Synergies and tradeoffs associated with the recovery of resources from waste

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The recovery of energy, water, and crop nutrients from human waste will be a central component of international development in the 21st century. This type of resource recovery meets the two objectives defined by the United States Agency for International Development (USAID) in their Water and Development Strategic Plan1, which are: 1) to improve health outcomes through the provision of water, sanitation, and hygiene (WASH) services, and 2) to manage water sustainably and productively in agriculture to enhance food security. Many farmers in developing countries are already recovering these resources, irrigating 20 million hectares with wastewater,2 which contributes towards global climate change mitigation strategies by offsetting the energy and material needs associated with the production of synthetic fertilizers. However, there is one problem—an estimated 1.5 billion people in the world discharge wastewater to sewer systems with no treatment.3 Based on global estimates, this untreated wastewater is used for one out of every six wastewater-irrigated hectares,4 putting many farmers, consumers, and their families at risk for diarrheal diseases, parasite infections, and even long-term health impacts such as malnutrition. As more communities obtain access to sanitation and wastewater treatment, technologies that recover energy from waste by capturing methane from biogas are being encouraged, and domestic wastewater treatment facilities are starting to be considered for their potential as net energy production facilities.5

For several years, my colleagues and I at the University of South Florida (USF) and the Center for Water and Environmental Sanitation (CASA) in Cochabamba, Bolivia, have studied the performance of wastewater management and sanitation systems in Bolivia, with a particular focus on technologies used in small cities, towns and periurban agricultural regions.6-14 Through this work, I have noticed some promising development opportunities, such as synergies between wastewater management and food production activities and the participation of farmers as stakeholders in the operation and maintenance of wastewater management services (Figure 1).

Figure 1. A farmer from Cochabamba, Bolivia discusses the benefits and tradeoffs of irrigating with reclaimed water from a municipal wastewater stabilization pond system (above); farmers in this region help manage and maintain the stabilization pond system, in return for irrigation water and access to the ponds to harvest nutrient-rich aquatic plants for use as animal feed or soil amendment (below).
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The Blind Spot: Hidden Tradeoffs of Resource Recovery Systems

There is an overlooked “blind spot” associated with the provision of resilient, context-appropriate wastewater resource recovery solutions, especially for periurban zones and for small, urbanizing cities: there are often unrecognized tradeoffs associated with technologies that recover water, energy and nutrient resources from wastewater. Indeed, there is evidence that some newer wastewater treatment technologies that are optimized for energy recovery (e.g. composting latrines and advanced anaerobic wastewater reactors that recover methane gas) may be inherently less efficient at eliminating viruses and human parasites.\textsuperscript{14-16} Traditional natural technologies, such as waste stabilization ponds (one of the most widely-used wastewater treatment technologies globally), are often very efficient at pathogen removal, are also much easier to operate and maintain, and can easily be integrated with agricultural irrigation systems.\textsuperscript{17} However, due to social, political, and economic pressures, many communities (especially in Latin America) are opting to trade in their pond systems for shiny new advanced anaerobic reactors, or in some cases, extremely energy-intensive technologies (e.g. activated sludge plants). These reactors are often viewed as more modern technologies,\textsuperscript{18} while natural systems such as ponds are considered outdated, even though evidence suggests that the reason some pond systems do not perform adequately is that they are overloaded or not maintained.\textsuperscript{13} Sadly, advanced reactors that replace ponds in these settings also tend to quickly experience operation and maintenance problems, especially in small cities with fewer resources and limited access to skilled labor (Figure 2).

In some cases, natural systems, such as waste stabilization ponds, may be more appropriate, especially in regions that can be closely linked to food production zones where access to nutrients and water is a priority.\textsuperscript{10} In other cases, energy recovery may be a greater priority, and technologies optimized for energy recovery may be preferred. In many cases, the determination of local priorities by a broad
range of stakeholder groups is not so straightforward, and it is often rare to find consensus. For example, in the southern periurban neighborhoods of Cochabamba, Bolivia, located near the Albarrancho wastewater treatment plant (which treats nearly 70,000 cubic meters of wastewater per day from the city of Cochabamba), some residents demand access to domestic gas, uncontaminated water for irrigation, and clean air, free of nuisance odors, while others oppose the implementation of the proposed crop nutrient and biogas recovery facility at the plant, requesting instead that the wastewater plant be shut down entirely. This demonstrates that the successful implementation of water, energy and nutrient recovery services at wastewater management facilities often relies just as much on societal structures as it does on the natural and engineered systems. A recent study found that up to 12% of the problems associated with wastewater treatment facilities in some regions of Bolivia were caused by social problems, not technical ones. Furthermore, concepts about best practices for water management and resource recovery are contingent on cultural value systems, and the implementation of new infrastructure can have unintended and unexpected returns for certain community groups.

As the world becomes more globalized and as populations shift from rural areas to urban centers, cultural diversity in cities will continue to increase, resulting in the potential clashing of different value systems and worldviews. Development solutions for this increasingly complex world call for diverse and progressive non-traditional partnerships in science, technology and innovation.

**The Solution: Non-Traditional Partnerships for Science, Technology and Innovation**

Partnerships for science, technology and innovation are an essential part of the solution to the extremely complex development challenges related to the management of resources at the nexus of water, energy, and food production. As many agencies seek to develop new technologies for water and wastewater management, renewable energy, agricultural productivity, and the prevention of diseases, it is indispensable that these new technology developments be made with collaboration from the following innovative and non-traditional partnerships: 1) academic partnerships between experts from the natural sciences, engineering, health, and the social sciences; and 2) broad participation between professional and community stakeholders from the WASH sector, the health sector, the agriculture sector, and the energy sector.

In many development programs, agricultural interventions are managed separately from water supply and sanitation interventions, which are managed separately from renewable energy interventions. Interdisciplinary collaboration in science, technology and innovation is also important (Figure 3). It is especially important to encourage non-traditional collaborations, not only between natural science and technology-driven STEM fields such as engineering, agriculture, the natural sciences, the social sciences, and health is necessary to develop resilient wastewater resource recovery solutions for the future.
biology, chemistry, and health, but also with social science fields that can offer human-based solutions, such as the emerging fields within applied anthropology that study societal issues related to water and waste.\textsuperscript{23,24}

**Local, Regional, National and Global Impacts of Resilient Wastewater Resource Recovery Systems**

While the coordination of such broad and diverse collaborative efforts can be challenging, the benefits of these partnerships will outweigh the costs. At the global scale, from a life cycle perspective, the recovery of water, nutrients, and energy can result in significant savings on carbon emissions, eutrophication of water bodies, and embodied energy. In one study in Bolivia, it was found that the reuse of water from a stabilization pond system can result in up to a 79\% reduction in the overall eutrophication potential associated with wastewater management services.\textsuperscript{9} In the same study, authors reported potential carbon footprint reductions of nearly 57\% if energy is recovered from an advanced anaerobic reactors.

At the national scale, wastewater resource recovery systems can be implemented to simultaneously meet multiple development goals in developing nations. In a previous study, I found that wastewater treatment systems in Bolivia can produce enough biogas to generate approximately 500 KJ per person per day.\textsuperscript{10} I also reported in the same study that the treated effluent from these systems contained enough nutrients to potentially produce food with an energy (calorie) content that is equivalent to 10 – 75 days’ worth of the recommended daily food energy intake for one person.

Regionally and locally, wastewater resource recovery can provide economic benefits for communities in the form of offset health costs and increased income related to agricultural production activities. In Central America, treated wastewater from one stabilization pond system serving a population of 25,000 people has been valued at more than $50,000 per year for its irrigation water value, and another $40,000 for the value of nitrogen and phosphorus contained within the effluent.\textsuperscript{25} In a region like the south periurban district of Cochabamba, Bolivia, where some people pay up to $5.00 per cubic meter of water, the economic impact of recovering resources from wastewater is likely much greater.

Finally, both water and food insecurity can cause stresses on the mental health of people, which is difficult to measure, and is therefore often left out of assessments. The authors of one study found that food insecurity levels can differ greatly for different ethnic social groups, even within the same community.\textsuperscript{26} It has also been reported that both men and women in periurban Cochabamba experience equivalent levels of emotional distress about water security issues, despite the fact that women are more burdened with every day water responsibilities at the household.\textsuperscript{27}

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