



TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF)

Five-Year Project Plan

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**Submitted by:
Kimberly Andrews Espy,
Senior Vice President for Research
Office for Research & Discovery**

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF)

1.1 Executive Summary

At the University of Arizona (UA), our plan for TRIF investments for the last five year period reflects the foundation of why universities do research and development (R&D): to attract outside resources to our state, expand economic opportunities for Arizonans and benefit the well-being of our citizens.

This past year, UA researchers were responsible for more than \$606M in R&D activity – ranking in the top 20 among our public university peers. Particularly deep R&D strengths in the physical sciences are reflected in our # 3 ranking – among the 634 universities surveyed by the National Science Foundation (NSF). UA's TRIF plan is centered on leveraging TRIF investments to bring in more monetary resources to our state and further our progress towards the 2025 R&D goals established by the Arizona Board of Regents. For each of our recurrent TRIF initiatives, the anticipated return is five times or greater the initial investment, based on our historic performance as well as the close alignment with upcoming federal opportunities and extant university strengths.

An important marker of our research success is the impact on our students. Active participation in university R&D, particularly in the TRIF areas, is critical to workforce development, part of our commitment to student engagement in R&D activities that prepare them for the high tech work environment of tomorrow. Students at all levels are being trained as innovators, with meaningful lab experiences that develop science skills, problem solving and entrepreneurial thinking.

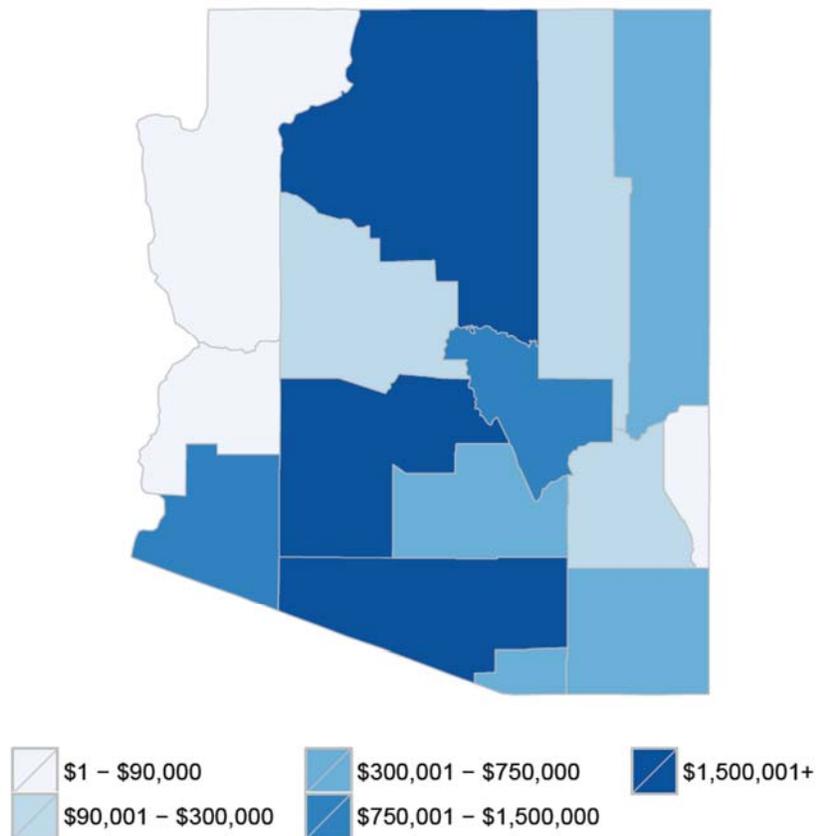
Data from the Institute for Research on Innovation and Science consortium revealed that between 2012 and 2014, UA's federal R&D funds directly employed an average of just over 2300 students per year (38% of the total of 6,091 individuals employed on federal research funds at the University, more than any other category of employee).

The University is promoting and accelerating the translation of research results into new products and services that benefit the health, security, and prosperity of Arizona. In the last 5-year TRIF planning period, commercialization of research results was a strong focus – with substantial investments in technology transfer activities through Tech Launch Arizona (TLA). This focus borne substantial fruit – from the beginning of the last five year period through FY15, 314 inventions were disclosed, 61 patents issued, 77 licenses or options executed, and 12 start-up companies were established from UA R&D. The present plan includes a continued focus on commercialization - and with our new participation in National Security Systems TRIF initiative and with the maturity of TLA – even greater results are anticipated.

Finally, R&D activity supports the bottom line of our local communities, state, and nation. From 2012 through 2014, UA R&D generated \$1.1B of direct economic impact through the purchase of equipment, technologies, and business relationships with private and public organizations nationally. Direct procurement with federal R&D funds from outside vendors was distributed across 760 US counties.

Although the majority of federal R&D funds are used directly for jobs and employment to execute the science, \$47M were used for equipment purchase, technology or service procurement and other business relationships across all nine Arizona counties. UA R&D has a wide-ranging, corner-to-corner, direct economic impact on our state.

Federal research award expenditures on vendors & subawards in Arizona counties, aggregated across 2012 Q1 - 2014 Q4



UA's TRIF plan includes activities under four initiatives: **National Security Systems (new), Space Exploration & Optical Sciences, Water/Environment/Energy Solutions, and Improving Health**. Fundamental to our approach to TRIF investments is the University's *Never Settle* strategic plan, which explicates our tactics to achieve our research ambitions: promoting our core strengths to address the grand challenges, boundlessly collaborating with others to increase local-to-global impact and improving our institutional infrastructure to help speed discovery, knowledge and application.

The thrust areas for each TRIF initiative were identified through an organized research

roadmapping exercise run by the Office for Research & Discovery (ORD), which was designed to generate areas that transcended a given discipline, was oriented to a grand challenge, broadly engaged campus researchers across disciplines, and aligned with external funding opportunities. These thrusts foster collaboration and promote innovations by driving cross-sector partnerships that will lead to scientific and technological solutions to grand challenges, and delivering tangible benefits to Arizona, the nation, and the world.

- **National Security Systems (NSS)** TRIF initiative impacts a broad range of R&D, translation and commercialization efforts at the University. UA is participating in this TRIF Initiative for the first time for this 5-year period, leveraging our newly created Defense & Security Research Institute (led by an experienced Director with deep government and industry expertise in NSS matters) and coupling our extant expertise in physical science that is the basis much of the technology used in defense and security applications with Arizona's existing high tech economy that has strong presence in national security and defense.

Arizona ranks fourth nationwide in aerospace industry payroll and fourth in aerospace revenue at \$14.9B, with more than 1200 Arizona based companies that make Arizona the country's third largest supply chain contributor in this area. UA's TRIF investment in national security systems will contribute toward continued growth in the defense industry and supporting infrastructure in Arizona.

The NSS initiative at the UA focuses on these main thrust areas: **Space Dynamics; Materials Design & Development; Imaging & Sensor Technologies; Cybersecurity** and **Biopreparedness and Surveillance: "One Health" Approach.**

Because UA is participating in the NSS initiative for the first time, the focus for the expected return on TRIF investment in NSS is on growing R&D activity – both

government and industry sponsored. This focus on expanding the “beginning” of the pipeline of innovation – R&D expenditures, will ensure longer-term dividends in later translation and commercialization. Our current base of DoD-related R&D expenditures is over \$22M, and our projected increase as a result of TRIF NSS investments is a 50% gain over this first, “start-up” period. Our tactics to realize this return includes new strategic faculty hires, investment in catalytic projects that seed large scale collaboration and industry partnering that are aligned with national needs, as well as education, outreach and training activities.

- **Space Exploration and Optical Solutions (SEOS)** TRIF initiative will add strategic capacity, incubate novel research directions and increase R&D, impact regional economic development, and expand opportunities for students by leveraging UA’s world-renowned expertise and resources in optics, astronomy, planetary science, missions and instrument development. Although Optics/Photonics is explicitly captured as a key industry sector by the ACA for Arizona, UA’s strong international reputation, talent base, and linkages in space exploration, advanced optics, photonics, and imaging technologies support growth in literally every industry sector in Arizona identified by ACA – from bioscience to manufacturing.

There were 191 companies who identify themselves as optics and photonics related industries in Arizona in 2014, an increase of 27% over the past decade, with an average wage of over \$61,000. This sector accounts for more than 25,000 employees, and is responsible for \$2.3B in revenue, over \$45M per firm. The majority (68%) are located in Pima County, and 46% have been in operation for more than a decade.

SEOS affords tremendous opportunities to advance UA’s *Never Settle* strategic plan through its continued investment in core research strengths in space systems, including scientific missions in astronomy, astrophysics, and space exploration. In

FY 2014, UA was ranked third in research activity in the physical sciences (\$124 million in expenditures) by the National Science Foundation. UA faculty led ALL institutions in research activity in Astronomy for each and every year in the past decade. UA's planetary science and missions are second to none. The TRIF plan focuses on applying these strengths to new challenges – such as image or sample returns from Mars, instrumentation for a lander on Europa or habitable planet discovery and exploration. TRIF investments in the SEOS initiative have a strong track record of delivering on the identified performance metrics.

SEOS programmatic areas for investment align with UA strengths and areas of Arizona and national need. The SEOS initiative at the UA focuses on four main thrust areas: **Space Exploration, Optics/Photonics; Imaging and Enabling Technologies, Informatics.**

The University expects to realize a substantial return on TRIF investment in SEOS through a combination of increased sponsored R&D awards in FY17 of \$60M annually, commercialization of valuable intellectual property from research activities, and training the next generation of leaders in this area. The planned tactics to realize this return are new strategic faculty hires, investment in catalytic projects that seed large scale collaboration and industry partnering aligned with national need, substantial funding in asset development to speed commercialization to the marketplace, as well as education, outreach and training activities to augment and enhance our high tech workforce.

- **Water, Environmental and Energy Solutions (WEES)** TRIF initiative seeks to develop novel, economically viable solutions to Arizona's water, environmental, and energy resources challenges with far-reaching societal benefits. The UA engages in R&D activities and cross sector partnerships that brings innovative ideas, technologies and resource management practices to address pressing

environmental, energy, and water challenges and to deliver tangible benefits to Arizona, the nation, and world.

The thrust areas identified in the WEES initiative plan are focused directly on areas of current and potential funding, partnerships with business and non-governmental entities, and high-priority workforce needs. The WEES initiative at the UA focuses on these main thrust areas: **Water Security in Arid Environments; Climate and the Earth System; Ecosystems, Conservation and the Earth's Biological Systems; Environmental Health and Contaminants; Advanced Energy Solutions and Integrated Research and Data Systems.**

WEES investments will bring significant public and private external R&D funding to the UA and Arizona by tactics such as recruiting world-class faculty in cutting-edge research areas, and by building interdisciplinary collaboration across campus and in partnership with Arizona businesses and governments, and training the next generation of leaders in this area.

The University expects to realize a substantial return on TRIF investment in WEES through a combination of increased sponsored R&D awards in FY17 of \$31M annually, commercialization of valuable intellectual property from research activities, and training the next generation of leaders in this area. The planned tactics to realize this return are new strategic faculty hires, investment in catalytic projects that seed large scale collaboration and industry partnering aligned with national need, substantial funding in asset development to speed commercialization to the marketplace, as well as education, outreach and training activities to augment and enhance our high tech workforce.

- **Improving Health (IH)** TRIF initiative is designed to accelerate UA R&D by successfully tackling complex and pressing health problems of critical importance to Arizona and the nation. UA's Improving Health investments are focused on

supporting R&D activities that improve the lives and health of our citizens, while creating high quality and high paying jobs within the state while engaging students in science to prepare them for high tech careers in the biosciences and beyond. The Arizona Commerce Authority (ACA) identifies biotech as a major target industry for growth.

The UA is the only academic enterprise in the state that links a research university with an affiliated level one trauma/world class teaching hospital, a comprehensive health sciences center, two colleges of Medicine (Tucson and Phoenix), and a collaborative bioresearch institute (BIO5 Institute) that spans R&D areas from agriculture to the Zika virus. With the newly cemented partnership with Banner Health and its commitments to the clinical research enterprise, the planned TRIF IH will accelerate the incorporation of research results into the health marketplace to benefit Arizona and enhance our quality of life.

The UA *Never Settle* plan calls for the following strategies to grow and support our bioscience economy: enhance translational research, grow the entrepreneurial climate, build critical mass of companies, advance R&D base, and expand STEM education to develop high tech talent. UA's IH plan aligns with these strategies.

IH areas for investment were carefully chosen to align with areas of Arizona and national need, for which UA faculty already have significant expertise, and which have the capacity to grow in impact, economic opportunity, and external funding when supported by this initiative. They are focused directly on areas of current and potential funding, partnerships with business and non-governmental entities, and high-priority workforce needs. The IH thrust areas are: **Biology of Aging and Age-Related Diseases; Precision Medicine by Enabling “Omics”; Advancing Health Outcomes through Technology; Infectious Disease and the Science of Microbiomes; Data Driven Discovery and Bioinformatics; Bioimaging and Enabling Technologies.**

IH investments will bring significant public and private external R&D funding to the UA and Arizona by tactics such as recruiting world-class faculty in cutting-edge research areas, and by building interdisciplinary collaboration through funding of catalytic projects among researchers across campus and in partnership with Arizona businesses, and training the next generation of biotech leaders and high tech workers.

The University expects to realize a substantial return on TRIF investment in IH through a combination of increased sponsored R&D awards in FY17 of \$60M annually, commercialization of valuable intellectual property from research activities, and training the next generation of leaders in this area. The planned tactics to realize this return are new strategic faculty hires, investment in catalytic projects that seed large scale collaboration and industry partnering aligned with national need, substantial funding in asset development to speed commercialization to the marketplace, as well as education, outreach and training activities to augment and enhance our high tech workforce.

Finally, planned IH equipment investments are designed to create long-term return on investment through ongoing master research agreements, such as, the currently successful partnership with Siemens for MRI pulse sequence development.

1.2 Outline of University mission and goals

The mission of the UA's TRIF plan is common across the NSS, SEOS, WEES and IH initiatives – to deliver economic value and public benefit to the state of Arizona.

The goals, although stated somewhat differently in each initiative, are fundamental and cut across each TRIF initiative:

- Increase external funding to our state
- Translate and commercialize R&D to create jobs for our Arizona economy for which our citizens are well prepared
- Provide public benefit that positively impacts our quality of life and well-being.

The University is committed to meeting the grand challenges of our day and developing the bold solutions for a better Arizona.

1.3 Outcomes

The outcomes of the UA's TRIF initiatives will focus on bringing the R&D out of the labs and into the real world to improve the lives of Arizonans. Outcomes across the TRIF initiative include: increases in R&D expenditures, invention disclosures, licenses and options executed, start-up companies and improved workforce development. Among the potential public benefits from our TRIF initiatives,

- advances in wearable technology that monitors clinical indicators in real time that can enable individuals to lead healthier lives
- unmanned mission, instrumentation or lander of destinations such as Europa or other habitable planets
- new technology to identify, classify, track and predict man-made objects in orbit that likely intend to threaten US commercial assets and to enable avoidance to secure protection and in space
- create "toilet to tap" technology that will help secure precious Arizona water resources and reduce energy utilization for our future generations in our region

1.4 Overall budget

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) SUMMARY

FINANCIAL SUMMARY	Budget FY 17	Budget FY 18	Budget FY 19	Budget FY 20	Budget FY 21
REVENUE					
TRIF Revenue	27,318,400	28,918,400	30,518,400	32,118,400	33,718,400
TOTAL	27,318,400	28,918,400	30,518,400	32,118,400	33,718,400
EXPENDITURES					
OPERATING BUDGET	22,428,400	24,028,400	25,628,400	27,228,400	30,718,400
CAPITAL BUDGET	4,890,000	4,890,000	4,890,000	4,890,000	3,000,000
TOTAL	27,318,400	28,918,400	30,518,400	32,118,400	33,718,400
SUMMARY BY INITIATIVE					
Improving Health	11,155,000	11,697,093	12,257,169	12,817,244	11,959,821
Space Exploration & Optical Solutions	6,852,500	7,273,532	7,697,226	8,120,921	9,017,115
Water, Environmental, Energy Solutions	5,607,500	6,007,534	6,407,573	6,807,612	7,680,150
National Security Systems	3,703,400	3,940,241	4,156,432	4,372,623	5,061,314
TOTAL	27,318,400	28,918,400	30,518,400	32,118,400	33,718,400

1.5 Marketing/Communications Overview

With this plan representing the last 5-year cycle in the approved 20 year TRIF authorization in Proposition 301, marketing and communications of the resulting outcomes and successes of TRIF investments will be critical in informing the public about the benefit of the program, as well as its short and long term importance in making Arizona a better place for its citizens. The key is to create a marketing campaign that provides real stories about tangible benefits that matter – characterizing or “painting a picture of” how TRIF affects everyone in the state and delivers a positive impact that matters to our economic viability and quality of life.

The ability to leverage the TRIF modest sales tax to support public investment in R&D that brings in new revenues to the State, bolsters key industry strengths and grows new jobs and businesses from corner-to-corner is a unique – and compelling – feature to be highlighted. However, to achieve the goal of sending a clear, positive message to external stakeholders about the value of TRIF, a coordinated effort among the three Arizona universities is critical. Common packaging of stories, with similarity in format, can be a

powerful way to demonstrate the collective value and importance of the program across the state.

In this collaborative context, the Research Communications division of the Office for Research & Discovery will work with the University's Chief Marketing Officer to promote the university's TRIF initiative in a variety of ways, with a focus on research impact, economic drivers, and public benefit.

Stories and projects will be identified that showcase impact of TRIF investments on Arizona – bringing outside resources into Arizona that are spent locally; technology and company creation, workforce development and the impact of the ensuing technologies, products, patents and public benefits that impact our quality of life.

The main vehicles for distribution include:

- Video assets that can be distributed and integrated in a number of venues to tell the impact stories and Arizona talent that the TRIF program has delivered
- Social media (Twitter, Facebook, etc.) to highlight UA activities and outcomes supported by TRIF. Currently, the marketing reach of UA social media accounts exceeds 1M.
- Traditional media tactics, such as press releases, to promote stories in venues of influence, with distribution to include local, regional and national media.
- University Relations distribution vehicles, such as UANEWS, that is sent electronically to media, influencers, community and other UA stakeholders.

ORD will regularly convene communicators from across campus to advance the development of compelling stories and anecdotes that can be used to showcase TRIF successes.

1.6 University Administration of TRIF

The Office for Research & Discovery, under the leadership of the Senior Vice President for Research, is responsible for the overall strategic planning and execution of this TRIF plan and resource deployment. ORD has identified and selected key leaders to guide the implementation within each initiative, who will work to encourage novel ideas and robust participation that enable the TRIF goals, as well as to intersect with university processes to ensure seamless operations. ORD regularly convenes R&D leadership to maintain focus on goals and provide avenues for problem-solving, and oversees the robust annual reporting process that enables any mid-course adjustments as warranted.

INITIATIVES

2. NATIONAL SECURITY SYSTEMS (NSS)

This 5-year period is the first time that the (UA) has participated in the National Security Systems (NSS) TRIF Initiative. With the new establishment of the Defense & Security Research Institute at the UA, and the recent completion of the strategic hiring of the Director, Austin Yamada from Virginia Tech after a long career at the Pentagon and in large defense contractor industry, UA participation in this initiative is timely. Director Yamada has initiated the staffing of the institute, and has developed the strategic thrust areas of concentration for the future. As with any new endeavor, this initiative will have a “start-up” period - where the focus is on building the enterprise – and expectations for return, especially directly from the planned NSS TIRF investments, are nominal. In this case, new hiring and getting these talented researchers established is the first order of business, and these professionals will then need to set up their laboratories before being able to successfully win competitive external funding. Furthermore, given that R&D activity is the platform for later commercialization activities (invention disclosures, patents, licenses and spin-outs), this initial five year period is focused is primarily on establishing the R&D thrusts; and thus external sponsored awards is the primary metric for return on investment in this area. This past year, the UA executed defense and security related R&D activities for Department of Defense sponsors of approximately \$22M. The UA’s first participation in the NSS TRIF initiative is designed to grow these expenditures 50% over the first 5 year period. These NSS investments designed to successfully growing R&D awards in this area during this first 5-year period then will set the stage for subsequent commercialization success in later years.

2.1 Investment description/rationale/justification

2.1.1 Brief overview of industry or area being addressed by the initiative to include benefit to Arizona

The new TRIF investment in National Security Systems (NSS) will impact a broad range of research and development efforts at the UA, promoting collaboration and stimulating

innovation to support Arizona's high tech economy — an economy with a strong grounding in national security and defense.

Arizona boasts optimal conditions for flying, training, and testing, unimpeded by commercial lanes, and is home to 20 military installations and hundreds of defense companies. Arizona's aerospace and defense total exports rose more than 21.8% from 2011 to 2014, reaching a total of \$3.47B. In addition, Arizona ranks fourth nationwide both in aerospace industry payroll and aerospace revenue at \$14.9B, and more than 1200 Arizona based companies make the state America's third largest supply chain contributor. Major defense players located in Arizona fuel the industry's national success, as well as support hundreds of firms in the acquisition and deployment supply chain. Top companies include Raytheon Missile Systems, General Dynamics C4 Systems, BAE Systems, ATK's Integrated Weapon Systems, and more. TRIF investment in national security systems will contribute toward continued growth in the defense industry and supporting infrastructure in Arizona.

The NSS initiative at the UA engages in R&D that fosters collaboration and promotes innovative solutions to defense and security challenges. Defense and Security is identified as a key research strength in UA's strategic plan, *Never Settle*, and comports well with the economic development goals of the state. NSS support of cross-sector partnerships will lead to scientific and technological solutions to defense and security challenges and deliver tangible benefits to Arizona, the nation, and the world. TRIF NSS investments will bring millions of dollars of public and private funding to the UA by recruiting world-class researchers in cutting-edge research areas, by building interdisciplinary collaborations across campus, and by creating and enhancing partnerships with Arizona businesses and state/local/tribal governments to address national security challenges.

The University's new TRIF NSS investment will help coalesce existing UA research strengths to obtain new opportunities for extramural funding, which in the longer run, will accelerate economic development in this area. First, NSS will engage defense agencies and advance partnerships with industry that are new to sponsoring supported UA

research. UA is ranked #3 by the NSF in research expenditures in the physical sciences, and have substantial competencies to bring to bear to national defense and security problems. Secondly, by identifying complex challenges in national security and defense that align with UA research strengths, collaborative, inter-disciplinary research teams will provide creative solutions that will positively impact the national security and defense interests of the nation and the State of Arizona. TRIF investment in NSS will pave the way for new, mutually beneficial partnerships between the UA, industry, academia and the federal/state/local/tribal governments by leveraging the University's excellence in the disciplines that play major roles in national security initiatives. Among these strengths are optical sciences, space/astronomy, engineering, materials, computing/informatics energy, medical and biomedical technologies, environmental research, cyber, autonomy, social sciences, and border security/intelligence. These new NSS TRIF investments will promote extensible growth in the Arizona economy in several ways, initially primarily by increasing R&D, which will contribute to the expansion of our existing "Optics Valley" in southern Arizona to address the broader national defense and security needs.

NSS promotes an interdisciplinary approach with newly combined strengths to catalyze compelling initiatives in areas of emerging interest for the Department of Defense (DoD), Department of Homeland Security (DHS), the Intelligence Community (IC), and other relevant federal agencies. In addition, NSS initiative connects with deans, department heads, faculty and administration to identify, develop and implement strategic R&D initiatives and associated infrastructure. In addition, NSS investment will provide opportunities to educate and train the national defense workforce of the future through synergistic partnering with agencies, industry and the university's departments. The overarching NSS goal is to provide national security and defense related expertise to help guide and focus UA strengths to develop/leverage/expand collaborations and partnerships that will help build UA's reputation as a "trusted agent" in the national defense and security community.

2.1.2 Discussion of mission, goals, values and vision

The mission of the new NSS TRIF initiative is to bring new external resources to Arizona, improve the economy of the state of Arizona through an integration of academic and technical leadership, and provide public impact to help solve complex problems in the national defense and security space by:

- Leveraging TRIF funds to increase external federal and private-sector R&D funding to scale capacity;
- Identifying and supporting key faculty hires in strategic NSS areas of need and/or opportunity across the UA campus to augment capability
- Creating new shared infrastructure and facilities that broadly benefit NSS research, the education mission of the University, and enable solutions to industry challenges;
- Supporting workforce development directly through student research teaming experiences with partnership among defense agencies, the University, and industry; and
- Setting the stage for innovation and commercialization activities of technology transfer, by spawning new invention disclosures, that will support licensing and the creation of new start-up companies in the future.

NSS values collaboration and innovation, and envisions a prosperous, secure Arizona.

Because UA is participating in the NSS TRIF Initiative for the first time, and thus there is no historical track record for this area. Furthermore, this first 5-year period is focused largely on establishing the personnel and infrastructure to enable success in procuring new R&D awards from DoD and related industry sponsors. However, with the establishment of UA's Defense and Security Research Institute and the supportive defense and security culture in Arizona, we anticipate increasing the total R&D expenditures from DoD by 50% over this initial period.

2.1.3 Description of programmatic areas for investment

The UA's strategic plan, *Never Settle*, has four pillars: engagement, innovation, partnerships and synergy; and TRIF investment programs address each of these pillars. In *Never Settle*, Innovation charges us to advance research to find better answers to the world's grand challenges to deliver public impact and benefit by:

- Promoting and building upon core strengths to address grand challenges for the state of Arizona and the world;
- Collaborating boundlessly to increase local-to-global impact;
- Engaging new strategic partners in the research enterprise to accelerate innovation;
- Improving institutional infrastructure to speed new discovery, knowledge, and application;
- Strategically attracting, educating, and engaging first-rate doctoral and other advanced degree seeking students in a variety of disciplines to grow the high tech workforce ;
- Improving recognition and support for collaborative and interdisciplinary research and scholarship; and
- Expanding economic development in our region through commercialization of research ideas.

These strategies guided TRIF investments in the NSS programmatic areas, which were carefully chosen to align with areas of Arizona and national need. The selected thrust areas in the NSS initiative are focused on generating impact for Arizona, for which UA faculty already have significant expertise, and which have the capacity to grow external funding and in the longer term, expand economic opportunity as results of the support by this initiative.

Because the NSS initiative is new for the UA, there is no historical data on which to link metrics of success. However, given the alignment of national need, strong industry base in Arizona, existing substantive R&D expertise in the physical sciences that comprise a

large part of the technology base in defense and security, and NSS TRIF investment strategy, the opportunity for substantive return on investment is high. Although this first 5-year period is one off focused “start-up”, the result of NSS investment is expected to increase our base of DoD-related funding by 50% over the period, demonstrated by a direct increase in federal grants, new external funding in collaboration industry partners, participation cooperative agreements, and award of task orders through the federal acquisition process and other transaction authorities.

2.1.3.1 Space Dynamics

The Challenge: Near-earth space may be characterized as becoming increasingly more congested, contested, and competitive. The dangers of orbital debris and the threat of “deliberate disruption” are becoming less notional and more probable each passing day. The proliferation of international space systems and capabilities along with an increase in the number of technologies that can physically threaten national security has led the U.S. Defense Department to redefine space as a contested environment. General Hyten, Air Force Space Command, has called attention to this urgent problem in the 60 minutes piece, *the Battle Above*. The need for R&D to better identify and classify space objects, to predict their orbital path and possible intent, are pressing grand challenges that limit our current capability to effectively manage space traffic, and to keep our commercial assets in space secure from threat.

UA Advantage: The UA is uniquely positioned to make substantive contributions to safer operations in near earth space by leveraging several UA research strengths in the space domain comprised primarily of research from three Colleges (Science, Engineering, and Optical Sciences) and six Departments (Aerospace and Mechanical Engineering, Astronomy/Steward Observatory, Computer Science, Optical Sciences, Planetary Sciences/LPL, and Systems and Industrial Engineering). The primary initiative in space dynamics concerns the behavior of space objects; the rigorous and comprehensive study of the causes and effects of the behaviors of objects in space, both natural and man-made.

This thrust area reflects the intersection of two of UA's extant core strengths called out in the university's strategic plan, *Never Settle*: informatics and space systems. The facilities, technologies, and educational programs related to the understanding of how objects behave in space position UA to provide access to existing capabilities (e.g., telescopes, instruments, and data), develop new data streams (e.g., new instruments or types of observing programs for existing telescopes, perhaps even new telescopes), provide analyzed data products (e.g., develop new techniques for data analysis produced with existing facilities, including targeting the analysis to solve specific problems or answer specific questions), and provide an integrated academic and operational environment in which to train and educate the next generation of talented post-graduate researchers, analysts, and operators who will sustain government and civilian initiatives and interests.

TRIF NSS investment in space dynamics will help integrate multi-disciplinary research to focus on near-Earth space object identification, classification, tracking, and prediction and to identify national security applications, which will enable realizing substantial new R&D funding sources. Finally, with the increasing commercialization of space, new opportunities to partner with large corporations (e.g., Raytheon Missile Systems), as well as smaller local Arizona entities (e.g. Rincon Research Corporation, Paragon Space) will be developed to address this need.

2.1.3.2 *Materials Design & Development*

The Challenge: The process of designing, manufacturing, and developing materials with desired properties for integration into advanced technologies must keep pace with demand from government and industry. Current practices typically involve a ten year investment from industry to qualify new materials reliably into target platforms due to the required human work force and infrastructure required to process, test, and validate materials properties through computational simulations. Therefore, an approach to designing materials with proven characteristics is needed that combines experimental processing and rapid manufacturing of materials with computational simulations of the processing and observed properties in order to accelerate materials innovation into the marketplace and incorporation into defense assets. Federal agencies and industry

partners are focused on supporting materials research that includes both computational simulation and experimental testing to rapidly design materials with proven characteristics. There is a national interest in meeting this demand with projects that could include sensors and networking, and computational and materials experts that have access to using state-of-the-art facilities and instrumentation required to manufacture materials, thus broadening our impact in the local materials marketplace.

UA Advantage: The UA is uniquely positioned to make significant impact on NSS challenges related to materials design and development by leveraging strengths in optical sciences and advanced materials; integrated computational materials science; materials synthesis, processing and fabrication, and energy. TRIF investment in this area will augment the technical expertise and leadership in materials manufacturing and processing science, precision mechanical, thermal, electrical and optical materials property measurement and structural characterization and predictive computational simulation of properties from nano to macro scale. Together with local industry and start-up companies in “Optics Valley,” TRIF investment will enable UA to conduct cutting edge research that will transition to commercial applications across a wide range of materials design and implementation for economic development opportunities in Arizona. Core research strengths in defense and security identified in UA’s strategic plan, *Never Settle*, will be enhanced by investments in this thrust area.

2.1.3.3 Imaging & Sensor Technologies

The Challenge: Imaging and related sensor technologies are foundational to a myriad of challenges in NSS, from deep space imaging to microscopic and biomedical imaging. While traditional UA imaging research has focused on astronomy and imaging science in general, NSS imaging challenges include applications in optimizing a detector for backside illumination in order to improve quantum efficiency and range of spectral response. Unmanned vehicles – that depend on a myriad of sensors for operation- have become an important and integral part of military capability in recent years, and also are used in agricultural and other land use applications requiring extensive aerial surveillance.

The next step with drone technology is to develop machines that fly themselves—autonomously--opening them up to a wider range of applications. To accomplish autonomy, drones must be able to sense, learn and respond to their local environment, without human piloting. The opportunities are vast, and the economic development impact high for a state like Arizona with so many defense entities and rural agricultural needs.

UA Advantage: The UA is uniquely positioned to make deep contributions to imaging technologies due to the history of success (note this area is identified as a core research strength area in *Never Settle*, the university's strategic plan) as well as the widespread expertise spanning many laboratories, departments and colleges. This research is at the forefront of technical and clinical developments in the areas of MRI, Optical Imaging, Image Perception, Image Processing, Ultrasound, Image Quality Assessment, Sensor development, and sensor fabrication. UA's Imaging Technology Laboratory is an industry leader in fabricating sensor solutions for a myriad of sponsors and needs. TRIF investment will enable expansion of capacity in this area to promote new interdisciplinary applications of imaging and enabling technologies towards the nation's defense and security, and forming the basis for new partnerships with industry large and small.

2.1.3.4 Cybersecurity

The Challenge: The US and its allies are facing the dire danger of potentially losing the "The War on Terror" in cyberspace, especially when many young people are being recruited, incited, infected, and radicalized on the web. Cyber faces machine-to-machine attacks, worms targeting smart phones, jailbreaking the cloud targeting virtual machines, ghostware that becomes active when not surveilled – all malicious threats that are invisible to the unsuspecting computer user, network manager, and have the potential to shut down commerce and threaten our national security. Malicious hackers continue to gain in sophistication and can attack everything from critical infrastructure to medical devices, and threatens our health, safety, and security. U.S. Cyber Command and the

National Security Agency recently said that cyberattacks are causing “the greatest transfer of wealth in history.” McAfee, a security-software company, estimates that the global cost of cybercrime exceeds \$1 trillion.

UA Advantage: UA is uniquely poised to provide innovative solutions to NSS challenges in cybersecurity by leveraging basic and applied research strengths in informatics--key UA research strength called out in the university’s strategic plan, *Never Settle*--and by using an integrated approach. Strong interdisciplinary teams, labs, and institutes including the Artificial Intelligence (AI) Laboratory, Dark Web project and the INSITE, are focused on the development of advanced information technologies, systems, algorithms, and databases for national security-related applications through an integrated technological, organizational, and policy-based approach to the science of intelligence and security informatics. The AI Lab is known for its adaptation and development of scalable and practical artificial intelligence, machine learning, statistical analysis, computational linguistics, and visualization techniques. TRIF NSS investment will leverage and help integrate AI advancements to address emerging challenges in national security. The AI Lab Dark Web project is a scientific research program that focuses on the international terrorism (Jihadist) phenomena via a computational, data-centric approach. UA researchers collect "ALL" web content generated by international terrorist groups and have developed multilingual data mining, text mining, and web mining techniques to perform link analysis, content analysis, web metrics (technical sophistication) analysis, sentiment analysis, authorship analysis, and video analysis in our research. The approaches and methods developed contribute to advancing the field of Intelligence and Security Informatics. Such advances will help NSS stakeholders perform terrorism research and facilitate national and international security cooperation. The UA is home to the AZ Secure, the NSF funded CyberCorps Scholarship for Service graduate program, to train the next generation of cybersecurity experts. With TRIF investments, these capabilities can be expanded to address a wider array of cybersecurity needs to advance national defense goals, realize more R&D awards to UA researcher to advance Arizona as a leader in this area.

2.1.3.5 Bio-preparedness and Surveillance: a One Health Approach

The Challenge: As the human population continues to increase and expand across our world and national boundaries become ever more permeable, the interconnection of people, animals, and the environment becomes increasingly more significant and impactful. Furthermore, the knowledge of how various disease agents can be used as weapons continues to increase, and poses potential threats to our national security. One Health is the integrative effort of multiple disciplines working locally, nationally, and globally to predict and prevent disease transmission between and among animals and humans.

The potential value of this one health approach is highlighted by converging factors, including:

- The world's total population exceeded 7 billion people in 2011, and it continues to increase;
- As our population expands, the contact between human and wild animal habitats increases, introducing the risk of exposure to new viruses, bacteria, and other disease-causing pathogens;
- Advancing technologies and science-based evidence is increasing the awareness, knowledge, and understanding of the interdependency of the health of humans, animals, and the environment;
- At least 75% of emerging and re-emerging diseases are either zoonotic (spread between humans and animals) or vector borne (carried from infected animals to others through insects); and
- Vigilant protection of our food and feed supplies from food-borne diseases, contamination and acts of terrorism is critical for human and animal health.

UA Advantage: UA is uniquely poised to support NSS by leveraging its medical school, newly formed veterinary school, biomedical research teams, and other unique UA assets including the VIPER Institute and the CyVerse cyberinfrastructure to apply this One Health approach to improve surveillance and bio-preparedness. Translational

Biosciences is identified as one of the core research strengths in UA's strategic plan, *Never Settle*. In the TRIF NSS initiative, UA will deploy its cyber infrastructure to enable rapid recognition of clinically significant biological events--whether they are due to disease outbreaks, contaminations or poisonings due to either natural causes or terrorism--and that have significance to the health and security of residents, leading to more effective decision making in health and emergency response at the federal, state and local level. UA will leverage big data approaches for a web-based system of near real-time data collection, and automated assessment and analysis to detect relevant disease conditions and symptoms in order to meet the bio-surveillance needs of key local and regional stakeholders, while providing awareness and transparency of events to state and national decision makers to improve clinical outcomes. The longer term goal is to also provide information on critical healthcare infrastructure and relevant interventional needs and care resources. Leveraging the cyberinfrastructure at UA powered by CyVerse (formerly iPlant, a \$100M 10-year UA-led project funded by the National Science Foundation), UA can become a hub for bio-preparedness by implementing analytic and visualization tools, adding additional data types (such as animal health and agricultural data, as the current integration with animal health zoonosis is limited), and capitalizing on UA's new Doctor of Veterinary Medicine degree program and the rich bioscience community in Oro Valley that support new start-ups and licensing of technologies to foster economic development.

2.2 Expected Outcomes as a result of TRIF investments

2.2.1 Specific and realistic outcomes that are clearly measurable

2.2.1.1 Return on investment

NSS areas for investment were carefully chosen to align with strength areas of Arizona industry and national security and defense needs. They represent topics for which UA faculty already have significant expertise, but also have the capacity to grow in impact and external funding when supported by this initiative. A reasonable return on investment

is expected in this initial startup period in the amount of new federal R&D funding for these focus defense and security areas flowing into Arizona. These funds will support not only UA, but also the broader Arizona industry and our partner Arizona universities.

Because the NSS initiative is new for the University, there is no historical data of past success upon which to precisely base expected return. However, the opportunity for reasonable return on investment is high because of the vibrant defense and security community in the state and our reasonable base of expertise in this area. Although this first 5-year period is focused largely on establishing the personnel and infrastructure to enable success in procuring new R&D awards from DoD and related industry sponsors, the establishment of UA's Defense and Security Research Institute and the supportive defense and security culture in Arizona support the anticipation of increasing the total R&D expenditures from DoD by 50% over this initial period.

New faculty hires and expansion in fields that are aligned with national funding will increase prospects for large return via grants, cooperative agreements, competitive procurements, and other transaction authorities. Potential new R&D funding sources that will be pursued as a part of NSS investments examples include:

- AFRL Center of Excellence for Astrodynamics;
- Department of the Navy Center of Excellence for High Energy Lasers;
- Cooperative Agreement with Air Force Research Laboratory;
- Cooperative Agreement with Army Research Laboratory;
- Cooperative Agreement with Air Force Office of Scientific Research;
- DAPRA, IARPA, ONR, and other competitive solicitations;
- Access to Other Transaction Authorities;
- Competitive procurements as a prime or sub; including potential classified research

Our equipment investments are also designed to create long-term return on investment through ongoing master research agreements, strategic educational partnership agreements. Targets for such relationships include industry partners with local roots, such as Rincon Research Corporation, Honeywell, and Raytheon Missile Systems, and large national companies like Lockheed Martin Corporation, Ball Aerospace, as well as government organizations like the Navy Research Laboratory (NRL), Army Research Laboratory (ARL), and the Air Force Research Laboratory (AFRL).

2.2.1.2 Technology transfer

Tech Launch Arizona (TLA), the UA unit responsible for commercialization of research ideas through technology transfer activities, will actively engage with the NSS initiative and affiliated faculty. TLA's partnership with the NSS Initiative will include funding of asset demonstrations to tune the outputs of R&D to marketplace needs, with interactions starting at the beginning of the research process and extending through to successful technology commercialization. TLA closely coordinates in the identification of faculty whose research and inventions may be the basis for expanded NSS commercialization opportunities.

Faculty members supporting NSS are self-motivated and highly innovative, and together with TLA staff, NSS activities will focus in this initial 5-year period of ensuring that the inventions resulting from R&D are disclosed in order to be translated later into strong technology for Arizona and the nation. NSS identifies promising faculty and new discoveries for attention by TLA (e.g., recipients of seed funds and attendees at workshops). Proof-of-concept fund investments will be made into promising disclosed technology to create additional value.

TLA tracks five key metrics for outcomes: invention disclosures; provisional patents filed; total licenses; startups; and asset development funding. Growth of invention disclosures illustrates the success of TLA's outreach efforts to faculty and staff. Approximately 60% of such invention disclosures result in a provisional patent application being filed. A license is the transfer of the University's rights in a particular invention to a third party in

order to move that technology to the marketplace. Asset Development investments make technologies more attractive to industry partners and further private investment. For select technologies, creating a new venture (startup) is the best commercialization path, resulting in new jobs and economic benefit to the region. For others, it is licensing technology to existing companies. The initial focus of TLA's NSS engagement will be fostering invention disclosures – the fundamental first step in the process. In preliminary work, identification of faculty, capabilities, and resources will enable DSRI to assemble appropriate teams. TLA will make available commercialization assessment and planning in support of key research proposals for this initiative. By the end of this first 5 year period, TLA expects a predictable stream of invention disclosures across the 5 NSS thrust areas, and asset demonstration funding.

2.2.1.3 Industry engagement (outreach, partnerships, collaboration)

Although NSS will benefit industry by providing relevant faculty expertise, core facilities and services, and workforce development, the focus is on the most frequent mode of industry engagement – that is, through partnering on federal acquisition proposals and by creating industry-academia teams that are stronger than either partner alone. In this first 5-year period of NSS TRIF Initiative participation, an expansion in industry funded R&D in the defense and security area is projected.

Another benefit that UA will provide is access to state-of-the-art equipment and services in core facilities. Significant investment has created unique resources that industry cannot generally operate and maintain on their own. NSS will track industry use of large scale equipment and facilities developed with NSS TRIF investments to demonstrate the value to business competitiveness in the marketplace.

A major effort will continue in linking industry with qualified students, including an exciting new TRIF supported mechanism sponsored by the ORD that brings together a team of undergraduate researcher, a graduate student team leader, and interdisciplinary university-industry R&D mentorship to conduct jointly funded R&D. These innovative teaming models will help prepare our students for collaborative work environment in

industry, satisfy increasing workforce needs and make Arizona a more attractive location for founding and growing Aerospace and Defense companies.

2.2.1.4 Workforce contributions

Workforce development will remain a high priority for NSS, from attracting Arizona students into STEM fields, preparing them with experiences that support the defense and security work environment and encouraging them to remain in Arizona for high tech employment. Furthermore, the establishment of a greater national security systems presence will provide more job opportunities to local citizens, which will greatly benefit all facets of the community.

2.2.1.5 Educational outreach

Due to the highly regulated research regime associated with national security in general, educational outreach initiatives must comply with national security regulations and guidelines. However, the NSS will endeavor to take proactive measures to ensure maximum educational outreach. Preliminary plans are underway to develop a University-government-industry-community center for R&D testing and evaluation to drive innovation, train students for high tech jobs, and support commercialization in Southern Arizona.

2.2.1.6 Government/Agency/Community Engagement (outreach, partnerships, collaboration)

NSS will continue to engage with local, state, tribal, and federal government personnel and agencies, foundations, technical societies, community organizations, and local and state aerospace and defense organizations, to spread the word about the challenge and excitement of national defense and security related research and innovation. Workshops and conferences are held regularly with national and state lawmakers, federal agency representatives, and industry and academic partners.

2.2.2 Annual metrics table of expected outcomes and timeline for achievement

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) NATIONAL SECURITY SYSTEMS

PERFORMANCE ANALYSIS	Projected FY 17	Projected FY 18	Projected FY 19	Projected FY 20	Projected FY 21
TRIF EXPENDITURES					
Total	\$ 3,703,400	\$ 3,940,241	\$ 4,156,432	\$ 4,372,623	\$ 5,061,314
FINANCIAL IMPACT OF TRIF INVESTMENT					
Sponsored Awards	1,000,000	2,000,000	4,000,000	8,000,000	10,000,000
Gifts & Other Sources	0	100,000	125,000	150,000	175,000
Royalty Income	0	0	0	0	0
TOTAL	\$ 1,000,000	\$ 2,100,000	\$ 4,125,000	\$ 8,150,000	\$10,175,000
TECHNOLOGY TRANSFER ACTIVITY					
Invention Disclosures Transacted	0	0	0	3	5
US Patents Issued	0	0	0	0	0
Licenses and Options Executed	0	0	0	0	0
Startup Companies	0	0	0	0	0
WORKFORCE CONTRIBUTION					
Postdoctoral Appointees	2	5	5	6	6
Graduate Students	4	10	11	11	12
Undergraduate Students	4	10	11	11	12

2.3 Initiative Structure

2.3.1 Organizational structure

NSS is administered by Austin Yamada, Director, UA Defense & Security Research Institute, coordinated through the Office for Research & Discovery. The director collaborates with deans, department heads and other University leadership to assure maximal impact in implementing NSS programs.

2.3.2 Advisory Board

The DSRI has two advisory boards. An External Advisory Board (EAB) consists of engaged and influential industry and community leaders. The EAB provides high level guidance and advice on strategy and investment, and helps communicate and connect UA national security systems activities to the greater Arizona Aerospace and Defense communities. A Faculty Advisory Board (FAB) consists of UA faculty with interests aligned with the NSS mission and is engaged in shaping and implementing the strategic research areas of investment.

2.3.3 Infrastructure

NSS leverages the infrastructure of the Office for Research & Discovery, the DSRI, and the other relevant supporting organizations on campus. Staff are primarily located in the Marshall Building, adjacent to the support services that deliver research development, strategic business support, communications and marketing, and philanthropic development. Equipment and core facilities supported by NSS funds are located in UA buildings most advantageous for usage.

2.3.4 Description of programmatic investments

At UA, TRIF NSS investment is designed to promote the economic development of the state by catalyzing innovative R&D in target areas of high impact aligned with Arizona businesses; engaging industry in support of R&D to accelerate the commercialization of research results into new products and services that benefit the health, security, and prosperity of Arizona; developing the future high-tech workforce – training students from elementary to graduate school to be science and innovation leaders who will create Arizona's bright future; and providing infrastructure through research services, computing, equipment and facilities that enables innovation and research.

TRIF NSS investments will accelerate capacity through strategic faculty hires in focused areas identified in the University's *Never Settle* strategic plan and further fleshed out in the ORD Strategic Research Roadmapping sessions held in 2015 with hundreds of

researchers across campus. Investments will be made in new transdisciplinary research initiatives to enhance competitive success for securing extramural funding and engage industry in R&D partnerships that accelerate the commercialization of research results and incorporation in defense and security technologies. TRIF will support the training and engagement of students while developing a high-tech workforce and will provide infrastructure that enables innovation and research through facilities and instrumentation.

2.3.4.1 Catalyzing innovative research

2.3.4.1.1 Strategic faculty hiring

TRIF investment will support high-impact hires in several research areas with national security systems application. Plans are developed with relevant deans and department heads, Provost, and Senior Vice President for Research to identify *catalyzing* faculty, who will supply critically needed vision and have the leadership and experience to lead and grow externally-funded programs in these priority areas. The table below describes targeted hires in each strategic area.

Potential TRIF hires in National Security Systems	
Theme	Expertise
Space Dynamics	Multidimensional data system integration
Materials Design & Development	Material Sciences; Computational dynamics
Cybersecurity	Data mining, machine learning
Imaging & Sensor Technology	Autonomous systems; Sensor development; digital signal processing
Biopreparedness & Disease Surveillance	Algorithm Processing Bioinformatics of disease transmission and prediction/forecasting; Decision support tool development

2.3.4.1.2 Transdisciplinary Research Initiatives

NSS will provide support for initiatives within the programmatic investment areas that show strong promise for large future return on investment using mechanisms for competitive internal grants focused on interdisciplinary teaming around grand challenges. Grant opportunities include funding for new programs, pilot projects, and research networks that will lead to new transdisciplinary research teams, equipment, and graduate student support. UA's Research Development Services and Tech Launch Arizona will work with researcher teams to ensure success in external funding that will lead to future in technology commercialization.

2.3.4.1.3 Engaging Industry & Advancing the Commercialization of Research

NSS is actively engaged with defense and security industries and is strongly positioned for growth. In addition to establishing constructs and vehicles for collaborative research programs, the colleges associated with NSS researchers host a variety of industry partnership programs that provide intimate engagement points for companies across the nation to engage students primarily at the graduate MS and PhD level, as well as with the faculty supervising their research. Recent growth in these programs has revealed that, in addition to technology access, industry partners on a national scale are using UA venues in their networking for business development in NSS areas. DSRI staff have the experience, and will continue to support, bringing personnel from industrial affiliates to the campus for collaboration in the context of externally-funded research projects for the NSS initiative. These visits serve two purposes: to establish our defense and security effort as a trusted partner for defense problems, as to inform our researchers of customer needs, both of which are designed to drive increased industry supported R&D funding. NSS also expects to advance intellectual property development and start-up companies, by focusing on increasing invention disclosures and providing asset demonstration funding to further enhance application opportunities and commercialization potential.

2.3.4.1 *Developing the High Tech Workforce & Outreach*

TRIF support will ensure cutting edge R&D in NSS and will facilitate UA relationships with local, state and national partners such as the U.S. Government and commercial industry. In addition, the R&D being performed by teams of UA researchers and students at all levels will be directly supported by government and industry customers that to support the need for a stronger, long-term robust workforce. Outreach efforts are aimed at engaging industry and federal defense and security related agencies. Professionals in NSS related research in particular have branded UA as a trusted source for optics, astronomy, deep space mission management, and related research, planning, and engagement.

2.3.4.2 *Infrastructure & Instrumentation*

A significant investment will be made into core facilities and instrumentation that will enable cutting-edge R&D in NSS areas. While user fees can defray a portion of the operating costs, initial equipment investment is supported by the University and the NSS TRIF initiative, generally with significant industry contribution through negotiated discounts. The newly established Strategic Educational Partnership with the Air Force Research Laboratory also facilitates the loan and/or donation of surplus government equipment to the UA. This equipment is available to all investigators at UA, other Arizona universities, and will be aggressively promoted as a resource to industry. Major areas of emphasis going forward are space dynamics, material sciences, biomedicine and cybersecurity.

2.4 Initiative budget table

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) NATIONAL SECURITY SYSTEMS

FINANCIAL SUMMARY	Budget FY 17	Budget FY 18	Budget FY 19	Budget FY 20	Budget FY 21
REVENUE					
TRIF Revenue	3,703,400	3,940,241	4,156,432	4,372,623	5,061,314
TOTAL	3,703,400	3,940,241	4,156,432	4,372,623	5,061,314
EXPENDITURES					
OPERATING BUDGET	3,703,400	3,940,241	4,156,432	4,372,623	5,061,314
CAPITAL BUDGET	-	-	-	-	-
TOTAL	3,703,400	3,940,241	4,156,432	4,372,623	5,061,314

2.5 Plan for sustainability

2.5.1 Anticipated funding sources for ongoing support

NSS activities will continue to be operationalized by the Office for Research & Discovery, the Defense & Security Research Institute, and relevant colleges into the future. UA ongoing support for the DSRI assures that a baseline level of activities, facilities, and administrative support are leveraged to support continued activity and growth into the future. NSS will continue to be very well positioned for continued growth in external funding support from federal research funding agencies including primarily DoD, but also DOE and NIH. This anticipated growth in funding includes the broad spectrum of large scale center grants to smaller scale individual investigator awards, as well as existing vehicles such as MURI's, STCs, and ERCs, as well as university spawned topics that are advocated and then propagated by agencies for subsequent competition.

Other sources of support include services through core facilities. A “win-win” with industry is achieved when equipment and services, not otherwise accessible for industry, are provided from the UA for an attractive price, which in turn supports the maintenance and growth of these facilities.

The Office for Research & Discovery enables these sustainability efforts through support

by Research Development Services (RDS), as well as two “business development” divisions, Strategic Business Initiatives (SBI) and the upcoming division to be initiated in FY17, Global Research Alliances. RDS provide full-service extramural funding assistance to UA researchers, from opportunity identification, proposal plan development and team building, to proposal management and reviews. SBI connects needs of the business community to the expertise of UA researchers, which results not only in additional industry support for research and development activities occurring at UA, but also more importantly forges partnerships that enable strong UA-industry teams to compete for significant federal contracts. Global Research Alliances performs a similar function, but focuses on developing strong UA, university, industry partnerships internationally.

Finally, a significant effort is being made in philanthropy. The Office for Research and Discovery, in concert with the UA Foundation, has just hired a Senior Director of Development to support transdisciplinary research. Given significant public interest in privacy and security, it is expected that philanthropy will cover a portion of interdisciplinary activities, albeit substantially smaller in magnitude compared to other TRIF initiatives.

2.5.2 Timeline for transitioning away from TRIF support

NSS TRIF investments are used for catalyzing new research and discovery in the national defense and security technology areas. The plan for this first 5 year period for this new NSS TRIF initiative is to use these funds to recruit productive faculty, provide enabling equipment, seed new research programs, foster industry engagement, and link faculty through graduate students – focused on growth in external federal and industry sponsored R&D. TRIF initiative Funds are also used for education, outreach and training. The impact of a possible end to TRIF will be the loss of the additional catalyzing activities for this sector will be substantial, particularly as the University of Arizona has just started its participation in this important initiative so critical to Arizona and its defense and security sector.

3. SPACE EXPLORATION AND OPTICAL SOLUTIONS

3.1 Investment description/rationale/justification

3.1.1 Brief overview of industry or area being addressed by the initiative to include benefit to Arizona

The Space Exploration and Optical Solutions (SEOS) Initiative program will leverage TRIF funds for continued strong return on investment by attracting external federal and private sector R&D investments, developing intellectual capital, and generating tomorrow's workforce to advance Arizona's high-tech economy. While Optics/Photonics is explicitly captured as a key industry sector by the Arizona Commerce Authority (ACA), UA's strong international reputation, talent base, and linkages in space exploration, advanced optics, photonics, and imaging technologies support growth in literally every industry sector identified by ACA¹ as key to Arizona. There were 191 companies who identify themselves as optics and photonics related industries in Arizona in 2014, an increase of 27% over the past decade, with an average wage of over \$61,000. This sector accounts for more than 25,000 employees, and is responsible for \$2.3B in revenue, over \$45M per firm. The majority (68%) are located in Pima County, and 46% have been in operation for more than 10 years.

In 2013 the National Research Council of the National Academies issued a report entitled, "Optics and Photonics: Essential Technologies for Our Nation," articulating both the enormous impact and future potential of optics and photonics for the US economy, quality of life, and national security². The report specifically calls for stronger coordination and federal investment in areas that are strongly correlated with UA's faculty-driven strategic planning focus topics of Space Systems, Imaging, Defense and Security, Informatics,

¹ <http://www.azcommerce.com/industries>

² Optics and Photonics: Essential Technologies for Our Nation, National Research Council of the National Academies, National Academies Press, Washington, DC., <http://www.nap.edu>, 2013.

Water/Energy/Arid Environment, and Translational Biosciences. Associated with the needs and opportunities captured in the NRC report, the SEOS team is also witnessing a provocative uptick in the engagement with “non-traditional” technology partners, ranging from corporations such as Uber to the very largest IT companies who are aggressively developing optical solutions in their interfaces between advanced information systems, humans, and the external world. Data in the report explicitly documents how optics and photonics underpin the products and services of a disproportionate share of the most productive companies in the US. Specifically, the NRC report identified 285 publically-traded companies with substantial optics dependencies, and while this amounted to only 1.7% of public US companies, these companies jointly employed 7.4 million individuals and had \$3.1 trillion revenue, which is 6% of the aggregate employment and 10% of the aggregate revenue of all public employer firms in the US.

This highlights a rich landscape and opportunity for SEOS to leverage its strong scientific and technological national and international leadership roles in partnership with private sector partners to transition technology into compelling economic development and commercial impact for Arizona, thereby advancing a significant component of UA’s strategic plan, *Never Settle*, in which “Optics” is identified as a core research strength.

The 2007 AASTA report³ noted that the total annual economic impact of research in astronomy, planetary sciences and space sciences in Arizona had already reached \$252.8 million, with capital investments exceeding \$1B and a total employment in these research areas in Arizona exceeding 3,300 jobs. SEOS also promises strengthened linkages into Arizona’s semiconductor sector which represents six percent (\$3 billion) of the U.S. market and 23,000 jobs⁴, and the Aerospace & Defense sector which currently contributes \$9 billion to the state’s economy, and ranks fifth in the U.S. in terms of employment with 94,000 direct and indirect jobs. SEOS will work collaboratively with UA’s

³ “Astronomy, Planetary Sciences and Space Sciences Research Opportunities to Advance Arizona’s Economic Growth,” report prepared by The Arizona Arts, Sciences and Technology Academy (2007).

⁴ <http://www.azcommerce.com/start-up/innovation-in-arizona/tech-community/key-industry-sectors>

Defense & Security Research Institute for collaboration on National Security Systems TRIF initiative to jointly support this sector.

SEOS also affords tremendous opportunities to advance UA's strategic plan, *Never Settle*, through its continued investment in core research strengths in space systems, including scientific mission in astronomy, astrophysics, and space exploration. In FY 2014, UA had more than \$124 million in expenditures in what the National Science Foundation classifies as "Astronomy" (including all of the activities of UA's Lunar and Planetary Laboratory, Department of Planetary Sciences, Steward Observatory, and the Department of Astronomy, as well as related activities in other units) in the NSF Higher Education Research and Development Survey.

The UA's single largest federally-funded project is OSIRIS-REx, a NASA-funded asteroid sample return mission for which \$800M is managed by the UA. This mission is the second NASA interplanetary effort managed by UA, following the Phoenix Mars Lander. In addition, several multi-million dollar instruments on spacecraft have been built at UA, most recently the OSIRIS-REx Camera Suite (OCAMS, a part of OSIRIS-REx), a project involving several UA departments, and tapping into UA's expertise in optics, engineering and planetary science.

UA is also home for the operations centers for the High-Resolution Imaging Science Experiment (HiRISE) at Mars. The UA operates or helps operate more than 20 astronomical telescopes around the world, including observatories in Arizona, Hawaii, Chile, and in space.

Steward Observatory's Richard F. Caris Mirror Lab (RFCML) is a unique national asset, producing the world's largest and most precise mirrors for telescopes, including the current largest facility in the world, the Large Binocular Telescope on Mount Graham, Arizona. Currently the RFCML is fabricating the 8.4m diameter mirrors that will be used in the Giant Magellan Telescope (GMT effective primary mirror aperture of 25m in diameter), under contracts that will total in value over \$150 million. When completed, the GMT will be used by UA researchers to continue our exploration of the Universe, from planets around nearby stars to the most distant galaxies.

Taken together, these assets and capabilities, coupled with new TRIF investments will advance a strong innovation ecosystem in SEOS.

3.1.2 Discussion of mission, goals, values and vision

The mission of this SEOS TRIF initiative is to bring new external resources to Arizona, improve the economy of the state of Arizona through an integration of academic and technical leadership, and provide impact and public benefit.

Goals include:

- Leveraging TRIF funds to obtain a high return-on-investment through increased federal and private-sector R&D funding to scale capacity,
- Identifying and supporting key faculty hires in strategic SEOS areas of need and/or opportunity across the UA campus to augment our capability,
- Creating new shared infrastructure and facilities that broadly benefit the SEOS research, education mission of the University, as well as enable solutions to industry challenges
- Supporting workforce development directly through student research teaming experiences and enhance the University's partnerships to companies,
- Expanding and encouraging commercialization activities through technology transfer, including both licensing and the creation of new start-up companies.

The SEOS team has a strong track record of delivering on specific TRIF performance metrics towards the vision. Historically, over the last four years of TRIF, SEOS initiative, every TRIF dollar invested resulted in a 10x return on investment. In the last four years, 142 invention disclosures were transacted, four new companies started and 40 new patents issued.

3.1.3 Description of programmatic areas for investment

The UA's strategic plan, *Never Settle*, has four pillars, engagement, innovation, partnerships and synergy, and TRIF investment programs cover each of these pillars. In

Never Settle, “Innovation” charges us to advance research to find better answers to the world’s grand challenges that deliver public impact and benefit by:

- Promoting and building upon core strengths to address grand challenges for the state of Arizona and the world
- Collaborating boundlessly to increase local-to-global impact
- Engaging new strategic partners in the research enterprise to accelerate innovation
- Improving institutional infrastructure to speed new discovery, knowledge, and application
- Strategically attracting, educating, and engaging first-rate doctoral and other advanced degree seeking students in a variety of disciplines to grow the high tech workforce ;
- Improving recognition and support for collaborative and interdisciplinary research and scholarship; and
- Expanding economic development in our region through commercialization of research ideas

These strategies guided the TRIF investments in the SEOS programmatic areas, which were carefully chosen to align with areas of Arizona and national need. The selected thrust areas in the SEOS initiative are focused on generating impact for Arizona, for which UA faculty already have significant expertise, and which have the capacity to grow external federal and industry funding, expand economic opportunity, as a result of the support by this initiative.

3.1.3.1 Space Exploration

The Challenge: Leveraging advanced optics as a critical tool to expand our understanding of the universe. Examples range from the obvious impact of powerful advanced telescope technologies to the less obvious ultra-sensitive laser interferometers in LIGO capable of measuring displacements less than one-thousandth the diameter of a proton, which very recently enabled the world’s first detection of gravity waves.

Key opportunities here include exoplanet research and the search for life on other planets within our galaxy, including the theory and modeling of exoplanet formation, geological evolution, and atmospheric science. There are also continuing needs driving aggressive technology for studies of cosmic origins, as well as unmanned mission instrumentation roles to destinations such as Europa and Mars, and sample returns from Near-Earth Asteroids and other Solar System targets. New space related companies in Tucson, such as World View/Paragon Space Ventures, drive home this opportunity ahead. Additionally, funding for observatory operations and instrumentation renewal and innovation is essential to the continued successes of UA faculty using the facilities of Steward Observatory in achieving UA's national leadership in research achievements and associated leading volume in astronomy research expenditures.

UA Advantage: UA is uniquely well-positioned in this thrust area, a core research strength area identified in *Never Settle*, UA's strategic plan, stemming both from its unparalleled infrastructure for large optics fabrication and metrology, and its home-grown talent driving world-leading sensor development, adaptive optics, instrumentation packages (imagers, spectrometers, coronagraphs) for the world's most powerful ground and space-based telescopes. Additional strengths include the theory and modeling of exoplanet formation, geological evolution, atmospheric science, stellar interiors and evolution, galaxy formation, cosmology, and opportunities for enhanced and coordinated campus-wide nm-scale materials analytics to support stronger future UA roles in sample-return missions. These capabilities uniquely position the UA and SEOS researchers to successfully meet the outlined challenges with the planned SEOS investments.

3.1.3.2 Optics and Photonics

The Challenge: Optics and photonics are becoming increasingly critical to applications ranging from information technologies to entertainment, from defense to biomedicine, or from manufacturing to fundamental science. The "Internet of Things" promises to bring even more application of optics as both a sensor and communications technology, including opportunities to leverage dramatic advances in photonic integrated circuit (PIC) technology. Specific opportunities here include packaging of PICs, encompassing both 3-

dimensional integration with high-performance electronics as well as their optical interface into systems. The strong emerging private-sector interest in augmented reality technologies and autonomous systems also offer major growth opportunities. These are nationally highly competitive areas that require strategic investment to realize the potential for strong economic impact to Arizona. The “Optics Valley” sectors account for hundreds of millions of dollars in revenue and thousands of high paying jobs in our region, with at least 32 first generation and 11 second generation spin-out companies. Deepening our TRIF SEOS investment in this area will advance the continued capacity and economic development in Arizona.

UA Advantage: Sustained investment has enabled UA to build outstanding faculty strength and national leadership in optics and photonics, a core strength area identified in UA’s *Never Settle* strategic plan. CIAN, the Center for Integrated Access Networks, is the only NSF ERC in the nation on optical communications technology, a hub for optical science and application. This center positions UA strongly in architectures and hardware solutions for future internet, data center, and big data management challenges. Another outgrowth of CIAN is faculty strength, facilities, and technology in fiber lasers which is strongly positioned to impact applications ranging from advanced microscopy in life sciences to high-power laser defense systems. UA also has strong expertise ranging from novel hardware and free-form optics design for augmented reality and autonomous systems to human subject perception studies of projected 3D light fields. UA’s role in the scientific leadership of AIM Photonics, the largest institute in the National Network of Manufacturing Innovation (NNMI) to date, provides a framework for cooperative new market application development with the nation’s strongest technology companies, leveraging unprecedented, and otherwise unaffordable, direct access to the most powerful semiconductor manufacturing technologies in existence globally.

3.1.3.3 Imaging & enabling technologies

The Challenge: Impact in both of the areas noted above requires leap-frogging advances in imaging technologies. Rapidly advancing technologies and data management are straining conventional design and information management approaches. New

approaches are required to maximize the efficacy of any imaging system design under a constraint (i.e., size, power, cost, or weight, etc.) for astronomical, biomedical, machine vision, or national security applications. There also are strong opportunities in computation and compressive imaging across a broad spectrum of applications and markets.

The UA Advantage: UA's is uniquely positioned to drive a holistic system-engineering approach to imaging system design. In addition to leverage long-standing strength in optical design, hardware, and fabrication, there is an outstanding opportunity to leverage foundational strength in the discipline of image science. Here the ultimate information content and decision process is central to an integrated approach encompassing imaging system acquisition adaptation, hardware design, and software algorithm design, all with a firm mathematical foundation.

Finally, UA's established faculty strength and infrastructure in fabrication technologies for specialized imaging hardware solutions are key to advancing SEOS objectives. In cooperation with corporate partners, these will enable harnessing innovations in imaging design and fabrication based on free-form optics, micro-optics in endoscopy, polarization optics, nonlinear optical microscopy, photonic integrated circuits, and recent exploration of magneto-optics for brain activity imaging. Imaging is a broad strength identified in UA's strategic plan, *Never Settle*.

3.1.3.4 Informatics

The Challenge: SEOS research areas are often critically linked to UA's faculty strength and infrastructure for computation and informatics, i.e., "big data". This facet becomes critically important in the context of the imaging objectives noted above, as managing through "big data" is increasingly an integral part of the imaging system objectives, constraints, and system engineering optimization. Other examples include the Large Synoptic Survey Telescope project, as well as aggressive planetary modeling and cosmic origins studies. In areas linking optics into defense systems, optical observation assets will need to interface into enormous, dynamic space situational awareness databases in a seamless way.

The UA Advantage: UA is well positioned to leverage and further expand its faculty strength and experience in big data problems, including the iPlant Collaborative and now CyVerse initiatives to address these challenges in a multidisciplinary environment. UA's deep and broad expertise in Informatics is recognized as a core research strength identified in *Never Settle*, which through SEOS investment can be realized.

3.2 Expected Outcomes as a result of TRIF investments

3.2.1 Specific and realistic outcomes that are clearly measurable

3.2.1.1 Return on investment

SEOS programmatic areas for investment align with UA strengths and areas of Arizona and national need. These areas have the capacity to grow in impact, economic opportunity, and external funding. We expect strong return on investment due to this alignment to result in substantive growth in new federal grant funds into Arizona. These funds will support not only UA, but also Arizona industry and our partner Arizona universities.

Major target federal initiatives include:

- National Science Foundation (Engineering Research Centers, Science & Technology Centers, Materials Research Science & Engineering Centers, Virtual Mobile Cloud Network for Realizing Scalable, Real-Time Cyber Physical Systems)
- NASA (Small Explorer missions and Space Technology Research grants)
- DOE including Advanced Research Projects Agency-Energy (ARPA-E)
- DOD (MURIs, DARPA/IARPA, AFSOR-Military Medical Photonics Program, NRL, Army-Photonic Materials)
- AIM Photonics

SEOS provides an opportunity to maintain its position as a premiere institution known for leading competed NASA Planetary Science missions and instruments. Instrumentation

opportunities in the next five years will include instrumentation for a lander on Europa and an imager to serve as a successor to HiRISE on a NASA Mars orbiter. Although UA has never had an instrument on a NASA Earth Sciences mission, the new Earth Dynamics Observatory cluster hiring initiative has that as a goal, one that will require participation from units across campus and SEOS investment. In addition, UA will continue to compete, either with the Principal Investigator or with teams proposing instruments, on the competed Planetary Science missions in the Discovery and New Frontiers program, which will each have at least one opportunities in this TRIF 5-year period. Finally, there will be opportunities for funding of cutting-edge laboratory facilities as NASA prepares for the return of samples from asteroids in the 2020s and Mars in the 2030s.

3.2.1.2 Technology transfer

Technology transfer is an important area of measuring the goals and economic outcomes of SEOS. The number of invention disclosures, the number of new patent applications and awards, and the number of licenses, options and start-up companies are the key technology transfer measures that are tracked. TLA is already well established in protecting optics-related IP and expects to grow engagements in space-related inventions, primarily in the area of instrumentation and analytics. TLA expects that 15% of all new licenses, options, and UA startup companies will be related to the Space Exploration and Optical Solutions initiative.

TLA tracks five key metrics for outcomes: invention disclosures; provisional patents filed; total licenses; startups; and asset development investments. Growth of invention disclosures illustrate the success of TLA's outreach efforts to faculty and staff. Approximately 60% of such invention disclosures result in a provisional patent application being filed. A license is the transfer of the University's rights in a particular invention to a third party in order to move that technology to the marketplace. Asset Development investments make technologies more attractive to industry partners and further private investment, and are a key tool to promote commercialization success

For select technologies, creating a new venture (startup) is the best commercialization

path, resulting in new jobs and economic benefit to the region.

3.2.1.3 Industry engagement (outreach, partnerships, collaboration)

UA has demonstrated success in how the many industry partnerships are a key element of the success of SEOS, especially in the optics and photonics areas. Such relationships are not only a vital source of revenue, but provide also a strong intellectual contribution by defining valuable areas of technological need and opportunity.

Under the auspices of the Office for Research & Discovery, an exciting new TRIF supported mechanism is being made available to further link industry, researchers and students, by bringing together a team of undergraduate researcher, a graduate student team leader, and interdisciplinary university-industry R&D mentorship to conduct jointly funded R&D. These innovative teaming models help prepare our students for collaborative work environment in industry, satisfy increasing workforce needs and make Arizona a more attractive location for founding and growing companies in the SEOS area.

3.2.1.4 Workforce contributions

Several SEOS federally-funded programs have strong education and workforce development activities. SEOS professionals continue to update curriculum to be current and on the cutting edge to produce graduates with the skills needed by industry. Our TRIF faculty hires will initiate SEOS educational content and related programs at the university, and the student body in SEOS academic programs will exceed 40 undergraduate and 75 graduate students completing their degrees each year.

3.2.1.5 Educational outreach

SEOS also emphasizes outreach efforts designed to attract students and teachers in K-12 schools and faculty in community colleges and technical schools to pursue careers in relevant SEOS disciplines. This includes highly active programs ranging from CIAN Research in Optics for K-14 Educators and Teachers (ROKET) to the Steward Observatory's programs at the Mt. Lemmon SkyCenter.

3.2.1.6 Government/Agency/Community Engagement (outreach, partnerships, collaboration)

Partnerships and collaborations in this case represent collaborations in the form of financial or measurable strategic support. Key measures are the number of master agreements, number of industrial affiliate memberships, and government and industry funded research awards.

3.2.2 Annual metrics table of expected outcomes and timeline for achievement

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) SPACE EXPLORATION AND OPTICAL SOLUTIONS

PERFORMANCE ANALYSIS	Projected FY 17	Projected FY 18	Projected FY 19	Projected FY 20	Projected FY 21
TRIF EXPENDITURES					
Total	\$ 6,852,500	\$ 7,273,532	\$ 7,697,226	\$ 8,120,921	\$ 9,017,115
FINANCIAL IMPACT OF TRIF INVESTMENT					
Sponsored Awards	60,000,000	62,400,000	64,896,000	67,491,840	70,191,514
Gifts & Other Sources	1,000,000	1,000,000	11,000,000	6,000,000	6,000,000
Royalty Income	120,000	124,800	129,792	134,984	140,383
TOTAL	\$61,120,000	\$63,524,800	\$76,025,792	\$73,626,824	\$76,331,897
TECHNOLOGY TRANSFER ACTIVITY					
Invention Disclosures Transacted	40	42	45	50	55
US Patents Issued	15	2	2	4	5
Licenses and Options Executed	15	17	18	20	22
Startup Companies	1	1	1	2	2
WORKFORCE CONTRIBUTION					
Postdoctoral Appointees	15	16	17	17	18
Graduate Students	40	42	44	46	49
Undergraduate Students	8	8	9	9	10

3.3 Initiative Structure

3.3.1 Organizational structure

The SEOS TRIF initiative is administered by the relevant deans (co-chairs indicated below), coordinated through the Office for Research & Discovery. SOES organizations

structure is comprised of two committees; the SEOS Administrative Committee and the SEOS Research Sub-Committee. These committees will include balanced representation from participating SEOS units to provide the necessary broad expertise.

3.3.2 Advisory Board

TRIF SEOS Administrative Committee: The SEOS Administrative Committee is responsible for approval and initiation of SEOS faculty searches, establishing the SEOS overall budget structure in conformance with ORD guidelines, and the high-level assurance that the goals of the SEOS initiative are being met.

- **Co-Chairs:** Thomas Koch, Dean, College of Optical Sciences; Professor of Optical Sciences and Electrical and Computer Engineering; Joaquin Ruiz, Vice President, Innovation and Strategy; Executive Dean, Colleges of Letters Arts and Science; Dean, College of Science; Professor of Geosciences; Jeff Goldberg, Dean College of Engineering
- Buell Jannuzi, Director, Steward Observatory; Department Head, Astronomy; Professor of Astronomy
- Tim Swindle, Director, Lunar and Planetary Laboratory; Department Head, Planetary Sciences; Professor of Lunar and Planetary Laboratory, Planetary Sciences, and Geosciences
- Jennifer Barton, Interim Director, BIO5 Institute; Professor of Biomedical Engineering, Electrical and Computer Engineering, Optical Sciences, Agricultural-Biosystems Engineering, and the BIO5 Institute
- Nasser Peyghambarian, Professor Optical Sciences, Professor, Materials Science & Engineering and Chair, Lasers & Photonics

TRIF SEOS Research Sub-Committee: SEOS Research Sub-Committee is responsible for the evaluation, and selection for funding, of research proposals provided through ORD, research faculty and staff hires, and programmatic issues in the implementation of SEOS funded research activities.

- **Chair:** Nasser Peyghambarian, Professor Optical Sciences, Professor, Materials Science & Engineering and Chair, Lasers & Photonics
- Buell Jannuzi, Director, Steward Observatory; Department Head, Astronomy; Professor of Astronomy
- Neal Armstrong, Regents Professor of Chemistry, Biochemistry, & Optical Sciences; Associate Vice President for Research
- Jennifer Barton, Interim Director, BIO5 Institute; Professor of Biomedical Engineering, Electrical and Computer Engineering, Optical Sciences, Agricultural-Biosystems Engineering, and the BIO5 Institute

3.3.3 Infrastructure

Major infrastructure associated with SEOS includes observatories and their operations, and optics and instrumentation shops of the Steward Observatory and the College of Optical Sciences which span from the 8.4m capabilities of the Richard F. Caris Mirror Lab to the upgraded 6.5m and diamond turning micro-optic fabrication in Meinel. Additionally, photonic integrated circuit fabrication and packaging, and fiber fabrication apparatus in Meinel, are critical components of the photonics program, and advanced materials diagnostics tools are key to LPL objectives for future sample return missions. Investments in both technical capability and mitigating gaps in support are required to advance the SEOS mission.

3.3.4 Description of investment mechanisms

At the UA, TRIF promotes the economic development of the state by: catalyzing innovative research in target areas of high impact aligned with Arizona businesses; engaging industry and accelerating the commercialization of research results into new products and services that benefit the health, security, and prosperity of Arizona; developing the future high-tech workforce – training students from elementary to graduate school to be science and innovation leaders who will create Arizona’s bright future; and providing infrastructure through research services, computing, equipment and facilities

that enables innovation and research.

TRIF investments will accelerate capacity through strategic faculty hires in focused areas identified in the University's *Never Settle* strategic plan, and further fleshed out in the ORD Strategic Research Roadmapping sessions held in 2015 with hundreds of researchers across campus. Investments will be made in new transdisciplinary research initiatives to enhance competitive success for securing extramural funding and engage industry and accelerate the commercialization of research results. TRIF will support the training and engagement of students while developing a high-tech workforce and will provide infrastructure that enables innovation and research through facilities and instrumentation.

3.3.4.1 Catalyzing innovation research

3.3.4.1.1 Strategic faculty hiring

Strategic faculty hiring will target the identification of the most brilliant, promising faculty in areas that are well-aligned to gaps in expertise and SEOS thematic objectives

Potential TRIF Hires in SEOS	
Theme	Expertise
Exoplanet Studies & Cosmic Origins	Observational astronomy; Optical, near-infrared, and mid-infrared instrumentation packages; Exoplanet formation, geological evolution, and atmospheric science
Mission and Sample Return	Mars, Europa, NEO mission specialists; Instrumentation package development; Nano-characterization

Optics/Photonics	Fiber device & subsystem technology; Semiconductor optoelectronics and photonic integrated circuits; Photonic integrated circuit packaging; Infrared technologies
Imaging and Enabling Technologies, Informatics.	Image science; Big data & algorithms; Optical design, fabrication & metrology; Remote sensing; Biomedical optics

3.3.4.1.2 Transdisciplinary Research Initiatives

Virtually all of the SEOS investment thrust areas are inherently transdisciplinary in nature by combining engineering, fabrication, and design of complex space or optical systems, or system engineering of image science, with base scientific or technological applications disciplines in Astronomy, Space Sciences, Life Sciences, and areas such as Communications, Information Technology, National Security, and Defense Systems.

Several areas identified are likely to benefit from a broader, coordinated cross-campus infrastructure that would also position UA for future major external funding sources such as NSF Engineering Research Centers (ERCs) or Science and Technology Centers (STCs). Examples might include an Imaging Technology Center, targeting the concept captured earlier for a holistic approach to the system engineering of imaging systems. Another example where a coordinated transdisciplinary center is likely to be productive is the area of augmented reality, where strong private-sector interests seek to blend advances in base technologies with a deeper understanding of human perceptual factors and potential long-term usage impact. Existing transdisciplinary initiatives that link into SEOS also include new National Security Systems TRIF Initiative administered by the Defense and Security Research Institute (DSRI), and WEES Initiative on the area of mission and instrument development related to earth remote sensing.

3.3.4.2 Engaging Industry & Advancing the Commercialization of Research

SEOS is actively engaged with industry and is strongly positioned for growth. In addition to establishing constructs and vehicles for collaborative research programs and securing new external R&D funding, SEOS also supports a variety of industry partnership programs that provide intimate engagement points for companies across the nation to engage students primarily at the graduate MS and PhD level, as well as the faculty supervising their research. Recent growth in these programs has revealed that, in addition to technology access, industry partners on a national scale are using UA venues in their networking for business development in SEOS areas.

SEOS has experience, and will continue to support, bringing personnel from industrial affiliates to the campus for collaboration in the context of externally-funded research projects and related initiatives. SEOS also expects to continue its admirable record of invention disclosures, intellectual property development and licenses, options, and start-up companies, to further enhance application opportunities and commercialization potential.

3.3.4.3 Developing the High Tech Workforce & Outreach

The workforce development portion of SEOS offers realistic and attainable solutions to the severe shortage of trained personnel in optical sciences and technology. Many of the SEOS workforce development objectives utilize leveraged funding from federal sources, including programs associated with the CIAN ERC and the AIM Photonics consortium, and large scale training efforts in Steward Observatory and Lunar and Planetary Laboratory. Strategies developed will improve undergraduate and graduate curricula in SEOS sciences, recruit students to SEOS-related career choices, and reach-out to optics and space systems companies through courses that include web-based, learning-centered technology. TRIF has helped support hundreds of graduate students doing cutting edge R&D in the key areas of optics, image science, astronomy, and remote sensing who have moving into careers at the forefront of technology development in government, industrial, and academic laboratories, bring national and international recognition of excellence to Arizona and often filling important jobs in the state.

3.3.4.4 Infrastructure & Instrumentation

A significant investment will continue to be made into core facilities and instrumentation that enable cutting-edge R&D and support industry partnerships. While user fees can defray a portion of operating costs, initial equipment investment is supported by university and TRIF funds, generally with significant industry contribution through negotiated discounts. This core equipment is available to all investigators at UA, other Arizona universities, and will be aggressively promoted as a resource to industry. Major areas of emphasis going forward are infrastructure and instrumentation that support astronomical observation, optics fabrication, materials characterization, and photonics equipment.

3.4 Initiative budget

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) SPACE EXPLORATION & OPTICAL SOLUTIONS

FINANCIAL SUMMARY	Budget FY 17	Budget FY 18	Budget FY 19	Budget FY 20	Budget FY 21
REVENUE					
TRIF Revenue	6,852,500	7,273,532	7,697,226	8,120,921	9,017,115
TOTAL	6,852,500	7,273,532	7,697,226	8,120,921	9,017,115
EXPENDITURES					
OPERATING BUDGET	5,852,500	6,273,532	6,697,226	7,120,921	8,017,115
CAPITAL BUDGET	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
TOTAL	6,852,500	7,273,532	7,697,226	8,120,921	9,017,115

3.5 Plan for sustainability

3.5.1 Anticipated funding sources for ongoing support

SEOS will continue to be well positioned for increased support from federal research funding agencies including NSF, DOD, DOE, DHS, and NIH, as well as from key industry partners. This includes the broad spectrum of Broad Area Announcements for smaller scale individual investigator awards, as well as existing vehicles such as MURIs, STCs, and ERCs, but also directly appealing to agencies with compelling value propositions to spawn programs that can be fit within broad national imperatives as was done with the

NNMI.

Strong industry partnerships are a key aspect of the strategic goals of UA's Never Settle strategic plan. SEOS anticipates generating new pathways to corporate-sponsored efforts, as well as corporate partnerships to secure new federal funding. Technology developed through TRIF will gain more support from our industry and government partners, and new faculty hires supported by TRIF will yield many new grants/contracts, technology, intellectual property, and trained talent to help grow Arizona industry.

Other sources of support include sales and service through core facilities. A "win-win" with industry is achieved when equipment and services, not otherwise accessible for industry, are provided from the UA for an attractive price, which in turn supports the maintenance and growth of these facilities.

The Office for Research & Discovery enables these sustainability efforts through support by Research Development Services (RDS), as well as two "business development" divisions, Strategic Business Initiatives (SBI) and the upcoming Global Research Alliances. RDS provide full-service extramural funding assistance to UA researchers, from opportunity identification, proposal plan development and team building, to proposal management and reviews. SBI connects needs of the business community to the expertise of UA researchers, which results not only in additional industry support for research and development activities occurring at UA, but also more importantly forges partnerships that enable strong UA-industry teams to compete for significant federal contracts. Global Research Alliances performs a similar function, but focuses on developing strong UA, university, industry partnerships internationally.

A significant effort is being made in philanthropy. The Office for Research & Discovery, in concert with the UA Foundation, has just hired a Senior Director of Development

3.5.2 Timeline for transitioning away from TRIF support

The transition plan for the next 5 years is to use TRIF to recruit productive faculty, provide enabling equipment, seed new research programs, foster industry engagement, and link faculty through graduate students. SEOS has an outstanding record of ROI with the

development of strong federal agency and private sector partnerships that leverage TRIF investments into external funding streams for sustainability, as well as commercializing research into the marketplace.

4. Water, Environmental, and Energy Solutions

4.1 Investment description/rationale/justification

4.1.1 Overview of Industry or Area Addressed by the WEES Initiative

Human well-being, economic prosperity, and security, all depend on environmental resources of water, energy, food, land, air, and biodiversity. The economic prosperity and health of the state of Arizona are particularly dependent on judicious management of its natural resources, including the efficient use of water; the sustainable use of energy, minerals, and agricultural land; and the protection of the clean air and scenic landscapes that attract people and businesses to the state. Arizona's arid climate, international border, and large areas of land managed by the federal government and native nations are also factors that impact sound and sustainable solutions to the environmental challenges in the State.

The TRIF Water, Environment, and Energy Solutions (WEES) initiative at the UA engages in R&D activities that advance innovative solutions to pressing environmental, energy, and water challenges of Arizona and beyond. In fact, the UA's strategic plan, *Never Settle*, calls out water/energy/arid environment as a core research strength targeted toward further strategic investment. WEES support of cross-sector partnerships will lead to scientific, technological, and policy-related solutions to water, environmental, and energy issues and deliver tangible benefits to Arizona, the nation and the world. WEES investments will bring millions of dollars of public and private funding to the UA by recruiting world-class faculty in cutting-edge research areas, and by building interdisciplinary collaboration across campus and in partnership with Arizona businesses and governments that translate into economic development opportunities for all.

WEES investments support the expansion of existing high-return activities, and will also seed exciting new initiatives in research, workforce development, and outreach. Investments will help secure adequate supplies of clean water and energy; and will provide the foundational knowledge and new technologies needed to optimize the sustainable use of Arizona's arid lands and ecosystems.



Integration of water, energy and environmental research is key. For example, energy-efficient water reuse and purification is important for municipal, agricultural, mining and energy production sectors, particularly with the unprecedented drought in the Colorado Basin. The intersection between water and energy is particularly relevant for some Native nations in Arizona that do not have connected water infrastructure on reservation communities and rely on energy to provide desalinated local water sources for residents.

WEES outcomes are consistent with Arizona's goals as articulated by the Arizona Commerce Authority (ACA): to create jobs and increase investment by attracting, growing, and creating businesses. Among target industries for investment identified in ACA's business plan are renewable energy, technology and innovation, and advanced manufacturing sectors. With more than 100 significant solar energy businesses in Arizona and ranked #3 nationwide in solar employment, breakthrough advanced energy solutions will drive substantial economic development to power our future. With significant funding available from the Department of Energy through ARPA-E and other mechanisms, the opportunities to support the Arizona economy are large.

WEES funds also help advance research, tech development, and industry collaboration for improving and testing water treatment technologies critical to advanced manufacturing and for consumptive water uses in innovative technologies. Investments in multidisciplinary transformational research focused on real-world challenges and solutions will help position Arizona as a leader in sustainable growth policies and the incubator of locally oriented and globally relevant water, environmental, and energy solutions. The research proposals seeded by WEES investments will bring millions of dollars of public and private funding to the UA, and deliver innovative ideas, assessments, information, and technologies that benefit Arizona as well as the nation and world. Innovative businesses that are created and grown based on outcomes from UA WEES researchers will be a core contributor to Arizona's technology sector and overall economic future.

4.1.2 Mission, Goals, Values and Vision

The mission of UA's WEES initiative is to develop the innovative and practical solutions necessary for water, environmental, and energy sustainability in Arizona and other semi-arid regions facing increasing demands on natural resources and the uncertainties of climate variability.

Goals include:

- Enhance UA's strengths, external funding, and diversity in the areas of water, energy, and environment by promoting interdisciplinary collaboration for science and technology development efforts that lead to innovative, practical solutions;
- Draw on UA's vast water expertise and community connections to develop new technologies and management approaches to ensure Arizona's water security;
- Capitalize on Arizona's strong renewable energy industry to develop R&D derived solutions aimed at securing sustainable energy resources for public well-being and a vibrant economy;
- Leverage the TRIF investment in strategic areas to increase public- and private-sector partnerships and funding;
- Seed projects that help train the next generation of scientists and engineers, and that have strong potential for technology transfer and commercial development of research ideas into the marketplace.

WEES has a strong track record of delivering on specific TRIF performance metrics towards the vision. Historically, over the last three years of the TRIF WEES initiative, every TRIF dollar invested resulted in nearly a 9x return on investment. In the last four years, 82 invention disclosures were transacted, five new companies started and 9 new patents issued. We expect continued strong return on investment, due to this alignment, to result in substantive growth in new federal grant funds into Arizona. These funds will support not only UA, but also Arizona industry and our partner Arizona universities.

4.1.3 Programmatic Areas for Investment

The UA's strategic plan, *Never Settle*, has four pillars, engagement, innovation, partnerships and synergy - TRIF investment programs cover each of these pillars. In *Never Settle*, Innovation charges us to advance research to find better answers to the world's grand challenges that deliver public impact and benefit by:

- Promoting and building upon core strengths to address grand challenges for the state of Arizona and the world
- Collaborating boundlessly to increase local-to-global impact
- Engaging new strategic partners in the research enterprise to accelerate innovation
- Improving institutional infrastructure to speed new discovery, knowledge, and application
- Strategically attracting, educating, and engaging first-rate doctoral and other advanced degree seeking students in a variety of WEES disciplines to grow the high tech workforce ;
- Improving recognition and support for collaborative and interdisciplinary research and scholarship; and
- Expanding economic development in our region through commercialization of research ideas

These strategies guided the TRIF investments in the WEES programmatic areas, which were carefully chosen to align with areas of Arizona and national need. The selected thrust areas in the WEES initiative are focused on generating impact for Arizona, for which UA faculty already have significant expertise, and which have the capacity to grow external federal and industry funding, expand economic opportunity, as a result of the support by this initiative.

4.1.3.1 Water Security in Arid Environments

The Challenge: Access to water is foundational to the economic and human prosperity of Arizona and other regions, particularly with its strong agricultural, mining and advanced

manufacturing sectors. As an arid state and water security is a top concern to citizens, governments, producers and industry. Achieving water security means ensured access to acceptable quality water for sustaining livelihoods, industry, human well-being, and ecosystems. Water is essential to energy, food, and health, giving water science, technology and management practices key roles in our state's and nation's futures. Transdisciplinary research and development is crucial if we are to adapt to ongoing drought, changing water demands, and reduced quality and supply reliability within a systems context that includes human consumption and agricultural use along with environment and culture. Better insights into multi-faceted questions including how groundwater hydrology impacts aquifer storage, how rainwater catchments aid resilience are needed. Understanding how ecosystems can be preserved, and how improved water treatment methods can expand water reuse to benefit all is critical to continued progress. Science and resource management research is crucial if we are to successfully integrate groundwater, surface water, conserved water, and reclaimed water into the consumptive water portfolio, thereby securing Arizona's water future.

UA Advantage: The UA is uniquely situated to mobilize science and technology expertise on water-related issues, so that researchers can solve real-world problems, increase our competitive advantage for federal and other grants, and bring tangible economic benefits Arizona. UA has exceptional expertise with over 280 researchers in 48 departments and programs, creating an ideal incubator for collaborative and synergistic endeavors. Water is a clear university priority, identified in the UA's *Never Settle* strategic plan as a core strength area. Situated within an arid lands "living laboratory", UA is an international leader in basic and applied water research and development, and has particular strength in water science, engineering, and management practice. UA has a proven track record of engagement in projects of all kinds, which give it long-standing links with industry, decision-makers, and other stakeholders in Arizona and throughout the Colorado River Basin region.

UA's experience developing novel technologies and industry engagement both for wastewater treatment and mining applications gives UA a competitive edge, and gives

partnering Arizona-based industries and highly skilled student workers an economic advantage in the burgeoning water-environment sector. Likewise, industry, government, and other collaborative connections offer strategic advantages when seeking funding for landmark R&D to address essential concerns about water availability, quality, drought, hydrology and water-energy-food nexus topics. The germane nature of UA's R&D efforts makes it ideally positioned to train next generation's high-tech workforce and to be a top resource for trusted communications on relevant water issues and solutions. Having ready access to credible information on Arizona's water reliability, reuse opportunities, and diversification is essential to attracting businesses, creating jobs, and boosting the state's economy.

4.1.3.2 Climate and the Earth System

The Challenge: The impacts of climate variability, especially drought, in Arizona can be severe, creating stresses on water resources, agriculture, ecosystems, energy, and public health. Droughts and more frequent heat waves increase the risk of severe forest fires, the need for and costs of air conditioning, and the incidence of diseases carried by mosquitos and dust. Climate and extreme event R&D, including understanding behavioral and environmental system responses to drought, delivers knowledge and tools that assist in decision-making associated with almost every sector of the Arizona economy. Arizona's prosperity is connected to drought and extreme events beyond the state as our industries, prices, and economy partly depends on conditions, supply chains, and consumer demand elsewhere. Therefore, understanding the global earth system is important to the future of the economics of the state, including how changes in the carbon cycle and other planetary processes are changing the climate and increase extreme events such as drought, how these changes then affect the state's water supply, food security, health, and economic vitality and how to develop technologies and strategies to respond.

UA Advantage: The UA has a rich array of climate science and application programs ranging from basic R&D to close collaboration with decision-makers in adaptive management practices. UA expertise is broadly interdisciplinary, involving natural and

social sciences, engineering, health, and economics/business. Identified as a core research strength in UA's strategic plan, *Never Settle*, the UA is a national leader in basic climate dynamics research, including paleoclimate, Earth-system modeling, and regional-scale climate and hydroclimate modeling, with special expertise regarding the desert southwest. UA researchers are also nationally and internationally recognized for our expertise in interdisciplinary climate science, including the integration of climate with water, carbon cycles, ecosystem, public health, energy, economics and policy, at global and regional scales, in addition for leadership in climate-change adaptation and climate and drought information for management and economic decisions. The University has world-class experimental and data facilities and our faculty have secured millions of dollars in external R&D funding, along with associated jobs and infrastructure for the state. Our focus on Arizona needs for outreach, education, and training assists our local communities, small businesses, and tribes to undertake crucial adaptation planning to secure long-term economic growth and job creation in Arizona through the commercialization of research ideas.

4.1.3.3 Ecosystems, Conservation, and the Earth's biological systems

The Challenge: Understanding the dynamics of the Earth's biological system is one of the great integrating challenges of the modern era and has direct implications for human habitability on our planet. Our future climate, health, landscapes, and food security are closely connected to the condition and behavior of millions of other species ranging from bacteria, fungi, and algae to plants and animals – small and large. The earth's ecology has changed substantially in the last century, thereby changing distributions and abundance of plants and animals, and impacting how we manage agriculture, wildlife, and environments for production and conservation. Key processes such as the breakdown of wastes, the spread of disease, and the production of food and timber are closely connected to biological communities at the microbial, local, and regional scales. The vast majority of molecular-scale processes are mediated in some way by microbial communities, which collectively can be thought of as "Earth's microbiome" – an area identified as a top federal research priority with the goal of linking molecular-scale

biological, chemical, and physical processes to natural and anthropogenic activities occurring at watershed, ecosystem, and larger scales.

UA Advantage: The UA has great strength across the biological sciences, earth sciences, ecology, and natural resources management that already bring millions of research dollars to the university and support society and economic decision making. This thrust area brings together two core strengths from UA's *Never Settle* strategic plan – bioscience and the environment. For example, the University is solving mine and other waste problems through microbes and plants that break down pollution, our expertise in agricultural ecosystems strongly support the state's economy and broader food security, and research in fish, wildlife, and forests contributes to important sources of revenue and recreation. Recent cluster hiring in genomics, earth observation, ecology, public health, and informatics/data has added exciting expertise, and we already have major research programs and facilities. New opportunities exist for UA's diverse expertise in environmental science and management to focus collectively on biodiversity and conservation to enhance ecosystem services that support economic development and public benefit. Associated start-up businesses in cutting-edge fields will attract investment, increase payrolls, and offer training to students in new approaches to problem solving and management, thereby boosting their attractiveness to employers. UA faculty have identified nearly 50 potential interdisciplinary research topics across several thematic areas where UA can excel, including public health, food security, foundational biodiversity, ecology and conservation, and ecosystems and national security.

4.1.3.4 Environmental Health and Contaminants

The Challenge: Living in a healthy and clean environment has become a principle of modern society and therefore understanding environmental health and addressing air quality concerns are a high priority for research and solutions. There is a strong need for academic investment and knowledge transfer on topics such as contaminant detection and remediation, environmental treatment technologies, real-time pollutant and particulate sensors, human exposure science, and risk assessment. Identifying,

assessing, and treating chemical, biological, and physical contaminants form the basis for abundant potential industry connection and collaboration.

UA Advantage: The UA has numerous departments and programs addressing environmental health and pollution – another thrust area at the intersection of two core research strengths from UA’s *Never Settle* strategic plan – translational bioscience and the environment. Cutting-edge research and development is being conducted on real-time water sensors, desalination facilities, and contaminant removal, and in connecting climate and weather forecasts to reduce the incidence of diseases such as dengue, malaria, asthma, and valley fever. Exceptional UA research programs and centers are investigating topics such as solvents in mine tailings, environmentally responsible mining technologies, cleanup, disease forecasting, air quality issues, and human exposure science, as well as internationally acclaimed clinical research in asthma and airway diseases UA’s investments in environmental health and pollution research offer a value-added proposition to the state by bringing a high-tech work force to regional industry, introducing and developing commercialization opportunities, and offering vital scientific connections to industrial collaborators, all of which bring substantial value to state’s economy. Interdisciplinary programs in natural, health, and social sciences have a particular focus on underserved populations facing particular environmental health risks, including Native Americans, Hispanics, children, and border communities. It is clear that technical innovation drives many of the world’s advancements and UA’s work in environmental health directly interfaces with industry to help foster knowledge-based economic value in Arizona and beyond.

4.1.3.5 Advanced Energy Solutions

The Challenge: As energy demands increase, creating reliable and resilient energy delivery systems sufficient to sustain and enhance our society are of paramount importance. The southwestern US, stretching from southern California to eastern Texas, contains nearly one-third of the US population and has abundant renewable energy sources, mainly solar but also wind and hydro. In Arizona, energy is also inextricably linked to the region’s most critical resource—water—and to the needs of underserved

populations in rural areas. Because energy resources underpin our lives and our economic viability, developing new technologies for energy solutions is critical for Arizona and beyond. There is need for new systems-level solutions that are flexibly targeted to address challenges of energy efficiency, distributed energy sources, smart grids, big data, and energy storage, and we need technology improvements that will provide low-cost, low-carbon, and economically profitable energy alternatives such as solar or algal biofuels. Connecting energy research to research on energy-intensive water and food systems and on climate and weather to ensure integrated and sustainable solutions.

UA Advantage: UA researchers are increasingly active in key energy research areas such as development and characterization of energy conversion and energy storage materials, bioenergy, real-time power forecasting of renewable energy inputs to regional power grids, more effective solar technology, development of “smart-grid” models, economic modeling of the impacts of adoption of renewable energy sources, testing of degradation mechanisms for photovoltaic energy conversion systems, incorporation of renewable energy and water sources into sustainable mining, and desalination of inland groundwater resources. These programs already bring in research dollars and take advantage of partnerships with local industries and utilities to test technologies and explore decision and investment options and spin off business opportunities. UA is poised to take a larger role in national energy research, but also to provide more energy solutions for Arizona as well as academic support for the state’s ever-growing energy industrial sector. This thrust area is a core strength from UA’s *Never Settle* strategic plan.

4.1.3.6 Integrated Research and Data Systems

The Challenge: Water, energy, and environment are deeply interconnected, not just in Arizona but throughout the world. The WEES proposed thematic areas—water, energy, ecosystems, climate, and environmental health—connect to each other and to broader scientific, social, and management priorities including public health, security, and economic development. There is an urgent need for integrated solutions at the nexus of food, energy, water, ecosystems, climate, and environmental health that take advantage

of innovative research in modeling, informatics, and remote sensing supported by high performance computing. For example, new streams of data on land use, genomics, atmospheric conditions, and human resource use need to be integrated so as to understand the connections between environment, health, and food production or the trade-offs between energy production, agriculture, and water supplies. More broadly, we need to understand how to manage the earth system to meet human needs without degrading water, land, or ecosystems beyond safe boundaries. Equally important is the challenge of effectively communicating these integrated challenges and solutions to the public, businesses, and to decision makers who can use the information to develop solutions and make wise choices in management practices.

UA Advantage: The UA has an unparalleled reputation for interdisciplinary research and high end information technology - a core strength, informatics, from UA's *Never Settle* strategic plan. It is especially well known for its interdisciplinary approaches to water, climate, and environment; for bringing together natural, applied, and social sciences; and for conducting work that is collaborative with stakeholders to develop integrated solutions. In environment and water the UA has developed important datasets and facilities for integrated research, including archives of detailed historical and spatial environmental data for our region and more broadly. The University also have the great advantage of being able to link top researchers in natural and social sciences to professional schools of engineering, business, public health, law, and medicine so as to ensure the delivery of relevant and economically sound solutions and to a land grant tradition of delivering agricultural and other resource knowledge and technologies to the state and society. Our reputation for looking beyond the earth to other planets is matched by our ability to understand and solve the problems of our own. Federal funding agencies as well as philanthropic organizations are keenly aware of the need for integrative research in nexus areas. Likewise, local governments, state agencies, industries, and businesses need user-centered research and data systems that can be utilized within the context of their operational areas. Integrated research and data systems are critical elements in most academic-industrial partnering efforts, helping new businesses establish and contributing

to the economic prosperity of the state. WEES will leverage the cyberinfrastructure through CyVerse (formerly iPlant) to understand large data sets to develop new technology solutions and businesses to today's grant scientific challenges.

4.2 Expected Outcomes

4.2.1 Specific and realistic outcomes that are clearly measurable

4.2.1.1 Anticipated return on WEES investments

The themes identified in this plan—water, energy, climate, ecosystems, environmental health, and integrated analysis—are focused directly on areas of current and potential funding, partnerships with business, and high-priority workforce needs. They connect, for example, to priority research areas to which funding has been allocated by federal agencies for environmental health, energy, and agriculture research and for environmental and water systems research under the US Global Change Research Program. These areas are also a priority for major philanthropic foundations and for private-sector investors and businesses seeking to reduce their environmental impacts and develop new opportunities in sustainable entrepreneurship.

UA faculty already compete very successfully for funding in the environmental arena, especially for federal science funding. Maintaining this high level of grant applications and success must be a priority in addition to seeking new sources of funding. WEES seeks to maintain our competitive advantage for continued funding, and anticipates an increase in environmental, water and energy R&D funding over the next five years.

New faculty hires and expansion in fields that are aligned with national funding targets will increase prospects for large return via grants. All WEES areas are pursuing options such as gifts, foundation support, and contracting to supplement grant funding. Examples include:

- There are many opportunities for UA to compete to renew or win large interdisciplinary grants (\$5 million or more) in water, energy, environment and the connections between them. This includes the potential to secure new multimillion-

dollar grants for Science and Technology Centers, Long Term Ecological Research sites, National Institutes for Environmental Health Sciences collaborations, earth systems satellite projects and information/data centers, and large international development programs.

- Federal, state, and local resource management agencies fund and use research on environment, water, and energy and to manage and guide critical forest, mineral, water, and recreational resources on public and private lands. UA can sustain its rich tradition of serving these stakeholders with reliable information on resources and with a well-trained workforce.
- The defense and security agencies and businesses are increasingly concerned about ensuring that environmental change and energy, food, and water insecurity do not threaten US interests and are supporting and using research in these areas.
- Increasing awareness of the connections between environment and health has generated research funding and applications from the National Institutes of Health as well as private business and philanthropic foundations. Fifty foundations have been identified that fund primary activities in energy policy, clean energy, energy efficiency, water and agriculture, and mitigation of climate change with total giving over \$7 billion.
- The US Global Change Research Program coordinates \$2 billion a year investments in university and federal research on environmental change implemented through the National Science Foundation, NASA, NOAA, EPA, and the departments of Agriculture, Interior, and Energy.
- There are many opportunities for research and development partnerships to develop new energy and water technologies with commercialization and application potential in areas such as renewable energy, water reuse, waste cleanup, food systems, sustainable mining, and health services. DOE has targeted \$110 million in FY17 for Regional Clean Energy Innovation Partnerships focusing on Clean Energy generation.

- Increased demand for high-quality education in science is supported by the knowledge, training, and outreach activities from kindergarten through adult provided by the UA. This benefits the state and can attract funding from government, private philanthropists, and the public to build a more successful workforce.

4.2.1.2 Technology Transfer

Tech Launch Arizona (TLA) continues to actively engage with the WEES initiative and faculty. TLA's cooperation with the WEES initiative will be extended beyond the initiative's funding of asset demonstrations to include broader cooperation from the beginning of the research process and extending through to commercialization. TLA closely coordinates in the identification of faculty whose research and inventions may be the basis for expanded WEES commercialization opportunities.

Arizona is ranked as the No. 1 state for alternative energy and a top ten state for solar energy, with over 8% of the nation's solar industry employment. Additionally, UA is ranked 2nd in the world for environmental research and has been building on its strengths through the Water, Environmental and Energy Solutions (WEES) Initiative to translate research far-reaching societal benefits in Arizona and the world.

TLA tracks five key metrics for outcomes: invention disclosures; provisional patents filed and awarded; total licenses; startups; and asset development. Growth of invention disclosures illustrate the success of TLA's outreach efforts to faculty and staff. Approximately 60% of such invention disclosures result in a provisional patent application being filed. A license is the transfer of the University's rights in a particular invention to a third party in order to move that technology to the marketplace. Asset Development investments make technologies more attractive to industry partners and further private investment. For select technologies, creating a new venture (startup) is the best commercialization path, resulting in new jobs and economic benefit to the region.

4.2.1.3 Industry Engagement

Industry engagement occurs through numerous WEES-supported centers and initiatives that garner input from private and public industry partners through technical advisory committees and respond to industry needs through partnering arrangements. Expected outcomes include engaging industry by developing, evaluating, and demonstrating technologies; developing training programs that target key industries; expanding industry-academic cooperatives and partnerships; and providing water, climate, energy, and environmental information to industry stakeholders in Arizona and beyond.

4.2.1.4 Workforce Contributions

WEES programs advance Arizona's high-tech workforce by impacting and enabling students through assistantships, wages, scholarships, grants, and research experiences. In addition, WEES programs provide continuing education to Arizona's citizens and professionals through conferences, workshops, short courses, and teacher training. Expected outcomes include employing, training, and engaging students in preparation for their entry to the workforce, professional training of K-12 teachers, and providing continuing education to the public through conferences, seminars, and workshops.

4.2.1.5 Educational Outreach

WEES programs offer educational outreach through websites, newsletters, op-ed contributions, presentations, and personal engagement with interested community members and stakeholders. Environmental, water, and energy topics are of particular interest to the public and requests for presentations are frequent. Expected outcomes include newsletters and other publications; continued development of websites; connection through social media; development and hosting of conferences, workshops and seminars; and partnering with tribal colleges on mine education modules.

4.2.1.6 Government/Agency/Community Engagement

WEES programs actively engage governments, agencies, and communities throughout Arizona and beyond. A strength of many WEES programs is their ability to simultaneously engage broadly and educate. Engagement requires faculty and staff involvement in maintaining contact lists, keeping interactions current, regular communications, and development of effective engagement mechanisms. WEES programs are trusted sources for information, analysis, and data, particularly regarding water, climate, energy, and environmental information. Expected outcomes include responding to data requests by local and regional governments and utilities in addition to outcomes listed under educational outreach.

4.2.2 Annual Metrics Table (See attached metrics table)

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) WATER, ENVIRONMENTAL AND ENERGY SOLUTIONS

PERFORMANCE ANALYSIS	Projected FY 17	Projected FY 18	Projected FY 19	Projected FY 20	Projected FY 21
TRIF EXPENDITURES					
Total	\$ 5,607,500	\$ 6,007,534	\$ 6,407,573	\$ 6,807,612	\$ 7,680,150
FINANCIAL IMPACT OF TRIF INVESTMENT					
Sponsored Awards	31,000,000	32,240,000	33,529,600	34,870,784	36,265,615
Gifts & Other Sources	3,400,000	3,536,000	3,677,440	3,824,538	3,977,519
Royalty Income	750,000	780,000	811,200	843,648	877,394
TOTAL	\$35,150,000	\$36,556,000	\$38,018,240	\$39,538,970	\$41,120,528
TECHNOLOGY TRANSFER ACTIVITY					
Invention Disclosures Transacted	20	21	23	25	27
US Patents Issued	2	2	2	4	5
Licenses and Options Executed	6	7	7	8	9
Startup Companies	1	1	1	1	1
WORKFORCE CONTRIBUTION					
Postdoctoral Appointees	85	89	94	98	103
Graduate Students	270	284	298	313	328
Undergraduate Students	110	116	121	127	134

4.3 WEES Initiative Structure

4.3.1 WEES Organizational Structure

WEES is administered by co-directors Dr. Sharon Megdal, director of the Water Resources Research Center; Dr. Diana Liverman, co-director of the Institute of the Environment; and Dr. Kimberly Ogden, director of the new UA Advanced Energy Solutions Institute, coordinated through the Office for Research & Discovery. These experienced leaders will ensure the coordination and integration embedded in this business plan.

4.3.2 WEES Advisory Board

WEES will have an external Advisory Board and an internal Advisory Committee. The existing Advisory Board membership represents the three primary focus areas of water, energy, and the environment. The board provides high-level input on the overall direction of the initiative and to ensure the relevance and connection of WEES activities to Arizona. WEES also plans to expand its existing 11-member Advisory Committee comprised of UA faculty. This committee will play a key role in determining funding priorities and reviewing proposals for new faculty hires, new research initiatives and grants, major equipment purchases, and other large investments.

4.3.3 WEES Infrastructure

Several facilities and infrastructure are utilized to successfully carry out the mission of WEES, the pilot plant scale water testing and treatment facility, WEST; the testbeds and evaluation facilities of the Arizona Advanced Energy Solutions Institute, high performance computing and storage in UITS, as well as facilities of the Water Resources Research Center and Institute of Environment.

4.3.4 WEES Investment Mechanisms

At the UA, TRIF promotes the economic development of the state by: catalyzing innovative research in target areas of high impact aligned with Arizona businesses; engaging industry and accelerating the commercialization of research results into new products and services that benefit the health, security, and prosperity of Arizona; developing the future high-tech workforce – training students from elementary to graduate

school to be science and innovation leaders who will create Arizona's bright future; and providing infrastructure through research services, computing, equipment and facilities that enables innovation and research.

TRIF investments will accelerate capacity through strategic faculty hires in focused areas identified in the University's *Never Settle* strategic plan, and further fleshed out in the ORD Strategic Research Roadmapping sessions held in 2015 with hundreds of researchers across campus. Investments will be made in new transdisciplinary research initiatives to enhance competitive success for securing extramural funding and engage industry and accelerate the commercialization of research results. TRIF will support the training and engagement of students while developing a high-tech workforce and will provide infrastructure that enables innovation and research through facilities and instrumentation.

4.3.4.1 Catalyzing Innovative Research

4.3.4.1.1 Strategic Faculty Hiring

The programmatic areas above leverage existing UA expertise but will benefit from strategic hires to bring in additional research funding and contribute to solving problems of the region and beyond. Hiring recommendations are distributed across WEES programmatic areas (see table below), and also include nexus activities and opportunities for newly emerging priorities and partner or opportunistic hires.

Potential TRIF hires in Water, Environmental, and Energy Solutions	
Theme	Expertise
Water Security in Arid Environments	Water security/groundwater/surface water; water quality/reuse - desalination
Climate & the Earth System	Regional climate modeling; carbon cycle analysis
Ecosystems	Biodiversity links to health or food; Earth microbiome
Environmental Health/contaminants	Environmental health risks or policy
Advanced Energy Solutions	Energy forecasting

4.3.4.1.2 Transdisciplinary Research Initiatives

WEES will provide support to new initiatives in WEES thrust areas through internal competitive grants focused on growing new interdisciplinary collaborations at large scale to realize strong continued growth in R&D, as well as to existing initiatives within the programmatic investment areas that have demonstrated early success and show strong promise for large future return on investment in order to further expand. Grant opportunities include funding for new programs, pilot projects, research networks that will lead to new transdisciplinary research teams, proposal preparation, equipment, and graduate student support. UA's Research Development Services professionals will be invaluable in growing our portfolio of externally funded work.

4.3.4.1.3 Engaging Industry and Advancing Commercialization

WEES investments in faculty, research programs, and equipment support water, environment, and energy efforts that provide knowledge integration and technology development that are critical to utilities, governments, commercial industries, and entrepreneurs in Arizona and beyond. Researchers are working with electric power companies to forecast and model energy power production. Others are collaborating with industry and government to develop new approaches to energy-efficient water reuse and regional food production systems. Major mining groups have engaged with UA researchers to develop, teach, and implement sustainable mining practices that protect

air and water quality. Eleven industry members are collaborating with water treatment investigators to advance high-tech water treatment and reuse research. WEES investments are designed to augment and expand industry funded R&D to advance partnerships and return on investment.

4.3.4.1.4 Developing High-tech Workforce and Outreach

WEES support of student training provides experience in fields such as water-quality technology, water science writing, informatics/imaging program implementation, and climate modeling. Using the exciting new TRIF supported mechanism to further link industry (non-profits included), researchers and students, WEES supports bringing together a team of undergraduate researchers, a graduate student team leader, and interdisciplinary university-industry R&D mentorship to conduct jointly funded R&D. These innovative teaming models help prepare our students for collaborative work environment in industry, satisfy increasing workforce needs and make Arizona a more attractive location for founding and growing companies in the SEOS area.

WEES also supports the award-winning Arizona Project WET which promotes water stewardship and K-12 STEM literacy through teacher professional development, student outreach, and community engagement. Outreach efforts are aimed at engaging industry, governments, and professionals in WEES research, and in particular have branded UA as a trusted source for water, drought, and climate information, research, planning, and engagement. Newsletters, web communications, seminars, conferences, and publications help showcase UA WEES TRIF investments to the broad stakeholder base throughout the state.

4.3.4.1.5 Infrastructure and Instrumentation

WEES funds instrumentation and infrastructure to enable innovative research and technology development at UA. This has been a very successful part of the WEES program to date and we propose to commit significant resources to shared and core equipment, high capacity computing, and other infrastructure needs over the next five years of the TRIF funding cycle by means of competitive grants.

4.4 WEES Budget

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) WATER, ENVIRONMENTAL & ENERGY SOLUTIONS

FINANCIAL SUMMARY	Budget FY 17	Budget FY 18	Budget FY 19	Budget FY 20	Budget FY 21
REVENUE					
TRIF Revenue	5,607,500	6,007,534	6,407,573	6,807,612	7,680,150
TOTAL	5,607,500	6,007,534	6,407,573	6,807,612	7,680,150
EXPENDITURES					
OPERATING BUDGET	5,607,500	6,007,534	6,407,573	6,807,612	7,680,150
CAPITAL BUDGET	-	-	-	-	-
TOTAL	5,607,500	6,007,534	6,407,573	6,807,612	7,680,150

4.5 Plan for Sustainability

4.5.1 Anticipated funding sources for ongoing support

WEES activities will continue to be operationalized by the ORD, topical interdisciplinary centers and institutes such as the Institute of Environment, the Water Resources Research Center, and Arizona Institute for Advanced Energy Solutions, and relevant colleges/departments into the future. UA ongoing support for these units assures that a baseline level of activities, facilities, and administrative support are leveraged to support continued activity and growth into the future. WEES will continue to be very well positioned for support from federal research funding agencies including NSF, DOE, DOI, and NIH. This includes the broad spectrum of center grants to smaller scale individual investigator awards, as well as existing vehicles such as EFRCs, STCs, and ERCs.

A significant effort is being made in philanthropy. The Office for Research & Discovery, in concert with the UA Foundation, has recently hired a Senior Director of Development to support transdisciplinary research. Given significant public interest in water, environment, and energy, it is expected that philanthropy will cover an increasing proportion of interdisciplinary activities.

Other sources of support include services through core facilities. A “win-win” with industry is achieved when equipment and services not otherwise accessible for industry are provided from the UA for an attractive price, which in turn supports the maintenance and growth of these facilities.

The Office for Research & Discovery enables these sustainability efforts through support by Research Development Services (RDS), as well as two “business development” divisions, Strategic Business Initiatives (SBI) and the upcoming Global Research Alliances. RDS provide full-service extramural funding assistance to UA researchers, from opportunity identification, proposal plan development and team building, to proposal management and reviews. SBI connects needs of the business community to the expertise of UA researchers, which results not only in additional industry support for research and development activities occurring at UA, but also more importantly forges partnerships that enable strong UA-industry teams to compete for significant federal contracts. Global Research Alliances performs a similar function, but focuses on developing strong UA, university, industry partnerships internationally.

4.5.2 Timeline for transitioning away from TRIF support

Over the next TRIF funding cycle, WEES plans to fund initiative investments through other means. WEES has an excellent track record for transitioning off seed funding, and WEES programs are fully committed and aggressively working to achieve sustainable funding sources for its activities. Anticipated funding sources for ongoing support include gifts and philanthropic funding, industry contract support through technology centers, foundation and private granting, and growing federal support as a result of additional WEES hires and by capitalizing on new funding priorities.

5 IMPROVING HEALTH

5.1 Investment description/rationale/justification

5.1.1 *Brief overview of industry or area being addressed by the initiative to include benefit to Arizona*

Arizona's TRIF investment in the UA Improving Health (IH) initiative is funding research to improve the lives and health of our citizens, while creating high quality jobs within the state, and engaging students in science to prepare them for the high tech jobs of tomorrow.

The Arizona Commerce Authority identifies biotech as a major target industry. Arizona clinical services provide care to over 6.5M persons, with Banner Health the largest private employer with 19 hospitals across the state. In 2015, the bioscience sector increased by 320,000 jobs, with an average annual pay of over \$67,000, resulting in \$21.4B in total annual earnings. In FY14, the last year for which data is available, the Arizona Universities delivered \$383M in academic biosciences R&D activity.

With continued TRIF investment in research and development that feeds the innovation pipeline, the growth of this sector will advance. In fact, the UA's strategic plan, *Never Settle*, calls out the translational biosciences as a core research strength targeted with further strategic investment. The UA IH initiative is an essential component of the development of Arizona's bio-industry, and a critical part of the Flinn Foundation's Bioscience Roadmap.

The Bioscience Roadmap calls for the following strategies to grow and support the bioscience economy: enhance translational research, grow the entrepreneurial climate, build critical mass of companies, advance research base, and expand STEM education and develop talent. UA's IH plan aligns with these strategies.

The UA is the only academic enterprise in the state that links a research university with an affiliated level one trauma/world class teaching hospital, a comprehensive health

sciences center, two colleges of Medicine (Tucson and Phoenix), and a collaborative bioresearch institute (BIO5 Institute).

The fledgling biotech industry in the Tucson area and across the state needs the presence and partnership of a strong research university and medical schools to provide a wellspring of innovation, infrastructure, and workforce development. UA IH fosters and funds collaborative projects that address major unsolved challenges in the life sciences, and guides those collaborations towards developing identifying therapeutic/diagnostic targets that lead to patentable products that will improve our quality of life. IH provides a physical infrastructure of high-tech equipment and services available to university and external users alike, and both attracts students to biosciences fields and provides them with the skills and experience to benefit Arizona's bioindustry.

5.1.2 Discussion of mission, goals, values and vision

The mission of the IH initiative is to increase external funding, create bioscience jobs and prepare the workforce, and provide public benefit that impacts the state, through fostering the formation of collaborative research teams made up of basic scientists, bioengineers, clinicians, pharmacologists, and agricultural experts to tackle the most pressing health and environmental challenges in the 21st century, finding bold solutions that will improve human lives in Arizona and beyond.

The overall goals of IH are to:

- Increase external funding by federal and industry sponsors by promoting excellence and transdisciplinary collaboration among investigators and scholars across the biosciences
- Advance translation of science discoveries and technology development into products, methods, and services that promote human health and well-being, and promote the economic development of the state of Arizona through commercialization of research ideas
- Develop the next generation bioscience workforce for Arizona through outreach programs to promote science literacy and share the wonders of bioresearch with our community and K-12 science teachers and their students, as well as create a vibrant

learning environment that draws in diverse students and offer opportunities for training at all levels of the STEM pipeline in preparation for high tech jobs in Arizona.

5.1.3 Description of programmatic areas for investment

The UA's strategic plan, *Never Settle*, has four pillars, engagement, innovation, partnerships and synergy – the TRIF investment programs cover each of these pillars. In *Never Settle*, Innovation charges us to advance research that delivers public impact and benefit by:

- Promoting and building upon core strengths to address grand challenges for the state of Arizona and the world
- Collaborating boundlessly to increase local-to-global impact
- Engaging new strategic partners in the research enterprise to accelerate innovation
- Improving institutional infrastructure to speed new discovery, knowledge, and application
- Strategically attracting, educating, and engaging first-rate doctoral and other advanced degree seeking students in a variety of IH disciplines to grow the high tech workforce
- Improving recognition and support for collaborative and interdisciplinary research and scholarship; and
- Expanding economic development in our region through commercialization of research ideas

These strategies guided the TRIF investments in the IH programmatic areas, which were carefully chosen to align with areas of Arizona and national need. The selected thrust areas in the IH initiative are focused on generating impact for Arizona, for which UA faculty already have significant expertise, and which have the capacity to grow external federal and industry funding, expand economic opportunity, as a result of the support by this initiative.

We expect strong return on investment due to this alignment to result in substantive growth in new federal grant funds into Arizona. Historically, over the last 4 year period of TRIF, IH initiative, every TRIF dollar invested resulted in nearly a 5x return on investment. In the last four years, 90 invention disclosures were transacted, 3 new companies started and 12 new patents issued. These funds will support not only UA, but also Arizona industry and our partner Arizona universities.

5.1.3.1 *Biology of Aging and Age-related Diseases*

The Challenge: Arizona ranks 14th among the 50 states for the total number of residents over age 65, with an increase of 11% in the population over age 55 in the last year alone. With more and more individuals living longer, the aging of the Arizona population will bring unique challenges in health care and opportunities for solutions in the future. People desire to live long, healthy, and independent lives, without the burden of disease. Critical R&D remains to be done to understand the processes of normal and healthy aging, determine the causes of age-related diseases, develop and test drugs, devices, and behavioral interventions to minimize handicap and disease, and maximize functionality and independence towards a higher quality of life. This last five years, progress is beginning to take hold with the increased focus of federal funding agencies, foundations, the awarding of the Nobel prize in this area in 2014, and the current Presidential Brain Initiative.

UA Advantage: UA is uniquely poised to conduct both basic and clinical research into the biology of aging and age-related brain diseases, such as Alzheimer's, Parkinson's and other degenerative conditions. This thrust area is one of the core strengths identified in the UA's strategic plan, *Never Settle*. Strong transdisciplinary teams have already been built that include faculty in Neuroscience, Medicine, Molecular and Cellular Biology, Surgery, Psychology, and other departments. The Arizona Center on Aging, The Evelyn McKnight Brain Institute, and the new UA Health Sciences Center for Innovation in Brain Sciences are facilitating studies ranging from brain imaging, to looking at molecular and genomic changes during aging, and dietary/exercise interventions. Together with our health and community partners, UA faculty have the infrastructure to translate their basic

studies into effective treatments and life-enhancing strategies for Arizonans, which ultimately will reduce health care costs and increase the chance for a healthy, productive, disease free long life.

5.1.3.2 Precision Medicine by Enabling “Omics”

The Challenge: “Omics” refers to the collective technologies used to explore the roles, relationships, and actions of the various types of molecules that are expressed in the cells of an organism as a result of physiological processes. The variation in these physiological processes, related to individual differences in background, genes, environment and lifestyle, is the basis for why a particular patient responds to particular treatment well, and another does not. Thus careful characterization of these products of expression through “omics” technologies is critical to develop individually targeted therapies to boost efficacy, improve health, reduce adverse exposures and reduce health care costs. This study ranges from detecting genetic mutations, to examining the role of gene expression in response to the environment, to measuring protein and metabolite production to advance patient-based R&D through precision medicine. Effort is needed in development of ever-more sensitive equipment, along with more sophisticated measurement and analysis techniques, and subsequent correlation to clinical outcomes to untangle the individual pathways for treatment success. In recognition of this need, the President announced recently a new federal agency funding initiative in Precision Medicine, which will drive new knowledge and solutions for the future in support of the development of new tools, knowledge and therapies to select treatments that work best for individual patients, thereby reducing healthcare cost.

UA Advantage: Precision Medicine is one of the core translational bioscience strength areas identified in the UA’s strategic plan, *Never Settle*. IH will leverage UA’s historic strengths in genomics, biochemistry, pharmacy, and translational medicine to build strength in the characterization of the products of gene expression including: proteins (proteomics), lipids/fats (lipidomics) and their metabolic products (metabolomics) – all important and accessible indicators of human health at the various levels of biological processes. One example area of development is clinical pharmacogenomics, where UA

researchers are translating genomic analyses to clinical diagnostics that guide precision therapeutics, particularly in cancer. Other teams are leveraging the diversity of Arizona to understand the biological characteristics that are more common among individuals of various racial/ethnic groups to tailor individual diagnostics and therapeutics to improve efficiency. The UA is well positioned through basic and clinical research in precision medicine to develop strategies that advance understanding of the factors contributing to individual health, disease, and personalized approaches to the disease prevention, early detection and treatment in support of the National Institutes of Health Precision Medicine Initiative (PMI).

5.1.3.3 *Advancing Health Outcomes through Technology*

The Challenge: From iWatch to FitBit, wearable technology that monitors clinical indicators in real time is becoming an accepted and ubiquitous method of aiding people to lead healthier lives. But the potential of wearable technology has barely been tapped.

From skin patches that can sense stress levels, to jewelry that can warn against falls and other physiological dysfunctions that are the precursor to disease, such technology also has the potential to optimize performance of elite athletes, warfighters, the disabled, and aging alike. The National Network for Manufacturing Innovation program, a White House initiative to support advanced manufacturing in the U.S. is an example of the recent attention to this opportunity. Others are the roles of robotics and simulation in advancing training for the next generation of independent technology. Holographic images offer the opportunity to acquire data without physical touch – allowing patients to stay out of clinics and hospitals, where the risk of acquired infections costs \$20B per year. R&D in this area – smart and connected health are critical to improving health for Arizona and beyond.

UA Advantage: UA will leverage the expertise of Engineering, Chemistry & Biochemistry, Health Sciences and our new interactions with the FlexTech Alliance through the Manufacturing Innovation Institute for Flexible Hybrid Electronics in development of sensor and wearable sensor technologies, miniaturization and optimization of signal processing, power, and wireless communication systems, and development of signal processing, analysis and informatics, to advance the technology of this emerging field.

The promise of these technologies is to advance population health on a grand scale – one of the key areas identified in UA’s strategic plan, *Never Settle*. With partners in Medicine, Eller College of Management, Tech Launch Arizona and Public Health, UA will turn and connect sensor responses into recommended actions to optimize health and performance, and will deploy new sensor systems with increasing sensitivity to the clinic, field and marketplace. UA is the academic scientific lead of the national team, the FlexTech Alliance, selected to further flexible hybrid electronics research that could reshape entire industries. In other areas, UA engineers and physicians are developing new robotics to sense diabetic neuropathy and signal impairment, so that treatment adherence can be improved to reduce health care costs.

5.1.3.4 Infectious Diseases and the Science of Microbiomes

The Challenge: Infectious disease is the major cause of death in low-income countries, and emerging infectious diseases threaten countries worldwide. Many of these diseases have their origin in animals, insects or the environment (e.g. Zika, Ebola). In Arizona, the impact of valley fever is specific and widely known, and offers a model of success of understanding the biological processes that have shaped the development of novel treatments. Zika, for example, is carried by the type of mosquito that is prevalent in Arizona, and yet does not carry the disease – which offers an opportunity for intervention to reduce disease and its health burden. Meanwhile, more is learned every day about the role of the human microbiome (both bacteria and viruses), which intimately affects both health and behavior, particularly for respiratory diseases that are considered to result from a combination of genes, environment and lifestyle.

UA Advantage: An interdisciplinary group of researchers from Immunobiology, Ecology and Evolutionary Biology, Animal and Comparative Biomedical Sciences, Public Health and others have significant strengths in this field and are pushing the boundaries of knowledge. For example, through a Flinn Foundation-supported pilot grant, researchers isolated and identified the virome of the human lung in health and infection. Others are leaders in understanding how the gut-brain interface is modulated by bacteria or modeling the spread of infectious agents. IH will help integrate these disciplines to enable new

discoveries of the role of microbes in human health and disease. Finally, cross disciplinary scholars are collaborating to understand transmission of Zika, how variation in the mosquitos in Arizona may inform strategies to stop transmission, and keep Arizona free of this disease. Together, this effort fits right in with the translational bioscience priority area identified in UA's strategic plan, *Never Settle*.

5.1.3.5 Bio-informatics and Data Driven Discovery

The Challenge: Big data is everywhere – and the biosciences are no exception. Bioinformatics combines computer science, statistics, mathematics, and engineering to analyze and interpret biological data, and integration across levels of analysis (genome to phenome). Bioinformatics is an especially integral part of understanding omics, and the need for strong bioinformatics undergirds the other IH research emphasis areas such as imaging, wearable technology, and ecosystem genomics. Big data approaches reveal patterns in data, including human clinical health information, that are not evident through experimental analysis alone, and enable the connection across levels of analysis not possible at experimental scale.

UA Advantage: Several recent investments by UA leave this field poised for explosive growth – why this area was identified as a core research strength in UA's strategic plan, *Never Settle*. The new NSF-sponsored CyVerse consortium (an outgrowth of iPlant) and our new university-wide translational bioinformatics institute brings strengths in extracting actionable knowledge from large data sets that span multiple levels of analysis. The partnership with Banner Health means that enormous amounts of de-identified health records data are available for researchers to seek novel associations that drive subsequent experimental and drug discovery work. New cross disciplinary teams are exploring using these approaches in predicting asthma events in advance to enable health care services to rapidly adjust to environmentally induced outbreaks. Bioinformatics is synergistic with growth in omics, as clearly the former enables the practical application of the latter. IH will further build the bioinformatics infrastructure to enable the highest quality and most rigorous collaborative bio research.

5.1.3.6 *Bio-imaging & Enabling Technologies*

The Challenge: Imaging has revolutionized our understanding of biology from the molecular to the human scale, elucidating both structure and function. The limits of our understanding of the basis of disease are largely a function of the limits of our observational imaging tools. Through application of rigorous theory, ever-advancing source and detector technology, and improved methods of sample preparation or accommodation of *in vivo* subjects, bio-imaging is enabling fundamental new discoveries in areas such as brain connectivity and function, as well as empowering patient-specific clinical treatment strategies.

UA Advantage: UA has tremendous strengths in image and optical science, imaging technology development, imaging methods, and clinical translation, seated in our world-class College of Optical Sciences, Biomedical Engineering, and Medical Imaging, as well as in our active applications community in Science and Health Sciences. IH seeks to leverage UA recognized research strengths in optical sciences/imaging described in its strategic plan, *Never Settle*, to further enhance bioimaging's reach through technology development, enabling new scientific discoveries, and improving clinical outcomes. The faculty that support biomedical imaging have established strong extramurally funded pre-clinical and clinical research programs that have fostered multi-disciplinary collaborations within the University (e.g., the College of Optical Sciences, Biomedical Engineering, Electrical and Computer Engineering, Psychology, Physiological Sciences, Speech and Hearing Sciences, Applied Mathematics, Cancer Biology, Chemistry) as well as with other universities, industry and the military. It serves as the hub and intellectual center for expanding collaborations and cultivating tremendous opportunities for growth and expansion in the increasingly important areas of molecular imaging, multi-modality imaging, and clinical translation. The research also plays a critical role in advancing the fields of cancer, cardiovascular, neurological, musculoskeletal, cross-sectional and non-invasive biomarker imaging technology, with the ultimate goal of translating basic science innovations and developments into clinical applications that impact patient care. This research is guided by the vision of integrating physical science and technology

development with the clinical mission of the department and university, pushing the frontiers of medical imaging technology, which will advance new diagnostics technologies and spin outs.

5.2 Expected Outcomes as a result of TRIF investments

5.2.1 Specific and realistic outcomes that are clearly measurable

5.2.1.1 Return on investment

IH areas for investment were carefully chosen to align with areas of Arizona and national need. The selected IH thrust areas are focused on generating impact for Arizona, for which UA faculty already have significant expertise, and which have the capacity to grow external federal and industry funding, expand economic opportunity, as a result of the support by this initiative.

A few of the major target federal initiatives for which the University expect to realize external funding include:

- BRAIN initiative (participating agencies include National Institutes of Health [NIH], National Science Foundation [NSF], Defense Advanced Research Projects Agency [DARPA], Food and Drug Administration [FDA], and Intelligence Advanced Research Projects Activity [IARPA])
- Cancer Moonshot (with NIH, FDA, Department of Defense [DoD], and Veteran's Affairs)
- Precision Medicine Initiative (NIH)
- Smart and Connected Health (NSF, NIH)
- Big Data to Knowledge- BD2K (NIH)
- Clyde Pepper Center on Aging
- Special opportunities expected to be announced for Zika Virus response among many others that will emerge over this five year period.
- Our equipment investments are also designed to create long-term return on investment through ongoing master research agreements, such as our current partnership with Siemens for MRI pulse sequence development.

5.2.1.2 Technology transfer

The faculty members associated with IH are highly innovative, and together with Tech Launch Arizona (TLA), IH will assure that their inventions are disclosed and translated into medicines, methods, devices, and diagnostics that better the lives of Arizonans. While TLA prioritizes licensing technologies to companies within Arizona, the breadth and research UA technology extends beyond Arizona. Technologies related to IH make up more than 50 percent of all inventions disclosed at the UA. IH identifies promising faculty and new discoveries for attention by TLA, e.g. recipients of seed funds and attendees at workshops. Asset development funding for Proof-of-concept and to enhance market readiness are made into promising disclosed technology to create additional value, and researchers who desire to start new businesses are supported in development activities.

TLA tracks five key metrics for outcomes: invention disclosures; provisional patents filed and awarded; total licenses; startups; and asset development. Growth of invention disclosures illustrate the success of TLA's outreach efforts to faculty and staff. Approximately 60% of such invention disclosures result in a provisional patent application being filed. A license is the transfer of the University's rights in a particular invention to a third party in order to move that technology to the marketplace. Asset Development investments make technologies more attractive to industry partners and further private investment. For select technologies, creating a new venture (startup) is the best commercialization path, resulting in new jobs and economic benefit to the region.

5.2.1.3 Industry engagement (outreach, partnerships, collaboration)

IH will benefit industry by providing relevant faculty expertise, core facilities and services, and workforce development. Frequently the mode of engagement is partnering on federal proposals - thus creating an industry-academia team that is stronger than either partner alone.

UA has demonstrated success in how the many industry partnerships are a key element of the success of IH, especially in industry sponsored R&D. Such relationships are not

only a vital source of revenue, but provide also a strong intellectual contribution by defining valuable areas of technological need and opportunity.

Under the auspices of the Office for Research & Discovery, an exciting new TRIF supported mechanism is being made available to further link industry, researchers and students, by bringing together a team of undergraduate researcher, a graduate student team leader, and interdisciplinary university-industry R&D mentorship to conduct jointly funded R&D. These innovative teaming models help prepare our students for collaborative work environment in industry, satisfy increasing workforce needs and make Arizona a more attractive location for founding and growing companies in the IH area.

Another benefit that UA will provide is access to state-of-the-art equipment and services in core facilities. Significant investment has created unique resources that industry cannot generally maintain on their own- such as the genetically engineered mouse models core, state of the art genetic sequencing equipment, high-end mass spectroscopy, and services such as statistics. Other efforts will continue to linking industry with qualified students, which advances workforce needs and make Arizona a more attractive location for founding and growing biosciences companies. The yearly Student-Industry Networking Event not only provides an opportunity for companies to meet and collect resumes from top UA biosciences and bioengineering students, but helps students understand what skill sets they must acquire during their education to be competitive in the workforce. Also, the BIO5 Institute is expanding its internship service, providing qualified pre-screened interns to local biosciences companies.

5.2.1.4 Workforce contributions

Workforce development will remain a high priority IH, from attracting Arizona high school students into STEM fields (and encouraging them to remain in Arizona for post-secondary education), to providing essential skills in software and data management through free workshops and for-credit courses. The KEYS (“Keep Engaging Youth in Science”) program celebrates its 10th year in 2016. Of the 278 students trained in KEYS, nearly two-thirds of the graduates choose to stay in Arizona for college, and the vast majority enter

STEM related degree programs. IH funds are being leveraged with significant federal grant funds and philanthropic donations.

5.2.1.5 Educational outreach

IH will continue to support educational outreach focused on Middle School and High School students. Tours of the Keating building and talks with IH scientists are provided to local and tribal high schools, and a major effort is put into the yearly Tucson Festival of Books' Science City. BIO5 Institute and College of Science co-sponsor this popular and growing event, which attracts over 130,000 Arizonans yearly with dozens of exhibits in themed tents including the science of the natural world, food, tomorrow, art, etc.

5.2.1.6 Government/Agency/Community Engagement (outreach, partnerships, collaboration)

IH will continue to engage with local, state, and federal government personnel and agencies, foundations, technical societies, community organizations, and local and state biosciences organizations, to spread the word about the impact and excitement of biosciences research and innovation. The BIO5 Institute performs hundreds of tours, events, and media touches annually. Tours of the T.W. Keating Biosciences Building, including a meet-and-learn with researchers and students, will continue to occur frequently for government (local, state, federal and international) officials and community members. Workshops and conferences such as the Tucson Plant Breeding Institute are financially self-sufficient and bring top scientists and policy makers from around the world to view Arizona's achievements, increasing our reputation and aiding in the development of mutually-beneficial relationship with a variety of academic, government, and NGO partners.

5.2.2 Annual metrics table of expected outcomes and timeline for achievement

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) IMPROVING HEALTH

PERFORMANCE ANALYSIS	Projected FY 17	Projected FY 18	Projected FY 19	Projected FY 20	Projected FY 21
TRIF EXPENDITURES					
Total	\$11,155,000	\$11,697,093	\$12,257,169	\$12,817,244	\$11,959,821
FINANCIAL IMPACT OF TRIF INVESTMENT					
Sponsored Awards	60,000,000	62,400,000	64,896,000	67,491,840	70,191,514
Gifts & Other Sources	600,000	624,000	648,960	674,918	701,915
Royalty Income	50,000	52,000	54,080	56,243	58,493
TOTAL	\$60,650,000	\$63,076,000	\$65,599,040	\$68,223,002	\$70,951,922
TECHNOLOGY TRANSFER ACTIVITY					
Invention Disclosures Transacted	40	42	45	50	55
US Patents Issued	1	2	2	4	5
Licenses and Options Executed	9	10	11	12	13
Startup Companies	1	1	1	2	2
WORKFORCE CONTRIBUTION					
Postdoctoral Appointees	100	105	110	116	122
Graduate Students	300	315	331	347	365
Undergraduate Students	320	336	353	370	389

5.3 Initiative Structure

5.3.1 Organizational structure

The BIO5 Institute will administer the IH TRIF initiative for the UA, with coordination under the Office for Research & Discovery. BIO5 is led by a director who reports to the Senior Vice President for Research at the UA, and the director collaborates closely with Deans and the Senior Vice President for Health Sciences, as well as department heads, to assure maximal impact in implementing IH programs.

5.3.2 Advisory Board

IH has three advisory boards. An external business advisory board (BAB) is populated with engaged and influential industry leaders. The BAB meets regularly to review progress, advise on strategy, and help communicate and connect what happens at UA to

the greater Arizona bioscience and biotech communities. A Deans' Board includes the deans of the colleges of Agriculture and Life Sciences, Engineering, Medicine, Pharmacy, and Science to assure that the programs of Improving Health are maximizing impact and synergizing with college-level activities, particularly with respect to strategic hiring, a major emphasis of this TRIF funding period. Finally, a Faculty Advisory Board is engaged in shaping and implementing the strategic research areas of investment and connections to faculty on the ground.

5.3.3 Infrastructure

IH leverages the infrastructure of the Office for Research & Discovery, the BIO5 Institute, and the UA Health Sciences to effectively deliver IH TRIF impact. Staff are primarily located in the T.W. Keating Biosciences Building. Equipment and core facilities supported by IH funds are located in the building most advantageous for usage; currently the majority are housed within the Keating building. The under-construction Biosciences Research Laboratory (BSRL) building will accommodate the increasing growth in IH investigators and activities. This building will house a state-of-the-art imaging resource in the basement with equipment, staffing, and support structures for *in vivo* imaging from small and large animals to clinical research.

5.3.4 Description of investment mechanisms

At the UA, TRIF promotes the economic development of the state by: catalyzing innovative research in target areas of high impact aligned with Arizona businesses; engaging industry and accelerating the commercialization of research results into new products and services that benefit the health, security, and prosperity of Arizona; developing the future high-tech workforce – training students from elementary to graduate school to be science and innovation leaders who will create Arizona's bright future; and providing infrastructure through research services, computing, equipment and facilities that enables innovation and research.

TRIF investments will accelerate capacity through strategic faculty hires in focused areas identified in the University's *Never Settle* strategic plan, and further fleshed out in the

ORD Strategic Research Roadmapping sessions held in 2015 with hundreds of researchers across campus. Investments will be made in new transdisciplinary research initiatives to enhance competitive success for securing extramural funding and engage industry and accelerate the commercialization of research results. TRIF will support the training and engagement of students while developing a high-tech workforce and will provide infrastructure that enables innovation and research through facilities and instrumentation.

5.3.4.1 Catalyzing innovative research

5.3.4.1.1 Strategic faculty hiring

IH will support high-impact hires in the programmatic areas for investment, with the goal to attract new external funding from the federal agencies, industry and foundations to Arizona. Specific hiring plans are developed with relevant Deans, the Provost and the Senior Vice President for Research to identify *catalyzing* faculty, who will supply critically needed expertise and/or have the leadership and experience to lead externally-funded programs in these priority areas.

The table below describes the areas identified for future hires in each strategic area.

Potential TRIF hires in Improving Health	
<i>Theme</i>	<i>Expertise</i>
Biology of Aging and Age-related Diseases	Molecular processes and biological basis of cell aging
Enabling Omics	Protein networks in immune system activation
Advancing Health Outcomes through Technology	Wireless/wearable sensors for stress detection
Infectious Diseases and the Science of Microbiomes	Gut-brain interface; Respiratory virome in acute and chronic disease
Bio-informatics	Imaging/electronic health records informatics
Bio-imaging & enabling technologies	Imaging of neural connectivity

5.3.4.1.2 *Transdisciplinary Research Initiatives*

IH will support targeted workshops and conferences in these thematic areas to bring together investigators across campus and across the state to identify strategic topics of high importance to Arizona, where we have a competitive advantage and can be a national and world leader. IH will promote and develop program teams and work plans to successfully compete for new interdisciplinary external funding. Seed grants will be made available to transdisciplinary groups of faculty seeking significant, targeted and defined external research funds for new areas of inquiry in these identified target areas. In addition, these investigator groups will be supported by Research Development Services to increase the probability of success in external funding.

5.3.4.2 *Engaging Industry & Advancing the Commercialization of Research*

IH is actively expanding its engagement engaged with bioscience industries and is strongly positioned for growth. In addition to establishing constructs and vehicles for collaborative research programs, the IH and the associated colleges host a variety of industry partnership programs that provide intimate engagement points for companies across the nation to engage students primarily at the graduate MS and PhD level, as well as with the faculty supervising their research. Recent growth in these programs has revealed that, in addition to technology access, industry partners on a national scale are using UA venues in their networking for business development in IH areas. IH has targeted industry partnerships in the biosciences to grow, and will continue to support, bringing personnel from industrial affiliates to the campus for collaboration in the context of externally-funded R&D projects to inform our researchers of industry needs.

Funds will be made available to support graduate and undergraduate students working on industry grants and contracts, providing an incentive and value-add to industry partners while simultaneously providing valuable experience to the students.

IH also advances intellectual property development and start-up companies, by focusing on increasing invention disclosures and providing asset demonstration funding to further

enhance application opportunities and commercialization potential. For appropriate initiatives seeded by IH, TLA will be brought into assure that inventions are protected and that targeted projects are further supported with proof-of-concept, market readiness activities that increase the licensing and commercialization appeal of the technology, as well as encouraging spawning new spin-out companies.

5.3.4.3 *Developing the High Tech Workforce & Outreach*

Bioscience companies operate in a team-based, adaptable environment that requires real-time collaboration and problem solving among diverse team members. Thus, IH will support teams of undergraduate and graduate students who create a *link* between two faculty members, enabling students to acquire multiple sets of valuable skills and initiate interdisciplinary collaborations. IH will also continue the emphasis on attracting high school students into STEM fields by supporting the “Keep Engaging Youth in Science” (KEYS) program in concert with the BIO5 Institute and the College of Pharmacy. This flagship high school program engages 48 students a year in a 7 week summer internship with training in biosciences skills and experience working in a BIO5 faculty member’s lab. Skill development in undergraduate and graduate students is promoted through workshops and courses on information and bio technology. Additionally, IH will match promising undergraduate and graduate students with bioindustry internships, through a formalized program with Arizona biotech companies.

5.3.4.4 *Infrastructure & Instrumentation*

A significant investment will continue to be made into core facilities and instrumentation that enable cutting-edge research and development. While user fees can defray operating costs, initial equipment investment is supported by university and TRIF funds, generally with significant industry contribution through negotiated discounts. This core equipment is available to all investigators at UA, other Arizona universities, and will be aggressively promoted as a resource to industry. Major areas of emphasis going forward are mass spectroscopy/analytical chemistry, and bioimaging equipment.

5.4 Initiative budget table

TECHNOLOGY AND RESEARCH INITIATIVE FUND (TRIF) IMPROVING HEALTH

FINANCIAL SUMMARY	Budget FY 17	Budget FY 18	Budget FY 19	Budget FY 20	Budget FY 21
REVENUE					
TRIF Revenue	11,155,000	11,697,093	12,257,169	12,817,244	11,959,821
TOTAL	11,155,000	11,697,093	12,257,169	12,817,244	11,959,821
EXPENDITURES					
OPERATING BUDGET	7,265,000	7,807,093	8,367,169	8,927,244	9,959,821
CAPITAL BUDGET	3,890,000	3,890,000	3,890,000	3,890,000	2,000,000
TOTAL	11,155,000	11,697,093	12,257,169	12,817,244	11,959,821

5.5 Plan for sustainability

5.5.1 Anticipated funding sources for ongoing support

IH activities will continue to be operationalized by the Office for Research & Discovery, the BIO5 Institute, and relevant colleges into the future. UA ongoing support for the BIO5 Institute assures that a baseline level of activities, facilities (Keating and BSRL), and administrative support are leveraged to support continued activity and growth into the future. IH will continue to be well positioned for support from federal research funding agencies including NIH, NSF, DoD. This includes the broad spectrum of Broad Area Announcements for smaller scale individual investigator awards, as well as existing vehicles such as P01s, STCs, and ERCs, but also directly appealing to agencies with compelling value propositions to spawn programs that can be fit within broad national imperatives.

Strong industry partnerships are a key aspect of the strategic goals of UA's Never Settle strategic plan. IH anticipates generating new pathways to corporate-sponsored efforts, as well as corporate partnerships to secure new federal funding. Technology developed through TRIF will gain more support from our industry and government partners, and new

faculty hires supported by TRIF will yield many new grants/contracts, technology, intellectual property, and trained talent to help grow Arizona industry.

A significant effort is being made in philanthropy. The Office for Research & Discovery, in concert with the UA Foundation, has recently hired a Senior Director of Development, and is actively seeking a Director of Development for Interdisciplinary Bioscience Programs. Given significant public interest in bioscience and health areas, it is expected that philanthropy will cover an increasing proportion of interdisciplinary activities. An endowment for the KEYS program has been established, and a major push will be made for that flagship program to be completely donor supported.

Other sources of support include services through core facilities. A “win-win” with industry is achieved when equipment and services, not otherwise accessible for industry, are provided from the UA for an attractive price, which in turn supports the maintenance and growth of these facilities.

The Office for Research & Discovery enables these sustainability efforts through support by Research Development Services (RDS), as well as two “business development” divisions, Strategic Business Initiatives (SBI) and the upcoming Global Research Alliances. RDS provide full-service extramural funding assistance to UA researchers, from opportunity identification, proposal plan development and team building, to proposal management and reviews. SBI connects needs of the business community to the expertise of UA researchers, which results not only in additional industry support for research and development activities occurring at UA, but also more importantly forges partnerships that enable strong UA-industry teams to compete for significant federal contracts. Global Research Alliances performs a similar function, but focuses on developing strong UA, university, industry partnerships internationally.

5.5.2 Timeline for transitioning away from TRIF support

IH TRIF funds are used for catalyzing new research and discovery in the biosciences. The plan for the next 5 years is to use these funds to recruit productive faculty, provide enabling equipment, seed new research programs, foster industry engagement, and link

faculty through graduate students. Funds are also used for education, outreach and training (EOT).

The 2015 Roadmap progress update by TEconomy Partners (formerly Battelle Technology Partnership Practice) revealed the following data:

- During the economic recovery of 2009-2014, bioscience jobs in Arizona increased 14.8%, nearly double the rate of Arizona as a whole;
- From 2002 to 2014, the number of Arizona bioscience establishments rose 4.2%, to 1,411;
- In 2015, while total NIH funding rose, Arizona's funding fell to \$151 million from \$158 million in 2014. From 2002 to 2015, Arizona's NIH funding grew 11.8%, far behind the top-10 funded states' growth of 40.1%.
- The value of bioscience-related academic research-and-development expenditures at Arizona's universities reached \$383 million in 2014.
- From 2002 to 2015, Arizona's universities have shown steady gains in developing bioscience intellectual property: invention disclosures, patent applications, patents issued, and licenses and options executed. The 2014-15 period compared favorably to the previous two years on all measures, including a 24% increase in bio-related university startups.

These 2015 Roadmap results underscore the critical need for renewal of TRIF investments in university research and development that drives job growth and public impact critical to catalyzing new levels of success in the biosciences for decades to come.