A Principal Investigator's Guide to Transferring Cybersecurity Technology to Practice (TTP) – Version 2

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PREAMBLE

NSF's canonical goal is to produce high quality, basic research that advances the state of knowledge. However, its goal has never been to create knowledge for knowledge's sake, but rather to conduct research that leads to a valued, transformative outcome, be it in the near or long term. Many important research projects that advance long term goals produce substantive intermediate results upon which subsequent important knowledge growth is founded.

This document focuses on research intended to produce *concrete, valued results in the near term* in an area where knowledge seems to grow at the speed of light: cybersecurity.

Virtually every aspect of modern society depends on network-enabled information technology. Furthermore, the ability to rely on IT requires the use of sound cybersecurity technology to not only define ways of identifying and dealing with security issues but also to provide means of improving the security properties of new technologies.

It is essential that NSF continue to focus on basic research into security technologies. However, acknowledged deficits in the security of computers and communications capabilities in the modern world drive an additional, urgent requirement. This is that funding agencies accelerate the pace at which the results of federally funded cybersecurity research transition from the laboratory into practical use through Technology Transfer to Practice (TTP).

In the current fiscal environment, those responsible for public funding of research are increasingly expected to demonstrate that the research programs they fund provide significant return on investment in terms of benefit to society. Furthermore, they are expected to show that there is a balance between funding research in pursuit of solutions to current (or expected) pressing issues and research intended to define the future of a technology area.

This recurring need for balance was evident in TTP workshop discussions as experts differentiated the market "pull" (the market identifying a major need) from the technology "push" (researchers and technology visionaries selling a new approach to defining and accomplishing a goal). As the separation between research efforts intended to benefit public vs. commercial markets blurs, the effects of transferring research results to practice are not limited to improving technical performance or states of understanding of existing technology. A research result might serve to define a new commercial market

that brings with it economic benefits to a community, a region, a nation, or a continent. Even in the case where the benefits of research are more abstract (e.g., a refinement of an existing algorithm or protocol design,) progress in an area may be accelerated by implementing research results that deliver improvements to the local or national academic computing or laboratory infrastructure to allow subsequent researchers to build upon those improvements.

In the case of cyber security, there might be other, broader-scale motivators for TTP. In particular, national security is affected by cyber security research findings. In this scenario, the desire for transfer to practice may be great, with significant time constraints associated with that desire. TTP can be a long, hard, complicated process with a host of risks that accompany the many prospective benefits. As in any new business area, the current success rate of TTP efforts is low, likely in the single digits.

The Trusted CI TTP team has developed a set of materials available at https://trustedci.org/ttp which includes TTP tools including the TTP Technical Readiness Level (TRL) assessment tool, as well as Business model and sustainability model tools such as the TTP Canvas[1].

To increase the number of successful TTP efforts, we have developed this guide. Two objectives of the guide are to:

(1) Encourage an increase in the number of attempted TTP projects and
(2) Increase the success rate of the TTP projects so undertaken.

There are three main parties to the TTP process: the funding agencies, the principal investigator(s), and the customers that will place research results into practice.

This “How to TTP” Guide is written primarily for Principal Investigators.

[1] Trusted CI Cybersecurity Research Transition to Practice (TTP) Playbook, January 2020. https://www.trustedci.org/technology-transition-to-practice

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A Guide to Transferring Cybersecurity Technology to Practice

1 INTRODUCTION

1.1 THE PURPOSE OF THIS GUIDE

The National Science Foundation (NSF) is the world's premier sponsor of basic research. It is clear that many NSF funded cybersecurity projects have resulted in significant advances in society, often through commercialization of research results. However, the NSF's traditional focus on basic research has resulted in relatively little effort devoted to moving NSF-funded research out of the laboratory and into the field or marketplace. If there is a deficiency evidenced in the last generation of NSF-sponsored security-related research, it is that only a small fraction of funded research results actually transferred to use in modern information systems.

In response to this problem, NSF funded a workshop series (http://soc.southalabama.edu/TTP/) in 2015 to identify barriers and solutions for promoting cybersecurity Technology Transfer to Practice (TTP). Additionally, the Trusted CI TTP program established in 2018 has hosted in person workshops, webinars and matchmaking between cybersecurity researchers and practitioners why may be interested in TTP for their research. This guide documents insights gained from these efforts.

A key goal of this guide is to help Secure and Trustworthy Cyberspace (SaTC) principal investigators to identify research results that should be transferred to practice and to then take appropriate actions to make the TTP process successful.

1.2 AN OVERVIEW OF THE WORKSHOPS

The two NSF-sponsored workshops were organized to identify barriers and solutions for promoting Technology Transfer to Practice (TTP). In particular, they initiated an intense, directed, conversation between key players in the SaTC community and other elements of the technology transfer ecosystem in an attempt to improve the rate of TTP from SaTC research results. Drawing on the experience and community ties of the PIs, a group of noted experts with experience in successful TTP of SaTC-related research to popular use were invited to share their experiences and opinions.

The two workshops were organized as two-day sessions, each focused on distinct market segments. The first workshop was held in February 2015, in Menlo Park, CA, and focused on those TTP efforts likely to target commercial markets. The second, held in Arlington, VA, in November 2015, focused on TTP efforts targeting public and academic markets (i.e. government and academic research users) and included discussions of issues unique to those communities. The findings from both workshops are consolidated in this document.

This guide includes a variety of voices with direct experience in the areas involved in the TTP process for NSF-funded research in SaTC. Contributors include PIs, entrepreneurs, venture capitalists and other

growth capital funding sources, program managers for relevant research programs active within TTP (including major initiatives and I/UCRCs,) and directors of major commercial research programs. A list of workshop participants is provided as an Appendix to this guide.

2 AN OVERVIEW OF TECHNOLOGY TRANSFER TO PRACTICE

2.1 TTP: WHAT IS IT AND WHY DO IT?

TTP is the process for delivering research results from the laboratory into broader use. TTP can be accomplished in many ways:

- creating a product for sale (commercialization),
- creating a product for free distribution (open source),
- creating a product or service for a specific company or governmental agency,
- incorporating research results into an existing product,
- incorporating research results into standards through NIST or an industrial standards body, etc.

While there is inherent value in conducting basic research, TTP amplifies this value by:

- ensuring that public investment in research provides a tangible benefit to society,
- providing benefit, at times significant, to investigators on both professional and financial fronts,
- providing investigators access to resources that are not available otherwise,
- many excellent ideas fulfil their potential only when the visionary behind the idea promotes its adoption.

2.2 THE TTP PROCESS

In the classic view of technology transfer, there exists a well-defined process model for performing TTP, featuring specific players carrying out specific roles, and an optimal means of executing the process. As in so much of the technology world, this TTP model has gone through significant change over the past decade, driven by the effects of increased computing power in combination with Internet connectivity.

Simply put, TTP involves the following three activities:

- Producing a discernable outcome from federally funded, transformative research,
- Establishing intellectual property protection for the outcome,
- Delivering the outcome to productive use by society.

These activities do not occur sequentially, though there are clearly some integral timing dependencies. More importantly, in the optimal scenario, provisions for each of these activities are included as an integral part of the research planning.

2.3 WHAT FORMS CAN TTP TAKE?

There are many ways that research results can be useful to society, e.g. as a new, stand-alone product, as a product that is a component or feature of a larger system, as a replacement for an existing product,

as a service, as a technological standard that will be implemented in many future products or services, or even simply as an idea upon which designs for other useful products are based.

The **research outcome,** whether it is a product, service, algorithm, or idea, is the focus of this guide. We are particularly focused on outcomes that result from cybersecurity research.

To be a candidate for TTP, a research outcome must meet several criteria, among them at least the following two:

1. It must be well-defined; that is, it must be possible to uniquely distinguish the outcome in the form of its Intellectual Property (IP) and there must be a way to protect that IP.
2. There must be a clearly defined or envisioned use and customer for the outcome.

An investigator who is considering taking an idea through TTP should consider these two issues from the beginning of the planning process. Because they are fundamental to the question of TTP, we use these two criteria to help categorize the different forms of TTP.

When TTP is mentioned, people tend to think "commercial entrepreneurial startup," but of course the two are not synonymous. In fact, the entrepreneurial startup model is one of the most complex and least frequently engaged TTP forms. Licensure can be much simpler and low cost, so may be the most employed TTP model in academia, allowing investigators and universities to minimize risk and share positive outcomes. In addition to startup and licensure, IP issues are also fundamental to these additional TTP forms: spinoff, open-source product, and informal TTP.

The type of client that is being approached represents another important consideration for the TTP approach that should be taken. For example, a commercialization attempt that targets a retail market (e.g. via an enterprise security software package) would entail a fundamentally different approach than one that transitions the same research result to a federal agency or as a company spinoff to an industry partner. For TTP targeting public sector markets, academia offers substantial opportunity for TTP, particularly in the cybersecurity area.

3 TO TTP OR NOT TO TTP: THAT IS THE QUESTION

3.1 IS THE TARGET TECHNOLOGY A GOOD CANDIDATE FOR TTP?

Not all research results are good candidates for the technology transfer to practice process outlined in this guide. One issue in classic technology transfer practice is the tendency in some communities to view optimal TTP as a technology-driven "push" instead of a needs-driven "pull" process. This doesn't mean that one option is always superior to the other; rather, it just indicates that there are different incentives associated with each. In this section, we'll set forth a typical decision process for determining whether your research results are good candidates for TTP, and if so, what paths might be optimal.

When the topic of taking new security technology to practice arises, most discussions go directly to the topic of commercial venture creations – i.e., does this result solve a pressing security problem, and if so, does it solve it well enough to generate considerable revenue as a commercial product? In this section, we'll walk through the questions that determine whether there's a need that can be satisfied by your research result.

The first and perhaps most important question that a PI should ask when considering selection of any research topic is "Does it satisfy an acknowledged, pressing need?" TTP for an idea, product, or service that does not meet a recognizable need is unlikely to succeed in even the best organized TTP effort.

Some indicators of this need can be determined by answering the following questions:

- *Does a solution based on your technology satisfy a pressing need?*
- *Does it satisfy this need within a market that is likely to have resources to deal with the need?*
- *Is that need clearly acknowledged by those currently authorized to deal with it?*
- *If not acknowledged as a current need, is it high on the list of recognized future needs and are there signs that future budgets reflect the prioritization of this need?*
- *Is the need likely to be amplified and codified in future regulations and/or policy requirements?*
- *If the need (and associated market) already exists, is your solution approach clearly superior to the current offerings? (If so, who will vouch for this?)*

3.2 WHO IS/ARE THE CUSTOMER(S)?

Regardless of the quality of the research outcome, TTP is not possible without a proven, or at least prospective, customer. There must be a reasonably clear vision of how the research outcome will be used to provide a solution for an organization or industry that will want to use the outcome. Furthermore, evidence must exist that they will have the means to acquire and implement the solution.

While most people tend to think of commercialization and startup companies when they consider TTP, customers come in many forms. Government and academia are also excellent customers that can use advanced cybersecurity research outcomes. While startups are a proven technique for cybersecurity TTP, spin-offs, licensure, and open-source models offer a variety of different means for aspiring entrepreneurial scientists to find users and deliver solutions to them.

PIs considering TTP should ask:

- *Who are the prospective customers?*
- *How many potential customers are there (that are likely to be readily accessible to you)?*
- *Are they in industries that are likely to purchase your solution?*
- *Does your solution solve an acknowledged problem for them, or does it present them obvious business opportunity?*
- *Have they any financial incentive to use your solution? (e.g., government mandate/regulatory requirement, financial or operational incentive)*
- *What is the general breakout of your public/private customer base?*
    - *Government/Academic*
    - *Commercial (including government contracting)*
    - *Domestic/Global*

Answering these questions is essential to determining if a research project is well-suited to a TTP effort. Still, at some point any "prospective customer" must turn into a real customer for TTP to succeed.

That process, known as "matchmaking," is one of the most important issues to prospective TTP PIs. One of the strongest messages derived from the TTP Workshops is the need to ensure that there is a good match between the research team and its client(s). This is complicated because professors are not

trained to be product developers and often do not have experience in development activities such as creating a detailed requirements specification. Similarly, prospective commercial and government TTP clients typically do not have experience with working with researchers to transition research ideas into the development process.

The key question is: How can an investigator who is interested in proposing a research effort with a TTP perspective find, or propose to find, suitable clients? The following are some ideas that emerged from the workshops:

1) Get help from a federal funding sponsor. Your NSF program officer is an obvious source for leads on finding suitable TTP clients. Funding officers at other agencies such as DHS and DARPA also have resources that can be helpful in connecting research producers and consumers.
2) Ask a mentor. As with many TTP questions, one of the best sources for information is an experienced mentor. As a rule of thumb, one of the first things that all first time TTP investigators should do is to find someone who is experienced with TTP in an area that is closely associated with the targeted work. Finding clients will come naturally to experienced mentors, who may have direct contacts, leads on good contacts, or an approach for identifying and courting suitable clients.
3) Network. Peer groups for investigators who are ready for TTP efforts are likely to include colleagues who have TTP experience or who are connected to agencies or companies that are prospective clients. Being TTP-aware when attending research conferences and other publication venues can generate ideas and contact opportunities. Don't hesitate to reach out to your peer group to get leads on prospective clients.
4) Attend trade shows. In addition to publication venues, investigators who are interested in TTP may elect to attend industry centered venues (such as RSA, AFCEA Technet, MILCOM, the Intelligence & National Security Summit, Homeland Security Conference, etc.) corresponding to the target market for their proposed solution.

TTP projects will not succeed if the product does not meet the client's need; nor will it succeed if the client expects more from the research team than they can deliver.

3.3 WHAT ARE THE RISKS?

As with any venture, there is risk associated with engaging the TTP process. A repeated theme of participants who have undertaken TTP activities is that luck is a critical factor in TTP success. Thus, TTP investigators must be aware of the risks, both to project success and more broadly with respect to long term impacts, and to available mitigations from the very beginning of the planning process. TTP risks come in many forms, the following among them.

3.3.1 Career

For young academic investigators career risks may be the most immediate risk and are a long-term risk. The risks are greatest for young investigators where they risk achieving tenure if they divert energy and time away from research and other academic endeavors in favor of TTP. This concern remains even though insights and opportunities that they gain by engaging in TTP activities may improve the quality of subsequent research and academic pursuits.

Academic investigators who have already achieved tenure face far less TTP risk than their untenured colleagues, as their positions are much more secure. Still, career risks exist for even the most senior TTP investigators. For example, the "publish or perish" rule is real; holders of doctoral degrees who have significant publication gaps can lose credibility and the opportunity that it offers.

TTP investigators can begin to assess this risk by considering the following:

- At their university, are attitudes and official policies positive regarding TTP or is there an air of being overly cautious, or discouraging to TTP?
- Do university faculty promotion and tenure policies discourage TTP involvement?
- Are there university incentives that acknowledge the value of TTP participation by research faculty?
- Does the university have mechanisms and policies that deal effectively with TTP issues such as non-disclosure, IP protection, and indemnity for faculty and students participating in TTP activities? Are these supported by university legal counsel or funded access to such experts?
- Does the university sponsor TTP resources, such as Business Incubator facilities and services? Are they well-suited to IT and cyber security startups?

3.3.2 Return on Investment

There is no doubt that TTP can be financially and professionally rewarding, even for projects where large payouts are not expected, or even possible. Even TTP efforts that do not result in positive cash flow can deliver knowledge and partnerships that will lead to subsequent highly successful projects.

Still, engaging the TTP process is not free. It goes without saying that it requires substantial investment of time, attention, and intellectual and emotional contributions. There may be sacrifices of family time and of other personal and professional interests, some of which may provide financial opportunity. The TTP process will also almost certainly require some personal financial contribution, from low-cost items such as local travel expenses, supplies, and communication resources to more substantial investments such as international travel, real estate requirements, consultants, etc.

While we do not have corroborating data on this topic, our experience, and that of the workshop participants, is that the percentage of TTP engagements that end up recouping all of their personal investment is less than 50%, with the percentage of TTP start-ups that end up in the "successful" category (i.e. that turn a profit) likely far lower.

3.3.3 Human Resources

Likely the greatest risk to TTP projects success can be captured in one question: How deep is your bull pen? Intellectual contribution in terms of both research and business are pivotal to success for research projects that intend to engage TTP. We will discuss issues associated with forming your team but highlight here that forming a team that is one-deep in critical skill sets creates substantial risk to project success.

3.3.4 Technical

As we noted earlier, by nature and training investigators tend (and prefer) to focus on generating innovative, transformative ideas, which also contributes to the opportunity for success in TTP. Unfortunately, there are many technical risks that can erode a TTP project's likelihood of success.

One of the fundamental differences between conducting basic and applied research is that while the operating environment for basic research experimentation need not be standard or even replicable, for applied research, the operating environment must be commercially viable or commercially compatible or there must be a clear path to porting the research output to a commercial environment. We term this "operating environment risk". When designing a research plan that intends to attempt TTP, the researchers should ensure that transition from the research environment to the anticipated operating environment can be efficiently accomplished.

For ongoing projects that are considering conducting TTP, the operating environment risk may be evident in the project prototype. As prototypes are usually generated after the concepts are reasonably mature, if the prototype is not TTP-viable, project success is at substantial risk. Similarly, for ongoing projects that have not incorporated TTP concepts from the beginning, the state of the prototype is a critical decision factor. Software stability and sustainability are critical to the TTP effort. This is often reflected in the project's adopted development standards. Absence of such standards is a significant TTP red flag.

A third technical risk that was repeatedly mentioned in both TTP Workshops is the availability of sufficient appropriate datasets, both for application testing and for verification and validation of the research outcomes. Such data is often difficult to acquire in many research areas, but data availability is considered a major issue for cybersecurity research. Lack of data, in quantity and/or quality, is a significant risk to TTP project success.

3.3.5 Business - Operational

Maybe the most obvious adjustment that academic investigators must make when engaging in the TTP process is the business focus that TTP demands. A few of the basic business issues that must be considered are encapsulated in the following questions:

- Will you need a separate business entity to house the effort?
- Do you have ready access to legal counsel?
    - Does that counsel have the required and current expertise in TTP?
- Do you have ready access to accounting and financial advice?
    - Do those advising you on these matters have current expertise in dealing with early-stage firms?
    - Do those advising you have expertise on any regulatory compliance or other requirements specific to the security industry or to customer bases you're likely to target (e.g., government or military)?

3.3.6 Legal Liability – Conflicts of Interest

Many PIs have been involved in a mixture of commercial and academic activities over the courses of their careers. It is important that, in the course of deciding to take on a proposed TTP process, one considers the question of conflicts of interest. These conflicts can take on a variety of forms:

- Have you (or anyone on your team or in your immediate family) been employed by a firm that would compete with your transferred product or service?
- Have you entered any non-compete agreements or other limitations of business activities that would affect this transfer?

- Are you affiliated with more than one institution? Is it clear which of the institutions share ownership of your IP with you and do you have documentation of this?
- Do you have investments in firms that have a vested interest in the success or failure of your TTP effort? If so, have you made provisions for those interests to be held in ways that are in compliance with securities law?

3.3.7 Business – Market Analysis

We previously noted the importance of identifying the need, and even the prospective customers, for the research outcome early in the TTP process. It is similarly important to recognize the competition that may exist in the target marketplace when considering TTP. Market analysis depends on such questions as:

- Are there competitors in the market?
- How mature are these competitors?
- How do their offerings compare to yours in approach?
- What are the typical production costs of your offering?
- How do the prices for your offer compare to your competitors?

3.3.8 Financial Liability

Businesses are (with few exceptions) based on contracts and agreements that can result in personal financial liability. Some of these exposures can be mitigated in the course of negotiating these agreements. As in other areas of risk, you should seek expert legal advice.

3.4 The Technology Readiness Level (TRL) Assessment tool[2]

The Technology Readiness Level (TRL) assessment tool – based on the NASA[3] and U.S. Government Accountability Office (GAO) TRL processes[4] - enables the researcher to identify the current state of the research, any gaps to operational deployment readiness, and develop a plan to progress to operational readiness for a user environment.

3.4.1 What does it do?

The TRL Assessment can be used to...

1. Describe the overall maturity of a technology.
2. Describe the maturity of each of the different subsystems and components that provide the functionality of the technology.
3. Discern what components need the most attention to make the technology operationally viable.

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[2] Trusted CI Cybersecurity Research Transition to Practice (TTP) Playbook, January 2020. https://www.trustedci.org/technology-transition-to-practice

[3] NASA - Final Report of the NASA Technology Readiness Assessment (TRA) Study Team, March 2016. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170005794.pdf

[4] US Government Accountability Office (GAO) - Technology Readiness Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects, August 2016. https://www.gao.gov/assets/680/679006.pdf

4. Communicate with stakeholders regarding the current state of development and future work.

TRL	Definition
1	Basic principles observed and reported
2	Technology concept or application formulated
3	Analytical and/or experimental critical function or characteristic proof-of-concept
4	Research validation in laboratory environment
5	Model or prototype demonstration in a relevant environment
6	Actual system completed and qualified through test and demonstration
7	Actual system proven through successful operations

This assessment tool is primarily derived from existing work by NASA and the U.S Government Accountability Office (GAO). This assessment is based on a simplified version of the NASA TRL model tailored to NSF funded research applicable to the cybersecurity domain. This tool can be used to capture the current state of different components which provide needed functionality to identify where efforts should be focused to mature the technology. As development continues it will be valuable to repeat the assessment to capture changes and identify components which are most in need of additional work to improve.

Each subsystem is a collection of related components which together serve a distinct functional need for the system to serve its intended purpose. The worksheet is designed to capture subsystems, the individual components of each subsystem, a TRL for each component, justification for the estimated TRL level, and a description of how each component is implemented, and its source. Each component should be assessed for a distinct TRL level, which will then inform the overall TRL for the technology. Trusted CI has produced a filled example TRL assessment worksheet for a hypothetical software technology which relies on a web application front end.[5] This example illustrates the methodology and should be used as reference when completing a TRL assessment. The following is a section taken from this example worksheet which describes components of the web interface subsystem.

Subsystem	Component	TRL	Justification	Implementation
Web Interface	Apache httpd	7	This is widely used open-source web server software. The installation is managed and supported by the hosting provider for the web server.	Provided by service provider

[5] https://docs.google.com/spreadsheets/d/19mlXCx3cg_IWFlxzTn0k2uvn1X_D01gde1mEFiwqvUc

	API endpoint	4	Basic API calls have been tested successfully. Additional functionality is being developed and further testing is planned.	Custom httpd module written to provide REST API
	Web GUI	5	Web UI prototype is functionally complete and has been fully tested across two out of three target browsers. Ready to begin usability and accessibility testing.	Custom JavaScript UI built using open-source library XYZ.

The first step is to complete a TRL assessment using the assessment tool available from the Trusted CI website.[6] Review the TRL definitions and fill the TRL assessment worksheet on the second sheet. Once this is complete, the result is a list of components and an estimation of their readiness as well as how each component contributes to the overall readiness of the technology.

Once the assessment is complete, the components which are most in need of additional effort and which are thus most important to implement improvements for can be identified. In many cases, these will simply be the components with the lowest TRL level. In some cases, however, the components with the lowest TRL level will be ones which provide ancillary functionality which is not key to the core value proposition of the technology for the intended user base. In these cases, the subsystems which provide core functionality should be prioritized instead and the TRL level should be used to choose from these subsystems' components.

Once components have been chosen for improvement, the exit criteria, and activities descriptions for the component's current TRL can be used as the starting point when determining appropriate development goals for that component. In the example above, the API endpoint component of the Web Interface subsystem has a TRL of 4, which is the lowest of the three components shown. The software activities at this stage are:

"Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant environments defined and performance in this environment predicted."

The justification for the TRL level of the component states that the basic functionality of the component has been tested and additional functionality is planned. To achieve TRL 5 for this component, the component would need to reach the exit criteria for TRL 4:

"Test performance of low-fidelity prototype demonstrating agreement with analytical predictions. Documented definition of relevant environment."

[6] https://www.trustedci.org/technology-transition-to-practice

Since the basic functionality of the component has been established and tested, the remaining activities to advance the component out of TRL 4 would be to identify and document the relevant environment for the component. As this component is a REST API implemented with an Apache httpd module, this would involve the documentation of relevant information about the system itself. There may be a variety of information which is important to capture. In this example it may include the expected interactions with the users of the API through HTTP methods, expected data flows between the related components of the system itself, and the types of connections allowed and how they are managed on the host system. Once this activity has been completed, the component moves to the next TRL level and planning can begin to meet the exit criteria for TRL 5.

The results of TRL assessments can be used to identify the set of components which need the most work to improve the maturity of the technology. They can also be used as a communication tool to describe the current state of the technology's development or convey why a particular development effort is needed.

4 THE PRINCIPAL INVESTIGATOR

4.1 WHAT ROLE DO I (AS A PI) WANT TO PLAY IN THIS TTP?

Perhaps the most critical question you must address in considering the transfer of your research results to practice is this – what role do you wish to play in the process? There are many roles you may be asked to play and it's very important to consider in advance which of them you wish to take on.

4.1.1 Principal (CEO)

Should you decide to use an entrepreneurial model to conduct your TTP, one role you may be asked to assume is that of CEO. In this role, you'll be expected to lead the firm, working with your team to define and commit to meeting the goals and milestones required to build the product(s) and services offered by the firm. You'll be responsible for working with them to identify the market served, and to sell the firm's offerings (and ultimately the firm itself) to customers. You'll be responsible for keeping your team staffed and on task, to add personnel and functions as they are needed, to identify and obtain resources needed to accomplish goals of the firm, and to determine when it's time to revisit and refine the goals. Should you take on external funding (e.g., venture capitalists or angel investors) it's your responsibility to locate and win that funding. Finally, you'll be expected to understand and accept that at any point in the firm's life, you may be asked to step aside when a different set of skills are needed to take the firm through its next stage of growth.

4.1.2 Technical Principal (CTO)

In many technology TTP startups, the logical role for a PI to assume is that of the Chief Technical Officer. In this role, you'll be expected to establish the technical vision for the firm, explaining it to your team (both management and technical) and other critical partners (including investors and major customers.) You'll have a critical role in forming the technology team, in leading them in planning the research and development of the products and services produced by the firm, then executing these plans, and representing their voices at the board level of the firm. At the beginning of the firm's life, you will likely be expected to provide the technology vision for the firm's offerings as well as the management and core technology direction for the team manifesting that vision; as the firm grows, your role will become increasingly abstracted from the hands-on technical tasks, as you provide the perspectives required to

keep the technology current and relevant to your major customers and those who influence them (e.g., industry analysts) Finally, as with the CEO, you may be expected to step aside when the board determines that a different set of skills are needed, though the probability of this occurring is likely less than with a CEO. What happens more often is that a CTO may choose to return to academia or active research, and in this case, you'll be expected to play a prime role in recruiting a suitable successor.

4.1.3 Influencer

Depending on the TTP path utilized, you will very likely be expected to serve as an influencer, be it in the role of a consultant or employee of the customer for your transferred technology. The amount of involvement expected can vary widely, depending on the recipient of your TTP.

4.1.4 Other Role

There may be other roles you are expected to play in enabling a successful TTP of your technology; these are as varied as those entities seeking to utilize your work.

4.2 What Commitment does this TTP require of me?

Even if you understand the roles you might serve in enabling the transfer of your technology to practice, you may still be unsure that you are willing or able to take on the commitment such a transfer requires. These are the very real resources TTP will require of you.

4.2.1 Time

No matter how much passion you have for a particular body of research, it takes time to pursue it. There are many hours spent performing analysis of difficult problem sets, designing, and implementing software, assembling and processing data sets, and analyzing results. Depending on the TTP path you choose to take, this process can take a significant commitment of time and effort on your part. Even when TTP takes IP transfer form (i.e. is patented and licensed), it takes time to negotiate with potential acquirers and legal counsel. It is worth seeking out someone who has performed a similar TTP in your area for advice as to what commitments are reasonable and expected.

4.2.2 Financial Commitment

The amount of financial commitment required by a specific TTP can vary widely, depending on the path taken and the resources provided by your home institution or other funding sources. At a minimum, you should expect to spend funds on retaining personal legal counsel to advise you on your IP rights and equity expectations for any TTP activity of which you're a part.

4.2.3 Other requirements

There are a significant set of investments you'll make over the life of a TTP effort, measured in time, effort, relationships, and opportunities foregone. These can vary widely, depending on the type of TTP process you utilize, and the amount and nature of support provided to you.

5 FORMING THE TTP TEAM

5.1 THE INVESTIGATORS

The PI forms the investigator team, identifying colleagues who offer novel contributions that are complementary to the research vision or that fill intellectual or operational gaps in the research plan. Collaborators may be faculty, staff, or students, but each must fill a well-defined role in the research plan.

An important consideration in forming the TTP team is to recognize that some research result must eventually become operationally maintainable. So, for example, the PI may prefer to associate with students who are able to keep good notes and are able to capture the reasons behind decisions that are made on-the-fly. If the research plan calls for the research team to produce a prototype, members with appropriate systems development skills and experience should be sought.

An especially critical consideration in forming the research team is whether any of the members have previous TTP experience. While having prior TTP experience on the research team is not an absolute requirement, both workshop audiences recognized the positive impacts of having members with prior TTP success.

5.2 THE ENTREPRENEURIAL TEAM

Leadership is critical in TTP efforts and not just in the research team. A key question to ask before engaging TTP is:

- Who is essential to transform this research result into a commercially viable solution?

As the lead researcher holds the key to success for the research output, the success of any TTP project largely rests with the *Product Visionary* (PV). The PV is that person who sees the end result, i.e. what the final product will look like, who the clients are (and end-users if the client is not so), which marketplace/competition will be relevant, etc. PIs are not generally expert in the business perspective that the PV must possess, so a PI might expect to spend substantial time on background if they are the PV. Alternatively, adding a team member with a business degree and/or business background to be the PV might be advantageous to a TTP project. Having a PV with prior TTP experience would be even better.

Similarly, few PIs for cybersecurity research projects have experience or training in required business processes, such as accounting, financial management, sales, marketing, intellectual property management, etc. An external PV or senior team member might be a good choice to handle these functions.

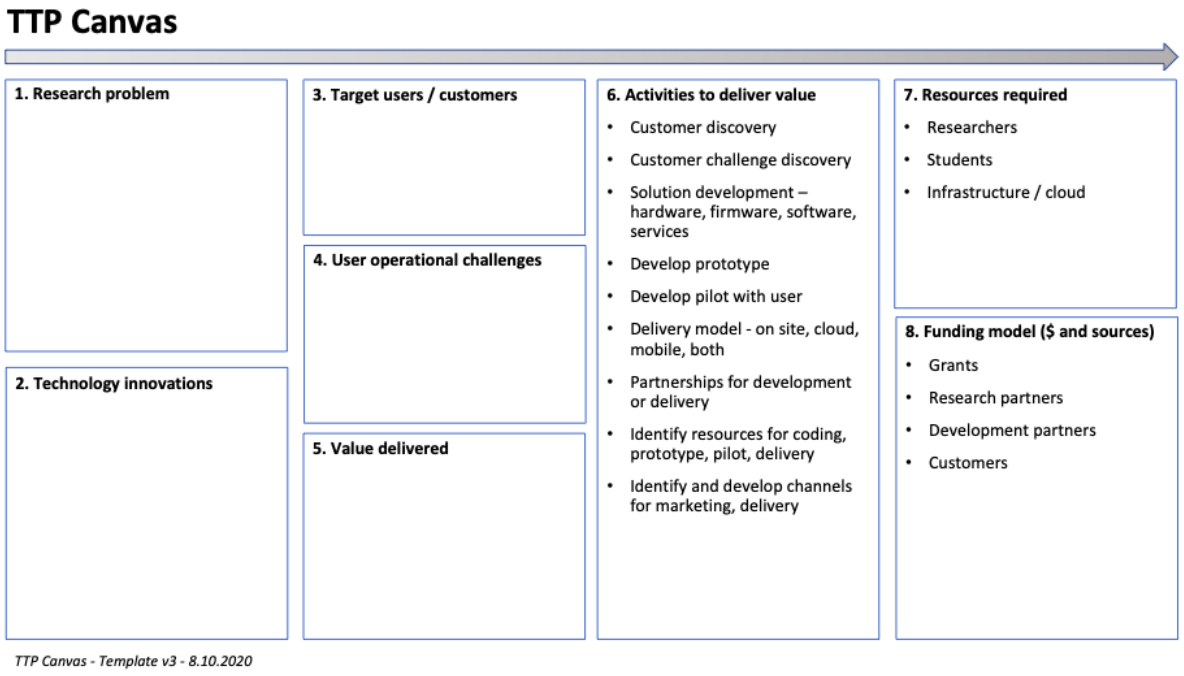
All but the most trivial of businesses have at least occasional need to engage legal counsel. New enterprises must form a solid legal plan to support their product and enterprise. That may mean that they should incorporate someone with extensive legal experience on the team or engage in some type of a retainer agreement. Servicing the legal need can require a substantial investment in legal fees if it is externally sourced.

Finally, cybersecurity research projects that target TTP almost always involve significant hands-on work that demands substantial technical support (e.g., network administration, software support, procurement, etc.) If these resources are not available in sufficient quantity and quality in the academic research environment, the TTP team must include specific means to fill the gap.

6 ENGAGING THE TTP BUSINESS PROCESS

6.1 TTP Canvas[7]

The TTP canvas - a business model canvas based approach similar to iCorps (NSF Innovation Corps)[8] - is a tool the researcher can use to clarify the value their research provides, the target clients, activities to progress the research to operational deployment, and a sustainability model. It can be used to describe a model for sustaining TTP efforts. It is tailored for situations where the goal may not necessarily be to develop a business based on the technology.



[7] Trusted CI Cybersecurity Research Transition to Practice (TTP) Playbook, January 2020. https://www.trustedci.org/technology-transition-to-practice

[8] The National Science Foundation Innovation Corps™ Teaching Handbook, January 2016. https://venturewell.org/wp-content/uploads/I-Corps-Teaching-Handbook-Jan16.pdf

The TTP Canvas was developed to enable a TTP Researcher to quickly clarify the purpose of their research, the potential value it can deliver to a user, the activities which need to be accomplished to Transition to Practice (TTP) successfully, and the sustainability model. It was modeled from prior work by Alexander Osterwalder[9] and the National Science Foundation Innovation Corps (iCorps) Business Model Canvas[10]. It has been customized for use in developing a plan to transition research to practice when the goal isn't necessarily to establish a business.

To use the canvas, use short declarative statements which provide answers to the trigger questions in each canvas section. Avoid jargon and try to keep each statement as direct and easily understood as possible. It may be helpful to treat each statement you put into a canvas as if it is a specific hypothesis which you intend to test.

6.1.1 Research Problem

What are you trying to do? Articulate your objectives without using any jargon.

Come up with a series of short statements which clearly describe what your solution does in terms which a layperson could easily understand.

6.1.2 Innovations

What is new in your approach and why do you think it will be successful? Are there other approaches being used to solve the same problem? If so, how is your approach different from these?

Articulate what's new about your research. If you know of any existing solutions which accomplish something similar, describe what is different about your approach. What are the most important differences about what you are trying to do? What makes your approach better?

6.1.3 Target Users

Who cares? If you are successful, what difference will it make?

Who will use this? Think of which users or customers would benefit from your research. If you have something broadly relevant or you are having difficulty identifying target users, consider common workflows in which the solution will be applicable. Who has these workflows? If specific industries or types of institutions are the target users, consider including information about the types of institution which would use your solution. Both the type of institution, and the role of the individuals who would be users or decision makers are valuable to capture.

6.1.4 User challenges

What challenges do these users have? Of those, what challenges will your solution address?

Describe specific needs of your target users. Of those, which needs do you think your solution could address? Consider the common, most important, or new activities, and current or emerging challenges of the target users. What do they need in order to accomplish these? Are any of these things particularly challenging for your target users currently? Of those, which ones could your solution address?

[9] http://alexosterwalder.com/

[10] https://venturewell.org/i-corps/team-materials/

6.1.5 Value Delivered

How does your solution address challenges for your users? How does this benefit your users?

Describe how your solution addresses challenges your target users have. Consider what a user would get out of using your solution. How are they better off using your solution compared to how they are currently doing things?

6.1.6 Activities

What do you need to do in order to deliver your solution?

The researcher should identify the activities needed to develop and deliver the solution based on their research and identify and acquire the resources to do the activities.

6.1.7 Resources & Costs

What do I need? What will it cost? How long will it take?

Capture specific resources which you will need. These may be time, money, human effort, raw materials, or any other resources you may need to complete the activities to deliver your solution. You may find it helpful to group resources into categories such as:

Personnel resources - students, professional staff, contractors
Infrastructure resources - web hosting, network infrastructure, cloud services, high performance computing resources, manufacturing, transportation

6.1.8 Funding & Revenue

How will I get the resources I need? What options are available to me which could provide me with what I need?

Describe how you will get the resources you need. Will you charge for a product or service? How much will you need to charge to break even? Will you establish a research partnership with a third-party who funds your work? Will you submit a grant proposal to a funding agency? What alternatives do you have if you don't get it? How will you account for recurring expenses as well as one-time costs?

6.2 Managing Intellectual Property

At its core, TTP involves the establishment and management of Intellectual Property – the research outcome itself. The "transfer" in question involves the sale of the intellectual property itself, either directly (via licensure to a third party) or by developing products and services based on the intellectual property. This can, depending on the business strategy a PI wishes to pursue, be retention of IP rights (and the exclusive rights to develop the products and services in a fashion under the PI's direct control,) a pure sale of the right to use results to someone else (via licensure or sale) or some combination of the two.

It's worth noting that both are fundamental to any venture creation. (i.e. if a PI decides to create a product or service startup based on their IP, financiers will require evidence that the PI holds a valid patent on the technology on which that startup's offerings are based.)

Patents are used to establish the ownership of a technology and to protect the inventors of a technology against theft of their inventions. (i.e., to prevent someone from falsely claiming ownership, profiting from it and, perhaps worse, keeping the actual inventors from accessing their inventions.) Patents are one of the cornerstones of intellectual property protection in the U.S. As patent law is a distinct specialty practice within the U.S., it is critical that you have an attorney with expertise in this area prior to taking on IP transfer, regardless of your TTP plans; furthermore, it is advisable to commence patent review of a research finding prior to taking other steps to publish or otherwise divulge the finding to the broader community.

One item that may be of particular interest to PIs for NSF and other US Government funded research is that under the Bayh-Dole Act, universities and contractors performing research under (non-classified) U.S. Government funding are assigned ownership of the results of that research and are free to patent those results and generate commercial returns from it. If you're an academic researcher, this means that your university owns the IP rights to the research you do. Another tenet of Bayh-Dole is the requirement that the university/contractor share those returns with the PI and other contributors to the effort. Institutions have royalty-sharing policies – it may well be worth researching the one your institution has adopted.

Patents are typically exercised by issuing **licenses** against them (i.e. by giving the licensing party permission to use the technology in return for some consideration.) Licensing options are diverse, each with their strengths and weaknesses, and again, expert legal counsel is advisable.

One major development in the past decade is the proliferation of open-source software and its associated license provisions. There are multiple available licenses, and it is critical to work with legal counsel to establish an appropriate schedule for doing patent filings before releasing prototypes as open source, so that you retain IP rights. A significant part of modern IP legal tradecraft involves the determination of what portion of one's research results should be released under open-source license (versus keeping them in closer hold). The volume of case law underway in this area means that this part of IP law is likely to change, at times drastically, for the foreseeable future.

6.3 Commercial Venture Creation

Another classical model of transferring technology to practice is that of forming a commercial venture to take your research results to market. This implies that you will form a technology startup and engage any of a number of strategic partners to advise, finance, and direct you in taking your products and services to targeted customers. This is an active area of interest and support, especially for the area of cyber security, and the resource section of this guide includes information on specific programs that may be useful. The following sections of this guide will dive deeper into the process used to determine whether commercial venture creation is an advisable path for a specific TTP.

7 Working with University Technology Transfer Processes

Many, if not all, investigators who desire to transfer their NSF-sponsored research into practice will have to deal with internal processes established in their home institutions. These processes are usually

designed to simultaneously assist investigators in navigating the TTP process and to protect the university. Thus, university offices may provide both resources and barriers to TTP.

7.1 TTP RESOURCES THAT MAY BE OFFERED BY UNIVERSITY TECH TRANSFER OFFICES

There are several common TTP resources that research universities offer investigators. These resources are often delivered through a technical or research park where companies that desire to collaborate with research scientists and developers may locate office staff, laboratories, and research equipment. These technology parks may also offer space for incubators that provide start-up and emerging companies with a physical footprint, administrative support, mentoring services, and other resources that can assist in the TTP process.

While resources in the university Tech Transfer office can be helpful to aspiring TTP investigators, they are almost exclusively intended to be gateways to enable PIs to acquire significant outside funding for TTP tasks. Over the course of the TTP workshop series, none of the participants had ever seen them sufficiently and fully support TTP efforts. This is not to say that university Tech Transfer offices should not be engaged, but it is important that the magnitude of impact that those resources will provide is uniformly very limited and it should not become a critical piece of the TTP plan.

7.2 TTP BARRIERS THAT INVESTIGATORS MAY ENCOUNTER FROM UNIVERSITY TECH TRANSFER OFFICES

While research universities uniformly encourage technology transfer, they are also generally aggressive in protecting university interests in the process. This goal of protecting the university's research investment generally dominates intellectual property policies for both faculty and student contributions. These policies often limit flexibility to some extent and for this reason, must be reviewed and a plan for navigating those barriers must be created prior to taking on a TTP effort.

Universities are also acutely aware of liability issues associated with technology transfer, so will rigorously guard any associated contracting processes. Legal caution can be valuable to TTP investigators, but it can also become a barrier to successful transfer.

Finally, universities are always cautious about compliance with federal, state, and university policy and will generally require rigorous compliance checks run through the technology transfer office.

7.3 ENGAGING UNIVERSITY TECH TRANSFER OFFICES

Most universities publish their technology transfer policies and procedures widely, e.g. on the university web site. As one goal of the technology transfer office is to assist investigators in the TTP process, there is usually staff available to respond to specific questions. It is well worth the time for TTP investigators to become intimately familiar with the university technology transfer web site in all its detail, which should provide the vast majority of information that is necessary for successfully navigating local TTP processes.

That said, web sites rarely cover all relevant issues and are similarly unable to provide a complete picture of the process. Having a mentor who has recently navigated the local process offers a big advantage in both limiting the negative impact of the barriers that might be encountered and leveraging all the resources that are available.

When problems are encountered, our experience is that Vice Presidents of Research (VPR) are happy to engage with faculty members who encounter problems in any area of the research and economic development ecosystem. Do not hesitate to reach directly out to assistant VPRs and VPRs in lieu of letting processes drag on indefinitely.

8 FUNDING: WHEN WILL I NEED IT AND HOW WILL I GET IT?

The TTP process can require access to significant resources, both intellectual and operational – virtually none of them come free. First, however, let's discuss the timing of funding needs.

There are costs associated with taking research results through the stages of technology transfer to practice. Though these costs may differ in scale, the timing of the need for funding is consistent for both commercial and public targeted TTP.

The first stage of funding is required to support your determining the feasibility of TTP. In the best of worlds, this is covered as part of late-stage funding of the research producing the results to be transferred. This is also the point at which patent filings and other preambles to securing intellectual property protections occur. Funding for the legal and administrative costs associated with these activities can be drawn from institutional sources, and at times is covered in the initial research grant.

The next phase of funding is required as you proceed with strategic planning. The costs incurred in this phase are typically administrative and may be modest. During this phase you will conduct the market analyses and develop a business/program plan outlining the path you decide to take. The source of funding here may well be considered internal/personal or institutional, consisting primarily of sweat equity on the part of the PI and any other parties involved in the TTP process. Many public and institutional resources are available to TTP teams at this stage of the process.

Once the strategic plan is in place, it's time to act on it. The funds required for this phase may be significant and covered by grant (in the case of public market targeted TTP,) seed stage venture or private funding (for commercial TTP) or some combination of the two. This is the phase when the TTP team/organization is formalized and staffed, market assessments conducted and marketing plans developed, and the business/program plans fleshed out at finer levels of detail. Once the desired goal is articulated, initial technology design and implementation is undertaken with the goal of placing a useful technology, product, or service in the hands of users. In the case of commercial startups, at the end of this phase, you would be expected to successfully sell your products and/or services to a set of pilot customers, collecting evidence of their value to the general market you're targeting. If your TTP takes the form of IP or public market offerings (e.g. open source software) your offer may be considered complete (and the need for funding minimal).

If, however, your TTP form or scale is longer term, during the last quarter of your seed funded stage of development, you would be expected to start a search for additional funding to support the growing of your customer base and the TTP team. In the commercial case, this would be the point at which you would commence a search for venture capital. Most venture capital firms will provide advice on their expectations for growth in return for funding they invest in your firm. With luck, you will find venture capitalists or other funding sources, executing formal agreements and receiving financing.

At this point, you and your team are considered an established firm. You would be expected to perform subsequent development to refine your technical offerings, correct deficiencies identified by users, and provide additional features that customers tell you they want. You would also be expected to recruit additional team members as needed to service growth in customers and product offerings.
Depending on your strategic plan and targeted market, you may grow aggressively, taking on additional rounds of external funding,

There are four general categories of funding that you may encounter in your TTP quest. We will define them here.

8.1 GRANTS

Grants are monies given to you or your institution to conduct research or related activities (including TTP) without any expectation of repayment. Grants can come from public (NSF, DHS, government at all levels) or private (foundations, organizations) sources. In addition to federal sources of assistance, many states and localities have established incubators and small business accelerator programs under their economic development departments. Examples of these include CyberMD (State of Maryland,) MACH37/ Virginia Center for Innovative Technology (State of Virginia) and AccelerateDC (Washington, DC).
Many include grant programs and access to angel funding networks. There are also numerous conferences and workshops targeting entrepreneurs in the security realm. These provide access to groups of potential investors, industry strategic partners, and educational materials for entrepreneurs.

The capital ecosystem for technology startups is rich and complex. They vary by a number of factors:

- The stage at which they invest.

  Investors tend to be specific with regard to when they are interested in providing capital to a growing firm. The points at which they are willing to invest can be: seed stage (i.e. before mature products and revenue from those products are available) or through funding increments that are delivered through the project period and that are defined in terms of accomplishment of predefined milestones on both product and business fronts. The stages at which firms are amenable to investing vary according to the size of the investments a firm makes or the amount of capital available to invest in a particular startup (they will often publicize this in on their website or other material targeting entrepreneurs.) One feature of the startup finance market is that of investors groups in which there can be a large number of small investors (often labeled “angel” investors) who can be amenable to making small, seed stage investments.

- The nature of their funding sources

  When your startup focuses on a specific vertical market (e.g., if you provide security solutions for nuclear power generation facility control systems) you may find funders who specialize in providing capital for those specific constituencies. Of note here are the investment funds associated with specific manufacturers or major vendors (e.g., Intel Capital, Microsoft, Qualcomm, and Google are but a few.) These strategic investors usually invest in later rounds of funding (i.e., when a firm is established, with customers and associated revenue,) but can provide connections that are critical to a startup’s growth.

- The market focus of their investment activity

  Different firms have different investment strategies. One element of these strategies is the market focus of the capitalist in question. Depending on the size of the capital firm, they may have an investment team with direct experience in the market in question (e.g., cyber security) and other investments in this target market. As much of the value of an investor lies in their ability to help you make critical connections necessary to enable your firm to grow, investors with a good track record in security specific investments (or in the market segment your solution seeks to protect) are likely to be of value to you.

- Their management style and reporting requirements

  A popular joke in the startup community is that forming a relationship with a venture capitalist is somewhat akin to entering a marriage. You will likely weather some of the most stressful experiences of your adult life with this person or team, and it's worth considering whether you're comfortable with their personalities, management style and expectations regarding control and reporting before entering the relationship.

8.2 Institutional funding

Institutional funding comes from academic, government, or other public institutions and is often relevant to TTP targeting public markets. The funding may come with some expectation of control over the products and services transitioned to practice.

8.3 Contracts

Contract funding enables your TTP efforts to perform specific tasks for customers. This sort of funding can take the form of a subcontracting agreement (as might exist between your TTP team and a government contractor,) or a specific variation on a venture capital model in which you are funded to amend your products to meet the needs of specific customers, who, in turn, purchase those amended products. When the contract tasking coincides with your strategic plan, contract funding can be beneficial to you, as it provides funding and often access to customers without expectation of repayment of those funds. In particular, the funds you gain from contract sources are *non-dilutive* (i.e., you aren't expected to exchange ownership and associated control of your firm for the funding.) In the case of contract funding, it is critical to negotiate appropriate IP rights for those portions of your TTP offering used to satisfy the contract requirements. In the case of public-market targeted TTP efforts, it is also important to negotiate ongoing support for revision and maintenance of your products, in order to prevent sustainability issues in the future.

8.4 Venture

Venture capital is an integral part of the commercial market targeted TTP. Venture capitalists (VC) are businesspeople who arrange funding for high-risk usually technology-centric businesses, using a combination of business and technical expertise to manage risk exposure. Venture capital is usually dilutive (i.e., the funding provided by VCs is treated as an acquisition of some ownership stake – shares - of the company) and firms can be extremely focused regarding the industries they finance. Most VCs will publish the specifications for the sorts of firms they'll consider financing (e.g. stage of development

of the company, revenue levels, etc.) and are willing to meet prospective investment targets well in advance of the funding event.

There is a specific scenario discussed in our workshop that can apply to some PIs and their transferrable technologies. One specialty investment entity who serves a retained set of clients, works in the following fashion:

- Equipped with an understanding of what their clients consider pressing problems, they survey the technology startup world for approaches that are good matches for those problems.
- They approach the firms in question to explore whether there is interest in adapting their offerings to meet the needs of the clients.
- If there is interest, they establish that there is indeed a good match between needs and offerings, negotiate a price for performing the adaptation of the technology, and establish a funding relationship with the startup.
- In a successful scenario, pressing problems are solved for their clients, and startups are provided with revenue-generating product lines and customers without expending equity to acquire them.

There are similar situations available in both commercial and public/academic settings that require additional adaptation of transferred technology to meet specific needs.

8.5 US GOVERNMENT OFFERINGS

NSF and other government organizations sponsor programs that are designed to assist investigators in successfully engaging in the TTP process. These programs can provide valuable resources, including funding, mentoring, best practices, etc.

8.5.1 NSF SaTC TTP Option/Perspective

Programs within NSF CISE began offering investigators an opportunity to request supplemental funding for their projects at the time of the proposal to incentivize TTP of their proposed research results. Within the Secure and Trustworthy Cyberspace program, the TTP option has evolved into a separate "perspective," where funding is provided to transition research results from prior SaTC projects into practice, funded as small and medium SaTC awards.

8.5.2 NSF SBIR/STTR

The Small Business Innovation Research Program (SBIR)/Small Business Technology Transfer (STTR) Program (http://www.nsf.gov/eng/iip/sbir/home.jsp) is a federally funded program that underwrites technological innovation and commercialization of the results. It is structured as a two-phase program, a short (6-12 month) exploratory phase, in which the feasibility of an approach is explored, that can potentially be followed by a longer (two year) development grant. It can be viewed as government-funded angel capital that is non-dilutive (i.e. unlike most venture capital, you do not give up equity in your firm in return for funding.)

8.5.3 NSF I-Corps (Innovation Corps, http://www.nsf.gov/news/special_reports/i-corps/)

The NSF Innovation Corps (I-Corps) is a program designed to enable engineers and scientists to identify their research results that are likely to be of commercial promise, equipping them to take those results

to market successfully. The program is built on modern models of technology startup practice and offers innovative entrepreneurship training and mentoring to academic participants. It is intended to encourage quick transfer of technology to product markets, thus helping customers solve pressing problems as well as encouraging economic development and associated high quality jobs. The program is a public-private partnership, and gives PIs and their students access to training, mentoring, and expert counsel as they assess their research results and then build successful commercial startups based upon them. There are specific TTP-community versions of I-Corp; information on these is available from the program website.

8.5.4 DHS

In the current TTP ecosystem of the U.S. Government, the responsibility for tracking and enabling timely transfer of federally funded security research results is shared between the National Science Foundation and the Department of Homeland Security. The general split of focus between the two entities is that NSF focuses on more theoretical, academic efforts, while DHS is focused on efforts that are more applied in focus (i.e., they are closer to being deployable to solve pressing issues involving the critical infrastructures DHS is charged with protecting). This split in focus is not hard and fast – if your research results could be viewed as falling into either domain, a discussion with the appropriate program manager is advisable.

9 TRAVERSING THE TTP STAGES

9.1 GENERAL TTP APPROACHES AND ASSOCIATED STAGES

Technology transfer requires coupling of several integrated processes. Depending upon the desired TTP channel utilized to transfer research results, the process models can vary widely in complexity and time and effort required. The following three process models capture the vast majority of academic TTP efforts.

9.1.1 Patent/IP licensure

As mentioned previously, any significant finding produced during research will likely be a candidate for patent protection. This is a complex process, and it, as discussed earlier, requires significant legal expertise and counsel to navigate the process. It is also, as mentioned before, fundamental to any transfer of research to use in revenue-producing situations (be that outright sale or licensing of patents to others, or use of the intellectual property as basis for a product or service.)

9.1.2 Academic or Government use

Once the technology has been recorded and protected by filings for patent protection, assessment of target markets is the next logical step. Should this assessment (or, for that matter, the original intent of the research in question) indicates that there is a non-commercial market target for the technology (e.g., it will be used to enhance protection of specific types of datasets held exclusively in federal research centers), one may well utilize any of a number of open-source mechanisms to make the technology available to the target market. In SaTC, such targeted technology is likely to take the form of open-source software, at times accessible as a managed service. There are several licenses associated with open-source software, each with their own features, and several repositories for such software.

Sustainability (i.e. the ability to fund maintenance and enhancements for given software products) is a source of some concern in open source communities. It is worth considering whether forming a small business expressly to support a given software offering (charging a maintenance and support fee to users) makes sense for that product.

9.1.3 Commercial Use

As indicated in the introduction to this guide, the discussion of TTP in many technology circles presumes that the majority of technology transfer occurs when research results are expressed in commercial products and services. This begs the issue of the other TTP targets and mechanisms, but also offers unique advantages (including significant returns on the time and energy invested in the original research as well as TTP). There are many variations on the core concept of building a saleable product and service offering, then assembling the business infrastructure around that set of offerings to deliver it to paying customers. Once the PI has determined that there is interest in pursuing this TTP strategy, we recommend that you utilize both the NSF-provided resources outlined elsewhere in this guide, as well as those provided to the general technology entrepreneurial community.

9.2 TTP Models specific to security-related markets and associated offerings

One joke regarding the security related technology market asserts that its catch phrase should be that of a popular telemarketer of the late 20th century "But wait there's more!" It'll be critical that you keep up with what is expected by customers to install and use your security product.

9.2.1 Tests and assessments of products before installation

Increasing numbers of customers, especially those in heavily regulated industries, may expect you to run your products through security-specific testing and assessments before they're considered for use in certain target centers. These requirements may extend to security-specific tests that you subject your software and systems to as part of standard testing and quality assurance. Such requirements take time and resources and should be reflected in development process plans, schedules, and budgets.

9.2.2 Tests and ongoing assessments once the product is installed

Another trend in critical customer circles is to expect to perform security specific tests on installed products to assure that your product doesn't negatively affect the security related management of the systems your product is meant to protect. Again, your product design and development should include provisions to assure this installation testing goes well, and your plans, schedules, and budgets should reflect any need for such activities (including any corrective actions that might be required).

9.2.3 Procedures for responding to newly discovered security problems (patches.)

Finally, given the rigor of attack upon modern operational environments, it is common for all parts of the operational system to be subject to attack, and for that attack to be successful from time to time. Security solution providers are expected to be capable of responding to attacks that successfully bring down their products and services, correcting the problems and restoring the systems to secure operation. Again, take these requirements into account as you construct maintenance plans and procedures for your products, and budget adequate time and revenue to cover these needs.

9.3 Sources of guidance

Depending on the TTP path you decide to take and the magnitude of the offering you choose to transfer to use, there are a plethora of guidance sources available for your use. Most of these overlap with the federal TTP funding agencies that are described in Section 8 above. For example, a logical place to start is NSF itself, which has TTP-specific programs for which you are likely eligible. Depending on the technology you've produced, DHS may also have programs that are a good fit for you. Reaching out to other members of the SaTC community who have transferred similar offerings to users is also advisable, as they are likely to have an idea of good sources of support as well as lessons learned. Finally, there are a bevy of online resources that target various channels for transfer (e.g., open-source software, startups, IP licensure, and target market user groups) that can help you sort through the various paths you might take.

9.4 Review cycles and tracking mechanisms

Expected review cycles and tracking mechanisms will likely depend on the path you select for TTP. These are usually defined and enforced by those who fund the transfer process (and can range from the research funding agency, your home institution (department or Office of Research,) or funding entities (review cycles are usually defined by venture capital or other funding entities, who will provide tracking mechanisms as part of the setup process prior to funding.) One difference worth noting between public and private funding sources is that the pace of private sources is likely to be significantly faster than for public, with more frequent meetings and an expectation of quicker responses to issues as they arise.

10 Advice from Veterans of the Cyber-Security Specific TTP World

10.1 "If I knew then what I know now…"

This workshop series was a rare opportunity to hear from a number of professionals who have gone through cyber-security technology transfer to practice on both public and private fronts. They represent a number of key constituencies in achieving TTP success (ranging from legal counsel and venture capitalists to PIs and government program managers) and were generous in sharing the insights they have gained over their years in this area.

10.1.1 Navigating the Transition from Academic PI to Commercial Startup

- "A key element of success in successful TTP is having a team leader who has passion for the proposed technology solution. Chances are, should the path chosen be a commercial startup, if the PI isn't involved in the startup, the TTP won't be successful. If you, as a PI aren't interested in being so involved (and if there is no alternate principal,) you should consider TTP using another path (e.g., licensing your technology to another firm.) "

- "Take the time to assess the expertise and world view of your university TTP office before deciding to involve them in a commercial effort. Many of those charged with overseeing TTP are unfamiliar with tech transfer approaches that are appropriate to cyber security or other information technologies and may well doom your prospects. In particular, some believe that the only sign of TTP success is a licensure revenue stream."

- "There is a fundamental mismatch of academic and commercial clock speeds. It is critical to be cognizant of this when considering whether to take your solutions to practice via commercial vs private paths."
- "Not all academic PIs are well-suited to being entrepreneurs. Those who are can increase the quality of their home institution in many ways, both directly (via the value of the firms they build in which the university owns equity) and indirectly (via their industry links and reputation.) Universities should consider ways of enabling entrepreneurial PIs to gain credit for their TTP pursuits as an integral part of a modern academic career."
- "One way of enhancing your ability to identify and service strong TTP 'pull' opportunities is to identify a likely target market and then attend an industry conference for that market (or otherwise access industry gatherings) to gain a better understanding of their needs."

10.1.2 "What the business texts don't tell you…"

- If you are interested in using the entrepreneurial path to TTP, industry analysts (e.g. Gartner, Forrester, etc.) are key allies as you define and refine your products to meet the needs of commercial markets.
- Though open-source software models are extremely popular, use of them should be considered in a grander strategy over the life of a technology or firm. Several firms started out with open-source offerings that were taken back into closer hold as the business matured. Others reported issues with ongoing maintenance and other support issues (sustainability) over time.
- Although many TTP texts and programs focus on IP licensure and venture capital-backed startups as if this were the only path for TTP, transferring technology to use by academic and/or government markets is also critical to the nation. This use of research results to enable other researchers to tackle large problems is an area in which the technology-driven "push" model can flourish. Such user bases can be more sophisticated and capable of making constructive suggestions as to how the technology might be adapted in order to move forward.
- It is important for PIs and the institutions which fund them to understand that over time, research results can cross the line from "push" to "pull." Security is a response function where advances in the sophistication levels of attacks can require responses that had been treated as purely theoretical in past discussions. Although one may presume that a body of knowledge is only of value to a tiny research community, this can change very quickly.
- Many states and local governments offer various forms of assistance to those seeking to perform TTP, ranging from incubators (offering low-cost rent, facilities, infrastructure, and access to other startup needs) to small business grants and finance programs. It is well worth exploring such sources of assistance available to you.

10.2 WHAT DOES THE LITERATURE SAY?

1. E. Ries, The Lean Startup - How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses, Crown Business, 2011.

The Lean Startup outlines an approach to TTP that focuses on minimizing the amount of capital needed to take a technology to use. It dovetails with a modern transformation in the IT TTP process world, and, though the focus of the book is on products servicing more consumer level needs than most cyber security offerings, it's still good reading for a prospective entrepreneur.

2. S. Blank, "Why the Lean Startup Changes Everything," Harvard Business Review, May 2013.

   Steve Blank, PhD, an academic and consultant in business, is a key influencer of modern thinking on technology entrepreneurship and TTP. This paper presents Blank's argument for Lean Startup and outlines how he argues that it has a lasting effect on models for modern entrepreneurship.

3. T. Benzel and S. Lipner, "Crossing the Great Divide: Transferring Security Technology from Research to the Market," IEEE Security and Privacy, Vol. 11, No. 2, pp 12-13, March-April, 2013.

   Benzel and Lipner , two influential members of the security research community were also part of an early security entrepreneurship; Lipner proceeded to join Microsoft, where he served as a lead security technologist. In this paper, they discuss many of the issues associated with TTP specifically for the cyber security market.

4. T. Benzel, W. Arbaugh, E. O'Brien, J. Sebes, and R. Rodriguez, "Crossing the Great Divide: From Research to Market," IEEE Security and Privacy, Vol. 11, No. 2, pp 42-46, March-April, 2013.

   In this paper, a number of members of the cyber security research community (several of whom successfully transferred their research results to commercially successful firms) discuss the issues associated with the cybersecurity TTP process.

5. D. Maughan, D. Balenson, U. Lindquist, and Z. Tudor, "Crossing the 'Valley of Death'- Transitioning Cybersecurity Research into Practice," IEEE Security and Privacy, Vol. 11, No. 2, March-April, 2013.

   Maughan, Director of Cyber Security Research for US-DHS, and a number of Cyber Security Senior Scientists from SRI International, discuss their findings from an ongoing study of TTP discussion issues specific to cyber security research TTP.

6. R. Bace, "Pain Management for Entrepreneurs: Working with Venture Capital," *IEEE Security and Privacy, Special Edition – Basics for Tech Transfer*, 2013

   Bace, former research director for the National Security Agency, who subsequently served as a cyber security specialist for a major venture capital firm, shares advice on acquiring venture capital funding for cyber security startups and managing the relationship between entrepreneur and venture capitalist through the life of the startup.

7. Juan Pablo Diánez-González, Carmen Camelo-Ordaz , "How management team composition affects academic spin-offs' entrepreneurial orientation: the mediating role of conflict," *The Journal of Technology Transfer*, Volume 41, Issue 3, June 2016

   A business academic discussion of how management team composition influences entrepreneurial TTP endeavors.

8. Gideon D. Markman, a, Phillip H. Phanb, David B. Balkinc, Peter T. Gianiodis, "Entrepreneurship and

university-based technology transfer," *Journal of Business Venturing*, Volume 20, Issue 2, March 2005, Pages 241–263

A set of business academicians report on a study they did of university tech transfer offices, reporting on what services were provided, those that appear to have been of greater value to PIs seeking to TTP research results, and those that were counterproductive. Great reading for a PI determining at what point (and to what extent) to involve the university TTP offices.

10.3 "THESE ARE THE RESOURCES I RELIED ON THE MOST..."

10.3.1 Colleagues

One point made time and time again was the importance of community support, especially from colleagues who have engaged in TTP activities in the past. Many of the issues and roadblocks that arise while conducting TTP are consistent, if not well-published, and advice from those who have faced similar challenges is likely to be of value to you.

10.3.2 Industry gatherings

Regardless of whether the TTP activity undertaken targets commercial or public/academic channels, it's critical to understand the constituencies and markets that use your technology. Industry conferences offer access to these users and an opportunity to better understand how to enhance and improve your offerings. There are online communities that can offer such opportunities as well, especially in open-source software circles.

10.3.3 Industry Analysts

Industry analysts (e.g. Gartner Group, Forrester, 451 Group) specialize in understanding specific technology markets, gaining this expertise by conducting research, interviewing major customers in specific markets, and publishing reports on noted needs and solution approaches. They counsel major users of products, the vendors who provide those products, and investors who invest in those product markets. Although full reports must be purchased, synopses are often available online and individual analysts are often present in industry gatherings and amenable to conversations.

11 CONCLUSION

The topic of transferring technology to practice is of critical interest today, especially in Cyber Security and Assurance research communities, where future funding may depend upon demonstrating a research result's ability to improve the state of security for some set of constituents. In our workshop series, we had the rare opportunity to discuss issues in the current TTP ecosystem, as well as those that are arising as the ecosystem adapts to a period of significant change. This workshop series has been especially valuable in that we've had the opportunity to acknowledge the value of transferring critical capabilities to constituencies that do not fit the criteria associated with commercial market segments. This is an acknowledgment that transferring enabling technologies for future research and exploration is of significant value to the nation, and that such transfer merits significant support as well.

In the guide we describe the TTP process and address issues of innovation, risk, resources, and

opportunities. This guide is designed for academic Principal Investigators who are considering or are engaged in TTP and discusses the role of the PI, considerations for forming the leadership team, the funding process, and advice from TTP experts. Our ultimate intent is to increase the number of investigators that decide to engage a TTP approach from the beginning of project planning and to facilitate the success of those who choose to engage TTP.

As those who conduct the research that produces the technological advances in question, PIs are a critical factor in improving TTP for security technologies. We hope that this guide (that synopsizes the findings of those workshops - and the experiences that instigated them) serves to guide PIs in negotiating this critical phase of research in Security and Assurance.

APPENDIX A – Workshop Participants

Workshop #1	
Name	**Company**
Barry Costa	Mitre
Roberto Perdisci	Uga
David Balenson	SRI
Donald Dixon	VC
Deborah Shands	NSF
Rebecca Bace	USA
Alec Yasinsac	USA
Angelos Stavrou	Kryptowire
Robin Sommer	ICSI
Jenny McNeill	SRI
Anita D'Amico	Secure Decision
Ulf Lindqvist	SRI
Jim Basney	NCSA
Robert Stratton	Mach37
Randy Sabett	Cooley LLP
Peter Kuper	IQT
William Arbaugh	Five Directions
Mark Cummings	Orchestral Netw
Matthew Alderman	Tenable
Richard Abramson	SRI
Chenxi Wang	CiberCloud
David Stampley	Kamber Law
Eric Byres	Byres Security
Wenke Lee	GaTech
Inder Monga	ESNet
Paul Vixie	Farsight Security
Robert Broberg	CISCO
Alberto Dainotti	UCSD

Workshop #2	
Name	**Company**
Alec Yasinsac	USA
Anita LaSalle	NSF - iCorps
Anita Nikolich	NSF
Becky Bace	USA
Bob Stratton	Mach37
Burt Kaliski	Verisign
Chris Ramming	Intel
Daniel Fabbri	Vanderbilt
David Balenson	SRI
David Corman	NSF - CPS
Don DuRousseau	GWU
Florence Hudson	I2
Gail-Joon Ahn	Arizona State
Jason Nieh	Columbia
Jeremy Epstein	NSF - SaTC
Matt Elder	Symantec
Mingyan Liu	Michigan
Peter Atherton	NSF - SBIR
Radu Sion	Stony Brook
Ralph Wachter	NSF
Steve Tuecke	Globus
Susan Sons	IU