NATIONAL SCIENCE FOUNDATION
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Dear Colleague Letter: FY 2016 Innovations at the Nexus of Food, Energy and Water Systems (INFEWS) Funding Opportunity on Nitrogen, Phosphorus, and Water

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Dear Colleagues:

In 2010, NSF established the Science, Engineering, and Education for Sustainability (SEES)[1] investment area to lay the research foundation for decision capabilities and technologies aimed at mitigating and adapting to environmental changes that threaten sustainability. Some SEES investments advanced a systems-based approach to understanding, predicting, and reacting to stress upon, and changes in, the linked natural, social, and built environments. In this context, the importance of understanding the interconnected and interdependent systems involving food, energy, and water (FEW) has emerged. In 2015, NSF Issued a Dear Colleague Letter (DCL): SEES: Interactions of Food Systems with Water and Energy Systems[2] to accelerate fundamental understanding and stimulate basic research on the connections and interdependencies among these three systems.

Through this Dear Colleague Letter (DCL), issued by the Division of Chemistry (CHE) in the Directorate for Mathematical & Physical Sciences and the Division of Chemical, Bioengineering, Environmental and Transport Systems (CBET) in the Directorate for Engineering, the NSF aims to specifically focus on advancing knowledge of the nitrogen and phosphorus cycles; the production and use of fertilizers for food production; and the detection, separation, and reclamation/recycling of nitrogen- and phosphorus-containing species in and from complex aqueous environments.

Humanity is reliant upon the physical resources and natural systems of the Earth for the provision of food, energy, and water. It is becoming imperative that we determine how society can best integrate across the natural and built environments to provide for a growing demand for food, water and energy while maintaining appropriate ecosystem services. Factors contributing to stresses in the food, energy, and water systems include increasing regional, social, and political pressures as result of land use change, climate variability, and heterogeneous resource distribution. These interconnections and interdependencies associated with the food, energy and water nexus create research grand challenges in understanding how the complex, coupled processes of society and the environment function now, and in the future. There is a critical need for research that enables new means of adapting to future challenges. The FEW systems must be defined broadly, incorporating physical processes (such as built infrastructure and new technologies for more efficient resource utilization), natural processes (such as biogeochemical and hydrologic cycles), biological processes (such as agroecosystem structure and productivity), social/behavioral processes (such as decision making and governance), and cyber elements. Investigations of these complex systems may produce discoveries that cannot emerge from research on food or energy or water systems alone. It is the synergy among these components, in the context of sustainability that will open innovative science and engineering pathways to produce new

knowledge and novel technologies to solve the challenges of scarcity and variability. This DCL, which is part of the Innovation at the Nexus of Food, Energy, and Water Systems (INFEWS) portfolio (http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf15040), addresses emerging science, technology, and engineering relevant to food, energy and water systems.

The availability of **nitrogen**, **phosphorus**, and **water** are the three main factors that limit our ability to produce enough food to feed the growing population of the planet. The **nitrogen** cycle is one of the most significant biogeochemical cycles on Earth, as nitrogen is an essential nutrient for all forms of life. Although freely available in the atmosphere as dinitrogen, access to fixed forms of nitrogen constitutes, in many cases, the most limiting factor for plant growth. The industrial production of ammonia for fertilizers via the current Haber-Bosch process is an energy intensive process that consumes 1-2% of the world's annual energy supply. For these reasons, the need for advanced catalytic methods for the reduction of dinitrogen to ammonia remains a requirement for sustainability in the food, energy and water systems cycle.

Similarly, **phosphorus** is also essential to plant and animal nutrition. Approximately 80% of the world's economically-viable phosphorus is obtained from "phosphate rock" that is localized in a single place, Western Sahara. Phosphate rock is a more concentrated commodity than petroleum, and like petroleum, the world's supply of phosphorus is threatened by political instability and monopolistic economic practices. Management of phosphorus is a bit of a paradox because, while the world may face a shortage of phosphorus-containing fertilizer later this century, many regions are currently afflicted with an oversupply in both inland and coastal waters causing algal blooms that can produce extremely dangerous toxins that can sicken or kill people or animals, create dead zones in the water, raise treatment costs for drinking water, and hurt industries that depend on clean water. The ability to provide field-deployable, inexpensive, and environmentally-and energetically-sustainable sensors for real-time application and monitoring of nitrogen or phosphorus-containing species to agriculture while reducing the amount of these species in waste or run-off streams would benefit food production, benefit water quality, and result in significantly less energy consumption.

The increased demands for fresh **water** for crops/livestock and energy production will significantly add to the current stress on non-renewable groundwater resources. It is estimated that seven billion people in sixty countries will experience water scarcity by 2050 at current rates of water usage. This will place additional stress on both food supplies and energy consumption rates. These needs necessitate scientific and technological innovations that will address global problems that center on fresh water. In particular, the food production system generates waste streams that are characterized by high concentrations of organic matter, nitrogen- and phosphorus-containing species in water. New approaches are needed to overcome the cost of inefficient and energy-intensive sequestration and removal/recycling of such species while also preserving water quality.

This component of the NSF Innovations at the Nexus of the Food, Energy and Waters Systems (INFEWS) investment is designed to advance a new understanding of the role of the chemistry of nitrogen, phosphorous, and water in the nexus of food, energy and water systems, "INFEWS: N/P/H2O." While fundamental science and engineering research will underpin solutions to these areas of national and international need, it must also be recognized that technological innovations themselves require resources for development and deployment. Ostensible solutions to the challenge of N, P and water supply cannot be premised on the assumption that energy, chemical feedstocks, and other required resources will be available in great abundance.

In FY 2016, the topics of interest in INFEWS: N/P/H2O include innovative, fundamental research to:

1. advance catalytic methods for the reduction of dinitrogen to ammonia and that will permit reductions in the energy requirements for fertilizer production;

2. develop new sensing modalities that will lead to field-deployable, inexpensive, and environmentally and energetically sustainable sensors for real-time monitoring of nitrogen- or phosphorus-containing species as they move, via agricultural run-off, to other water systems; and
3. gain understanding of the supramolecular recognition and binding of environmentally-relevant nitrogen- and phosphorus-containing species. Such efforts are essential for the selective and efficient detection, sequestration/separation, and recycling of these elements as well as for water purification efforts.

Proposals in response to this investment area should be submitted to the existing program of interest in the CHE and CBET within the existing submission windows (deadlines) of the programs. The proposal title must begin with "INFEWS N/P/H2O:". Other than the proposal title, the cover page should be prepared as a regular unsolicited proposal submission to the program. The most competitive proposals will address how the project conceptually advances innovations at the nexus of the food, energy, and water systems and sustainability of the proposed solution, i.e., the monetary and energetic costs for translation and scale-up.

Proposals are welcome from either multiple or single investigators. Interdisciplinary proposals that involve principal investigators traditionally supported by the two participating divisions (CHE and CBET) are also welcome. Such proposals should be submitted to the most relevant program in either CHE or CBET. CHE welcomes proposals responding to this Dear Colleague Letter (DCL) in all programs, while CBET welcomes proposals responding to this DCL in the Environmental Engineering, Environmental Sustainability, or Catalysis and Biocatalysis Programs. Please consult the Divisional webpages for more details on specific interests.[3],[4]

The challenges at the food, energy, and water nexus are frequently international, and experts around the globe have relevant expertise and resources. Proposals including international collaboration are encouraged when those efforts enhance the merit of the proposed work. The U.S. team's international counterparts generally should have support or obtain funding through their own national or regional sources.

Proposals may be submitted in combination with other solicitations. For example, if there are strong collaborations with industry, the Grant Opportunities for Academic Liaison with Industry (GOALI)[5] solicitation can be used in conjunction with this effort. Similarly, proposals may be submitted in combination with the Facilitating Research at Primarily Undergraduate Institutions: Research in Undergraduate Institutions (RUI) and Research Opportunity Awards (ROA)[6] solicitation. These proposals should be submitted to the appropriate solicitation and add INFEWS to the title (For example, RUI: INFEWS N/P/H2O: Name of your proposal). Other mechanisms such as EAGER[7] and INSPIRE[7] may also be appropriate, but principal investigators are required to check with the cognizant program officers for additional guidance. For general questions about INFEWS, email the listed representatives in either CHE[8] or CBET[9].

To see examples of awards made under the Food-Energy-Water investment area, visit the NSF Award Abstracts Database,[10] and enter "food, energy, and water" in the "Search Award for:" dialogue field. Alternatively, please visit the webpages of the disciplinary programs of interest in the participating divisions. Under each program, find the link to recent awards made in that program and look for those that contain "FEW" in the proposal title.

We are excited by the opportunities in the INFEWS area and encourage our communities to contribute to our sustainable future by participating in this important funding investment area. If interested, please contact the Program Officers listed in References 8 and 9, not the signatories of this DCL, for assistance.

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References

1. Science, Engineering and Education for Sustainability NSF-Wide Investment (SEES): http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504707
2. SEES: Interactions of Food Systems with Water and Energy Systems DCL: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf15040
3. Division of Chemistry webpage: http://www.nsf.gov/div/index.jsp?div=CHE
4. Division of Chemical, Bioengineering, Environmental and Transport Systems (CBET) webpage: http://www.nsf.gov/div/index.jsp?div=CBET
5. GOALI: http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504699
6. RUI: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf14579
7. EAGER or INSPIRE: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=gpg
8. CHE Program Officers: Tim Patten (tpatten@nsf.gov), Suk-Wah Tam-Chang (stamchan@nsf.gov), Lin He (lhe@nsf.gov), and Colby Foss (cfoss@nsf.gov).
9. CBET Program Officers: William Cooper (wcooper@nsf.gov), Bruce Hamilton (bhamilto@nsf.gov), and Robert McCabe (rmccabe@nsf.gov).
10. NSF Awards Search: http://www.nsf.gov/awardsearch/