Understanding and Guiding Complex Systems to Achieve Multiple Societal Goals

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Agricultural & Biological Engineering Department

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Purpose

- Discuss major societal goals as complex systems, such as water, food, one health
- Emphasize the necessity of using convergent systems approaches to understand and transform them
- Discuss past & current initiatives that demonstrate these characteristics

1971-2021 50 IWRA International Water Resources Association

Complex Systems

- Complex systems differ from complicated systems (Ottino, Nature, 2004)
- Complex systems have emergent behavior, some of which may be unintended, unwanted
- Decomposing a system and analyzing sub-parts do not necessarily imply the behavior of the whole
- Example complex systems: ecosystems, economies, world-wide web, spread of viral infections, **One Health?**
- Grand challenges, Societal goals

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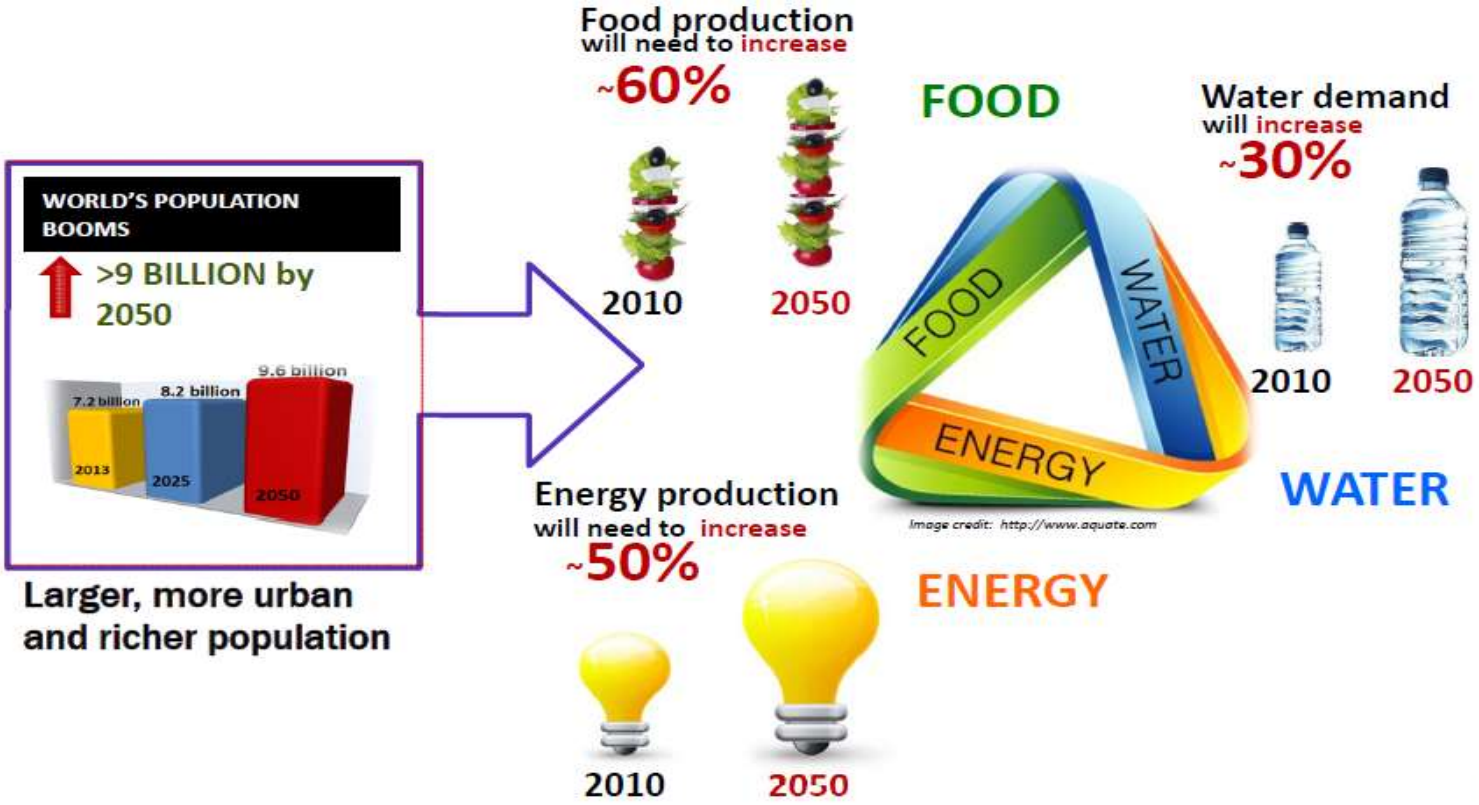
NSF & USDA-NIFA INFEWS* Initiative (2016-2020)

Food, Energy, and Water Systems: Challenges for 2050

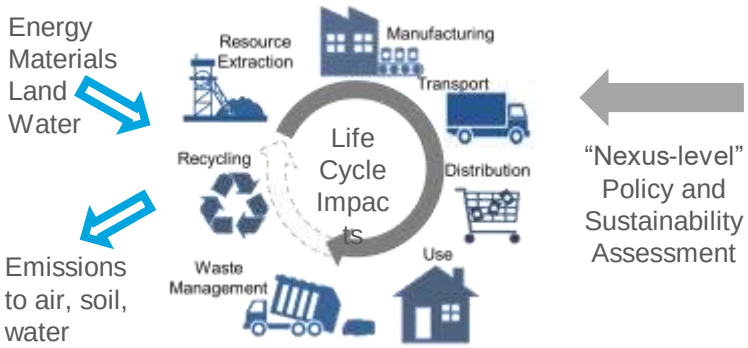


*Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS); Source - NSF

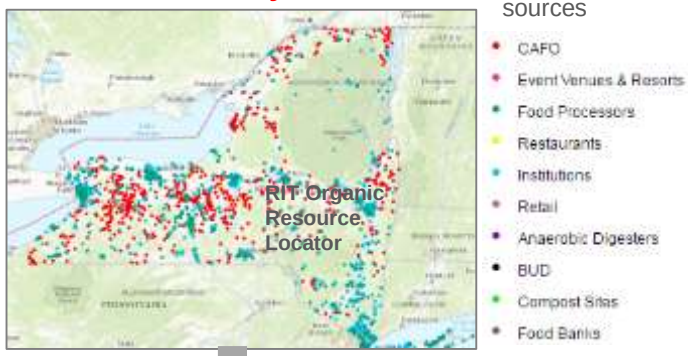
Example - INFEWS/T3: Managing Energy, Water, and Information Flows for Sustainability across the Advanced Food Ecosystem

Motivation: Up to 40% of produced food is not consumed by humans, wasting energy and water resources

Goal: Create and evaluate novel, integrated *policy*, *waste management*, and *technology* solutions to reduce environmental impacts of food waste, while maximizing efficient use of energy and water



Research Focus: New York State FEW Ecosystem



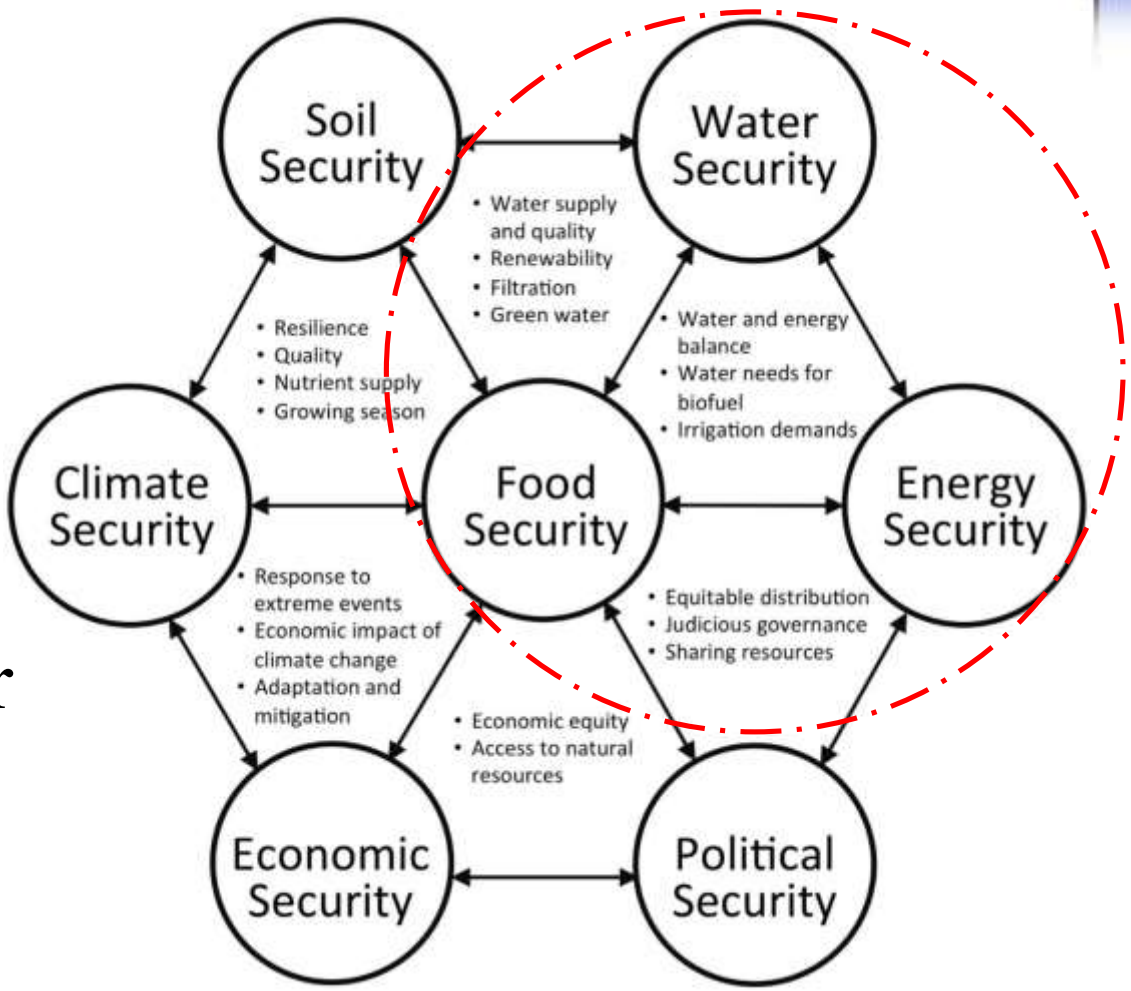
Heterogeneous food waste

Photos by Tom Trabold, RIT

Credit: Callie Babbitt (PI), RIT (cwbgis@rit.edu)

FEW systems interact with other systems

One can visualize complex systems through different lens (including emphasizing food or energy or water or other systems



Provided by Ximing Cai, UIUC: (Source: United Nations University)

Food & Agricultural Systems

- Food and other agricultural products are essential for human survival, a major **national security issue**; demand is increasing
- Agriculture uses considerable **water** and **energy**, is highly sensitive to **climate**, contributes to climate change, may negatively impact the **environment** and **biodiversity**, and contributes to **human health** outcomes, provides **economic** opportunities
- Agricultural and food systems **have adapted to climate, their physical, social, cultural, economic, and policy environments to** provide affordable food to meet rapid growth in demand
- But they are **complex systems,** vulnerable to changes in factors noted above and to shocks (weather extremes, pandemics, pest outbreaks, policy changes, markets)

Need to Transform Food & Agricultural Systems (FAS)

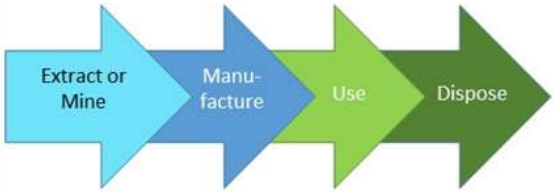
- Recent NASEM* reports assessed problems & emphasized that current FAS are unsustainable
- They concluded that **continued incremental advancements to existing FAS systems are not adequate**; **transformations are necessary** and should be a high priority
- **However, the reports did not provide insights on what systems approaches should be or on how to transform existing FAS**
- **Current food systems are mostly linear** (E. MacArthur F., 2019)
- **Transformative FAS designs are needed** that account for complexities of multiple interdependent sub-systems and their interactions with other societal functions and the environment

*National Academies of Sciences, Engineering, and Health

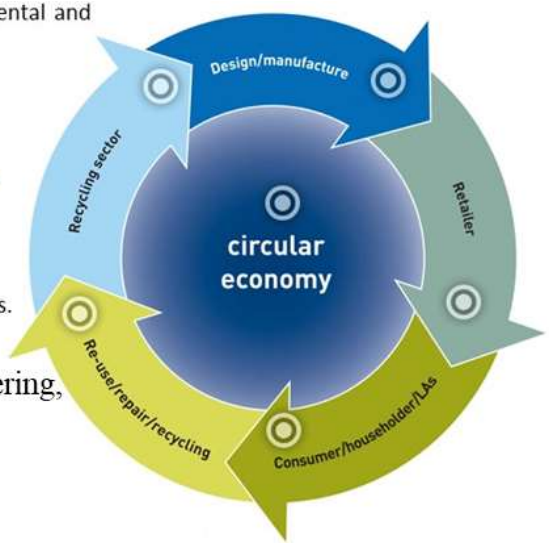
Circular Economy Systems Concepts Can Guide Transformations

- **Circular economy** – a systematic approach to economic development that benefits businesses, society, and the environment.
- **Inspired by nature**. Waste does not exist in nature – one organism's waste is food for another.
- **Circular Economy Principles help guide transformations**
  - design out waste and pollution,
  - keep products & materials in use, (reuse, repair, refurbish, recycle)
  - regenerate natural systems
- Sustainability of Food Systems – outcome of circular systems

Figure 1. Circular Economies have important environmental and sustainability advantages over linear economies.



Linear Economies has many environmental challenges.



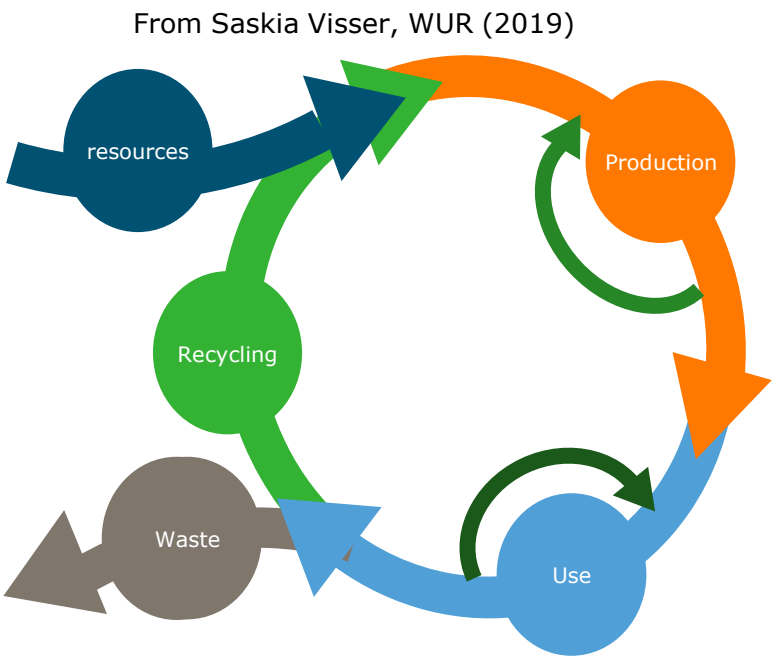
From: Rick Koelsch, Biosystems Engineering, Univ. Nebraska. 2020.

Creating Circular FAS

- Define system; identify its components, boundaries, scale, and environment
- Specify indicators and metrics for analysis of alternative solutions
- Identify losses, inefficiencies, and wastes from system and their impacts.
- Envision solutions that can potentially achieve circularity, sustainability, and resiliency
- Consider future transformations over time, with near- and longer-term solutions, for projected climate and other boundary conditions
- Use data and models to predict system performance, including tradeoffs among the objectives
- Field to market systems: inputs, production, processing/packaging, transport, consumption and wastes

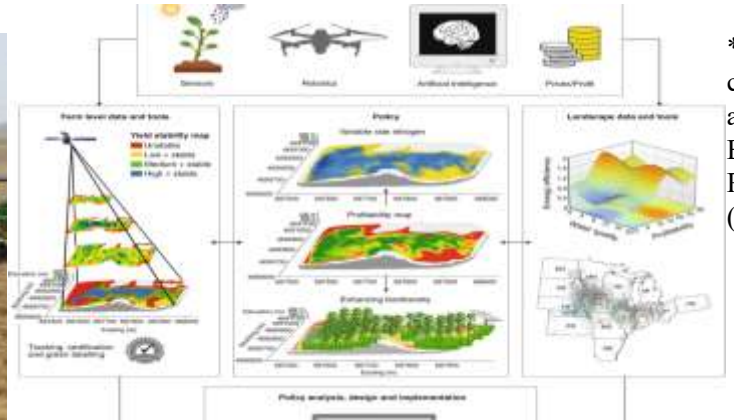
Key Resources, Cycles in Food & Agricultural Systems

- Energy
- Water
- Carbon
- Nitrogen
- Phosphorus
- Food, product mass



*Create Circular Production Subsystems

Optimize (2020-2025)	Replace/Reduce (2025-2035)	Redesign (2035-2050)
Digital Agriculture Spatially variable rate Fertilizer, Seeds, Agrochemicals **Precision Conservation** Idle unprofitable land for C credits, nutrient reduction, biodiversity, use "green" E,N,W inputs **Regenerative Agriculture and Soil Health Practices** Crop rotation, Cover crops; No tillage.	**New traits/genetics** Root systems to optimize water and nitrate use efficiencies. Traits resistant to diseases **Renewable energy** On farm energy generation for field operations and drying, mitigation **Recycle** Collect drainage water for fertigation, wastes for nutrients **Revise Incentives**	**New Processes** Electrification of Haber-Bosch Process **New Sources** Biological Nitrogen Synthesis **Smart Systems** Autonomous electrical robots for agronomic practices



*Example for corn production, adapted from Basso et al. 2021, Resource (March/April).

Professional Societies (ASABE, Others)

- Professional society of agricultural & biological engineering (ASABE) has a long history of collaboration with other engineering and science disciplines across public & private sectors.
- In 2020, ASABE adopted Circular Economies for Food & Agricultural Systems as a long-term priority goal
- Studied different FAS; published special issue of RESOURCES Mar/Apr 2021; planned annual meeting program (July 12, 2021)
- Building collaboration among professional societies (ASABE, Tri-Societies, AAEA, IFT, ADSA, AIChE, others)
- National Academy of Engineering efforts

Mar/Apr, 2021 Issue

What about Systems addressing Water, Food, and Health?

- Societal Goals imply need for use of Systems Approach, considering Complex Systems concepts
- Convergent systems approaches are needed to adequately understand and guide them to achieve multiple goals
- Strong interest by multiple disciplines, businesses, science and engineering academies
- What about water, food, health systems? SDGs? Addressing climate change? etc?