INFEWS/T3: Advancing Technologies and Improving Communication of Urine-Derived Fertilizers for Food Production Within a Risk-Based Framework

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Project Summary

Overview: Cycling of nitrogen (N) and phosphorus (P) through food production, consumption, runoff water and wastewater are influencing environmental degradation and the subsequent risks to human health. We currently use energy intensive and environmentally unsustainable methods to create N and P fertilizers. Concerns over P limitations and the energy intensity of creating N from atmospheric nitrogen warrant a move toward alternative fertilizer options. The primary source of N and P in human-dominated environments is food, and the nutrients in food that is consumed by people ultimately ends up either in landfills or wastewater effluents. There is a critical need to recover nutrients and redirect them to productive use in support of food production, in an energy efficient manner. This proposal addresses a way to achieve this using technologies that can be applied from the household to regional scale, and communication and public education methods that are grounded in a risk-based framework. To achieve the goals of this project, we have assembled a collection of investigators and senior personnel with a history of working together and expertise in waste treatment technologies, environmental chemistry and biology, agriculture, communications and human behavior, and risk assessment as it pertains to wastes, urine and urine-derived products.

Intellectual Merit: This proposal seeks to advance energy efficient N and P recovery in the US through development of technologies that produce safe urine-derived fertilizers (UDFs) via urine diversion. We will use a data-informed, risk-based approach to compare the safety of synthetic fertilizer, Class A biosolids from municipal wastewater treatment, and UDF based on the fate of emerging or heavy metal contaminants during processing and field trials involving growth of lettuce, carrots or hay. The urine processing methods to be evaluated during this study are informed by several years of experience using World Health Organization procedures, which do not reduce bacterial counts in UDF products. Instead, we will evaluate a collection of technologies by assessing their effectiveness on nutrient recovery efficiency, fertilizer product volume reduction, product aesthetics and capacity to reduce undesirable contaminants, including target reduction of viruses, bacteria, trace organic contaminants, and antibiotic resistance genes. This project will be the first known effort to extend UDF product generated by the technologies selected for this study through crop field trials and to conduct a comprehensive monitoring campaign in support of a risk assessment. We anticipate that social acceptance of using UDF for food is low in the US, mainly due to a lack of information about the risks it offers in comparison to conventional (synthetic fertilizer, biosolids) methods. Our project integrates an assessment and communication program that involves surveys, focus groups and the development of approachable and visually pleasing education materials that target potential users with prior or no experience with urine diversion and recycling. Then, after completing a risk assessment informed by two seasons of crop studies, we will use methods successfully applied to advance public acceptance of potable water reuse to this urine-centered project and its outcomes.

Broader Impact: We will identify and demonstrate energy efficient technologies that provide a significant benefit over conventional centralized nutrient management of wastewater by generating urine-derived fertilizers. Although the promises of environmental and public health protection offered by the technologies to be evaluated through this project are great, there is a need to convey the information about the technology in a way that consumers, farmers, regulators, city planners and other stakeholders can understand and use to make informed decisions. A strength of this proposal is the unique integration of our technical team with our social science team, and the integration of tasks associated with both. Through this project, we will engage in activities that directly offer benefits through professional training (student summer internships), unique forums for student and public learning (development of case-based learning tools; a new course; and construction of a urine diversion and UDF-processing facility for application to non-food crop at the University botanical gardens), and information dissemination (an annual Urine Diversion and Recycling Summit and themed sessions at a national conference).

Context Statement

Separation of urine at the source (urine diversion) followed by collection and processing to create urine-derived fertilizers (UDF) is a viable approach that has seen some success in Europe and is ripe for implementation in the US as part of the move toward better wastewater management. Urine collection and recovery will have a vast impact on the US FEW system from the household to the regional scale. Urine diversion using specialized flush toilets and urinals for the generation of UDF can: ***(i) Enhance food security by recovering most of the nitrogen (N) and phosphorus (P) in food***. Human urine contains 70-80% of the N and 50-70% of the P in the domestic sewage collected and centrally treated through wastewater treatment in the US, but less than 1% of the flow.[62] The urine produced in the US annually could supply 90% of all nitrogen fertilizers used in domestic wheat production.[79] Furthermore, the nation's urine contains 75% as much phosphorus as all the food that is produced and consumed domestically (our calculation). Each person excretes enough urine daily to provide the nutrients required to grow the wheat needed to produce a loaf of bread.[80] ***(ii) Reduce the energy associated with fertilizer production and treatment of nutrient-polluted water***. The energy required to produce N via the Haber Bosch process is 43 kJ/g N.[88] After it is taken up by crops, eaten by humans, and excreted into the wastewater system, the energy required to remove the resulting N pollution is between 45-109 kJ/g N, depending on whether an external organic carbon source is used for denitrification.[68] Thus the total energy cost to synthesize N into fertilizer and then remove it from wastewater is 88 to 152 kJ/g N. The Rich Earth Institute's non-optimized methods for pasteurization and reverse osmosis concentration produce N fertilizer using only 19 kJ/g N in electricity. Through optimization, this figure is expected to decrease further. Not included in this figure is the benefit of recycled P, which otherwise requires 29 kJ/g for mining and extraction and 45 kJ/g for removal from wastewater.[68] ***(iii) Reduce water consumption by reducing flushing.*** Implementing source separation, which significantly reduces water use to flush toilets, would save over 1 trillion gallons of drinkable water a year.[75] ***(iv) Improve water quality.*** Nutrient pollution to waterways is the primary driver of growing wastewater treatment infrastructure costs in US cities.[118,119] Since the price tag for adding nutrient control at centralized wastewater treatment plants is around $50 billion,[118] domestic utilities are starting to consider the cost savings incurred by supporting community-scale urine diversion, which offsets the cost associated with constructing and operating enhanced nutrient removal at centralized treatment facilities.[48]

Advanced wastewater treatment is a critical element of the safe water system enjoyed in the developed world, but unfortunately it is inefficient from the perspective of food and energy. The current US infrastructure does not facilitate recovery of nutrients at all facilities, which could otherwise be used to support agricultural production. The energy required to operate centralized wastewater nutrient removal systems is only growing as more cities in the US face more stringent nutrient removal requirements. Source separation facilitates the production of urine-derived fertilizers via processing technologies that are energy efficient, yield a high nutrient product, eliminate contaminants of emerging concern, and reduce odors. It is an economically and environmentally attractive option to immediately reduce nutrient emissions in unsewered areas at the household scale (e.g., Cape Cod), or in high density apartments and office spaces served by underperforming treatment plants. Potential barriers to the growth of source separation and urine-derived products are the cost of infrastructure change, and human reluctance and perceptions that are based on uninformed impressions of the safety and impact of such practices. Therefore, advancing urine-based technologies requires an informed communication strategy, such as the successful approaches used to develop a higher level of public acceptance for water reuse.

Considering the complex integration of food production, technology, water quality sciences and social sciences, our team tackles this complex FEW system by compiling a well-established team that bridges across academia and practice. The project co-PIs cover water quality engineering (Love and Wigginton; engineering directorate), environmental chemistry (Aga; chemistry directorate), and social behavioral sciences (Hardin, Directorate for Social, Behavioral and Economic Sciences) at NSF, and USDA SARE funding from the USDA for Noe-Hays.