSR | Air Force Office of Scientific Research |
| ARL | Army Research Laboratory |
| ARO | Army Research Office |
| ARPA-E | Advanced Research Projects Agency–Energy |
| ASD(R&E) | Assistant Secretary of Defense for Research and Engineering |
| ASpIRE | Automatic Speech Recognition in Reverberant Environment |
| BES | Basic Energy Sciences |
| CDC | Centers for Disease Control and Prevention |
| CHESS | Cornell High Energy Synchrotron Source |
| CIF | Center Innovation Fund |
| COCOM | Combatant Command |
| COMPETES | Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science discovery and invention |
| D&I | |
| DARPA | Defense Advanced Research Projects Agency |
| DBRAG | Defense Basic Research Review |
| DDR&E | Director of Defense Research and Engineering |
| DHS | Department of Homeland Security |
| DOC | Department of Commerce |
| DOD | Department of Defense |
| DOE | Department of Energy |
| DOJ | Department of Justice |
| DSO | Defense Sciences Office |
| DTRA | Defense Threat Reduction Agency |
| DURIP | Defense University Research Instrumentation Program |
| EAGER | Early-concept Grants for Exploratory Research |
| EEC | Division of Engineering Education and Centers (NSF) |
| EERE | Energy Efficiency and Renewable Energy |
| EFMA | Office of Emerging Frontiers and Multidisciplinary Activities (NSF) |
| ELT | Engineering Leadership Team |
| ERC | Engineering Research Center |

| | |
|---------|---|
| ENG | Directorate for Engineering (NSF) |
| EFRI | Emerging Frontiers in Research and Innovation |
| ESP | early stage portfolio |
| FDA | Food and Drug Administration |
| FI | frontier idea |
| FOA | Funding Opportunity Announcement |
| FY | fiscal year |
| GCD | Game Changing Development |
| HEOMD | Human Exploration and Operations Mission Directorate (NASA) |
| HHS | Department of Health and Human Services |
| I-Corps | Innovation Corps |
| I/UCRC | Industry/University Cooperative Research Center |
| IARPA | Intelligence Advanced Research Projects Activity |
| IDA | Institute for Defense Analyses |
| IIP | Division of Industrial Innovation and Partnerships (NSF) |
| IPA | Intergovernmental Personnel Act |
| IRC | Internal Research Council |
| IT | information technology |
| LDRD | Laboratory Directed Research and Development |
| MDA | Missile Defense Agency |
| MQCO | Multi-Qubit Coherent Operations |
| MURI | Multidisciplinary University Research Initiative |
| NASA | National Aeronautics and Space Administration |
| NCI | National Cancer Institute |
| NewLAW | New Light and Acoustic Wave Propagation |
| NIAC | NASA Innovative Advanced Concepts |
| NIH | National Institutes of Health |
| NIJ | National Institute of Justice |
| NIST | National Institute of Standards and Technology |
| NNSA | National Nuclear Security Administration |
| NOAA | National Oceanic and Atmospheric Administration |
| NSF | National Science Foundation |
| OCO | Requests for Application |
| ODNI | Office of the Director of National Intelligence |
| ONR | Office of Naval Research |
| OSD | Office of the Secretary of Defense |
| OSTP | Office of Science and Technology Policy |
| PA | Program Announcement |
| PAR | PA with special receipt or review considerations |
| PFI | Partnerships for Innovation |
| PI | principal investigator |
| PM | program manager |
| QDR | Quadrennial Defense Review |
| R&D | research and development |

| | |
|---------|--|
| RDT&E | Research, Development, Test, and Evaluation |
| RFA | Request for Applications |
| RTD | research, technology, and development |
| S&T | science and technology |
| SBIR | Small Business Innovation Research |
| SETA | Systems Engineering and Technical Assistance |
| SMD | Science Mission Directorate (NASA) |
| STMD | Space Technology Mission Directorate (NASA) |
| STPI | Science and Technology Policy Institute |
| STRG | Space Technology Research Grants |
| STTR | Small Business Technology Transfer |
| T&E | test and evaluation |
| TDM | Technology Demonstration Mission |
| TRA | Technology Readiness Assessment |
| TRL | Technology Readiness Level |
| USAID | United States Agency for International Development |
| USBR | United States Bureau of Reclamation |
| USSOCOM | United States Special Operations Command |

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| 14. ABSTRACT NASA's Space Technology Mission Directorate (STMD) is responsible for development of crosscutting and pioneering technologies and capabilities in the agency. In support of an STMD internal review, STPI examined the organization and management of early stage portfolios of other agencies in the Federal Government. This report provides case studies of early stage portfolios in the Department of Defense, the Department of Energy, the Intelligence Community, the National Science Foundation, and the National Institutes of Health. The case studies are derived from interviews with program managers or officers of early stage programs in the departments and agencies. Findings are presented in the following categories as they relate to early stage research and development: definition and approach, budget, personnel allocation and management of investment, transition, and evaluation of success. | | | | | |
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