Food Energy Water Nexus Conference

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The food-energy-water (FEW) nexus can be broadly described as an approach that considers the interactions, synergies, harmonization, and trade-offs between water, energy, and food when considering management of these resources[1]. As of 2016, the United Nations estimates that although access to FEW resources have increased significantly within the past 15 years, about 800 million people are still considered food insecure, about 800 million lack safe drinking water, and approximately 1.2 billion lack access to electricity[2]. Current food production accounts for 90% of freshwater consumption and 30% of global energy consumption, which is even more substantial considering 25-30% of food produced is lost at postharvest and processing stages. By 2050, it is expected that water and food demands will have increased by over 50%, creating a myriad of challenges including malnutrition, poor health and sanitation, as well as migration[3]. Meeting human needs while simultaneously safeguarding climate, ocean alkalinity, biodiversity, and other natural systems is a complex global challenge, but not impossible with the development of sophisticated scientific and engineering technologies.

Current food production and increasing demands

Food production currently accounts for 90% of global consumption of fresh water and 30% of global energy consumption. Much of this water and energy is wasted, as 25–30% of food produced is lost at the post-harvest and processing stages. As the world population increases, so too will the demand for food and fresh water, along with the number of people battling malnutrition and poor health and sanitation. By 2050, water and food demands are expected to increase by more than 50%.

The vital need for optimizing resources

Currently, several factors exacerbate the issue of scarce and ineffectively used resources. For example, fossil fuel production, biofuel production, and shale gas extraction are water-intensive but are used widely to meet energy demands. Increasing urbanization and infrastructure expansion also make it difficult to manage resources efficiently. A growing population will require more food and clean water to maintain a good standard of living for all. It has become clear that optimizing resources within the FEW nexus is vital to ensuring resource security in the future.

Optimizing resources within the FEW nexus is vital to ensuring resource security for the future. Converting food waste to energy sources has been one promising technological advancement. For instance, the anaerobic digestion of food products allows for the formation of methane and carbon dioxide which can be

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[1] Mabhaudhi T., Mpandeli S., Madhlopa A., Modi A.T., Backeberg G., Nhamo L. Southern Africa's water–energy nexus: Towards regional integration and development. Water. 2016;8:235. doi: 10.3390/w8060235.
[2] Scanlon, B. "The food-energy-water nexus: Transforming science for society" Water Resources Research Volume 53, Issue 5 (2017)

[3] Mpandeli, Sylvester *et al*. "Climate Change Adaptation through the Water-Energy-Food Nexus in Southern Africa." International journal of environmental research and public health vol. 15,10 2306. 19 Oct. 2018, doi:10.3390/ijerph15102306

used as biogas. Food waste could also be used as a substrate for biomethanation resulting in high biogas yields. However, these methods have limitations as the enzymes needed are sensitive to suboptimal conditions. Additionally, achieving a high yield requires the manipulation of a complex multivariable system, including variables such as temperature, pH, carbon to nitrogen ratio, volatile fatty acid concentration in the bioreactor, the quantity of feed processed in the reactor per day (organic loading rate), concentration of ammonia in the reactor, the hydraulic retention time, among others[4]. Much of the food waste that is to be converted into an energy source requires pre-treatment, as various degrees of polymerization, crystallinity, ligand content, pectin content, and other factors can affect the biogas yield produced, thus increasing the cost of the technology. Therefore, there is much research still being conducted to develop technologies can be utilized on an industrial scale with relatively high product yields.

Reusing food waste

A major topic related to the FEW nexus is the ability to reuse food waste by converting it to useful chemicals or energy sources. A research team at the Univ. of Connecticut, led by Julia Valla, focuses on converting food waste into biochars via pyrolysis. The biochars serve as precursors for the production of activated carbons, which can be used for water purification.

Food wastes can also be converted into biogas, which can be used as an energy source. A group of researchers at the Univ. of Texas at Austin, led by Michael Webber, established an analytical framework to assess the energy availability of consumer waste and determine the feasibility of replacing energy sources such as natural gas with biogas produced via anaerobic digestion. Webber et al. note that this framework could help legislators formulate policies regarding food collection and use programs.

Implementing such a program would have several advantages, as it would reduce the amount of food waste in landfills, as well as reduce natural gas usage, thereby minimizing greenhouse gas emissions. However, implementing a citywide consumer food waste collection program would come with a host of logistical challenges.

Waste-to-energy conversion

Waste-to-energy conversion is an emerging research area, as wet, solid, and gaseous wastes are high-impact resources that could be used to produce biofuels, heat, and electricity. Supercritical water gasification (SCWG), a process that can convert biomass to hydrogen-rich gas, has also gained popularity among researchers. Supercritical water (SCW), i.e., water whose temperature and pressure are above its critical point, has different properties than regular water and steam, including a different density, viscosity, and dielectric constant. These unique properties allow SCW to be used to dissolve and gasify organic compounds. Another method being studied by researchers is hydrothermal processing, which can be used to process diverse blends of waste feedstocks and is, therefore, a good option for use in industry.

Another research group, led by Michael Timko at Worcester Polytechnic Institute (WPI), converts waste to bio-oil via a high-temperature, high-pressure process known as hydrothermal liquefaction. The bio-oils produced are suitable for the transportation and heating industries. This process requires expensive homogenous catalysts that are difficult to separate and neutralize. Therefore, Timko's laboratory is studying new catalysts such as hydroxyapatite that can improve the yield of bio-oil and are easier to regenerate than traditional catalysts.

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[4] Paritosh, Kunwar *et al.* "Food Waste to Energy: An Overview of Sustainable Approaches for Food Waste Management and Nutrient Recycling." BioMed research international vol. 2017 (2017): 2370927. doi:10.1155/2017/2370927

Continuing research about the FEW Nexus

As the world population grows and natural resources become more scarce, research about the FEW nexus will likely expand and evolve. Optimizing resource use will involve interdisciplinary research and collaboration among stakeholders to develop and improve technologies, create more accurate models, and implement policies to encourage waste minimization. Thinking about food, energy, and water as highly integrated systems can allow the tradeoffs and benefits of decisions to be more accurately analyzed, as well as new opportunities to be identified.

In recent years, the focus on environmental policy in the US has broadened to include pollution prevention and considerations of sustainability. This shift has been facilitated by the availability of models and approaches which improve our understanding of environmental impact on our ability to predict future problems. Providing reliable results for environmental, economic, and societal outcomes associated with technological change requires an extreme range of modeling capabilities to resolve specific impact across a broad system. Currently, several tools and metrics have been developed to assess various products, processes, and activities related to the FEW nexus. For instance, indicators such as ecological, water, land, carbon, energy, and material footprints can be used to measure natural resource sustainability boundaries. Additionally, life-cycle assessments (LCA) can help to quantify emissions, consumption, and assess environmental and health impacts of new technologies[5]. An underlying requirement in developing these assessment methods is data science, such as big data and big computing. For instance, descriptive modelling frameworks help to provide a detailed understanding of complex connections and evolving consequences of regional-to-global dynamics within FEW systems. These analyses will allow for predictions that will guide policy related to the FEW nexus. Moving forward, approaches capable of quantifying a broad range of outcomes across a long time horizon are needed. These approaches must allow analysis at a sufficient level of depth to represent specific production processes, social interactions, investment decisions, and ecosystem activities while maintaining sufficient breadth to encompass system-wide effects. The development of methods and models to do this will require building connections between existing models through interdisciplinary collaboration.

FEW Trends Panel Conclusions

Lastly, we held a panel with a few prominent experts working on Food, Energy, and Water Technologies about their thoughts regarding the future of the field. The responses below are based on their answers. We would like to thank Michael Timko (Worchester Polytechnic Institute), Ryan Calder (Johns Hopkins University), Ahmed Mohamed (The City College of New York), Bassel Daher (Texas A&M University).

<u>What are some technologies we are pivoting away from, and what new technologies we will see implemented?</u>

We are generally pivoting away from technologies due to concerns about toxicity, such as incineration. Technologies such as anaerobic digestion, gasification, pyrolysis are all technologies associated with a lower toxicity, and are currently being studied by researchers. However, before implementation on an industrial scale, certain considerations such as the product, the market, and the conversion technologies must be analyzed to assess the economic feasibility as well as the feasibility of implementing in a particular region. Many factors can act as barriers to implementation, including the public opinion of the technology being implemented. Therefore, more research needs to be done to determine the situations in which the technology would be profitable, which must be accompanied by financial backing as well as community-

[5] McGrane, S. "Scaling the nexus: Towards integrated frameworks for analyzing water, energy and food" (2018)

wide acceptance. Involving all stakeholders at the project conception can increase the chance of successful implementation, as it would allow for early input by investors, stakeholders, and the community. Environmental models can also be helpful in determining the effects of the technology on the local community. However, environmental systems often respond unpredictably, therefore more research is needed to determine trade-offs and examine the effects of various policies.

Government greenhouse gas mandates can be helpful for the acceleration of these technologies. However, current technologies and policies can hinder this development. For instance, a city’s distribution grid must be able to accommodate the renewable energy produced. Regulations regarding factors such as space limitations for energy storage and a lack of procedures for testing and handling failures can act as obstacles as well. Therefore, the implementation of new technologies not only benefits from increased government action, but also regulation framework that takes into account inputs from stakeholders and investors.