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A Preliminary Concept for a Model of Federal Technology Transfer

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A Preliminary Concept for a Model of Federal Technology Transfer

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Executive Summary

The National Institute for Standards and Technology (NIST) launched the Return on Investment (ROI) Initiative in April 2018 to help improve the commercialization and other impacts of Federal research and development (R&D) investment. To solicit input on its ROI Initiative, during the summer of 2018, NIST collected feedback from academic and private sector stakeholders by holding four public forums and issuing a Request for Information (RFI), which would inform the development of a draft Green Paper. In August 2018, NIST tasked the IDA Science and Technology Policy Institute (STPI) with summarizing the feedback and recommendations from the RFI and forums for the draft Green Paper.

Researchers at STPI conducted a review of technology transfer literature[1] to provide an informed framework from which to summarize the feedback and recommendations. The literature review served to complement and provide supplementary considerations for NIST as they implement the Green Paper findings. As part of this review, the research team also identified various technology transfer models and frameworks published in the literature. We identified various theoretical models largely focused on university to industry technology transfer. In addition, we also found there was a dearth of published literature that addressed models specific to U.S. Government and Federal Laboratory activities.

The team sought to develop a preliminary concept for a new model that more accurately reflected federally funded technology transfer activities, outputs, and outcomes. The model aligns with any agency's activities while capturing the entirety of the U.S. Government's technology transfer objectives. We identified the following specific objectives for the model:

- Illustrate and describe existing federally funded technology transfer activities, inputs, outputs, and outcomes in a model that can be applied across varied agency missions and contexts;
- Illustrate and describe the interrelationships among R&D and technology transfer resources, policy, programs, activities, and external drivers; and

[1] STPI's paper, entitled *A Review of Technology Transfer Literature*, is forthcoming and provides the results of the review.

- Identify opportunities for measuring Federal technology transfer performance by determining the direct relationships between technology transfer activities, measures of effectiveness, and expected outcomes.

This paper describes the simple, high-level model, which outlines the relationships across contextual factors, inputs, activities, outputs, and outcomes related to Federal technology transfer; and presents detailed models for three components of technology transfer—pre-transfer, transfer, and post-transfer.

The model is advantageous in capturing Federal technology transfer activities compared with other published models in the literature in various ways:

- There is a distinction of Federal resources and funding for (1) performing R&D, and (2) supporting technology transfer activities, suggesting complementarities *and* potential tensions between these resources as a technology is matured;
- Technology transfer resources can be used throughout all aspects of pre-transfer, transfer, and post-transfer;
- Federal technology transfer activities occur across technology readiness level (TRL) 1 through TRL 9, including knowledge-based R&D outputs, and the maturity of the knowledge or technology can influence outreach strategies, in particular because the value of the R&D output may not yet be fully understood;
- An R&D output can be used for various transfer mechanisms, for instance dual use technologies produced for U.S. Government consumption may be transferred across Federal Laboratories and commercial entities, as appropriate, through varied collaboration agreements, and not all R&D outputs may be considered for Federal transfer activities;
- Technology transfer outcomes align with varied agency missions, for instance, R&D occurring at agencies that have operational needs may intend on developing R&D outputs for U.S. Government consumption;
- Feedback includes effectiveness measures for technology transfer milestones—e.g., developing and executing an outreach strategy, executing the transfer mechanism, and maturing the technology—to inform future resource allocation decisions; and
- Feedback includes the possibility that projects and technology transfer activities, if unsuccessful, may end at various milestones, and, as such, can inform future resource allocation decisions.

The model identified potential feedback from effectiveness measures throughout pre-transfer, transfer, and post-transfer activities that may help agencies determine performance, outcomes, benchmarking, best practices, and areas for improvement:

- Pre-Transfer
  - Success rate for attaining interest from potential partners
  - Broad effectiveness, including efficiency and sufficiency, of technology transfer resources to support the development and execution of the outreach strategy
  - Efficiency and effectiveness of adjusting the outreach strategy
  - Rationale and measures for the inability to attain interest
- Transfer
  - Success rate for obtaining commitments to transfer mechanism (e.g., licenses, collaborative agreements)
  - Broad effectiveness, including efficiency and sufficiency, of technology transfer resources in support of obtaining commitment to transfer mechanisms
  - Rationale and measures for the inability to obtain commitments to transfer mechanism
- Post-Transfer
  - Success rate for maturing the technology
  - Broad effectiveness, including efficiency and sufficiency, of technology transfer resources in support of technology maturation
  - Rationale and measures for the inability to mature the technology
  - Measures of technology transfer impacts (e.g., commercial and economic measures, such as startups and jobs, U.S. Government acquisitions, and impacts on legal and regulatory frameworks, such as national, State, and local government or industry standards)

Several potential applications of the Federal technology transfer model could be taken to validate the preliminary concepts in the model, including:

- Obtain more information about and map agency-specific programs and activities to key model elements and relationships: Mapping agency-specific programs and activities to the model may provide areas where more information about technology transfer activities in pre-transfer, transfer, and post-transfer could be obtained;
- Identify potential gaps in existing agency activities: Gaps may be identified including where there is insufficient information or data collected to understand the contribution of those activities to technology transfer outcomes; and

- Identify opportunities to develop or use measures of effectiveness and impacts to evaluate Federal technology transfer activities focused on pre-transfer, transfer, and post-transfer: The model presents discrete activities for pre-transfer, transfer, and post-transfer that suggest measures of effectiveness could be assessed at those major milestones to inform resource allocations.

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1. Introduction

The National Institute for Standards and Technology (NIST) launched the Return on Investment (ROI) Initiative in April 2018 to help improve the commercialization and other impacts of Federal research and development (R&D) investment. NIST's ROI Initiative directly responds to Cross Agency Priority (CAP) Goal 14 of the President's Management Agenda to improve the transfer from federally funded technologies from laboratories to the market (PMA 2018). This CAP Goal, led by the Office of Science and Technology Policy (OSTP) and NIST, is organized around five strategies:

- Identify regulatory impediments and administrative improvements in Federal technology transfer policies and practices;
- Increase engagement with private sector technology development experts and investors;
- Build a more entrepreneurial research and development (R&D) workforce;
- Support innovative tools and services for technology transfer; and
- Improve understanding of global science and technology trends and benchmarks.

To solicit input on its ROI Initiative, during the summer of 2018, NIST collected feedback from academic and private sector stakeholders by holding four public forums and issuing a Request for Information (RFI),[2] which would inform the development of a draft Green Paper. In August 2018, NIST tasked the Science and Technology Policy Institute (STPI) with summarizing the feedback and recommendations from the RFI and forums for the draft Green Paper. The Green Paper's preface stated its purpose.

> This Green Paper provides a summary of key stakeholder inputs and identifies findings by NIST that will help inform future deliberations, decision-making, and implementing actions by the relevant departments and agencies that could further enhance the U.S. innovation engine at the public-private interface (NIST 2019).

[2] The RFI can be accessed through the Federal Register: https://www.federalregister.gov/documents/2018/05/01/2018-09182/request-for-information-regarding-federal-technology-transfer-authorities-and-processes.

STPI conducted a review of technology transfer literature[3] to provide an informed framework from which to summarize the feedback and recommendations. The literature review served to complement and provide supplementary considerations for NIST as they implement the Green Paper findings. As part of this review, STPI also identified various technology transfer models and frameworks published in the literature. STPI identified various theoretical models largely focused on university to industry technology transfer. In addition, STPI also found there was a dearth of published literature that addressed models specific to U.S. Government and Federal Laboratory activities.

STPI sought to develop a preliminary concept for a new model that more accurately reflected federally funded technology transfer activities, outputs, and outcomes. This model provides NIST and other Federal R&D funding agencies with general concepts to help map how their activities support the CAP Goal and U.S. Government-wide technology transfer outcomes. STPI's model includes decision logic, in particular by providing considerations for activities based on whether technology transfer efforts at various stages are or are not successful.

A. Model Objectives

STPI intended for the model to align with any agency's activities while capturing the entirety of the U.S. Government's technology transfer objectives. STPI identified the following specific objectives for the model:

- Illustrate and describe existing federally funded technology transfer activities, inputs, outputs, and outcomes in a model that can be applied across varied agency missions and contexts;
- Illustrate and describe the interrelationships among R&D and technology transfer resources, policy, programs, activities, and external drivers; and
- Identify opportunities for measuring Federal technology transfer performance by determining the direct relationships between technology transfer activities, measures of effectiveness, and expected outcomes.

B. Methodology

1. Review of Models in Relevant Literature

STPI's approach to identify literature on technology transfer models involved identifying relevant technology transfer journals and publication databases, and defining search terms to query and identify relevant publications. STPI has conducted prior studies

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[3] STPI's paper, entitled *A Review of Technology Transfer Literature*, is forthcoming and provides the results of the review.

on Federal technology transfer broadly (Peña 2016; Howieson et al. 2011; Howieson et al. 2013; Lal 2013), and from these studies, developed an existing bibliographic database of about 500 technology transfer peer-reviewed articles published between 1980 and 2012. STPI identified the top 10 technology transfer journals drawn from our database to target search queries using "federal" AND "technology" AND "transfer," and limited publication years from 2012 to 2019 to identify more recent articles. STPI supplemented this search with the queries applied to two major publication databases: Scopus and Web of Knowledge. These searches resulted in 21 articles describing models or frameworks for technology transfer. STPI reviewed these articles, found relevant cited references in these publications, and supplemented the initial publications with an additional 21 articles. Select findings from this review are described in Chapter 2. Review of Select Technology Transfer Models.

2. Approach to Develop the Model

STPI engaged in the following steps to develop the Federal technology transfer model:

- Identified variables and important factors for Federal technology transfer that could be used in the model;
- Established a "red team" composed of STPI researchers with backgrounds in evaluation and technology transfer and facilitated brainstorming sessions to obtain continuous feedback;
- Sought additional feedback on early drafts of the model from select Federal agencies and the broad evaluation research community via a poster presentation at the American Evaluation Association 2019 Annual Conference;
- Integrated feedback to develop a simple model and three detailed models for pre-transfer, transfer, and post-transfer components of the technology transfer process.

C. Organization of Report

The remainder of this report is organized as follows:

- Chapter 2 describes select technology transfer models and general findings based on STPI's review of the literature;
- Chapter 3 outlines important definitions for the reader to understand the scope of the model;

- Chapter 4 presents the simple, high-level model, which outlines the relationships across contextual factors, inputs, activities, outputs, and outcomes related to Federal technology transfer;
- Chapter 5 presents detailed models for three components of technology transfer—pre-transfer, transfer, and post-transfer; and
- Chapter 6 concludes with potential next steps regarding the use of the model.

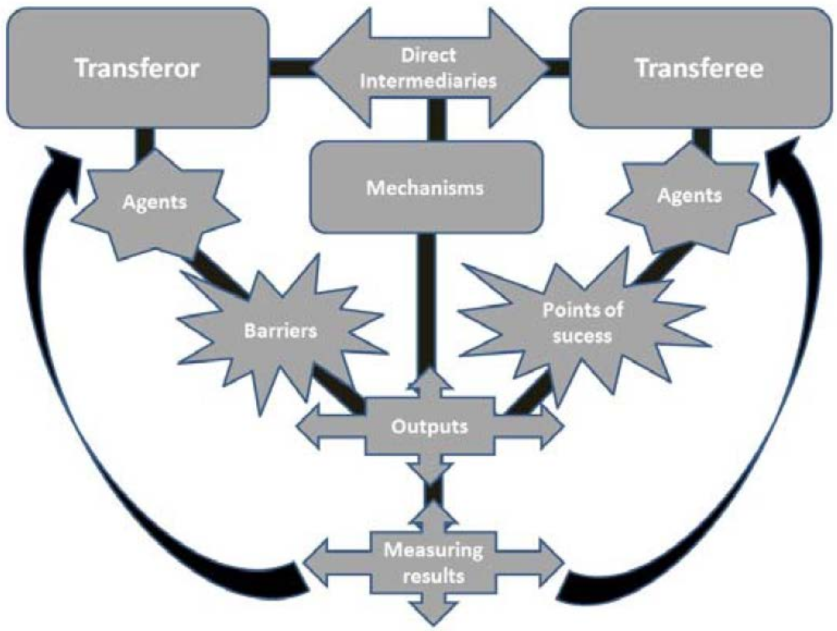
2. Review of Select Technology Transfer Models

STPI reviewed the publications on technology transfer models and described findings from select models, in particular to denote the breadth of scope and activities included in those models. Technology transfer models have focused on various aspects of technology transfer processes, and, to some extent, innovation, through the lens of technology, management, and social science disciplines. These perspectives provide varied concepts for analyzing Federal technology transfer. Some of the simplest models, usually used in the context of university technology transfer, are linear and dynamic models. The linear model, also known as a "technology push" model, described the linear progression of basic research through its development to market commercialization (Godin 2006):

basic research → applied research → development → production and diffusion

This influential model was disseminated and used by many academic organizations, economists, and policy makers, and consequently, for many years science policy carried a linear conception of innovation and technology transfer. However, its oversimplification led to revised dynamic models that accounted for multiple feedback loops between steps in the process (Bradley et al. 2013).

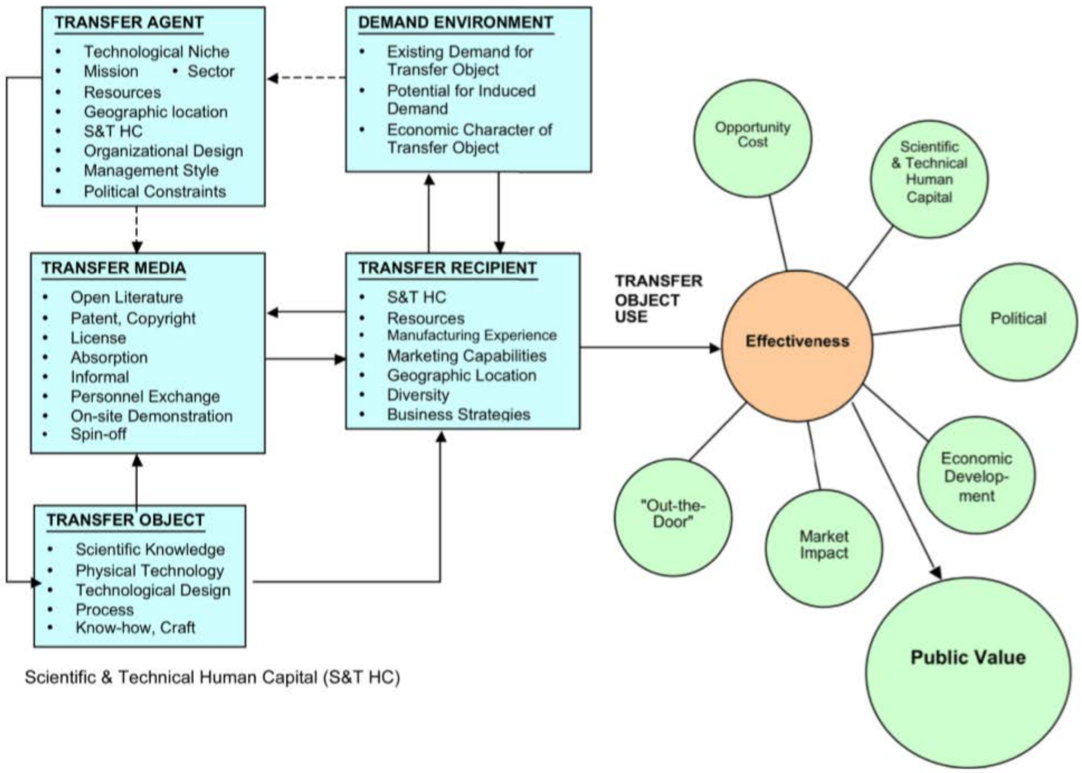
Pagani et al. (2016) conducted a systematic review of technology transfer models using papers from 1990 to 2015. They classified the models into categories based on the interactions between the organization transferring technology or knowledge, to the organization receiving. Notably, the authors observed that "every model found [from the literature search] was designed for a specific [organization's] need." Additionally, models took either a qualitative (studying factors that influence technology transfer effectiveness) or quantitative (measure significant parameters that portray technology transfer effectiveness) analytical approach. The authors generated an adaptable, generic model as a tool for organizations to clarify their own technology transfer process and diminish risks of failure (Figure 1).



Source: Pagani et al. 2016

Figure 1. Generic Model of Knowledge and Technology Transfer

Bozeman et al. (2015) presented a contingent effectiveness model, which represents the technology transfer process through transfer agents and recipients, in addition to criteria to determine technology transfer effectiveness (Figure 2). Notably, the authors proposed the addition of a public value criterion. This criterion was added to recognize that transfer agents within the public sector are under organizations in pursuit of broad public-interest goals, which are ultimately influenced by public values. Other key criteria were market impact, economic development, political advantage, development of scientific and technical human capital, and opportunity cost. Their literature review catalogued other technology transfer process models by these criteria.



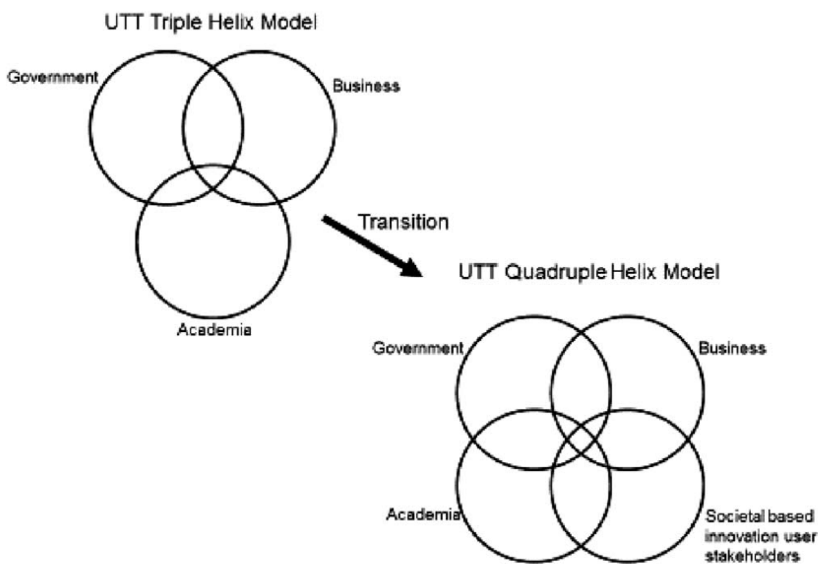
Source: Bozeman et al. 2015

Figure 2. Contingent Effectiveness Model

A. Models Focusing on University Technology Transfer

Many research articles are concerned with models of technology transfer from university to industry and are focused on economic aspects of the process. For example, Van Norman et al. (2017) used a technology transfer logic model to examine commercialization mechanisms for a university technology transfer office (TTO). Their objective was to provide university researchers with technology transfer guidelines to follow. The authors note TTOs commercialize research largely with licensing patents and copyrights to industry. This model highlights the possible motivations for individual researchers to participate in technology transfer, which include royalty income, commercial funding for research, and societal impact. Further analysis on university technology transfer process models was conducted by Mendoza et al. (2018) through a systematic literature review. Particularly, the authors parsed through mechanisms of technology transfer, and organizations and factors involved in the process; nevertheless, they conclude "a generalized model of [university] technology transfer is not easy to find." Baglieri et al. (2018) reached a similar conclusion, through the lens of business models. They go further to argue that the main weaknesses of technology transfer evaluation studies are their narrow scope (considering only formal relationships) and overuse of numerical (in particular, economic) measures for assessing technology transfer effectiveness.

Etzkowitz and Leydesdorff conceptualized the triple helix model in 1995, which described the interactions and corresponding roles between universities, industry, and government as the main agents in technology transfer. The initial roles of each institution were universities as the primary producers of knowledge, industry engaging in commercialization, and governments as market regulators. The authors acknowledged that such roles evolve to include characteristics of other institutions or to create hybrid institutions—thus governments play a dynamic role in the technology transfer process. One such hybrid institution is a TTO, which can be established by universities or Federal agencies to commercialize research. Critiques of this model stem from its implicit economic assumptions including market-oriented drivers and economic growth being stimulated from knowledge intensive activities. Evolved models have been developed from the triple helix one in order to account for further complexities (Figure 3, Miller et. al. 2016).

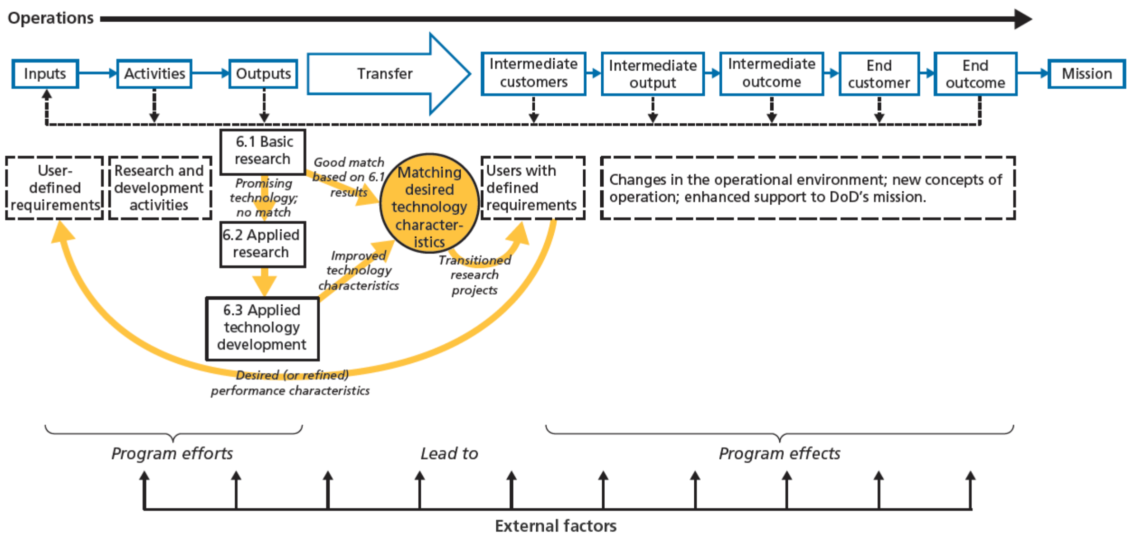


Source: Miller et al. 2016, originally adapted from Carayannis and Campbell 2009
Note: UTT = university technology transfer

Figure 3. Triple and Quadruple Helix

B. Models Focusing on Federal Technology Transfer

While there may be similarities among models and some of the factors considered, in the Federal Government, different agency missions imply different outcomes in technology transfer. For example, Landree et al. (2018) wrote about technology transfer associated with government funded research. The authors examined Department of Defense (DOD) R&D designed to develop capabilities to meet DOD mission needs. A logic model was created for two purposes: 1) to provide scope on successful technology transfer and 2) to guide the development of technology transfer measurements. In addition, they provided an illustrative example on how one could use their model to track successful technology transfer (Figure 4). Given the high variation of DOD laboratory missions, the authors note that a single model to track corresponding measures or outputs is difficult to establish. Moreover, it is easier to trace the success of technology transfer stemming from applied research over basic research since their model was developed from DOD laboratories, which skew towards an applied focus.



Source: Landree et al. 2010

Figure 4. Schematic of Connection Between Logic Model Elements and Technology Transfer

Similarly, Krishen (2011) examined technology development and interfaces with commercial markets in the space sector. The modeling considered both technology push and technology pull and highlighted the need to combine them. In the case of push, agency researchers identify new technologies or methodologies with potential commercial applications that focus on the Federal agency's missions and programs. Pull, in contrast, results in technology transfer from marketplace or agency mission and program demands for new technology that pulls technology to appropriate users. Significantly, development of technology in Federal agencies is justified by the needs for agency systems, projects, and programs.

Economic impact is not the only goal from Federal technology transfer; many agencies explicitly cite other goals such as national security, safety, environmental well-being, and other considerations associated with their public missions. The agency mission can determine the scope of the technology transfer activities pursued. For example, in its annual report, the United States Geological Survey (USGS) states the delivery "of science information is a primary purpose" (Department of the Interior 2018). As such, a prominent metric reported by the USGS is the number of publications authored by USGS personnel, disaggregated by type of publication. The Department of Agriculture conducts research on wildlife damage management strategies, with a biological and social responsibility mission in addition to an economic development mission. Their technology transfer activities "do not necessarily involve the transfer of intellectual property" (Department of Agriculture 2017). Important technology transfer metrics for their agency, therefore, relate to cooperative agreements and institutional partnerships across the public and private sectors. Meanwhile, agencies such as the Department of Transportation (DOT) prominently feature case studies of success stories in their annual reports. These success stories highlight improvements to safety outcomes. This is consistent with DOT's strategic goal of distributing "innovative practices and technologies that improve the safety and performance of the Nation's transportation system" (DOT 2018).

STPI reviewed the literature on models and frameworks for technology transfer and found that none comprehensively described the extent of federally funded activities to support technology transfer. STPI's review identified certain limitations of existing models:

- The scope of technology transfer in the literature is inconsistent, focusing on either knowledge or technologies; and there appears to be no common definition of technology transfer;
- The diverse outcomes based on varied Federal agency missions are not well captured, demonstrating a limited Federal organizational perspective;
- Feedback from external factors to provide context influencing the conduct of and processes for R&D and technology transfer is not well represented;
- Feedback from follow-on R&D resources and the role of technology maturation as part of technology transfer processes is often missing altogether, rather models largely focus on university or market-oriented mechanisms and miss the broad perspectives influencing technology transfer processes across the entire science and technology (S&T) enterprise; and
- Feedback from measurement and performance evaluation activities is not well represented, in particular as providing evidence to allocate resources and make investment decisions concerning technology transfer strategies.

3. Model Scope

A. Definitions

For the purposes of the model, STPI broadly defined Federal technology transfer based on the definition used in the NIST Green Paper (as cited in FLC 2013):

> In the context of Federal activities, technology transfer often refers to the movement of knowledge and results—such as products, techniques, tools, data, and inventions—from intramural Federal R&D out of laboratories and into practical application (NASEM 1997). Given that about two-thirds of Federal R&D expenditures support research by non-Federal scientists and engineers, technology transfer, for the purposes of this Green Paper, also encompasses the activities of these extramural partners. In addition, throughout this Green Paper, "the process by which existing knowledge, facilities, or capabilities developed under Federal R&D funding are used to fulfill public and private need" is referred to as technology transfer (FLC 2013).

For the purposes of this paper, the definition of technology transfer includes the transfer of knowledge and technology-based R&D outputs as well as those produced broadly by federally funded performers, including intramural and extramural communities.

Other related terms, such as technology transition, can be confused with technology transfer. For instance, DOD uses the term technology transition to imply that an application of the technology has been integrated into a system that DOD has or will acquire. Different uses of the term technology transition have indicated that the source of the technology could be Federal Laboratories, non-Federal (e.g., commercial industry, universities), or some combination thereof. For the purposes of the model, STPI considered technology transition as part of the NIST Green Paper's overarching definition of technology transfer.

STPI also considers spin-on and spin-off as part of the NIST Green Paper definition of technology transfer.[4] From a Federal perspective, spin-on occurs when a company or university develops a technology, which is acquired by the U.S. Government. This technology may or may not have initially been funded by the U.S. Government. Spin-off occurs when a federally funded technology is applied or utilized by an individual or entity for commercial purposes. Both spin-on and spin-off are included in the technology transfer definition. The technology would fulfill either a U.S. Government or commercial need, and

[4] Spin-in and spin-out are sometimes used in lieu of spin-on and spin-off, respectively.

Federal R&D funding may be used to mature the technology for specific purposes and functions, in particular for spin-in.

B. Technology Transfer Outcomes

STPI developed the model around three technology transfer outcomes. While every Federal agency's technology transfer activities may not encompass all aspects of these outcomes, they represent outcomes that can be applied across the U.S. Government's objectives for technology transfer as a whole.

- Commercial market and non-Federal consumption: Federally funded R&D can lead to discoveries and technologies developed for the commercial market. These technologies may be spin-off applications from a dual use technology developed for the U.S. Government.
- U.S. Government consumption: Federal R&D resources can also support the maturation of technologies specifically for adoption by the U.S. Government, either fully or in combination with non-Federal resources. The U.S. Government may ultimately acquire the product or service from a commercial entity.
- Advancing S&T fields: This outcome can be viewed as an intermediate as well as a long-run outcome since the outcome can be achieved from R&D outputs at varied maturity levels. In addition, these outcomes may not solely rely on Federal technology transfer processes—for instance, R&D outputs can contribute to advances in S&T fields despite not being shared or transferred outside of the researchers and organizations developing them. Eventually, these discoveries may contribute to the other two aforementioned outcomes. Advances in S&T fields can also stem from knowledge transfer of R&D outputs that are data products, and standards development, which may influence the broader context— such as legal and regulatory frameworks and emerging technologies—that then drive priorities for R&D resources.

4. Description of the Simple Model

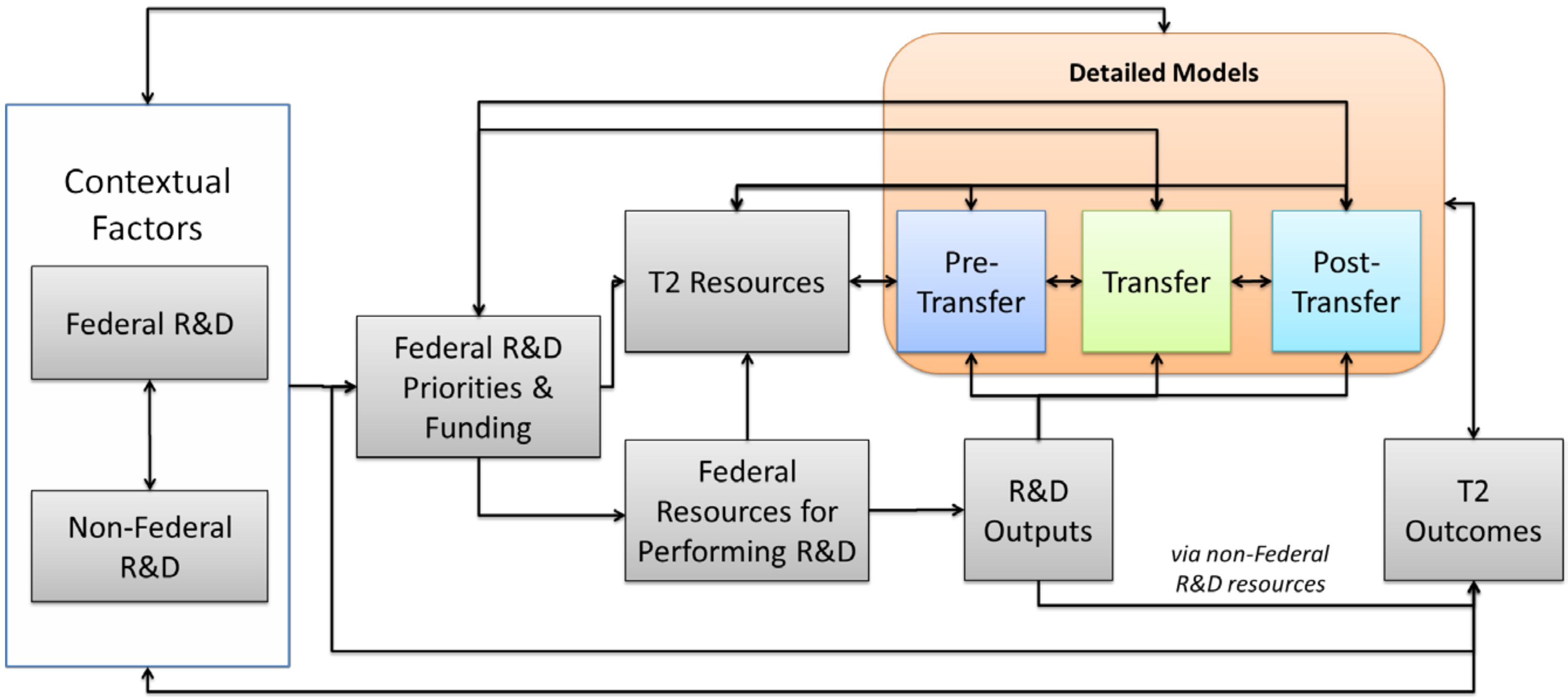
Figure 5 provides a diagram of the simple, high-level Federal technology transfer model, including three components—pre-transfer, transfer, and post-transfer—which are subsequently described in detailed models later in this paper. The "nodes" in the simple model represent results of activities that lead to or stem from Federal funding and technology transfer activities. The arrows connecting the nodes convey how one node influences another. The arrows are uni- or bi-directional depending on the relationship to the connecting nodes, as inputs that influence or outputs that are influenced by the other nodes. This section describes each of the nodes and the relationships in Figure 5.

A. Contextual Factors

The context for conducting R&D comprises factors that influence how the U.S. Government, academia, private industry, and other stakeholders in the S&T enterprise perform R&D. In the model, this context comprises factors that influence both Federal and non-Federal R&D.

1. Context for Federal R&D

The context for Federal R&D identifies the underlying conditions that lead to Federal R&D. For example, there are U.S. Government mission needs to be satisfied. The U.S. Government also engages in R&D projects that are shaped by aims to resolve societal demands and needs, such as national and global challenges. In addition, the U.S. Government operates under immense legislative and regulatory frameworks and complex processes for conducting R&D and engaging in technology transfer mechanisms.



Note: Pre-transfer is designated by a blue box; transfer is designated by a green box; post-transfer is designated by a teal box; and other model components are designated by grey boxes. Detailed models for pre-transfer, transfer, and post-transfer are described in the subsequent chapter.

Figure 5. Simple Model

2. Context for Non-Federal R&D

The context for non-Federal R&D identifies the driving factors behind non-Federal R&D from commercial companies, universities, or non-profit entities, which include similar societal demands and needs as well as mission needs that provide the context for Federal R&D. This node includes the external environment for business opportunity, which may vary as a function of who is performing the R&D. For a commercial company, R&D focused on societal demands may be undertaken when there is a clear and likely opportunity for realizing an acceptable ROI through sales in the marketplace. Similarly, R&D investments by a commercial company to meet a U.S. Government mission need may be based on expected sales to the U.S. Government. The entrepreneurial perspective also applies to universities since federally funded faculty researchers may wish to establish their own spin-off endeavors based on the market landscape and opportunities. Several studies provide further details on many of these and other contextual factors relevant to technology transfer broadly.[5]

3. Feedback

There is a bi-directional arrow between the context for Federal R&D and the context for non-Federal R&D, which means that these nodes interact with one another. Federal R&D, in part, influences and is influenced by non-Federal R&D, such as commercial market investments. For example, certain commercial applications may be tailored for U.S. Government needs and mission needs indicate sales opportunities. Knowledge of the U.S. Government's R&D interests as well as mission needs may be factors that influence the business case for non-Federal R&D. On the other hand, commercial R&D can be used to pursue one approach to achieve a specific capability, while U.S. Government R&D may be used to pursue another approach. It is also possible that U.S. Government investments would not be made if the private sector investments were not ongoing.

There is also feedback between the contextual factors and pre-transfer, transfer, and post-transfer, for instance:

- For pre-transfer, this feedback involves providing awareness of research plans and results to facilitate transfer strategies and insights into the marketability of federally funded R&D efforts.
- For transfer, this feedback includes opportunities for non-Federal resource commitments and R&D partnerships. Transfer mechanisms can be established

[5] See, for example, Kumar et al. 2015; Mendoza and Sanchez 2018; Battistella et al. 2016; and Bozeman et al. 2015 for studies identifying contextual factors and their influence on technology transfer.

for joint research that leverages investments from non-Federal R&D organizations.

- For post-transfer, this feedback includes non-Federal R&D contributions to mature the technology until the technology is ready to be produced and sold to the U.S. Government or the public. In some cases, maturation occurs jointly, and in other cases, maturation may be fully funded by a non-Federal entity.

In addition, feedback between the contextual factors and technology transfer outcomes includes how the adoption and successes of the technology for discovery, commercial products, or U.S. Government consumption can drive future R&D and technology opportunities as well as Federal and non-Federal legal, regulatory, and policy frameworks, and vice-versa.

B. Federal R&D Priorities and Funding

Contextual factors provide important considerations for decisions on project priorities and funding levels, and, thus, are inputs into Federal R&D priorities and funding. The context provides the state-of-the-art to help agencies identify gaps and potential investments in R&D capabilities that are needed. Priorities and funding decisions can involve assessing the likelihood of technical success, resource requirements, the expected amount of time to achieve results, the impacts of success, the status of existing programs, the urgency of the requirement, among other factors.

A distinction in the model from others published in the literature is the acknowledgment of two aspects of Federal priorities and funding—in providing Federal resources for (1) performing R&D and (2) supporting technology transfer activities.

1. Federal Resources for Performing R&D

Federal resources for performing R&D involve funding used to establish federally funded R&D programs and projects, including support for physical and human capital—such as researchers, students, research infrastructure, and equipment data. It encompasses resources for R&D carried out by Federal Laboratories, U.S. Government intermediaries, universities, commercial entities, and non-profits. These resources are used to support R&D projects that may or may not be initially intended for technology transfer, and may include R&D that is intended solely for U.S. Government consumption or basic research projects intended to generally advance the state of knowledge in an S&T field.

Figure 5 also shows a connection to transfer and post-transfer activities from Federal resources for performing R&D. That link illustrates that there are some R&D funding programs with specific goals to transfer technology and stimulate innovation in the U.S. economy (e.g., Small Business Innovation Research [SBIR] and Small Business

Technology Transfer [STTR]). These programs are aimed at supporting R&D for commercialization, not solely to meet a U.S. Government mission.

SBIR and STTR

SBIR and STTR programs represent the Nation's largest sources of federally funded early-stage technology development. These programs are administered by the U.S. Small Business Administration through 11 Federal agencies with about $2.5 billion and about 160,000 awards granted annually (in 2016). The SBIR program comprises three phases:

- Phase I attempts to achieve feasibility and proof of content
- Phase II attains a higher maturity of the R&D efforts
- Phase III pursues commercialization

SBIR is funded with 3.2% of extramural research budget for all agencies with a budget greater than $100 million per year; STTR is funded with 0.45% of extramural research budget for all agencies with a budget greater than $1 billion per year.

Collaboration with a research institution is a prerequisite for an STTR award.

Source: SBIR n.d.; SBIR 2016

2. Technology Transfer Resources

Technology transfer resources characterize the Federal personnel and monetary resources applied to identifying, developing, and managing technology transfer opportunities. Traditionally, these may include outreach activities to identify interest in the knowledge and technologies produced from R&D. From a Federal perspective, this node includes technology transfer tools and services that provide access to information about ongoing research and available federally funded technologies to prospective R&D collaborators or commercial partners. For instance, Federal agency websites, intellectual property or software catalogues, and other information portals, such as FLCBusiness, a searchable Federal Laboratory database hosted by the Federal Laboratory Consortium for Technology Transfer (FLC), can facilitate R&D collaborations (see Box: What is FLCBusiness?).

What is FLCBusiness?

FLCBusiness is an online platform acting as the "one stop shop" for information about the mission, capabilities, programs, facilities, equipment, and contacts of Federal Laboratories. This tool also inventories technologies available for licensing, funding opportunities, and publications.

Source: FLC n.d. https://federallabs.org/flcbusiness

Technology transfer resources could also include entrepreneurial R&D training to provide researchers with resources to frame their research in a commercially amenable direction. This training provides researchers with resources to help them engage with commercial entities and potential customers to identify market opportunities for their discoveries (see Box: Select Federally Funded Entrepreneurial R&D Training Programs).

In addition, entrepreneurial R&D training can provide researchers with resources to enable an entrepreneurial mindset for conducting present and future R&D.

Select Federally Funded Entrepreneurial R&D Training Programs
I-Corps is a training program started in 2011 by the National Science Foundation (NSF) for extramural researchers receiving Federal funding. The training curriculum centers on real-world, immersive learning that gives researchers entrepreneurial experience in translating an innovation into a product or service. Participants receive mentoring, engage in customer discovery, and develop regional networks. Due to the success of this start-up accelerator program, I-Corps has expanded to other agencies such as the Department of Homeland Security, DOD, the National Aeronautics and Space Administration (NASA), the National Institutes of Health, the Department of Energy (DOE), and the Department of Agriculture.
DOE's Lab-Embedded Entrepreneurship Program (LEEP) takes top scientists and engineers with entrepreneurial experience and embeds them within Federal Laboratories. Participants work with early-stage research while also receiving training and development, and together these research and entrepreneurial efforts allow LEEP to facilitate the commercialization of DOE innovations.
Source: NIST 2019, https://www.nsf.gov/news/special_reports/i-corps/about.jsp; https://www.energy.gov/eere/amo/lab-embedded-entrepreneurship-programs

Technology transfer resources are used to support the three technology transfer components defined in the model as pre-transfer, transfer, and post-transfer. These activities include tools and services that aid in the dissemination of knowledge or technologies, analyses to determine the value proposition of alternative dissemination routes, such as publications and conferences, the development of technology transfer strategies around those options, and the technology transfer offices and staff that support these functions.

3. Feedback on Federal R&D Priorities and Funding

Pre-transfer, transfer, and post-transfer have feedback loops into Federal R&D priorities and funding. These feedback loops represent the need for additional Federal funding to mature the technologies sufficiently throughout these technology transfer components. In addition, insights on the effectiveness of pre-transfer, transfer, and post-transfer activities may also provide considerations for prioritizing Federal funding.

4. Feedback on Technology Transfer Resources

Four inputs provide insights on the effectiveness of technology transfer resources:

- Feedback from pre-transfer activities includes (1) how well information on federally funded R&D discoveries is disseminated, including how well the information attracts an R&D collaborator or commercial partner; (2) how successfully technology transfer tools and services are used in those activities;

- Feedback from transfer activities includes the effectiveness of the technology transfer mechanisms used to disseminate the knowledge or technology;
- Feedback from post-transfer activities is less direct—while technology transfer resources play a smaller role in the maturation of transferred technology, successful maturation may offer insights into the effectiveness of technology transfer resources that are used in this process; and
- Feedback from technology transfer outcomes may serve as partial but potentially powerful evidence of technology transfer resources effectiveness, and this evidence may be useful for attracting future partners for other R&D outputs.

C. R&D Outputs

The performance of R&D generates R&D outputs. R&D outputs represent a series of intermediate results from federally funded R&D, including those that are knowledge and technology-based. Since the process of maturing technologies into products or services that can be used by the public or the U.S. Government is often a long one, R&D outputs may evolve from knowledge and proof of concept to more mature technologies that are ready to be introduced into the marketplace.

R&D outputs are necessary, in combination with technology transfer resources, to conduct pre-transfer, transfer, and post-transfer activities. R&D outputs impact pre-transfer, transfer, and post-transfer activities and lead to technology transfer outcomes in various ways:

- For pre-transfer, R&D outputs are publicized to inform individuals and organizations about technology transfer opportunities, including opportunities to share knowledge (e.g., via publications), R&D collaborations, and licensing technologies, among others. They are also the basis for determining both scientific and commercialization opportunities and the direction to take the research to maximize those opportunities;
- For transfer, R&D outputs are the ultimate results that are transferred through varied mechanisms;
- For post-transfer, R&D outputs advance in maturity levels as the knowledge is further applied and technology matures; and
- For outcomes, R&D outputs are applied to advance S&T fields and sufficiently mature knowledge and technologies leading to commercialized products and sales to the public or the U.S. Government. This can occur via Federal resources, non-Federal resources, or a combination thereof.

D. Technology Transfer Components

This paper describes Federal technology transfer activities in three components—pre-transfer, transfer, and post-transfer (refer to Chapter 5. Detailed Models for Technology Transfer Components):

- Pre-transfer activities create or improve the conditions for increasing the probability of technology transfer, including outreach strategies, such as for knowledge dissemination or to further mature the R&D outputs as needed;
- Transfer activities represent the establishment of transfer mechanisms occurring at discrete points in time; and
- Post-transfer activities mature the knowledge and technology to the point that it can achieve technology transfer outcomes, such as it can advance S&T fields and be sold to the public or acquired by the U.S. Government.

E. Technology Transfer Outcomes

Technology transfer outcomes represent long-run impacts from R&D as described in Chapter 3. Model Scope. Technology transfer outcomes may influence the context for both Federal and non-Federal R&D as well as Federal R&D priorities and funding by generating new areas of and opportunities for R&D.

5. Detailed Models for Technology Transfer Components

STPI developed three detailed models to describe three components of Federal technology transfer—pre-transfer, transfer, and post-transfer.

A. Pre-Transfer Activities

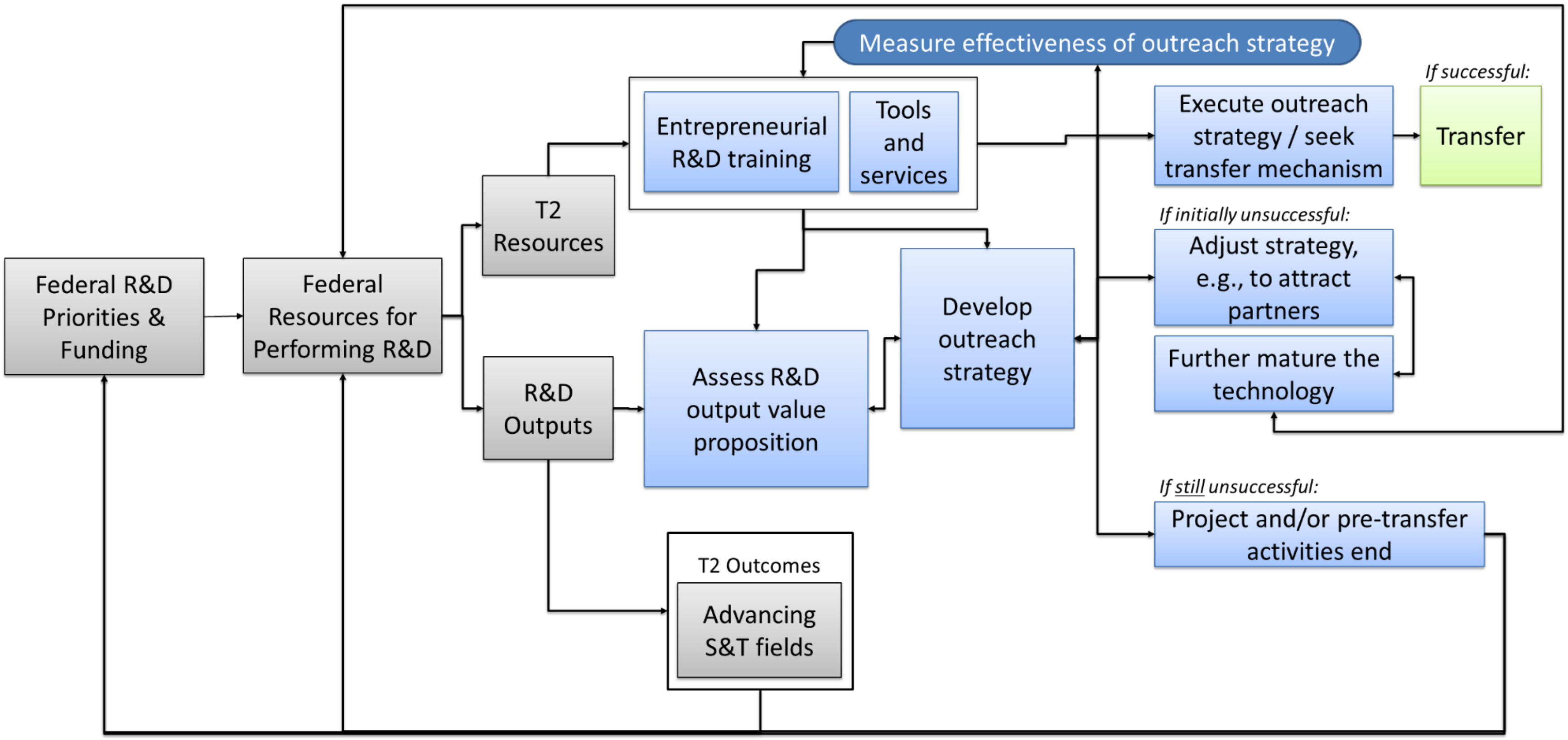
Pre-transfer activities represent federally funded activities to disseminate information about, in particular, federally funded R&D outputs, such as discoveries and data, and broadly, the federally funded S&T enterprise, such as facilities, expertise, and capabilities. These activities facilitate the pursuit and establishment of transfer mechanisms (Section B. Transfer Activities).

Not all R&D outputs may be considered for Federal pre-transfer activities. The detailed model assumes that all R&D outputs contribute to the outcome for advancing S&T fields. In addition, it may be that the R&D output is not intended to be initially transferred. Researchers may continue to receive Federal funds to further their research trajectory until the R&D matures sufficiently and there is a value proposition to share and transfer the knowledge or technology.

Pre-transfer activities occur with R&D outputs at varied maturity levels, including basic research, applied research, prototype, and demonstration. Federal agencies can define maturity via nine technology readiness levels (TRLs): TRL 1 is the earliest level indicating that basic principles were observed and reported; TRL 9 is the most mature level indicating the actual system was proven through successful mission operations (refer to Appendix A for further TRL descriptions).

Several high-level activities are depicted in the pre-transfer model (Figure 6).

- Assess R&D output value proposition
- Develop the outreach strategy
- Use of T2 resources: entrepreneurial training, tools, and services
- Execute outreach strategy and seek transfer mechanism
- Adjust strategy
- Further mature the technology
- Measure effectiveness of the outreach strategy



Note: Pre-transfer activities are designated by blue boxes, transfer activities are designated by a green box, and other model components are designated by grey boxes.

Figure 6. Pre-Transfer Detailed Model

1. Use of T2 Resources: Entrepreneurial Training & Tools and Services

Technology transfer resources, such as tools and services and entrepreneurial R&D training, support the assessment of the value proposition of R&D outputs and the development and execution of technology transfer outreach strategies. The successful use of tools and services may also depend on the entrepreneurial skills of the researchers or the technology transfer professionals themselves.

- Entrepreneurial R&D training: Entrepreneurial R&D training can take many forms—for example, federally funded researchers and laboratories may have a mentoring program or bring in entrepreneurs-in-residence to provide advice on projects and support an entrepreneurial culture. Federally funded researchers may also have opportunities to participate in formal training, such as NSF's I-Corps or similar programs. The overarching objectives of these efforts include:
  - Translating science into practical applications and understanding potential uses of R&D outputs;
  - Understanding the needs of commercial entities in order to attract their investments; and
  - Presenting R&D outputs in a way that convinces potential investors of its value.
- Tools and services: Tools and services help provide the target audiences or the public with information about R&D outputs in a readily accessible way, such as:
  - Online websites and informational materials (e.g., brochures) provide information about federally supported R&D organizations, their S&T capabilities, researchers, outputs, and the like;
  - Outreach events—such as industry days with Federal Laboratories, U.S. Government intermediaries, universities, industry, venture capitalists, and State or local governments—help to publicize R&D outputs and can be used to understand a target audience's needs to identify further opportunities to transfer the knowledge or technology; and
  - Professional networking and other outreach efforts (e.g., via meetings) are other ways to informally spread awareness.

These examples can help researchers identify S&T communities, organizations, researchers, and industries to target for knowledge exchange and collaboration opportunities and, ultimately, contribute to the development of outreach strategies. They also support technology push by raising awareness to potential collaborators and commercialization partners about the federally funded R&D outputs available and ways to reach out to the federally funded R&D organization or researchers to pursue transfer partnerships. As such, these tools and services may also support transfer, for instance, in providing the platforms themselves for disseminating knowledge or technologies (refer to Chapter 5.B. Transfer Activities). Technology transfer offices and professionals across the U.S. Government, Federal Laboratories, and other federally funded organizations, play an important role in supporting these functions.

2. Assess R&D Output Value Proposition

There may potentially be multiple intended technology transfer outcomes from R&D outputs. For example, the development of a technology for U.S. Government consumption could have dual use applications and also be developed for the civilian commercial market. Additionally, there may be outcomes for advancing S&T fields when the R&D is funded for U.S. Government consumption or commercialization benefits. For any given R&D output, pre-transfer activities may be pursued for any combination of the three technology transfer outcomes, simultaneously.

Several considerations to assess the value proposition of the R&D outputs as a function of potential outcomes include:

- Why the R&D output is being considered for transfer, i.e., the expected technology transfer outcome;
- Risks, such as technical and financial, including whether the R&D output is patentable;
- Likelihood of success, where success is measured in the context of establishing a transfer mechanism and achieving the desired outcome.

A market analysis could also be conducted that is informed by the contextual factors for Federal and non-Federal R&D (refer to Chapter 4.A. Contextual Factors) to:

- Determine the relationship between the broad research area and potential knowledge or transfer collaborations and commercial market opportunities;
- Identify the gaps in the S&T domains or niche in the commercial market that the R&D output can fulfill;
- Estimate the market size, potential value, and targeted consumers and partners if the aim is commercialized technology;
- Identify other technologies that could compete with or complement the technology;
- Evaluate how the R&D approach could be changed in order to fulfill the gap or niche; and
- Promote a decision to implement the changes.

Federal R&D performing organizations may have centralized resources available to support these assessments, primarily through technology transfer offices. However, Federal R&D resources, as distinguished as distinct from technology transfer resources, could be used to accomplish such analyses. This situation poses potential tensions for researchers and R&D program managers, who may be reluctant to use R&D funding for activities other than scientific research.

3. Develop Outreach Strategy

The assessment of the R&D value proposition will lead to insights used to develop the outreach strategy, or the actual activities to disseminate the knowledge or technologies and reach out to potential partners (e.g., where, how, and when outreach and social media activities are conducted). The following factors may be considerations for development of the outreach strategy:

- Technology transfer office professionals' interactions with researchers and existing target organizations in targeted industries;
- Characteristics of collaborators and companies as potential partners (e.g., small businesses, research subject matter expertise, manufacturing expertise, business planning), including their risk tolerance for maturing technology with relatively higher technical or financial risks;
- Technology transfer incentives for potential partners;
- Transfer mechanisms available, which depend on the specific legal or regulatory policies governing the agency's activities; and
- Prioritization of R&D outputs and identified opportunities to transfer.

Certain R&D outputs may be developed with the intent to be transferred to the broad S&T community to further advance S&T fields. While there may be no immediate commercial or U.S. Government applications, the U.S. Government generally desires that the generated knowledge be shared with (disseminated to) other potential contributors not only for the advancement of the ideas but also for eventual commercialization or U.S. Government consumption. Outreach strategies for disseminating knowledge to the scientific community deal with finding the most effective fora to inform the S&T communities with interest of new discoveries that could be applied in future R&D. The strategy could attempt to maximize readership through careful consideration of publication outlets, presentations at conferences, and use of professional and social networks and media to informally share the information.

Some federally funded R&D outputs may not be amenable for the commercial market. This is often associated with mission- and operationally-oriented agencies, such as DOD and NASA. For example, certain munitions or explosive materials may have no commercial application. However, R&D not amenable for the commercial market may still be amenable for technology transfer. The U.S. Government would be the beneficiary of this transfer and it would ultimately plan to acquire the technology assuming the results successfully satisfy the U.S. Government's requirements. There may also be dual use projects that could have potential applications in the U.S. Government and for the public.

4. Execute Outreach Strategy and Seek Transfer Mechanism

If execution of the outreach strategy is successful, the pre-transfer activities lead to the establishment of a transfer mechanism. Through execution of the outreach strategy, researchers or the technology transfer office would be able to identify if there is interest in disseminating the knowledge or commercial interest to transfer the technology.

5. Adjust Strategy

In the execution of the outreach strategy, it is possible that the knowledge or technology may not be sufficiently mature for transfer. For commercial outcomes, potential reasons may include limited market potential, high maturation costs, or applications with little commercial interest. Consequently, the outreach strategy may be adjusted to reflect insights regarding the interests from the S&T community and industry. In addition, the quality and quantity of the outreach efforts could be lacking and could be intensified. Furthermore, it may be unclear why the outreach strategy is initially unsuccessful and consequently there may be uncertainty about how to correct the situation. Continued market analyses and other assessment activities can both identify new opportunities and determine how the development effort should change to take advantage of these opportunities.

6. Further Mature the Technology

Before knowledge or a technology can be transferred to the S&T community or a commercial entity, it must be mature enough to garner interest or attract commercial partners. Consequently, maturing the technology to a level where there will be commercial interest is an important pre-transfer activity. If funding sources are found, then the R&D can continue and be further matured, potentially leading to new R&D outputs. These new R&D outputs could be assessed for further value and opportunities that lead to new outreach strategies.

7. Measure Effectiveness of the Outreach Strategy

Broad measurements of the effectiveness, including efficiency and sufficiency, of pre-transfer activities could be considered at various instances throughout the development and execution of outreach strategies. Such measurements support the determination of gaps, benchmarks, and best practices. They provide a basis for determining technology transfer resource requirements. This feedback could also be used to improve the allocation and use of technology transfer resources.

The results of measuring effectiveness, efficiency, and sufficiency can provide feedback to inform the adjustment of strategies and resources to analyze the value proposition of R&D outputs and execute outreach strategies. A quantitative approach could to be considered, including:

- Time involved to develop and execute strategies;
- Costs to determine, adjust, and pursue a new R&D direction if needed to further mature the technology for the S&T community or market;
- Success rate in R&D outputs that are intended for transfer versus those that are actually transferred, which includes tracking the R&D outputs involved in pre-transfer activities; and
- Time to terminate pre-transfer activities if there is no technology transfer opportunity identified.

8. Projects and/or Pre-Transfer Activities End

If R&D funding is unavailable after all potential funding sources are pursued and outreach strategies are unsuccessful, pre-transfer activities end and the project may stop altogether. When this occurs, there is some feedback to contextual factors for Federal and non-Federal R&D resources by informing future R&D project definition and resource allocation decisions.

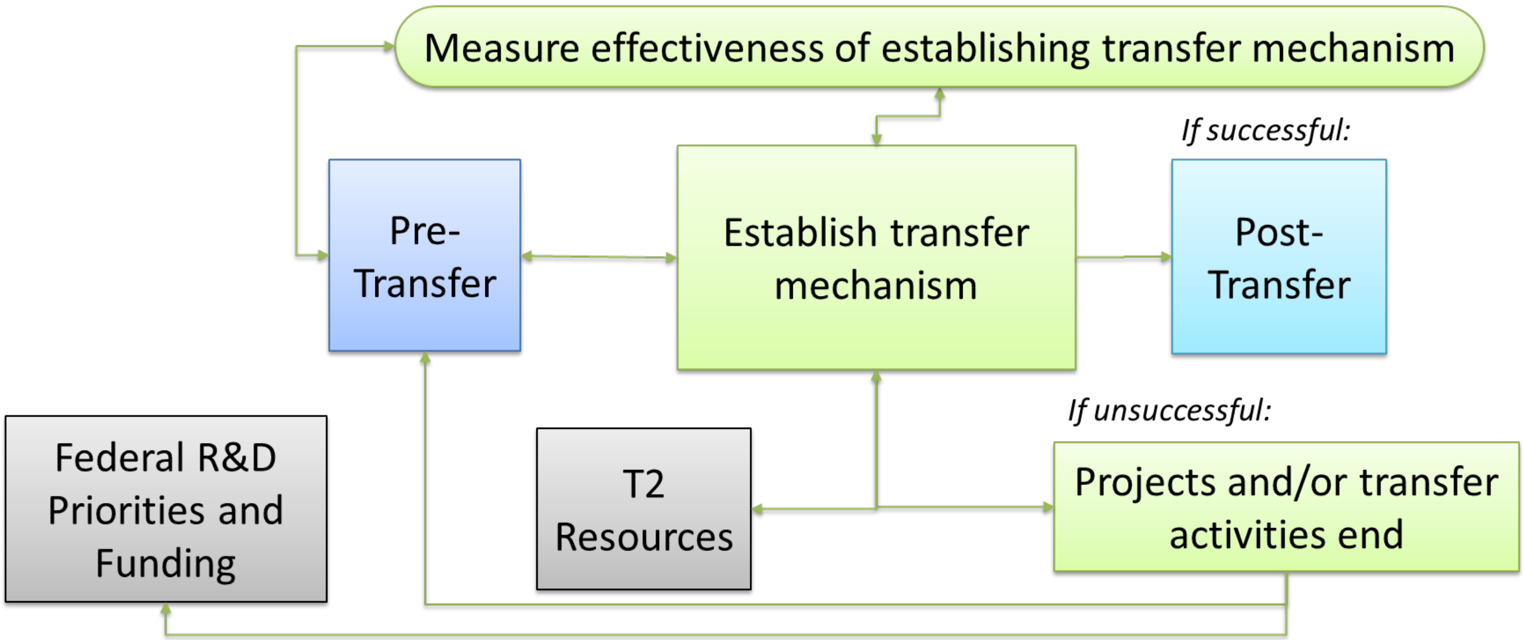
B. Transfer Activities

Transfer activities represent the specific activities and mechanisms used to transfer R&D outputs. Transfer occurs in different ways, depending on the intended outcome and situation. Table 1 provides a non-exhaustive list of transfer mechanisms, some of which are aimed at disseminating R&D outputs as tacit or explicit knowledge or as technology, such as transferring intellectual property or equipment. If transfer activities are successful, this means that a transfer mechanism has been established and post-transfer activities will be pursued (Figure 7).

Table 1. Select Transfer Mechanisms

Knowledge	Technology
Agency foundations	Application and issued patents
Collaboration agreements (e.g., CRADAs)	Collaboration agreements (e.g., CRADAs)
Consulting services	Commercial test agreements
Courses, workshops, seminars, and demonstrations	Copyright
Data and software releases	Equipment use agreements
Education partnership agreements	Facility usage agreements
Entrepreneur-in-residence programs and mentorship	Invention disclosures
Entrepreneurial R&D training	Material transfer agreements
Field Days	Patent licenses
Intramural research training awards	Public-private partnerships, (e.g., consortia)
In print through technical or professional journals	Test service agreements
Laboratory or industry showcases	
Magazines and other print or digital outlets, (e.g., press releases)	
On television or radio	
Orally at conferences and professional meetings	
Partnership intermediary agreements	
Personnel exchange mechanisms	
Professional networking, e.g., discussions with colleagues	
Specifications and standards development	
Watching someone doing something	
Watching a video of someone doing something	
Research parks and open campuses (e.g., co-location)	
Venture capital forums	

Source: NIST (2019); FLC "T2 Mechanisms" https://federallabs.org/t2-toolkit/t2-mechanisms; and Hughes et al. (2011) taken originally from Ruegg (2000) and FLC (2009)



Note: Pre-transfer is designated by a blue box; transfer is designated by green boxes; post-transfer is designated by a teal box; and other model components are designated by grey boxes.

Figure 7. Transfer Detailed Model

1. Establish Transfer Mechanism

Transfer may occur across varied technology maturity levels. Transfer mechanisms to advance S&T fields may happen at maturity levels ranging from TRL 1 to TRL 9. Transfer mechanisms to advance S&T fields aim to disseminate knowledge of R&D outputs to S&T communities so that further advances via application of the R&D outputs can be pursued. These mechanisms can be activities that lead to the transfer of tacit or explicit knowledge, such as publications and conferences.

Transfer mechanisms for commercialization include contractual agreements, in which a commercial entity may invest non-Federal R&D resources to mature a technology until it can eventually sell applications of that technology to the public or the U.S. Government. These transfer mechanisms are governed under legal and regulatory frameworks that can differ across agencies, such as their terms and conditions on the treatment of intellectual property, which can affect the ease or difficulty of forming some partnerships.[6] In addition, other legislation facilitates the establishment of partnerships by creating a role for intermediaries.[7] Transfer does not occur until the commercial partner commits these resources by finalizing the transfer mechanism, providing the agreed upon framework to transfer the knowledge, intellectual property, data, and other R&D outputs. The activities involved in forming partnerships involve negotiating and establishing agreements, including the use of technology transfer resources to analyze the legal, regulatory, and technical elements of the partnerships.

Transfer mechanisms for U.S. Government consumption specifically involve requirements and identifying companies to advance the knowledge or technologies to meet those requirements, often through a competitive contractual arrangement. As the technology matures, the U.S. Government may enter into a production or procurement contract, again typically awarded competitively, to produce the product or provide the service.

2. Measure Effectiveness of Establishing Transfer Mechanism

Since technology transfer resources are used to support the establishment of transfer mechanisms, broad feedback measures help identify ways to improve their effectiveness, efficiency, and sufficiency. Determining best practices, benchmarks, and relevant information can be used to manage the resources applied to establish the transfer

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[6] For example, Other Transaction Authority applies to several agencies. Space Act Agreements are another example specific to NASA via the National Aeronautics and Space Act of 1958 Public Law 85-568, 51 U.S.C. § 20113.

[7] For example, Partnership Intermediary Agreements, see 15 U.S.C. § 3715 – Use of partnership intermediaries.

mechanism. Measuring effectiveness, efficiency, and sufficiency of technology transfer resources could provide information to improve prioritization of future transfer mechanisms, the relative success rate of one mechanism relative to others, and reallocation of resources to those that are found to be most effective.

3. Projects and/or Pre-Transfer Activities End

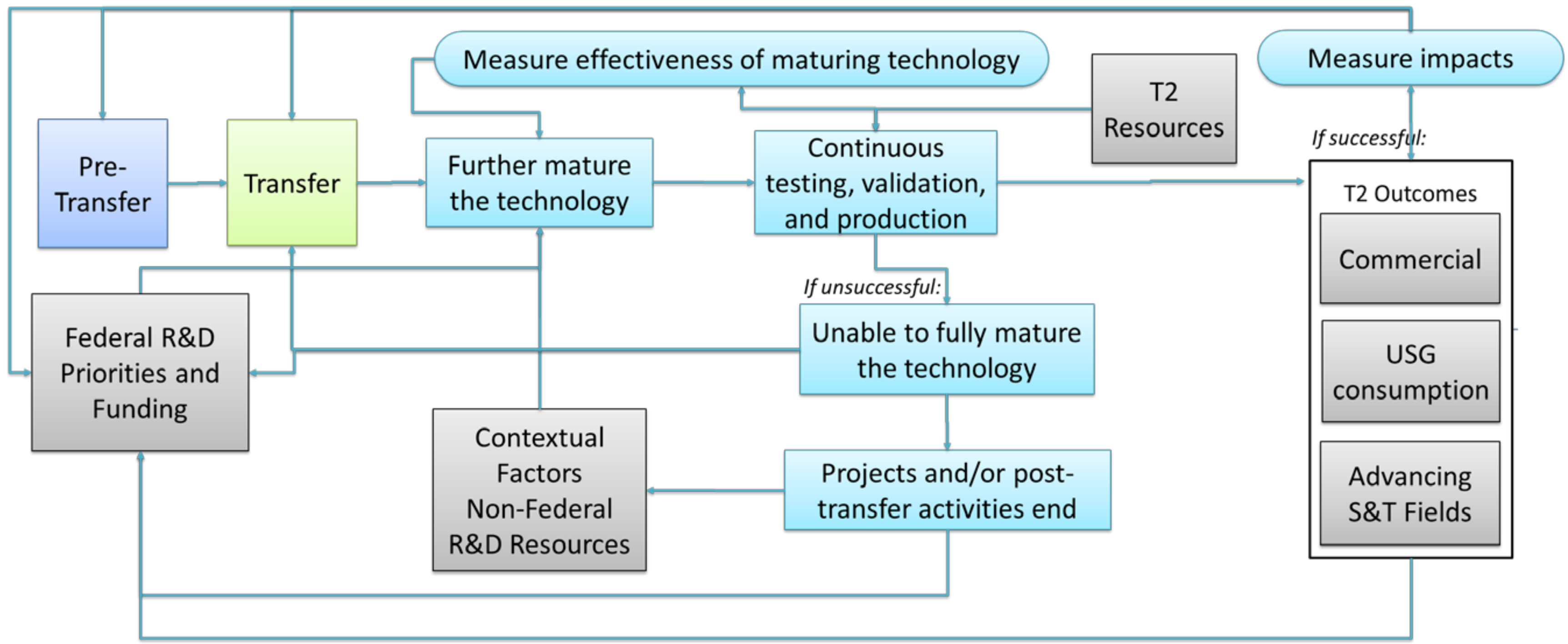
If transfer activities for a specific mechanism are unsuccessful, another transfer mechanism may be more appropriate and an adjustment of the approach for transfer may be pursued. This process feeds back into pre-transfer activities, which could continue to aid in the identification of another potential partner, outreach strategy, or transfer mechanism. If the project is no longer feasible and there is no further interest after further consideration of the transfer activities, the project or transfer activities may stop.

C. Post-Transfer Activities

Post-transfer activities follow directly from the establishment of a transfer mechanism. Post-transfer activities represent the maturation of the knowledge or technology to achieve TRL 9 and, ultimately, technology transfer outcomes (Figure 8). When the technology is fully matured, three technology transfer outcomes can occur simultaneously, advances in S&T fields, commercialization for non-Federal consumption, and U.S. Government consumption. In addition, these outcomes provide feedback on the context for non-Federal R&D and Federal R&D priorities and funding by influencing future R&D projects and the need for additional R&D resources to further mature technologies. Technology transfer resources could also be used to support post-transfer activities, including the continued role of the TTO, entrepreneurial R&D training efforts, and tools and services to help assess and adjust direction as the knowledge or technology matures.

1. Further Mature the Technology

While both Federal and non-Federal R&D funding and resources may be used for post-transfer activities, the preponderance of funding to further mature the knowledge or technologies is expected to be non-Federal, such as venture capital, for commercial applications. For post-transfer activities aimed at U.S. Government consumption, maturation resources may be principally provided by the U.S. Government because the research is being conducted to enable the U.S. Government to acquire and use the results to satisfy a mission need. For post-transfer activities aimed at commercialization, maturation activities continue as long as the business case outlook (determined by a market analysis) is positive and resources are available to perform the R&D. There could be reasons for which the U.S. Government may wish to continue maturation despite a weak business case. These situations include R&D that has potential high risk and high payoff, with a low probability of commercial success.



Note: Pre-transfer is designated by a blue box; transfer is designated by a green box; post-transfer is designated by teal boxes; and other model components are designated by grey boxes.

Figure 8. Post-Transfer Detailed Model

2. Continuous Testing, Validation, and Production

Continuous testing, validation, and production activities mature the knowledge and technology to TRL 9, in which the application of a technology is validated, and provide resources to establish the capability for production. Some federally funded R&D programs directly support technology maturation activities, such as SBIR and STTR programs. Technology maturation may continue as long as the U.S. Government remains interested in product development and resources are available for continued R&D. Non-Federal organizations may also be interested in fully supporting testing, validation, and production, at which point the U.S. Government may no longer be directly involved with the outcomes of the technology.

Technology transfer resources can be used to analyze market and technical risks, inform the direction of the R&D, and examine the business case for the technology. Technology transfer resources could also be used to support the viability of commercial entities further maturing the technology through entrepreneurial R&D training and other entrepreneurship resources. Technology transfer outcomes are achieved when the technology is fully mature and a production capability is established, including manufacturing and development of the business case for the technology.

3. Measure Effectiveness of Maturing Technology

Broad measures of effectiveness, efficiency, and sufficiency of post-transfer could include information about which R&D outputs were transferred for further maturation, to what TRL level were they matured, which did not mature, the resources expended, and reasons why maturation was unsuccessful. Such measures may provide insights to inform efficient and effective allocation of R&D resources for technology maturation.

Feedback from broadly measuring the effectiveness, efficiency, and sufficiency of post-transfer activities informs decisions on both Federal and non-Federal R&D investments in the future. Metrics could be collected to document the number of R&D outputs taking this successful path along with the associated resources and timelines.

4. Unable to Fully Mature the Technology

If Federal or non-Federal resources (e.g., funding, skilled personnel, and facilities) are not available, the project will stopped, potentially until resources are available. Technology transfer resources could aid in identifying if a project should be stopped via technical risk and market analyses or because the U.S. Government's requirements will not be met. The inability to fully mature the knowledge or technology can occur if U.S. Government requirements or non-Federal needs change or the commercial business case is no longer viable. Another influence is technical risk. If the application cannot be matured to TRL 9 or it becomes too expensive to complete maturation, the project is likely to be terminated.

Generally, analysis of post-transfer effectiveness, efficiency, and sufficiency could also provide insights on the reasons why the expected level of maturation could not be achieved. Metrics could be collected on the number of projects that are stopped because of insufficient resources, resources previously expended, and the reason for any changes in priority. Metrics could also identify whether follow-on resources eventually become available to continue maturing the knowledge or technology. If that happens, post-transfer activities restart.

5. Projects and/or Post-Transfer Activities End

Projects or post-transfer activities can discontinue because of the inability to mature the knowledge or technology negates the value proposition or business case for continuing. In addition, there may be no alternative course of action after review of the technical, financial, and other risks involved in continuing testing, validation, and production. It is possible that the U.S. Government's requirement evolved or the U.S. Government's and non-Federal needs for meeting the requirement changed. This could occur as a result of new information and contextual factors driving new requirements, such as a new or emerging S&T discovery. It is also possible that the underlying knowledge or technology itself is found, through post-transfer activities, unable to deliver the performance needed to meet the requirement or business case. If that happens, the U.S. Government may no longer be interested in providing further resources to mature the knowledge or technology. In addition, the U.S. Government may decide to allocate its limited R&D funding resources to other, higher priority projects.

6. Measure Impacts

Impact measurements support an assessment of ROI once the outcomes are achieved. There are several potential approaches to measuring the ROI associated with R&D priorities and funding. From an economic perspective, one possibility is the size of new markets or the magnitude of changes to existing markets both globally and in the United States. There is also a qualitative benefit to the U.S. Government being better able to perform its missions derived from technology transfer or U.S. Government consumption. Examples of qualitative benefits include fielding an improved defense capability, discovering a more effective medical treatment, and mitigating climate change, among others.

In addition, data collection may provide the U.S. Government with greater insight into a commercial company's business case. The U.S. Government could use insight from these activities to determine when it no longer needs to invest in technology maturation. The model suggests that ways to measure "returns" can emerge during technology maturation activities. Establishing data collection processes prior to achieving the technology transfer outcome can aid in future analytical efforts to measure ROI. Measures on the effectiveness of post-transfer activities may point out the need for improved efforts to initiate further pre-transfer and transfer activities as part of technology maturation and to allocate the resources necessary to perform them.

6. Conclusions

STPI developed a model to illustrate and compartmentalize Federal technology transfer activities into three major components—pre-transfer, transfer, and post-transfer activities. The model is advantageous in capturing Federal technology transfer activities compared with other published models in the literature in various ways:

- There is a distinction of Federal resources and funding for (1) performing R&D, and (2) supporting technology transfer activities, suggesting complementarities *and* potential tensions between these resources as a technology is matured;
- Technology transfer resources can be used throughout all aspects of pre-transfer, transfer, and post-transfer;
- Federal technology transfer activities occur across TRL 1 through TRL 9, including knowledge-based R&D outputs, and the maturity of the knowledge or technology can influence outreach strategies, in particular because the value of the R&D output may not yet be fully understood;
- An R&D output can be used for various transfer mechanisms, for instance dual use technologies produced for U.S. Government consumption may be transferred across Federal Laboratories and commercial entities, as appropriate, through varied collaboration agreements, and not all R&D outputs may be considered for Federal transfer activities;
- Technology transfer outcomes align with varied agency missions, for instance, R&D occurring at agencies that have operational needs may intend on developing R&D outputs for U.S. Government consumption;
- Feedback includes effectiveness measures for technology transfer milestones—e.g., developing and executing an outreach strategy, executing the transfer mechanism, and maturing the technology—to inform future resource allocation decisions; and
- Feedback includes the possibility that projects and technology transfer activities, if unsuccessful, may end at various milestones, and, as such, can inform future resource allocation decisions.

The model identifies potential feedback from effectiveness measures throughout pre-transfer, transfer, and post-transfer activities that may help agencies determine performance, outcomes, benchmarking, best practices, and areas for improvement:

- Pre-Transfer
  - Success rate for attaining interest from potential partners
  - Broad effectiveness, including efficiency and sufficiency, of technology transfer resources to support the development and execution of the outreach strategy
  - Efficiency and effectiveness of adjusting the outreach strategy
  - Rationale and measures for the inability to attain interest
- Transfer
  - Success rate for obtaining commitments to transfer mechanism (e.g., licenses, collaborative agreements)
  - Broad effectiveness, including efficiency and sufficiency, of technology transfer resources in support of obtaining commitment to transfer mechanisms
  - Rationale and measures for the inability to obtain commitments to transfer mechanism
- Post-Transfer
  - Success rate for maturing the technology
  - Broad effectiveness, including efficiency and sufficiency, of technology transfer resources in support of technology maturation
  - Rationale and measures for the inability to mature the technology
  - Measures of technology transfer impacts (e.g., commercial and economic measures, such as startups and jobs, U.S. Government acquisitions, and impacts on legal and regulatory frameworks, such as national, State, and local government or industry standards)

Several potential applications of the Federal technology transfer model could be taken to validate the preliminary concepts in the model, including:

- Obtain more information about and map agency-specific programs and activities to key model elements and relationships: Mapping agency-specific programs and activities to the model may provide areas where more information about technology transfer activities in pre-transfer, transfer, and post-transfer could be obtained;
- Identify potential gaps in existing agency activities: Gaps may be identified including where there is insufficient information or data collected to understand the contribution of those activities to technology transfer outcomes; and

- Identify opportunities to develop or use measures of effectiveness and impacts to evaluate Federal technology transfer activities focused on pre-transfer, transfer, and post-transfer: The model presents discrete activities for pre-transfer, transfer, and post-transfer that suggest measures of effectiveness could be assessed at those major milestones to inform resource allocations.

Appendix A. Technology Readiness Levels

The following table of TRL definitions, descriptions, and supporting information for determining the TRL level is a verbatim extraction from DOD's Technology Readiness Assessment Deskbook (2009).[8]

Table A-1. TRL Definitions, Descriptions, and Supporting Information

TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.

[8] The Department of Defense Technology Readiness Assessment (TRA) Deskbook is available at http://www.acqnotes.com/Attachments/Technology%20Readiness%20Assessment%20Deskbook.pdf

Table A-2. TRL Definitions, Descriptions, and Supporting Information (cont.)

TRL	Definition	Description	Supporting Information
5	Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include “high-fidelity” laboratory integration of components.	Results from testing a laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the “relevant environment” differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology’s demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.

Stone and Lane (2012) developed a model for guiding the research, development, and production phases of product development that includes the role of evaluation. Parallels can be drawn between the nine stages of that model and the nine TRLs.

- Stage 1: Define need, goal, and role. This would roughly correspond to TRL 2, which is the lowest TRL level where an application is considered.
- Stage 2: Validate innovativeness and value to target markets. This could align with TRL 3 because validation generally requires a proof of concept.
- Stage 3: Conduct research. While technically research is occurring at all TRLs, it could be argued that research after proof of concept occurs at TRL 3 and 4.
- Stage 4: Business case and development plan. Development activities could begin when research is conducted in relevant environments, which corresponds to TRL 5.
- Stage 5: Implement development plan. Similar to Stage 4, this would also begin at TRL 5.
- Stage 6: Testing and validation (prototype refinement). At TRL 6, prototypes have been validated in a relevant environment.
- Stage 7: Production planning and preparation. This could be analogous to a demonstration in an operational environment per TRL 7.
- Stage 8: Launch. This corresponds to TRL 8 since it requires demonstration of the actual system in an operational environment.
- Stage 9: Post launch review. This stage aligns with TRL 9 because that is the point that the system is finally proven through mission operations.

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Abbreviations

CAP	Cross Agency Priority
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DT&E	Developmental Test and Evaluation
FLC	Federal Laboratory Consortium for Technology Transfer
LEEP	Lab-Embedded Entrepreneurship Program
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
OSTP	Office of Science and Technology Policy
PMA	President's Management Agenda
R&D	Research and Development
RFI	Request for Information
ROI	Return on Investment
S&T	Science and Technology
SBIR	Small Business Innovative Research
STPI	Science and Technology Policy Institute
STTR	Small Business Technology Transfer
T2	Technology Transfer
TRL	Technology Readiness Level
TTO	Technology Transfer Office
USGS	United States Geological Survey
UTT	University Technology Transfer

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14. ABSTRACT

The IDA Science and Technology Policy Institute (STPI) reviewed technology transfer models published in the literature and sought to develop a new model that more accurately reflects federally funded technology transfer activities, outputs, and outcomes. This model provides NIST and other Federal R&D funding agencies with general concepts to help map how their activities support U.S. Government-wide technology transfer outcomes.

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