# TRANSITIONING FOOD AND AGRICULTURAL SYSTEMS INTO CIRCULAR ECONOMIES

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## Abstract

Food and agricultural systems (FAS) are increasingly facing multiple challenges of higher food demands, environmental degradation, and limited availability of land, water, and other natural resources. Further, consumers are increasingly aware of the necessity to sustainably produce food and other agricultural products, leading industries to invest in sustainability research and development. Industries are exploring the use of circular economy principles to guide their transitions to more productive, efficient, and sustainable. These efforts, along with reports from the national academies and other groups have concluded that our food and agricultural systems must be transformed to sustainably produce growing demands for products, pointing out systems approaches are necessary in agriculture and other sectors. In this paper, we summarize concepts of circular economies for food and agricultural systems, explain why these holistic systems concepts are useful, and highlight initiatives that are underway or are being developed for different types of FAS systems in the U.S. and elsewhere.

## Introduction

Food and agricultural systems (FAS) provide food, fiber, energy, feed, and other products for consumers, and they are intricately interwoven with human existence. FAS are often misunderstood as being only farming systems. But they are more complex in that they encompass the full range of activities from production to consumption and management of byproducts. In the U.S., FAS have quadrupled production of food and fiber since 1930, and now they contribute over 22% of GDP to the economy, employ more than 28% of the workforce, and are critical to our national security. These remarkable achievements have been fueled by advances in genetics, soil science, machinery, fertilizers, agrochemicals, and many technological innovations. This combination of advances has enabled our FAS to meet demands for safe food and other products at affordable prices. However, FAS are now at an inflection point. The combination of increased greenhouse gas (GHG) emissions, limited freshwater and other natural resources, and losses of biodiversity and ecosystem health pose threats to our ability to continue increasing supplies of FAS products. Additionally, between 30 to 50% of produced foods are wasted, with nitrogen, carbon, and other resources being dumped into landfills, thus preventing their use in other products valuable to society and limiting progress toward sustainable systems. Many of these problems emerge from the fact that our current FAS are mostly linear; they follow the path of take-make-use-waste-pollute, as noted in an Ellen MacArthur Foundation (2019) report.

The National Academies of Science, Engineering and Medicine (NASEM) conducted several studies recently in which they emphasized the importance of including all components of the FAS value chain from field to fork and beyond. These reports pointed out that current FAS are not sustainable, especially when considering that while there are declining availabilities of land and fresh water per capita, anticipated future global food demand is expected to increase by 50-70% by 2050. Furthermore, climate change will indiscriminately threaten all our industrial-, traditional-, and family-based FAS. One NASEM report (NRC, 2015) proposed a scientific framework for assessing strengths and weaknesses of different approaches to measure the sustainability of American agriculture. Another report (NRC, 2019a) indicated that continued incremental changes in current systems will be insufficient to meet future challenges; the study recommended rethinking and redesigning FAS systems to address multiple goals by adopting convergent systems approaches and considering tradeoffs among multiple goals. Further, an additional NRC report (NRC, 2019b) identified five grand challenges: 1) sustainable supply of food, energy and water, 2) curb climate change and adapt to its impacts, 3) design a future without pollution and waste, 4) create efficient, healthy and resilient cities, and 5) foster informed decisions and actions. Each of these reports emphasized a need for using a holistic systems perspective with contributions from a wide range of disciplines to achieve needed transformations. Although these past NASEM studies

consistently identified problems and recommended more research using systems approaches, they did not include information about what systems approaches are needed that will lead to solutions to anticipated challenges.

**Circular Economy for Food and Agricultural Systems Concepts**

The Ellen MacArthur Foundation (2019) emphasized that food systems encompass "***the full value chain of producing food for human consumption, from agricultural activities and other means, through handling, transportation, storage, processing, distribution, consumption to organic (including human) waste management and disposal/reintroduction in to productive use ('looping')***". That 2019 report suggested that most of our existing FAS are not circular when considering farm to fork and beyond, but instead are mostly linear with multiple points along supply chains where wastes and losses are discarded, thus trapping nitrogen, phosphorus, and other resources that may damage the environment. This and other reports talked about the need to transition our existing FAS into circular economies.

***A circular economy is a systematic approach to economic development designed to benefit businesses, society, and the environment.*** This concept recognizes the importance of the economy needing to work effectively at all scales – for producers, big and small businesses, consumers, organizations, and the environment at local to global scales. This is not a new concept. It has been useful in guiding other sectors to be more sustainable, but it has not been widely embraced for agriculture and food systems.

Recent reports (Ellen MacArthur Foundation, 2015, 2019) identified three important principles of a Circular Economy regardless of the type of systems being addressed. We have found that these principles are also useful for considering circular FAS. Additionally, we have added a fourth principle that should be considered when rethinking and redesigning circular FAS systems. Although this fourth principle may be implied, we believe that it must be considered simultaneously with the other three principles when different disciplines converge to consider research needs for system transformations to create circular economies. These four principles are:

1. *Design out waste and pollution,*
2. *Keep products and materials in use, and*
3. *Regenerate natural systems,*
4. *Provide products to meet societal needs, including economic benefits to producers and others in the product supply chains (from farm to fork and beyond), and to the environment.*

Circular systems are needed to replace the current mostly linear systems that take, make, use, and discard losses and wastes. Figure 1 shows a schematic of circular FAS, adapted by Ellen MacArthur Foundation (2015) from concepts first presented by Braungart and McDonough (2002). This diagram shows food and agricultural production systems on the left side along with consumers and users in the center, and the mining and manufacturing aspects of production and supply chains on the right side. It emphasizes the recovery and use of losses and wastes from some processes to use as input to others for reducing overall system leakages and minimizing losses that contaminate the environment. However, considerable work is needed to achieve the goals implied in this figure. Each type of food and agricultural product supply chain has its own system components, boundaries, environments, losses, and inefficiencies across the entire value chains from production through use and waste streams. Flexibilities and options are needed that consider unique environmental, social, economic, and other characteristics to implement circular economy concepts for specific FAS.

**Initiatives Now Underway in the U.S. Toward Circularity in FAS**

Now however, a number of food and agricultural enterprises recognize that this approach is important as they consider future production and marketing developments. Several new initiatives are aimed at accelerating progress toward circular FAS in the U.S. Although FAS academic and public research efforts have not paid much attention to this approach in the U.S., this is happening now, led partly by industry efforts and by recent studies of the NASEM. The NASEM Board on Agriculture and Natural Resources (BANR) is planning a new study that builds on their past studies in which recommendations were made for integration across disciplines and use of systems approaches to address the complex challenges now faced by our FAS. In 2020, BANR voted to conduct a comprehensive national academy study on transitioning food and agricultural systems into circular economies by 2050. The rationale of this study is that major changes to our existing FAS are essential in order to achieve multiple goals of increasing production to meet needs of our still growing population, of reducing atmospheric greenhouse gases, of conserving natural resources and reducing wastes, of regenerating soils, of considerably reducing environmental footprints, and of increasing

resiliency of FAS. The BANR is cooperating with three other NASEM Boards in planning the study that should begin during 2021.

In addition, the American Society of Agricultural and Biological Engineering (ASABE), led by President Sue Nokes

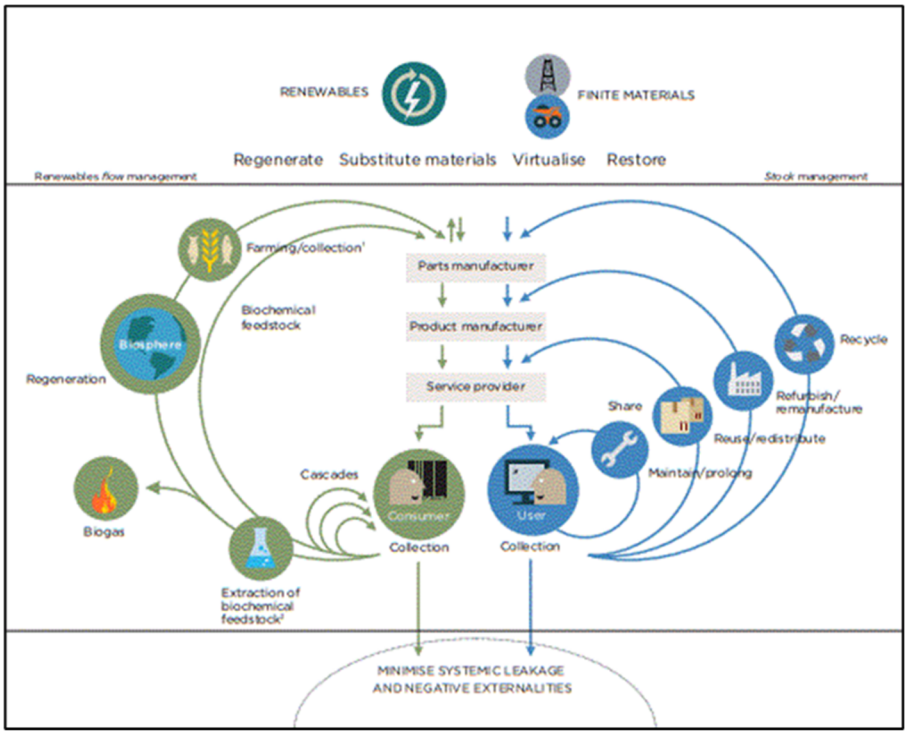


Figure 1. Schematic of a circular economy. Adapted from an Ellen MacArthur Foundation (2015) report that was originally based on a figure from Braungart and McDonough (2002).

and the ASABE Board of Trustees, adopted Circular Food and Agricultural Economy Systems as a high, long-term priority. The ASABE conducted its own internal studies in 2020 to identify what this new priority would mean for this professional society and for the stakeholders it serves, and how they might work with other societies to provide the more holistic systems approaches that are so urgently needed. Recently, the ASABE initiated cooperation with leaders in other professional societies, realizing that accomplishing FAS circularity will require a wide range of disciplines, convergent systems approaches, and public-private partnerships. The professional societies that already are involved in discussing joint efforts include the ASABE, the Tri-Societies (Agronomy Society, Crop Science Society, and Soil Science), the Agricultural and Applied Economic Association (AAEA), and the Institute of Food Technologies (IFT), and others will likely join later. These professional societies are considering how they can work together to jointly address research and broader impact needs for advancing toward circular FAS. Although transformations are needed, we believe that this can be accomplished through collaboration across disciplines to reimagine FAS and create roadmaps to achieve the changes by transitioning systems over time.

It is clear that there are many opportunities for transitioning toward more circular FAS, and there are some good examples of how this can be done. These opportunities include some that could be implemented in the short term whereas others that need innovations in science, technology, and/or policy to enable the needed transitions. In an initial internal analysis conducted by the ASABE, six different FAS were considered by different working groups. Results of these studies are scheduled for publication in the ASABE Resources journal in the March 2021 issue (see Jones et al., 2021). These food and agricultural systems studies clearly showed that solution options, research needs, and pathways for transitioning vary considerably. However, there are important common considerations that should be considered regardless of system. These include the need to 1) have diverse disciplines, industries, and stakeholders involved to fully identify and study the complex systems, 2) carefully identify the selected system's components, boundaries, scale, and its environment, 3) identify current losses, inefficiencies, wastes, and impacts along the full value chain of each FAS; 4) consider scenarios of future environmental conditions and drivers of change; 5) envision

solutions that achieve circularity, sustainability, and resiliency goals, 6) use data, models and other tools for predicting envisioned system performance for each scenario, including tradeoffs among objectives, 7) develop standards for measuring and documenting progress toward multiple goals, and 8) develop a transitioning plan that takes into account immediate, intermediate, and longer term opportunities for transforming FAS that lead to multiple, sustainable societal benefits. These ideas for transitioning undoubtedly need to be reconsidered when a wide range of disciplines and stakeholders work together to achieve solutions that will enable our FAS to build on the widely-known reputation of farmers being "Stewards of the Land" such that future FAS can become widely recognized as "Stewards of the Earth".

## Discussion

Some FAS industries in the U.S. are already working on ways for their businesses to achieve circularity so that they can more reliably and sustainably meet increasing demands from consumers for more sustainable products. In addition, there are research efforts in academia that are developing technologies to solve pressing problems associated with specific components of food and agricultural systems. These research efforts are creating new technologies and management systems that can help transitions of existing FAS into circular systems. However, very little has been done in academia until now to address the complex interactions of component subsystems along the supply chains to understand how technologies, policies, and individual societal goal often are in conflict. A more holistic approach is needed to consider not only specific goals and technologies, but also the entire systems. Unless this is done, piecemeal advances and conflicting objectives will continue to restrict progress toward meeting the multiple goals of increasing production, reducing environmental footprints, and more efficiently using resources. This is true even though some funding agencies, including USDA-NIFA, NSF, and others, are increasingly recognizing the need for more systems approaches (such as the recent NSF-NIFA funding initiative on "Innovations at the Nexus of Food, Energy, and Water Systems, INFEWS)". We believe that funding opportunities will be available in the future to enable the convergence of disciplines, technologies, and policies that will lead to FAS that operate as circular economies. Through these efforts, FAS can provide solutions that address multiple social, economic, and environmental challenges by sustainably providing food and other agricultural products to consumers.

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