4. Project Description

4a. Table 1: List of core participants in the UMD Global STEWARDS NRT program.

Participant	Role	Univ. of Maryland Affiliation	Discipline(s)
Amy R. Sapkota	PI	Assoc. Prof., MIAEH, CONSERVE (Director), CFS^3	Water and Food Microbiology, Environmental Microbial Genomics
Gili Marbach-Ad	Evaluator	Res. Assoc. Prof. CMNS TLC (Director)	Program Assessment and Evaluation
Allen Davis	Co-PI	Prof., ENG, MWRRC (Former Director)	Environmental Engineering, Water Resources
Janie Dubois	Co-PI	JIFSAN, IFSTL (Director), CFS^3	Food Science and Agricultural Chemistry
Nathan Hultman	Co-PI	Assoc. Prof., CGS, GCRI, ERC	Energy and Environmental Policy
Xin-Zhong Liang	Co-PI	Prof., AOSC, ESSIC	Atmospheric and Oceanic Science, Earth System Science, Food-Energy-Water Nexus Decision Support
Jianghong Meng	Co-PI	Prof., NFSC, JIFSAN (Director), CFS^3 (Acting Director)	Food Safety, Applied Nutrition, Microbiology
Shirley Micallef	Co-PI	Assoc. Prof., PSLA, CONSERVE, CFS^3	Agricultural Microbiology, Food Safety, Environmental Metabolomics
Mihai Pop	Co-PI	Prof., UMIACS, CBCB, CONSERVE	Bioinformatics and Computational Biology
Amir Sapkota	Co-PI	Assoc. Prof., MIAEH, CONSERVE	Applied Environmental Health Science, Climate Change Impacts on Health

Abbreviations: AOSC: Atmospheric and Oceanic Science; CBCB: Center for Bioinformatics and Computational Biology; CFS^3: Center for Food Safety and Security Systems; CGS: Center for Global Sustainability; CMNS: College of Computer, Mathematical, and Natural Sciences; CONSERVE: CONSERVE: A Center of Excellence at the Nexus of Sustainable Water Reuse, Food & Health; ENG: A. James Clark School of Engineering; ERC: Energy Research Center; ESSIC: Earth System Science Interdisciplinary Center; GCRI: Global Change Research Institute; IFSTL: International Food Safety Training Laboratory; JIFSAN: Joint Institute for Food Safety and Applied Nutrition; TLC: Teaching and Learning Center; MIAEH: Maryland Institute for Applied Environmental Health; MWRRC: Maryland Water Resources Research Center; NFSC: Nutrition and Food Science; PSLA: Plant Science and Landscape Architecture; UMIACS: University of Maryland Institute for Advanced Computer Studies. **Additional Participants:** Our team includes 24 additional members from academia and government (see Table 4).

Our core participants (Table 1)—all leaders in their respective food, energy, and water fields—bring expertise from five UMD colleges/schools across the biological, physical, agricultural, social, engineering, and computer sciences. The core participants have strong and consistent research and mentoring records, and have demonstrated commitment to the integration of stakeholder-driven research, outreach and education. As such, they are uniquely positioned to lead a successful NRT program to further actionable science that can affect global change with regard to the food-energy-water (FEW) nexus.

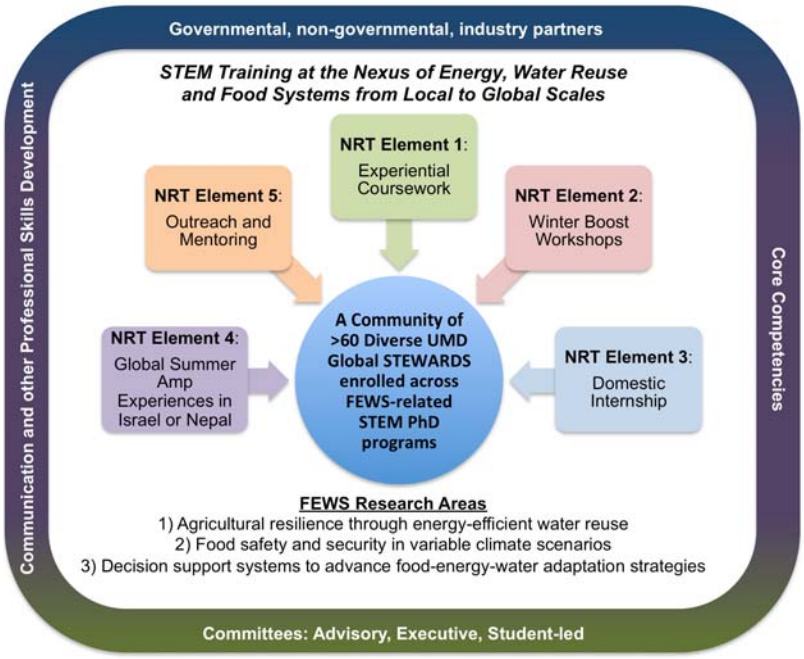
PI Amy R. Sapkota has proven leadership as the PI of CONSERVE: A Center of Excellence at the Nexus of Sustainable Water Reuse, Food & Health (funded by the U.S. Department of Agriculture, National Institute of Food and Agriculture). The mission of CONSERVE is to facilitate the adoption of transformative on-farm treatment solutions that enable the safe use of nontraditional irrigation water on food crops. Through this Center, she initiated the interdisciplinary CONSERVE Scholars program that trains and inspires the next generation of leaders engaged in sustainable water reuse on food crops. The proposed NRT program: a) leverages the successes and lessons learned from this existing research-oriented, non-curriculum based, experiential training program; b) expands our approach to develop a formal, innovative, STEM graduate education model that encompasses more broadly-defined FEW systems; and c) operationalizes international training elements. Moreover, the NRT will allow our existing food-water focused team to formally integrate with world-renowned energy researchers, earth scientists and engineers in collaborative, interdisciplinary research and training of future leaders.

4b. Theme, Vision, and Goals

Theme: Innovations at the Nexus of Energy, Water Reuse and Food Systems

Population growth and climate variability are crippling our global food, energy and water resources, jeopardizing both ecological and human health.[1, 2] For instance, high-quality freshwater sources used to irrigate food crops are dwindling worldwide, and modern farming practices aimed at increasing yields to feed ever-expanding populations have exigent needs for energy[3]. These pervasive problems require transformative science, engineering and policy solutions that not only minimize waste but also facilitate reuse at the FEW nexus[3], such that security across these systems can be achieved for future generations. **The development of sustainable FEW solutions can only come about through interdisciplinary training of our future scientific leaders[4] via graduate educational models that encompass systems-based thinking and focus on strengthening professional skills and cultural competencies.**

Figure 1: UMD Global STEWARDS NRT Program at a Glance



To address this critical need, our overarching aim is to establish the UMD Global STEWARDS (**S**TEM **T**raining at the Nexus of **E**nergy, **WA**ter **R**euse and Foo**D S**ystems) program (Figure 1), an interdisciplinary, experiential graduate education model that will prepare a cadre of future leaders focused on ***the rapidly emerging need for innovations at the nexus of energy, water reuse and food systems from local to global scales***. Engaging in this theme will involve *research and training that addresses all of the 2018 NSF NRT INFEWS priority interdisciplinary efforts: 1) "research that builds the fundamental knowledge base on the FEW systems"; 2) "research that creates innovative solutions to minimize waste and resource consumption, and/or encourage reuse within the [FEW] systems;" 3) "developing new ways to integrate heterogeneous data on complex FEW systems;" 4) "training a workforce to understand that these multifaceted interactions are impacted by physical, chemical, biological, social, cultural, behavioral, and economic processes;" 5) partnering "with industry, government, community and non-profit stakeholders that work within the FEW nexus;" and 6) "curriculum that prepares trainees to communicate across INFEWS related disciplines" and with multiple stakeholder groups.* In addition, to meet NSF's commitment of supporting diverse cohorts of STEM graduate students and to ultimately achieve diversity among future FEW nexus leaders, our program will engage underrepresented minorities and women, who will be equipped with the technical and professional skills necessary for success in research and related careers across multiple sectors. These UMD Global STEWARDS will be exposed to a range of FEW topics in three integrated research areas (Figure 2) that are aligned with existing strengths of our participating faculty members: 1) Agricultural resilience through energy-efficient water reuse; 2) Food safety and security in variable climate scenarios; 3) Decision support systems to advance food-energy-water adaptation strategies.

UMD is uniquely positioned to support STEM graduate training and research focused on these FEW nexus areas, and UMD Global STEWARDS will greatly benefit from programmatic integration across the multiple, federally-funded UMD Centers and Institutes that focus on FEW solutions. These programs include CONSERVE: A Center of Excellence at the Nexus of Sustainable Water Reuse, Food and Health; the Joint Institute for Food Safety and Applied Nutrition; the Center for Food Safety and Security Systems; the Center for Global Sustainability; the Joint Global Change Research Institute; the Energy

Research Center; the Earth System Science Interdisciplinary Center; and the Teaching and Learning Center. Moreover, our established relationships with government, industry and non-profit partners, and our close proximity to Washington, DC, will serve to enhance the experience of our NRT trainees through domestic internships and networking opportunities that will facilitate career placements upon completion of their degrees.

Figure 2: UMD Global STEWARDS Integrated Research Areas

Framing the Problem

Similar to other research institutions, UMD has historically relied on traditional graduate STEM education models that focus on producing experts in highly specialized fields.[4, 5] Through this approach, graduate students focus on a thin slice of science, typically through densely-packed curricula and highly targeted scientific investigations within their field of study.[5] This traditional educational model can pinhole graduates into a narrow trajectory involving more-specialized post-doctoral training[5-8] and an ultimate career in academia. And yet, numbers of tenure track positions have been on the decline over the past twenty years and the continuing downward trend is anticipated to continue in the near future.[9, 10] Thus, there is a great need to inject new, innovative STEM graduate education models that focus on interdisciplinary training to not only prepare our future workforce of academic researchers and leaders but also open up future career trajectories across additional sectors including industry, government and the non-profit arena.[11]

Additionally, while there is incredible variation across STEM graduate degree programs with regard to professional development, our overall observation is that the majority of STEM programs have significantly underdeveloped formal professional training to build skills such as technical writing; communications to diverse audiences (including researchers in other fields, policy makers, the general public, and other stakeholders); budget and project management; leadership; mentorship; and conflict resolution, to name a few. As a result, recent graduates often must play catch-up and gain these skills "on the fly" in order to be successful across a range of career settings. Another critical issue is that U.S. STEM graduate education programs continue to be characterized by a severe underrepresentation of historically marginalized groups including women and people of color.[12, 13] Moreover, in this rapid age of globalization, particularly with regard to FEW systems where future FEW scientists (working either domestically or abroad) will engage with individuals from myriad cultures, there is a significant overall gap in cultural competency training—a gap that must be addressed in creative, experiential ways in order to produce future, global-ready STEM graduates.

Vision and Goals

Stakeholder-Driven Process to Formulate a Solution that Complements Existing UMD Approaches: To address these overall shortcomings in graduate STEM educational models and begin to envision our FEW-based UMD Global STEWARDS program, we took a step back and engaged in a ***stakeholder-driven process***. First, we held brainstorming sessions with PIs of currently funded NSF NRT programs at UMD, including Colin Phillips (the PI of a former IGERT and an ongoing NRT in Language Science) and Michelle Girvan (the PI of an ongoing NRT in Computation and Mathematics for Biological Networks, COMBINE). Common themes emerged from these discussions: 1) students taking ownership in training

program elements is key; 2) peer mentorship is critical; 3) seamless involvement of funded and non-funded trainees makes for an engaged "community of science"; 4) ideas of sustainability and scalability should be folded into the program from the outset; and 5) faculty engagement can be inconsistent, but this challenge needs to be overcome for optimal mentor-mentee relationships.

Next, we held listening sessions with 10 current PhD students (from UMD Colleges/Schools participating in this NRT proposal) who are either current trainees in our existing UMD NRT programs or hope to be part of a future UMD Global STEWARDS NRT. During these sessions, students told us they are eager for more exposure to 1) oral communication strategies targeted to multiple stakeholder groups; 2) technical writing; 3) project and business management; 4) interdisciplinary, project-based learning activities; and 5) opportunities for expanding worldviews through international internships.

Finally, to tap into the perspectives of potential future employers (the ever-important stakeholders), we surveyed the Advisory Committee of CONSERVE (a USDA-funded Center at UMD, PI Amy Sapkota) that includes experts across the FEW disciplines working in government, industry, non-profits and academia. Interestingly, the opinions of CONSERVE Advisors were largely in concert with those of our current students (Box 1).

Box 1. Perspectives of FEW employers across varying career sectors on the preparedness of recent FEW graduates.

"…for me, the most important thing when dealing with nexus and similar interdisciplinary issues is the ability to communicate effectively across disciplines. It's really about us getting out of our silos and comfort zones and to get to see things from another's perspective. The earlier these kinds of conversations/interactions take place in one's career the better. Graduate programs therefore need to create these opportunities for students from the onset of their studies and to make it part of their research as well."

"*Most of the students have been very well trained in specific sciences but have generally lacked the broader picture of their field outside of research."*

"Few [new graduates] have "industry" or "government" experience, and are generally unaware of the connections between science, public policy, economics, communications, etc."

"Coming from the produce sector, which [is] fast paced and [where] work life balance is challenged, we struggle with candidates taking ownership, hyper-awareness and collaborative efforts across different levels of the business. The candidates come in with the formal educated skill sets but lack the professional maturity to cope with the demand of the business."

We incorporated the information gathered through this stakeholder-driven process into our vision and programmatic goals for this proposed INFEWS NRT. **Our vision is to develop an innovative, interdisciplinary, STEM graduate education program that will become a national model for the preparation of lifelong learners, stellar science communicators and distinctive professionals poised to realize transdisciplinary FEW nexus solutions to ensure food, energy and water security for future generations.** To achieve this vision, our **programmatic goals** are to: 1) satisfy eight core competencies that are essential for conducting interdisciplinary research[4, 14] (Table 2); 2) prepare future FEW leaders who are trained in interdisciplinary team science and equipped with the communication and other transferable professional skills necessary to succeed across academic, industry, governmental and non-governmental sectors; 3) disseminate transformative STEM training, research and evaluation advances relevant to the FEW nexus; 4) increase the participation of women and underrepresented minorities in STEM fields relating to the FEW nexus; and 5) establish a novel, sustainable and scalable graduate education model.

Table 2. Eight Core Competencies of UMD Global STEWARDS interdisciplinary training and research program[4,14]
1. Incorporate and apply depth of knowledge in one discipline or field of study
2. Identify strengths and critique weaknesses of multiple disciplines
3. Synthesize the approaches and tools from multiple disciplines to evaluate and address a research problem
4. Work in a team with individuals trained in different disciplines
5. Communicate research based on one discipline or field of study to academic researchers trained in different disciplines
6. Communicate interdisciplinary research to nonacademic audiences (stakeholders and general public)
7. Incorporate and apply ethics, conflict resolution, and professional skills to practice in the context of research studies, policy development, communications, and teamwork
8. Understand and appropriately respond to the unique combination of cultural variables and the full range of dimensions of diversity that professionals bring to team science

Adding Value to Current Graduate Training Programs: Our UMD Global STEWARDS will be selected from existing UMD doctoral programs relevant to the FEW nexus, including those based in the life sciences; earth system sciences; environmental engineering and computational sciences; natural resource management; and energy

and environmental policy (See **Section 4g**). The trainees will participate in five NRT Elements (Figure 1 and **Section 4c**): Element 1) Introductory and advanced experiential coursework; Element 2) Intensive, annual "Winter Boost" workshops (based on the "Winter Storm" workshop model of UMD's existing Language Science NRT[15] (See **Section 4c**); Element 3) A domestic internship based in a non-academic setting; Element 4) An interdisciplinary "Global Summer Amp" broadening experience in Israel or Nepal; and Element 5) Involvement in FEW-related outreach and mentoring. Professional development activities will be woven throughout the NRT elements and will address topics such as technical writing, communication, project management, ethics and conflict resolution. In addition, trainees will take ownership in the NRT program by participating in student-led committees and Annual UMD Global STEWARDS Symposiums throughout the duration of their degree programs.

Sustainability and Scalability: By basing certain elements of our proposed program on the successes of ongoing UMD NRT programs, we are building our approaches into complementary systems that are already achieving sustainability on our campus. In the same fashion as the existing UMD NRTs, our trainee program will be designed, from day one, to extend beyond NRT-funded trainees, seamlessly integrating NRT-funded and non-NRT-funded students in a "community of science" that reaches across five UMD Colleges/Schools. This inclusive approach will help to infuse our program's vision, goals and approaches across campus, with the aim of broadening and transforming STEM graduate education, even beyond FEW disciplines. This expansion of STEM educational programming is in line with current UMD priorities whereby institutional resources have been dedicated to increasing and enhancing STEM programming: to date, UMD offers 93 STEM graduate degrees and this number continues to grow.

Moreover, through our collaboration with Dr. Gili Marbach-Ad, the Director of the Teaching and Learning Center who will lead our internal evaluation and assessment approach, our best practices will be effectively shared through existing mechanisms within UMD and beyond. We will disseminate our approaches and findings across institutions through: 1) publications and presentations; 2) our social media outlets (e.g., website, Facebook, and Twitter) that will include detailed information that enable our approaches to be replicated; and 3) our academic, governmental, non-governmental and industry partners, who will integrate our interdisciplinary approaches into practice. Moreover, we will expand our scope via outreach efforts among undergraduates, secondary school students, and the general public. By leveraging our existing and extensive outreach infrastructure within our CONSERVE Center, we can ensure that our efforts will be far-reaching.

4c. Education and Training

Program Scope: We anticipate training more than 60 UMD Global STEWARDS (30 with full stipends and an additional >30 benefitting from one or more aspects of our NRT program). The expectation is that UMD Global STEWARDS will remain part of the STEWARDS community throughout the remainder of their graduate education, particularly as active participants in student-led committees, seminars, the Annual Symposium, and mentoring new STEWARDS (See Table 3 **and Section 4g**). Our NRT trainees will be drawn from the following broad FEW-related disciplines:

> ***Life Sciences:*** from UMD doctoral programs in Environmental Health Sciences; Food Science; Agricultural and Resource Economics; Molecular and Cellular Biology; and Bioinformatics, Computational Biology and Genomics
> ***Earth System Sciences:*** from UMD doctoral programs in Atmospheric and Oceanic Sciences; Geology; and Geographical Sciences
> ***Engineering and Computational Sciences:*** from UMD doctoral programs in Civil and Environmental Engineering; Mechanical Engineering; Chemical and Biomolecular Engineering; and Computer Science
> ***Natural Resource Management, and Energy and Environmental Policy:*** from UMD doctoral programs in Environmental Science and Technology; and Environmental Policy

Global STEWARDS will be engaged in a broad range of FEW systems research within three integrated research areas that address some of the most critical FEW-related societal issues of today as well as the near and distant future. (Figures 1, 2 and **Section 4d**): 1) Agricultural resilience through energy-efficient water reuse; 2) Food safety and security in variable climate scenarios; and 3) Decision

support systems to advance food-energy-water adaptation strategies. Research and training will coalesce across our five NRT elements (detailed below) and, taken together, will: 1) integrate our core competencies; 2) provide innovative training in interdisciplinary science and professional development; and 3) infuse cultural competence and global perspectives into our students' education.

NRT Element 1: Introductory and Advanced Experiential Coursework *(Addresses Core Competency #1, 2, 3, 4, 5, 7, 8)*

Within-discipline training: While the unique aspects of our NRT program will emphasize interdisciplinary FEW systems training and professional development, as well as experiential and global experiences, it is **still critical that each student develop a deep level of knowledge within their "home" STEM degree program** (Competency #1)**.** This will be achieved through 1) advanced discipline-specific coursework; 2) discipline-specific seminars; and 3) focused, culminating dissertation research.

Interdisciplinary training: Each trainee will also take an **Introductory INFEWS Course** (3 credits), an advanced **INFEWS Project-Based Practicum** (3 credits), an **INFEWS Seminar Course** (1 credit) and an **INFEWS Elective** (3) that is based outside of their "home" FEW discipline. Some or all of these courses can be integrated into "home" degree program requirements such that time-to-degree is not impacted.

The **Introductory INFEWS Course** will be a new 600-level course that will cover broad FEW nexus topics, focusing on our three research areas and how integration across the biological, physical, social, behavioral and computer sciences will be critical in solving FEW systems challenges. The course will cover FEW nexus issues from molecular to societal levels and from local to global scales. The course content will be conveyed through lectures, student-led discussions, field-trips, guest lectures and case studies focused on domestic and international FEW challenges. **What makes this course unique is that we bring strong expertise in food safety and public health into FEW nexus frameworks, a rarity amongst FEW teams, which will make for an extremely applied and societally relevant discourse.**

After the introductory course, our Global STEWARDS will engage in our advanced **INFEWS Project-Based Practicum** that will be team-taught by NRT Co-PIs. To emphasize our multi-pronged methods of addressing a range of FEW issues from local to global scales and embracing a systems-based approach in the development of solutions, trainees will be engaged in two project-based studies throughout the duration of the semester: one study will focus on a local FEW challenge that will heavily employ engineering and life-sciences based approaches and solutions; and the second study will encompass a more global focus that requires the use of earth system sciences frameworks and computational methods to arrive at solutions. For example, in a given semester, trainees could be involved in the following:

1. *Study 1 (Local scale):* Envisioning a small-scale, energy-efficient, water reuse system to grow food crops on campus rooftops
2. *Study 2 (Global scale):* Developing a FEW model framework that represents the coupled nature of food and bioenergy production and water and its responses to environmental forcings and human interventions

Through these projects, students will gain hands on experience in research methods and data analysis approaches across varying FEW disciplines. They will also have an opportunity to be integrated into a FEW research project that they otherwise would not have had the opportunity to engage in. The specific projects addressed in any given semester will be determined by which specific Co-PIs are leading the course; the stage of the associated Co-PIs research project; and the interests of the trainees. Since trainees will be drawn from a number of disparate STEM disciplines, each student will bring a diverse set of expertise to the projects, creating a microcosm for interdisciplinary team science. The experiences gained through this practicum course will be integrated across other NRT program elements. For instance, students can present on one of their group studies in the **seminar** course described below, and findings from these studies can serve as fodder for technical writing exercises during **Winter Boost** workshops (described below), some of which may result in peer-reviewed manuscripts.

Throughout the UMD Global STEWARDS program, our trainees also will organize (See **Student-led Committees** below) and participate in a weekly **INFEWS Seminar Course**. The goals of this course are to introduce trainees to an array of FEW nexus research, enable trainees to hone their oral communication skills, and allow for engaging discourse across FEW disciplines. To achieve these goals, the weekly (1-hour) seminar will include a number of formats: 1) Two short (20-minute) research presentations by NRT faculty with complementary research interests, followed by discussion of the

presentations in a way that promotes interdisciplinary discourse; 2) One presentation (40-minute) of a seminal FEW nexus paper, led by two NRT students drawn from different disciplines and followed by student-led discussions; 3) Two short (20-minute) research presentations by NRT students on their ongoing research projects or studies conducted as part of the **INFEWS Project-Based Practicum** (above); and 4) One research presentation (40-minute) by a visiting leader in FEW nexus research.

Finally, the **INFEWS Elective** course will be selected from existing food, energy, water and other cross-cutting courses such as those listed below. Students will be required to take one **INFEWS Elective** *outside of their own discipline.* Additional optional electives can be taken if desired.

> **Food:** MIEH 773, Foodborne, Waterborne, Airborne Infectious Diseases; MIEH 735, Food Toxicology; PLSC433, Technology of Fruit and Vegetable Production; AGNR687, Innovation and Commercialization for Graduate Students in AGNR
>
> **Energy:** PLSC425 Green Roofs and Urban Sustainability; ENME467 Engineering for Social Change; ENME701 Sustainable Energy Conversion and the Environment; ENST605 Energy and Environment; ENPM624 Renewable Energy Applications
>
> **Water:** AOSC663 Water and Climate Systems; AOSC680 Introduction to Earth System Science; AOSC617 Atmospheric and Oceanic Climate; ENCE689G Seminar; Remote Sensing of Global Water; ENCE630 Environmental and Water Resource Systems I; ENCE651 Chemistry of Natural Waters; ENCE652 Microbiological Principles of Environmental Engineering; ENCE635 Geographic Information Systems for Watershed Analysis
>
> **Cross-cutting:** BSCI411 Bioinformatics and Integrated Genomics; CMSC643 Machine Learning and Data Mining; CLFS665 Ecology and Global Change; CMSC725 Geographical Information Systems and Spatial Databases; GEOL437 Global Climate Change: Past and Present

Professional development: Throughout each of the required courses, Global STEWARDS will begin to hone professional skills. For instance, in all courses (with the exception of a few electives), students will practice **oral communication skills** (targeted to relay information to researchers across differing disciplines) by completing formal presentations. In order to evaluate progress, peer feedback forms (including quantitative and qualitative questions) will be completed every time a trainee presents in an NRT course. These forms will be incorporated into our evaluation program to inform trainee development. In addition, through our **INFEWS Project-based Practicum** course, trainees will have the opportunity to practice interdisciplinary **teamwork skills**, and step into and out of **leadership roles,** engaging in **peer-to-peer mentoring**, depending on how each chosen project integrates with their "home" STEM discipline.

NRT Element 2: Annual "Winter Boost" *(Addresses Core Competency #2, 4, 5, 6, 7, 8)*

The Nexus of Interdisciplinary Training and Professional Development: As noted above, our "Winter Boost" workshops will be modeled after the existing and very successful UMD-based "Winter Storm" NRT program.[15] Like Winter Storm, Winter Boost will be completely student "owned and operated" (See **Student-led Committees** below), and will be run annually over an intensive two-week period in the middle of January (between semesters). During this two-week period, all trainees will participate in a variety of cross-cutting workshops and activities. Every year Winter Boost will vary, but it will always consist of a mixture of events that 1) focus on professional development; and 2) spark interdisciplinary thought processes and future collaborative research ideas. Professional development workshops will include those focused on **science communication to diverse groups including the media** (led by NRT participating faculty including Cynthia Baur, an expert in risk and science communication who directs the UMD Horowitz Center for Health Literacy); **technical writing** (led by the UMD Graduate School Writing Center); **ethics** (led by faculty members in the School of Public Policy); **grant writing** (led by Debra Weinstein, the Research and Development Specialist in the School of Public Health); **leadership and conflict resolution** (led by the UMD Center for Leadership and Organizational Change); **career planning and job market navigation** (led by the UMD Career Center); and **diversity, inclusion and cultural competence** (led by UMD ADVANCE, a program that was initially supported by NSF and sustained by UMD). Meanwhile, FEW nexus interdisciplinary trainings during Winter Boost will involve **research methods workshops**; **data analysis workshops** (led by the NSF-funded National Socio-Environmental Synthesis Center (SESYNC))**; faculty and student talks;** and **field trips** to a) local

businesses (such as EcoCity Farms in neighboring Riverdale, MD) that incorporate FEW systems approaches in their business models; and b) CONSERVE demonstration sites (including the UMD Wye Research and Education Center) where we are currently developing and implementing energy-efficient, water treatment systems to enable the safe reuse of water on food crops. In addition, Winter Boost workshops will be integrated with our **Global Summer Amp** program (described below), by dedicating a portion of the workshops to discussions and exchanges (leveraging the state-of-the-art global classrooms that are sponsored by the UMD Office of International Affairs) with our partners in both Israel and Nepal, including research talks from Israeli and Nepali faculty and graduate students. These sessions will serve to begin to enhance the **cultural competence** of our Global STEWARDS.

NRT Element 3: Domestic Internship *(Addresses Core Competency #3, 4, 6, 7, 8)*

Interdisciplinary training: In addition to the experiential courses and Winter Boost workshops that our trainees will take, each Global STEWARD will engage in hands-on training off-campus through an internship with a non-academic partner at the FEW nexus. These domestic internships will take place over 150 hours (15 weeks X 10 hrs/week) and can be completed either during the semester or throughout the summer. The broad goals of the internship will be to enable each trainee to: 1) establish, implement, and evaluate internship learning objectives; 2) integrate FEW research concepts and theory in non-academic research endeavors; 3) improve communication and professional skills; 4) gain an understanding of the sponsoring organization with regard to, administration, research, funding issues, policy issues, and program activities and evaluation; and 5) assume specific responsibilities for planning, implementing, administering, and/or evaluating some specific part of the sponsoring organizations' research program(s). To ensure appropriate internship placements, we will require trainees to prepare a CV and a personal statement describing their specific internship learning objectives. These materials will be shared with our non-academic partners and matches will be made. Both pre-internship orientations and post-internship evaluations will be conducted for trainees and hosts in order to establish expectations for all parties; harmonize the internship experience for all trainees; and ensure that trainees and hosts are benefiting from the program. For internship placements, we will leverage our strong, existing UMD partnerships with local centers of research excellence including: the **USDA Agricultural Research Service**, Beltsville Agricultural Research Center; the **FDA Center for Food Safety and Applied Nutrition**; **CosmosID**, a microbial genomics platform focused on pathogen detection and microbiome analysis relating to food, water and other environmental media; the **Water Environment and Reuse Foundation**, which "provides exceptional water research to advance science and technology"; the **National Oceanic and Atmospheric Administration's National Centers for Environmental Information**; and the UMB Francis King Carey School of Law, **Environmental Law Program** *(See Letters of Support).* Participating faculty Rachel Rosenberg Goldstein and Daniel Kugler, faculty in UMD Extension, will also leverage strong connections that have developed with Maryland growers, community stakeholders, and other extension specialists to enable internship opportunities for interested STEWARDS. As our program matures, we will develop additional partnerships and solidify other internship sites based on the needs and interests of our trainees.

Professional development: Through the internship process, Global STEWARDS will hone **skills necessary for job applications** (including crafting effective CVs and personal statements), develop **teamwork** skills and be exposed to **project management concepts.** Trainees will also have the opportunity to apply **communication skills** learned through our Winter Boost workshops in real-life settings where, in some cases, they will **communicate science** to stakeholders, including policy makers.

NRT Element 4: Interdisciplinary "Global Summer Amp" Broadening Experience *(Addresses Core Competency #2, 3, 4, 5, 7, 8)*

Interdisciplinary training: Beyond domestic internships, all funded trainees will engage in one Global Summer Amp program, where Global STEWARDS will travel together for approximately two weeks to Israel or Nepal, working on FEW nexus issues with our existing partners at Hebrew University of Jerusalem's (HUJI) Robert H. Smith Faculty of Agriculture, Food and Environment, the Arava Institute for Environmental Studies (Arava), and Kathmandu University (KU) (*See Support Letters*). The Global Summer Amp program will leverage off of our existing, yet limited, CONSERVE International Scholars program, where interdisciplinary groups of graduate students and post-docs have traveled for 2-3 week periods to Israel and the West Bank to work with local off-grid communities in the development of low or

no energy water reuse systems for food crop irrigation. STEWARDS who travel to Israel and the West Bank will continue to research these systems, learning from our Israeli partners who are world leaders in sustainable, energy-efficient water reuse for food production. STEWARDS who travel to Nepal, a country that could immensely benefit from the development of these reuse systems, will perform needs assessments and initiate the transfer of these technologies to rural Nepali communities. Multiple UMD Global STEWARDS faculty members have experience conducting FEW-related research in Israel and/or Nepal. Of note, **Amy and Amir Sapkota** both completed Fulbright Senior Researcher Scholarship programs from January-June 2017 in Nepal; and **Amy Sapkota, Shirley Micallef, Mihai Pop, Xin-Zhong Liang** and **Amir Sapkota** are all jointly collaborating with faculty members at HUJI and Arava. The Global Summer Amp trips will be registered with the State Department and all trainees will be covered by the UMD travel insurance program. Moreover, the research teams will adhere to UMD risk management policies and have risk management briefings before the trips. We anticipate that as the NRT progresses and additional connections are made with other countries in need of FEW nexus solutions, the number of countries available to STEWARDS will expand.

Professional development: The Global Summer Amp experience will provide trainees with an amazing opportunity to **broaden their cultural and world perspectives**. Through engagement (along with our HUJI, Arava and KU partners) in local, off-grid communities, trainees will improve their **communication skills** through **teaching and outreach,** and further develop **cultural competence**. In Israel and Nepal, English is a working language; therefore, there should be limited language barriers with our partners.

NRT Element 5: FEW-related Outreach and Mentoring *(Addresses Core Competency #4, 6, 7, 8)*

The Nexus of Interdisciplinary training and Professional development: The Global STEWARDS will also have a number of opportunities to hone their **communication** skills through outreach and mentoring targeted to underrepresented undergraduates and secondary students, as well as the general public, including agricultural and non-agricultural communities. STEWARDS will engage in outreach and mentoring with undergraduates by 1) connecting with students through the Center for Minorities in Science and Engineering, which provides support services and outreach programs to recruit, retain and graduate minority students; and 2) linking into undergraduate fellowship programs currently funded in the School of Public Health, including UM ADAPT and UM STAR (PI Sapkota is a faculty mentor for both), which provide traditionally under-represented undergraduate students with two years of ethics, research, and career development training to enhance their potential to apply for and complete graduate degrees. Once connections have been established and trainee-undergraduate pairs have been matched, trainees (with support from their primary advisors) will take undergraduates under their wings, collaborating on specific elements of their ongoing FEW research projects. To formalize these relationships, undergraduates will register for 2 independent study research credits with the associated NRT faculty member. Beyond undergraduates, Global STEWARDS will have the opportunity to mentor secondary students through the National Council for Science and the Environment's (NCSE) EnvironMentors program, a youth mentoring and college preparation program targeting underrepresented high school students throughout the U.S. (PI Sapkota is a former Baltimore EnvironMentor). UMD is a current NCSE member, and through the NRT, we will become an active EnvironMentors Chapter where Global STEWARDS will become formal mentors of underrepresented high school students with the overall goal of exposing these students to FEW-related STEM research and career trajectories.

Trainees will also engage in outreach with the public (both agricultural and non-agricultural communities). CONSERVE, our existing USDA-funded Center, has an established outreach and extension infrastructure that will be leveraged. Trainees will be folded into ongoing public outreach efforts including UMD's Annual Maryland Day (which welcomes >70,000 visitors to campus every April) and the College of Agriculture and Natural Resources' Open House, a family friendly event held annually at the Central Maryland Research and Education Center, which is designed to showcase the "visionary research, impactful extension programs, and academic programs [that will] prepare the next generation of change agents." During these events, we will present demonstrations of FEW nexus science in action, relaying the critical role of interdisciplinary scientific teams in solving the wicked food-energy-water challenges facing society today. In addition, through our partnerships with the UMD, School of Public Health's Community Engagement, Environmental Justice and Health program, we will mobilize outreach efforts in local, underserved communities that are proximal to UMD. Each of the above-mentioned

outreach and mentoring activities will be organized by the student-led *Outreach and Mentoring Committee* (see below) in collaboration with the NRT Program Coordinator and NRT Director.

Throughout the NRT Experience:

Student-led Committees: As noted above, during our **stakeholder-driven process** to envision this NRT program, a key message was that enabling students to take ownership in training program elements was critical for success. Thus, to operationalize student "owned and operated" NRT elements, we will establish the following **Student-led Committees:** 1) the *Seminar Committee* will establish the formats and schedules of our weekly seminars; 2) the *Winter Boost Committee* will organize workshop sessions, speakers, and field trips; 3) the *Internship Committee* will organize our pre-internship orientation and post-internship evaluation (in collaboration with our Evaluation and Assessment team, below); 4) the *Outreach and Mentoring Committee* will schedule outreach efforts; and 5) the *Social Committee*, will organize informal meals and outings for Global STEWARDS throughout the year. Student leads on each committee will coordinate efforts with both the **NRT Director** and the **NRT Program Coordinator** (See **Organization and Management** below). Through involvement in these committees, students will take on **leadership roles** and hone **organizational skills,** as well as utilize a number of different **communication skills** (written and oral) with diverse stakeholders while planning events.

The Annual UMD Global STEWARDS Symposium: Each year, we will host a one-day UMD Global STEWARDS Symposium to showcase our research and training activities. The symposium will include a keynote presentation from a leading FEW nexus researcher outside of our NRT program, as well as short talks from our faculty, students and non-academic partners. In addition, all NRT students who have just completed either their first or second years in the program will be required to present posters, and NRT students from all other years will be encouraged to do the same. The event will be widely publicized across campus and to our local partners.

Table 3: Student participation in UMD Global STEWARDS NRT throughout their PhD programs.

NRT Elements	Year of Doctoral Program			
	1	2	3	4+
Element 1: Degree requirements in "Home" STEM Degree Program				
Element 1: Interdisciplinary INFEWS courses				
Element 1: INFEWS weekly seminar				
Element 2: Annual Winter Boost workshops				
Element 3: Domestic internship				
Element 4: Global Summer Amp in Israel or Nepal				
Element 5: FEW-related outreach and mentoring				
Mentorship				
Student-led committees				
Annual UMD Global STEWARDS symposium		ALL ELEMENTS		

Timeline: UMD Global Stewards (both NRT-funded and non-NRT-funded) will be involved in NRT activities throughout their doctoral training. Trainees will not be recruited directly into the full NRT program as 1st year students (See **Section 4g**). Instead, we will engage 1st year graduate students in certain elements of the program (Weekly Seminars, and our Annual Symposium), guide their application process during that 1st year, and expect them to fully engage in all program elements from their 2nd year until graduation. Table 3 outlines the typical experience of trainees throughout our NRT program.

4d. Major Research Efforts

In line with our NRT training approaches, the overarching goal of our research efforts is to carry out integrated, interdisciplinary studies--from local to global scales and from molecular to societal levels--to transform our understanding of FEW systems and translate scientific findings into impactful policies that ensure resilience and sustainability of these resources for future generations. Among our team of core interdisciplinary faculty participants, we have exceptional expertise in traditional FEW nexus research areas that focus on the development of predictive, and computational modeling approaches, as well as cyber-enabled interfaces and cyberinfrastructure, to characterize FEW system interactions and develop meaningful decision support systems *(Co-PIs Liang, Hultman and Pop)*. In addition, other members of our team bring robust expertise in engineering, water reuse, food safety and public health into FEW nexus frameworks (*PI Sapkota, Co-PIs Davis, Dubois, Meng, Micallef*, *Sapkota)*. This provides unique perspectives that can facilitate innovative solutions that do not cause unintended consequences with regard to ecosystem health, food safety and public health. The supporting faculty participants in our NRT program (Table 4) will bring additional expertise that spans the breadth or FEW-related disciplines

represented in the NRT. Among the participants, there are numerous existing cross-disciplinary interactions, multiple international collaborations, as well as new collaborations expected as a result of our NRT program. Together, we form an integrated science, engineering and policy community and we expect that, through our NRT students, new research projects will link faculty and partner experts across disciplines, creating truly transdisciplinary research efforts. Our research will target a range of topics within three complementary research areas summarized below.

Table 4. The methodological expertise of our supporting faculty and partner participants.

Name	**Affiliation**	**Relevant Expertise**
Cynthia Baur	UMD; Prof., Dir., Horowitz Center for Health Literacy	Best practices and guidelines in health communication and health literacy
Rita Colwell	UMD; Distinguished Univ. Prof., Comp. Biol., Bioinformatics and Genomics	Global infectious diseases, water, and health
Hector Corrado-Brava	UMD; Assoc. Prof., Comp. Sci., Ctr. for Bioinformatics and Comp. Biol.	Computational genomics, bioinformatics
Robert Buchanan	UMD; Prof., Nutr. and Food Science, Ctr. for Food Safety and Security Systems	Food safety, quantitative microbial risk assessment, and HACCP systems
Barton Forman	UMD: Asst. Prof., Civil and Env. Eng.	Water, energy, machine learning
Rachel Rosenberg Goldstein	UMD; Asst. Res. Prof., Dept. Agri. and Res. Econ.	Extension, environmental microbiology, water quality testing
Melissa Kenney	UMD; Assoc. Res. Prof. Earth Sys. Sci. Interdisciplinary Ctr.	Adaptive environmental decision making for complex systems
Gerrit Knapp	UMD; Prof., Sch. of Architecture, Planning and Preservation, Dir., National Ctr for Smart Growth Res. and Ed.	Economics and politics of land use planning, impacts of environmental policy
Daniel Kugler	UMD; Asst. Dean, International Programs in Agriculture & Natural Resources	Agricultural economics, extension
John Lea-Cox	UMD; Prof., Plant Sci. and Landscape Architecture	Systems-based solutions for water reuse in greenhouses and nurseries
Paul Leisnham	UMD; Assoc. Prof., Dept. of Environmental Sci. and Tech.	Socio-ecological determinants of watershed health
Masoud Negahban-Azar	UMD; Asst. Prof., Dept. of Environmental Sci. and Tech.	Sustainable technologies for water reuse and water quality management
Devon Payne-Sturges	UMD, Assist. Professor, Applied Environmental Health	Racial and economic disparities in exposures to environ. contaminants
Todd Treangen	UMD; Asst. Res. Sci., Ctr. for Bioinformatics and Comp. Biol.	Bioinformatics software development and analysis pipelines
Paul Turner	UMD; Assoc. Prof., Applied Environ. Health	Food toxicology
Kate Tully	UMD; Asst. Prof., Plant Sci. Land Arch.	Agroecology, sustainability of food sys.
Sacoby Wilson	UMD; Assoc. Prof., Applied Environmental Health	Community-univ. partnerships on environ. health and justice issues
Stephanie Yarwood	UMD; Asst. Prof.; Dept. of Environmental Sci. and Tech.	Impact of environmental factors on microbial communities and ecosystem function
Robert Percival	UMB, School of Law; Robert F. Stanton Prof. of Law and Dir., Env. Law Program	Global energy, environmental and natural resources law
Emmanuel Mongodin	UMB; Asst. Prof., Inst. for Genome Sci.	Microbial genomics, comparative genomics and metagenomics
Manan Sharma	USDA-ARS; Res. Microbiologist	Survival and persistence of foodborne pathogens in pre-harvest settings
Michael Pappas	UMB, School of Law; Prof.	Gov. responsibilities and private rights in managing energy, water, food resources
Andrea Ottesen	FDA; Res. Area Coordinator, Ctr. for Food Safety and Applied Nutrition	Metagenomic data to describe ecologies associated with high risk crops
William Piermattei	UMB; Managing Dir., Environmental Law Program	Interdisc. student projects addressing international environmental issues

Research Area 1: Agricultural resilience through energy-efficient water reuse

Summary of Pressing Issues: Seventy percent of global freshwater resources are used for agriculture.[16] Climate variability and change will continue to place severe stresses on agricultural water security, and it is estimated that total agricultural water consumption will need to increase by nearly 20% to meet global demands for food by 2050.[2] Irrigation is not only water intensive but also energy draining, as groundwater must be pumped and then often moved between watersheds.[2] For instance, in California, 8% of the state's total energy is devoted to agriculture and 70% of this energy is used to pump groundwater.[17] Meanwhile, in Pakistan's Indus Basin, groundwater pumping to support large-scale irrigated agriculture accounts for 61% of direct energy use.[18] Thus, to ensure future agricultural resilience globally, alternative water sources, technologies and production approaches will need to be tapped to conserve groundwater and reduce energy requirements associated with pumping. These approaches include the exploration of safe and sustainable water reuse systems that can be coupled with precision irrigation approaches to not only maximize every drop but also protect food safety and public health.[2, 3]

Research Questions and Methodologies: To address these complex issues, members of our team *(PI Sapkota; Co-PIs Davis, Micallef, Pop, and Sapkota; and Supporting Faculty Corrado-Brava, Kugler, Lea-Cox, Treangen)* are engaged in ongoing (through our USDA-NIFA funded Center, CONSERVE) and proposed activities that are seeking answers to the following questions, to name a few: 1) What low-energy, on-farm water treatment technologies can be developed and implemented to facilitate the safe and sustainable use of nontraditional irrigation water sources including advanced treated wastewater (e.g. recycled water), return flows, pond water, brackish water, and processed wash water?; 2) If water reuse approaches are adopted, what types of monitors and analytical methods can be installed and employed to provide farmers with accurate water quality data?; 3) What are the social, behavioral, economic and regulatory factors that influence the use of nontraditional irrigation water sources on food crops in varying world regions?; and 4) What are the most effective approaches to integrate FEW scientific findings into outreach programs for agricultural and nonagricultural communities? To address these questions, methodologies across the biosciences, computational sciences, engineering, social/behavioral sciences and economics are being utilized: from next-generation sequencing, bioinformatics and liquid chromatography mass spectrometry for the analysis of water quality data; to survey design and real-time, willingness-to-pay economics experiments for understanding the societal context of agricultural water reuse. To expand our reach, we will leverage existing collaborations in Israel—a world leader in agricultural water reuse—and apply our approaches in other water insecure areas of the world, including Nepal, where team members have recently initiated FEW research collaborations.

Research Area 2: Food safety and security in variable climate scenarios

Summary of Pressing Issues: As noted above, climate change is modifying the relationships between FEW systems. For instance, we are facing increases in the frequency, duration and intensity of extreme events, including extreme heat or cold and extreme precipitation or severe drought, and these extremes are negatively impacting food, energy and water resources. In the context of food systems, much of the research to date has focused on the impact of these extremes on crop yields and food security.[19] For example, recent climate simulations have projected a mean change in yield of −8% across eight major crops by the 2050s across Africa and South Asia.[20] Nevertheless, food safety (while understudied with regard to climate change) will be heavily impacted as well.[19] Recent studies by several of our team members provide evidence that we are already experiencing increases in the incidence of foodborne salmonellosis and campylobacteriosis as a result of temperature and precipitation extremes.[21, 22] Other recent studies, as well as reports from the Intergovernmental Panel on Climate Change (IPCC), suggest that we will experience increased mycotoxin contamination on food crops, an increased prevalence of pathogenic *Vibrio* in coastal waters, and increased harmful algal blooms contaminating shellfish, to name a few.[19] Several members of our team are currently researching these issues including *PI Sapkota; Co-PIs Meng, Dubois, Micallef, and Sapkota; and Supporting Faculty Colwell, Buchanan, Goldstein, Sharma, Ottesen and Turner.* However, additional food safety research that integrates across FEW systems is necessary to better characterize the issues and develop sustainable adaptation strategies.

Research Questions and Methodologies: To advance the field, participating NRT faculty members will be able to integrate more easily across disciplines to focus on the following research questions (to name a few): 1) What climatic factors influence the survival and persistence of foodborne bacterial pathogens, and their transmission from water and soil to food crops that are eaten raw (produce and leafy greens)?; 2) How can food safety and security be ensured under both drought and flood scenarios, utilizing energy

and water conservation approaches in the pre-harvest setting?; 3) How will climate extremes impact mycotoxin production in staple food crops grown in temperate climates?; and 4) What types of impact modeling and climate scenario analyses can best inform global food safety risk assessments? The methodologies used in studies aimed at addressing these questions will include traditional pathogen detection methods; plant-microbe interaction studies, crop management studies, next-generation sequencing and bioinformatics approaches; impact modeling; scenario analysis and risk assessment.

Research Area 3: Decision support systems to advance food-energy-water adaptation strategies
Summary of Pressing Issues: FEW systems are inherently interconnected, and the importance of these interplays is increasing as demand for food, energy and water resources grows.[23] Thus, as our climate changes and adaptation strategies are developed, we must integrate heterogeneous data and models from multiple disciplines in order to optimize decision-making at the FEW nexus.[24] To date, a number of visualization, modeling and assessment approaches have incorporated interdisciplinary data and models to better understand trade-offs at the FEW nexus given differing future climate scenarios. In order to be effective, integrated data and models need to operate at comparable spatial, temporal and conceptual dimensions; however, food, energy and water data are often collected by separate entities in most states and countries, and are therefore often inconsistent across scales.[25] In addition, current integrated models still lack the technical detail and complexity sufficient for upstream strategy and policy development.[23] Despite these challenges, participating team members *(Co-PIs Liang and Hultman, and Supporting Faculty Barton Forman, Melissa Kenney, Stephanie Yarwood)* are tackling these issues, integrating state-of-the-art knowledge and modeling across climate, hydrologic, agronomic, biogeochemical, engineering and economic sciences. The integrated models that are being developed are then applied to address specific scientific challenges or pressing societal issues such as those associated with multi-scale interactions and coevolution of food and bioenergy production, water quantity and quality, and climate and hydrologic processes in response to environmental forcings and human interventions.[26]
Research Questions, and Methodologies: To further this research, it is critical that the following questions be answered: 1) What are the synergistic opportunities and challenges arising from FEW interdependencies?; 2) What policies and management practices for bioenergy, land, and water resources emerge from the nexus approach to achieve FEW system resilience?; 3) What are the institutional barriers concerning the refinement and use of FEW integrated assessment and modeling approaches?;[23] and 4) Will large-scale deployment of reused water for irrigation sufficiently leverage the water demand for major food production especially during droughts? The methodologies used to address these questions will include tools that can be made dynamic to incorporate operational climate monitoring and prediction practices in a systems perspective such that short-term local decisions can be linked with regional and global feedbacks. Infrastructure will be built with modeling capabilities for projecting future trends in water and energy resources/food productions and recommending adaptation strategies in response to societal and environmental changes. This infrastructure will synthesize laboratory, data and modeling research results regarding fresh water availability, reused water quality, energy inputs, crop options and productivity, and economic and policy analyses pertaining to the use of reused water sources for irrigation. It will include the metrics and tools that are keenly useful to policy and decision makers.

4e. Broader Impacts

Through our integrated, interdisciplinary training and research approaches, our trainees will become adept at working and communicating across FEW disciplines, enabling transformative discoveries that can only be realized through transdisciplinary approaches and systems-based thinking. As a result of our formalized outreach and mentoring programs (targeted to underrepresented undergraduates and secondary school students), the impacts of our training efforts will extend to and imprint upon our even younger cohorts of future scientific leaders.

Actionable science to affect societal change through transformative FEW-nexus solutions: The fundamental knowledge generated by our interdisciplinary team of faculty and students, as well as the innovative solutions that are discovered to minimize waste and encourage reuse across the FEW nexus will affect societal improvements around the globe. Specifically, we envision that our interdisciplinary research will serve to 1) reduce agricultural water and energy footprints; 2) protect food safety, security and public health while ensuring FEW resilience; and 3) advance sustainable FEW adaptation strategies (Figure 2). Each of these impacts will have ramifications from local to global scales, directly impacting

communities engaged in the delivery and use of food, energy and water including farmers, municipalities, industries, and regulators, and indirectly impacting any community touched by these resources: all of us.

A diverse, globally competitive STEM workforce: At the heart of our NRT program, we will 1) train the next generation of students who will further FEW nexus solutions; and 2) enable them to develop the communication and other professional skills necessary to translate their research into practice. In addition, the integration of core competencies, such as honing interdisciplinary teamwork and strengthening leadership skills will bolster success in a wide range of professions. Our interdisciplinary project-based practicum course, domestic internship and global broadening experience will help students further hone the ability to understand and appropriately respond to a range of cultural variables and diversity across professional environments. Moreover, as a result of our targeted recruitment efforts, we expect that our program will result in an increase in the participation of women and minorities in STEM fields that are relevant to the FEW nexus. In addition to concentrated efforts to recruit students from underrepresented groups (See Outreach letter and **Section 4g**), we will extend our diversity-related efforts to earlier stages of the pipeline through our trainees' outreach activities. NRT participants will mentor undergraduates, with a focus on women and minorities, in meaningful interdisciplinary research, and expose secondary students to STEM problems that require a combination of skills at the FEW nexus.

Sustainability and Scalability: Our program is intended to be sustainable and scalable beyond the initial cohorts of UMD Global STEWARDS and beyond the initial funding period. Aside from the STEWARDS who will participate directly in the full program and the non-NRT-funded students who will participate in one or more elements of the NRT, plans are in place for transmission of the training innovations across UMD, across institutions and across career stages (See **Section 4b** and **Section 4c, NRT Element 5**). In particular, UMD is committed to continuing and expanding upon the core elements of the program after the end of the funding period. For instance, the School of Public Health, the academic home of PI Sapkota, has pledged to continue our program's interdisciplinary coursework well into the future. In addition, INFEWS seminars will continue through the partnerships between CONSERVE, CBCB and JIFSAN, which will be cultivated by our NRT program. Through our efforts, we aim to facilitate transformations in graduate STEM education both within the FEW disciplines and beyond.

4f. Organization and Management

NRT Leadership: Amy Sapkota will be the UMD Global STEWARDS ***NRT Director***. She will: 1) serve as a liaison between NSF and the NRT team; 2) chair the NRT Executive Committee (See below); and 3) direct and oversee all NRT-related student, faculty, and staff activities. Sapkota will be supported by the ***NRT Deputy Director.*** To ensure full engagement of all Co-PIs, the **Deputy Director** position will rotate across all Co-PIs, with 2 Co-PIs serving in this position each year. The NRT Director and Deputy Directors will receive input from the internal and external evaluators, the external Advisory Board, and a representative from the Student-led Committees to ensure program progress. Sapkota, as well as each of the Co-PIs, bring extensive management experience to the leadership team.

The PI will be aided by an ***NRT Project Coordinator*** who will facilitate the recruitment and selection process, manage budgets, and assist the Student-led Committees in coordinating seminars; Winter Boost workshops; domestic internships; outreach and mentoring activities; and social events. In the first year of funding, the NRT Director and Project Coordinator will work closely with four of the Co-PIs, Pop, Liang, DuBois, and Micallef (see Table 1), all outstanding graduate educators, to develop the high level, innovative education plan. This plan will be evaluated (See **Section 4h**) and refined per recommendations from the External Advisory Committee.

NRT Committees: The *Executive Committee* (EC) will include the PI and Co-PIs. The EC will meet twice monthly, and each member will be selected to oversee a specific element of the NRT program. For instance, one EC member will oversee the recruitment and selection process (in collaboration with the NRT Project Coordinator) and another member will coordinate with our internal and external evaluation team to ensure that we are not only meeting our evaluation milestones but also being responsive to resulting recommendations. In addition to our EC, we will have a number of active Student-led committees (See **Section 4b,** Student-led Committees), as well as an external *Advisory Board* (See **Section 4h**) that will coordinate with our evaluation and assessment team to monitor program performance and makes suggestions for program refinement.

Internal and External Evaluators: Dr. Gili Marbach-Ad will be our *Internal Evaluator* and lead the evaluation and assessment efforts (**See Section 4h**). She will work in collaboration with our *External Evaluator,* Mark Connelly, as well as our external *Advisory Board.*

4g. Recruitment, Mentoring, and Retention

Recruitment: Based on the experiences of previously-funded graduate training programs on our campus, we will not leverage the NRT program as a recruiting tool, and thus, it is unlikely that we will recruit 1st year doctoral students directly into the UMD Global STEWARDS program. Instead, we will work closely with all participating core faculty members, supporting faculty members, and targeted FEW-relevant doctoral programs to highlight the overall interdisciplinary opportunities of our program to students who have already matriculated into FEW nexus-related doctoral programs. Recruitment, therefore, will be an extended and ongoing process. First, students will begin to participate informally through involvement in seminars, workshops and outreach activities. Then, eligible students will formally apply to the STEWARDS program after they are already engaged in the UMD INFEWS research community.

Selection Process: To be considered for the UMD Global STEWARDS NRT, students will submit and complete an application including a CV, transcript and research statement that details how the student's educational and career goals will be enhanced through involvement in the NRT program. The application will be reviewed by a selection committee including core faculty members and supporting faculty members (as well as students, once the program is established).

Mentoring: Retention and success depends on successful (co-) mentorship. UMD Global STEWARDS will have at least three levels of mentoring engagement that will contribute to preparing successful interdisciplinary scientists after the STEWARDS leave the supportive NRT environment. First, each trainee will be mentored by their **primary advisors** in their "home" degree program. Second, when each of our UMD Global STEWARDS are formally accepted into the NRT program, they will be matched with a committee of three participating faculty members representing each of the three areas of the FEW nexus. These **Advisory Committees** will work with Global STEWARDS to formulate an educational plan that balances the required discipline-specific coursework of their STEM degree programs with the interdisciplinary elements of the NRT program, ensuring that trainees are exposed to a balance of perspectives. The FEW Advisors will also serve as liaisons between trainees and our non-academic partners, assisting Global STEWARDS in planning their domestic internships and global experiences. Finally, through our previous experiences, we have seen that students (especially those from disadvantaged backgrounds) who are closely connected to other students have a far higher likelihood of success. Therefore, senior STEWARDS will be expected to take on at least one newly accepted STEWARD mentee, who they will mentor until they graduate (and hopefully beyond).

Diversity: **The promotion of diversity is a top priority at UMD** where minority students comprise about 20 percent of the graduate student population, international students comprise about 31 percent, and female students comprise close to 50 percent. Beyond these numerical representations, the promotion of a diverse and inclusive environment that ensures retention and ultimate success of underrepresented minorities and women is a top priority. Since 2010, UMD, led by a Chief Diversity Officer within the Office of Diversity and Inclusion, has been focused on improving diversity and inclusion in areas of Leadership, Recruitment and Retention, Climate, Education, Research and Scholarship, and Community Engagement. UMD has been recognized for its diversity and inclusivity in several recent awards. In 2015 UMD was awarded *Insight into Diversity* Magazine's Higher Education Excellence in Diversity (HEED) Award. In 2016, UMD was named the 10th Best College for African Americans by *Essence* and *Money* Magazines. And for four years in a row, UMD has been named a Top-LGBT-Friendly University by Campus Pride and the *Huffington Post*.

As highlighted in Table 5, the School of Public Health and the Department of Plant Sciences and Landscape Architecture have had significant success with regard to recruiting and graduating women and underrepresented minority PhD students. We are constantly working to improve these numbers, and the participating faculty on this proposal includes one-third women and several underrepresented minorities who can serve as faculty role models for these targeted groups. To ensure that we recruit qualified, engaged women and underrepresented minority students, we will connect with two existing NSF-funded UMD programs: the Louis Stokes Alliance for Minority Participation (LSAMP) Bridge to the Doctorate (BD)

Fellowship and the ADVANCE Program for Inclusion, which focuses on women's representation, retention, satisfaction, and professional growth through strategic networking across disciplines and initiatives that transform the culture and policies of the institution. PI Sapkota (a recipient of an ADVANCE award) will work in concert with the Project Coordinator, Executive Committee, and Student-led Outreach and Mentoring Committee to provide clear, high quality information about the Global STEWARDS program such that the LSAMP BD Fellowship program and the ADVANCE program can highlight this unique opportunity to students and faculty. By collaborating with the LSAMP BD Fellowship program, our NRT will be able to connect with, recruit and support accomplished minority students interested in research and training at the FEW nexus. Involvement with UMD's ADVANCE program (including seminars and workshops during Winter Boost) will assist us in improving our understanding of the challenges faced by women in professional settings, as well as the targeted strategies that can be employed to help address these issues.

Table 5: University of Maryland-PhDs from related disciplines, 2013-2017. Average Time-To-Degree (TTD), total number of PhDs graduated, total number and percentage of female, and total number and percentage of underrepresented minorities (URM) from 2013-2017. *Data from Institutional Research Planning and Assessment, UMD.*

Department	Avg TTD	Total PhDs	Female	URM	% Female	% URM
Public Health	6.48	92	66	20	72	23
Nutrition and Food Science	5.06	33	20	1	61	3
Computer Science	5.88	143	22	2	15	1
Plant Science and Landscape Architecture	3.74	12	8	2	67	17
Atmos and Oceanic Science	5.36	25	10	0	40	0
Civil and Env Eng	5.72	80	24	3	30	4
Public Policy	6.02	30	15	1	50	7

In addition, we will interface with the Graduate School's Office of Diversity and Inclusion to ensure recruitment of the best and brightest students, including students from historically underserved and underrepresented populations. This office also supports programs to support and retain these students while fostering a sense of community on campus. This is achieved through active programming, such as **PROMISE: Maryland's Alliance for the Graduate Education and the Professoriate,** a university system-wide effort focused on increasing not only the number of minority students receiving PhD degrees but also the number of those students entering the professoriate in STEM fields. PROMISE provides infrastructure support to programs by **providing support and professional development advice for graduate student recruitment, retention, community building, PhD completion, and transition to career**. We will hold dedicated information sessions regarding these programs with the Global STEWARDS so that they are aware of and fully utilize these centralized programs that connect underrepresented minority graduate students across the University of Maryland System campuses.

4h. Performance Assessment/Project Evaluation

Assessment and Evaluation Team: Our multi-faceted assessment and evaluation approach incorporates internal and external evaluation processes, as well as an external Advisory Board. Our **Internal Evaluator**, Dr. Gili Marbach-Ad, will lead assessment and evaluation efforts. As Director of the Teaching and Learning Center and Internal Evaluator for COMBINE, a funded NSF NRT at UMD that focuses on Network Biology (PI, Girvan), she has a proven track record for assessing STEM professional development programs. Moreover, Marbach-Ad is highly regarded nationally for her expertise, and has disseminated her effective practices in a recently completed book.[27] She will work in close collaboration with our **External Evaluator**, Mark Connolly, Associate Research Scientist and Principal Investigator at the Wisconsin Center for Education Research, University of Wisconsin-Madison. Connolly has extensive expertise in STEM educational reform and is the PI of the NSF-funded "Longitudinal Study of Future STEM Scholars" (DUE-0817537), a seven-year, mixed-methods study of the impacts of doctoral teaching development programs on early career academics. He is also the PI of "Talking about Leaving Revisited", a large study funded by the Alfred P. Sloan Foundation and the NSF (DUE-1224550) that evaluates how student learning experiences shape national and institutional patterns of STEM persistence.

Marbach-Ad and Connolly will work in collaboration with an external **Advisory Board**, composed of distinguished FEW experts, from academia, government, and industry, who have demonstrated interest and experience in interdisciplinary research, training and professional development. **Chuck Gerba**, a Professor of Microbiology and Environmental Sciences at the University of Arizona, is internationally recognized for his research on the transmission of pathogens through food, water and land applied wastes. He is a fellow of the American Academy of Microbiology, American Association for the Advancement of Science, and the International Water Association. **Kent Messer**, a Professor at the University of Delaware, is the Unidel Howard Cosgrove Career Development Chair in Environment, the Director of the Center for Experimental & Applied Economics, and the Co-Director of the USDA Center for Behavioral & Experimental Agri-Environmental Research. **Jeremy Vanderzyl** is the Technical Services Manager of Duncan Family Farms, a multi-regional certified organic farming operation that contract, grow, and deliver baby leaf items and other specialty crops to the largest value-added processors around the globe. They also engage in extensive community outreach initiatives including *Green Waste Program,* and *Farm to School.* **M. Sundar** is the Global Lab Director of Life Sciences at Air Liquide, a world leader in technology solutions for industry and health. The company is present in over 80 countries and employs >65,000 individuals. Air Liquide has over 35 years of experience in water treatment solutions. **Kenneth Kunkel** is a Senior Scientist and Science Lead for Assessments at the Cooperative Institute for Climate and Satellites within the National Oceanic and Atmospheric Administration's National Centers for Environmental Information. Dr. Kunkel's research focuses on climate variability and change with an emphasis on extreme events including heavy precipitation, heat waves, cold waves, and winter storms.

The **Advisory Board** will work with evaluators Marbach-Ad and Connolly to: 1) develop clear and realistic annual assessment goals; 2) reflect on progress, successes, opportunities and challenges; 3) develop, refine, validate, and implement assessment instruments that enable measurable and publishable outcomes; and 4) generate effective vehicles to disseminate NRT training outcomes and gained insights. Over the 9-year history of the Teaching and Learning Center, Marbach-Ad has developed a battery of assessment instruments to evaluate graduate student professional development; she will refine and expand these tools as needed to encompass the project goals. Connolly's primary responsibilities will be to: 1) meet twice a year with Dr. Marbach-Ad and annually with the **Advisory Board** to review and provide guidance on assessment plans, instruments, data collected, and their interpretation; and 2) conduct an external audit of the evaluation's implementation, methods, and conclusions.

Framework and Goals for Assessment and Evaluation: The UMD Global STEWARDS NRT program has several overarching programmatic goals that were developed through a stakeholder-driven process (See **Section 4b,** Vision and Goals). Specifically, we aim to: 1) satisfy eight core competencies that are essential for conducting interdisciplinary research[4, 14] (Table 2); 2) prepare future FEW leaders who are trained in interdisciplinary team science and equipped with the communication and other transferable professional skills necessary to succeed across academic, industry, governmental and non-governmental sectors; 3) disseminate transformative STEM training, research and evaluation advances relevant to the FEW nexus; 4) increase the participation of women and underrepresented minorities in STEM fields relating to the FEW nexus; and 5) establish a novel, sustainable and scalable graduate education model.

Five Levels of Program Evaluation: To generate and implement constructive feedback on our programmatic goals, Marbach-Ad will employ and oversee a multifaceted strategy that encompasses five levels of program evaluation: 1) participation; 2) satisfaction; 3) attitudes/perceptions about learning; 4) application; and 5) impact [27-31]. As detailed below, we will assess these elements on short-term, intermediate, and long-term time scales as appropriate, using a combination of quantitative and qualitative methods. Our comprehensive assessment and evaluation plan will provide the constructive feedback and documentation necessary to continually improve the program, ensure that it will be sustained at UMD beyond the term of the grant, and demonstrate that it can serve as a national model for collaborative, interdisciplinary scientific research. In addition, since we are employing the same effective evaluation approaches for multiple graduate training programs on the UMD campus, we will be able to effectively compare impacts across programs, enabling us to formulate and refine the most compelling strategies for growing these models on our campus and beyond.

1) Participation: We will use program records and participant surveys to collect data on Global STEWARDS, including their demographics, their motivations for participating in the program, and their level of engagement in specific program activities (coursework, internships, outreach, etc.). These data

will be used to ensure the program is serving a diverse audience and will help us understand how to motivate student engagement.

2) Satisfaction: We will collect data on trainee satisfaction with the program and its activities through surveys, focus groups, and interviews. We will ask trainees to reflect on the program and suggest changes to increase satisfaction for future students. The Executive Committee, Program Coordinator, and course instructors will use these data in the short term to improve individual program components (e.g., courses, "Winter Boost", symposium).

3) Attitudes/perceptions about learning: Using surveys of all participants and case studies of a subset of participants, we will probe the skills and knowledge gained by Global STEWARDS participating in the training program activities. For example, with a comparison group of students from the life sciences, earth system sciences, engineering, computer sciences and policy who are not participants in the NRT program, we will use pre- and post- surveys to measure confidence of acquired research skills (e.g., scientific writing, data analysis, data interpretation, and presentation). We will adapt existing rubrics for this purpose, including the Research Oriented Learning Activities (ROLA) rubrics for assessing scientific data analysis and presentation skills.[32, 33]

4) Application: This level includes the collection of data about the trainees' abilities to apply what they have learned to their research, communication, collaboration, and mentoring activities. This application will be assessed via collection of artifacts (e.g., trainee CVs, conference abstracts, publications, course-specific writing assignments), interviews with trainees, and interviews with their research and internship supervisors. Assessments will focus on the development of communication skills, leadership and teamwork skills, and participation in mentoring networks. Our approach will incorporate existing tools,[34] as well as tools developed specifically for this project by Marbach-Ad to document skill development and establishment of interdisciplinary professional connections.

5) Impact: To more deeply understand the impact on program participants, we will undertake a longitudinal, qualitative assessment by following three students (one from each participating discipline) using a case study approach. Students will be interviewed at regular intervals during their first two years in the program to learn about their development as interdisciplinary research scholars. Concurrently, we will periodically interview their faculty advisors and course instructors. These data will provide a holistic picture of trainee development and insight into program strengths and weaknesses, which will be invaluable for mid-course program refinement. We will supplement these qualitative data with quantitative data on trainees' productivity (publications, degree completion, and time to degree), funding support, and job placement. Data collection will extend beyond the 5-year grant term as necessary to document the accomplishments and career trajectories of program participants. The NRT program's ***impact on the participating disciplines and the institution as a whole*** will be assessed in the long-term by documenting changes to disciplinary and institutional culture. For example, we will track how our NRT program encourages further University investment in NRT-related fields (e.g., investment in faculty, seed money for center proposals, changes in graduate program course requirements) and how it affects hiring trends related to NRT goals (e.g., preferences for those with explicitly interdisciplinary training).

In order to increase the internal validity of our evaluation so that we can attribute what is identified to the NRT, we will use a quasi-experimental design, when appropriate, that will also track a control group of UMD graduate students in the biological, physical, agricultural, social, and computer who are not NRT participants. For participants and controls, we will collect artifacts such as conference abstracts and publications to assess whether our trainees improved their skills to a greater extent compared to controls. These artifacts will be assessed by our evaluation team and NRT faculty based on the Association of American Colleges and Universities' VALUE rubrics. For conference presentations and peer-reviewed publications, we will also track acceptance rates and impact factors in order to quantitatively measure the success of our trainees compared to the control group. Finally, we will seek advice from other NRT programs regarding how to incorporate more unbiased, direct measures into our program assessment.

Assessment activities will follow an iterative annual cycle that will begin prior to the fall semester with goal setting, followed by the collection of data during the academic year, and the review of data at an annual spring meeting of the advisory board. Recommendations from the external evaluator and

advisory board will then be incorporated into the revised training program during the summer months and implemented the following fall semester.

4i. Recent Student Training Experiences *(Focused on graduate students only)*

As described above, **PI Amy Sapkota** initiated the interdisciplinary CONSERVE Scholars program as part of her ongoing Center of Excellence, CONSERVE. The research-oriented (non-curriculum based) program targets underrepresented minorities and women, including undergraduates, graduate students, post-docs and early career professionals (technicians). In addition, **Amy Sapkota** has mentored 5 post-doctoral fellows (3 women, 2 men), 6 PhD students (all women) and 8 Master's (MS) students (7 women, 1 man), and served on the committees of 20 additional graduate students. Her students and post-docs have gone on to fulfilling careers in both academia and government. For example, Shirley Micallef (Post-doc) was recently promoted to Associate Professor with tenure at UMD and is serving as a Co-PI on this proposal; Sutyajeet Soneja (Post-doc) is currently an American Association for the Advancement of Science Fellow at the U.S. Agency for International Development; Rachel Rosenberg Goldstein (PhD '13) is a Research Assistant Professor at UMD; and Prachi Kulkarni (PhD '16) is a Research Associate at the U.S. Department of Agriculture. Finally, **Amy Sapkota** developed and administered the internship program (for 5 years) for her department's MS degree students.

Co-PI Davis has advised/co-advised 14 PhD students; 6 of these students are female. He has also advised 48 MS students with research thesis (7 female), and 5 BS Honors Thesis students. These graduates have gone on to various positions in academia, industry, and public service. Other post-docs, undergraduate students and high school students have been and are mentored in the environmental engineering laboratories. Prof. Davis has a strong record of publishing with researchers that he has mentored, disseminating their work to the environmental engineering and science communities.

Co-PI Dubois has mentored 2 PhD food analysts from China in 4-month internships and 5 early-career PhD scientists. She has trained over 100 professionals from the food safety sector from around the world and she continues to offer informal mentorship to many of them as they seek new laboratory methods or capabilities. The breadth of her experience, especially in the area of international cooperative approaches to the development of food safety systems, will help ensure that the NRT program is impactful both locally and globally, while building partnerships that will ensure its sustainability beyond the granting period.

Co-PI Hultman has mentored 25 PhD students (chairing 12 dissertations), 40 MS students in the Public Policy program, and three post-docs. These students are primarily in the areas of climate, energy, and policy; and a focus of the research-oriented students is on both modeling energy transitions and interview-based methods for understanding policy outcomes. His former students have gone to work in academia (Georgia Tech, Tsinghua University), government (Department of Energy, EPA), national labs (PNNL, NREL), think tanks (Brookings), and non-governmental organizations (World Resources Institute and many others).

Co-PI Liang's experience includes mentoring 23 (18 PhD and 5 MS) graduate students and 13 postdocs at the interface of climate, water, food, energy, environment, and economy, including 1 African American. Liang's former graduate students and postdocs have gone on to work in government and academia (NASA JPL, NOAA NCEP, DOE ORNL, China Meteorological Administration, China Marine Environmental Forecast Center, Yeungnam University), and in private firms (Amazon, Google).

Co-PI Meng's experience includes mentoring 30 (17 PhDs, and 13 MS students) graduate students and 11 postdocs at the interface of Food Science and Microbiology, including 1 African American and 3 Hispanics. Meng's former graduate students have gone on to work in academia (in faculty positions at such institutions as Ohio State University, Louisiana State University, Hong Kong Polytechnic University, and China's Northwest A&F University), in government (at U.S. Food & Drug Administration, Department of Agriculture, China's Food & Drug Administration), and in private employment (Kraft, and Cargill).

Co-PI Micallef has advised/co-advised 5 PhD students (2 graduated, 3 current; 3 female) and 4 MS students with research thesis (2 graduated, 2 current; 3 female). She has also advised 6 post-docs (4 completed, 2 current; 4 female). These graduates and post-docs have gone to various positions in academia (CONSERVE post-doc) and federal government (one MS and two post-docs at FDA, one MS at USDA, one PhD in leadership position in S. Korea). She has a strong record of publishing with advisees and presenting research findings at international meetings to the food safety community.

Co-PI Pop has mentored 17 PhD students (4 female, 13 male), 2 MS students (1 female, 1 male), and 6 postdoctoral scientists (2 female, 4 male). He is also active in mentoring undergraduates: he initiated a summer internship program in computational biology (2009-Present), and created a First-year Innovation and Research Experience stream centered around reconstructing the genome of the diamondback terrapin. Several of his graduate students are now in academia (2 faculty at Johns Hopkins University, staff scientist at U. Penn), federal government (NIH), and private industry (Genentech, Google, Square).

Co-PI Amir Sapkota has mentored 1 research assistant professor, 4 post-doctoral fellows, 7 doctoral students, and 10 MS students (the majority of whom have been underrepresented minorities). His students have gone on to work at prestigious institutes including the National Institutes of Health, the New Jersey Department of Environmental Health, USAID, and USDA.

4j. Results from Prior NSF Support

PI Amy Sapkota has not received NSF funding in the past five years. However, over the past 11 years she has secured or helped to secure over $30.7 million in federal research funds from USDA-NIFA, the National Institutes of Health (NIH), the Centers for Disease Control and Prevention (CDC) and others, and of that she has overseen $14.6 million as the PI. As mentioned above, her most closely related project is the CONSERVE Center of Excellence, a 4-year Center funded by NSF's INFEWS partner agency, USDA NIFA, that seeks to facilitate the adoption of transformative on-farm water treatment solutions that enable the safe use of nontraditional irrigation water on food crops, effectively reducing the nation's agricultural water challenges that are exacerbated by climate change.

Co-PI Hultman: "CAREER: Policy for low-carbon technology investment: A comparative international perspective on emerging economy responses to climate change" (Award #1056998, $400,000, 04/01/2011 to 01/31/2018). This project addresses motivations that emerging economy firms have to invest and innovate in low-carbon technology. The project assesses how firms in emerging economies respond to international and domestic energy policies when making low-carbon investment decisions. Engaging approximately 10 MS and PhD students over the course of the study, the work took a comparative case approach to investigate the differences in deployment and international policy participation in solar photovoltaic and wind electricity generation in South Korea, India, Brazil, and South Africa. Through field research and interviews, curriculum and research group development, and associated modeling, we assessed policy influences for low-carbon investment decisions in these countries and technologies. The project prepared **Hultman** to engage in U.S. climate and energy policy development at the White House from 2014-2016. Five papers have been published to date.

Co-PI Liang: "INFEWS/T1: A modeling framework to couple food, energy, and water in the teleconnected Corn and Cotton Belts" (EAR-1639327) will develop, evaluate, and apply a modeling framework to transform understanding of how current and future U.S agriculture functions across a range of scales, in order to address impending food-energy-water nexus challenges. The project will develop a scale-dependent approach for coupling, predicting and applying the interactive water, carbon, and nitrogen cycle processes with agricultural, hydroengineering, and economic practices in a realistic manner, and improve the scientific basis for decisions in sustainable agricultural food and bioenergy practices, water resources management and pollution assessment, hydroengineering design, and adaptation and mitigation strategies. The project will deliver a tool to support policy and decision-making on adaptation and mitigation strategies, and train five PhD students and four postdoctoral researchers from relevant disciplines in a transdisciplinary research framework. So far, six papers have been published.

Co-PI Pop: "Graphs to Diversity: extracting genomic variation from sequence graphs" (PIs: Pop, Kingsford, IIS-0812111). This award supported the development of novel algorithms for analyzing genome assembly graphs in order to uncover genomic variation--an important consideration in metagenomic data. The work resulted in 13 publications in peer-reviewed journals, and contributed to the training of 6 graduate students. Furthermore, this award helped initiate a summer internship program that has trained over 40 undergraduate and high school students since its inception in 2009.

Co-PIs Davis, Dubois, Meng, Micallef, and Amir Sapkota have not received NSF funding in the past five years; however, they have been consistently well-funded by a number of other federal agencies including USDA, FDA and NIH.

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