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Bio-circularity: A Path to Sustainable Production?

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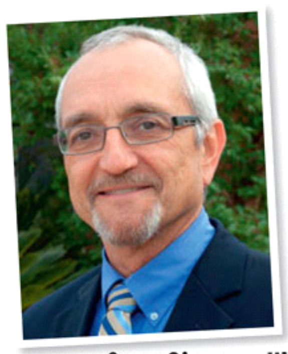

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The Earth is a closed system that has evolved for millennia, only recently hosting humans. The Earth system includes physical and biological recycling processes naturally linked as circular systems. The inter-related processes are dependent on "buffers" containing temporarily stored resources for their reuse.

Think of the water cycle. The entire southwest of the U.S. depends on the winter snow in Colorado to fill the lakes, rivers and aquafers, which act as buffers for storage. Creative engineering then provides clean water for towns and cities or a hydroelectric dam for electrical power or locations of outdoor leisure recreation. The cycle is dependent on the processes of water evaporation, transport through the atmosphere, and delivery of rain and snow in distributed locations to maintain the river flow. This water cycle system is large, essentially continental in size, with thousands of storage sites such as lakes, ponds and aquafers. That's nature. It's huge and diverse, and well beyond what a man-made system could begin to match.

Yet, we speak of achieving sustainability by developing relatively small circular systems composed of processes where each consumes resources (water, energy, etc.) to generate the desired product such as our food. In addition, by-products that are unwanted are produced and discharged into the environment, not as "wastes," but to become the input resource for the other processes in the system.

To achieve circularity of a production process, the consumption of resources and the production of by-products for all the processes within the circle must be continuous and exactly matched in production rate, or else an imbalance of input resources to by-products will occur and the circularity fails. This is to be expected and it's manageable by the inclusion of storage buffers to balance the flow of resources by storing and then discharging them in the precise rate required by each process.

An example is the MISAS, a Modular, Integrated, Sustainable Agriculture System project at the UA-CEAC with its goal of demonstrating circularity. Dr. Goggy Davidowitz and several other multidisciplinary subject experts have established four processes of "crop" production that have been combined within a shared series of input and output resources. Controlled environment agriculture technology is the basis of a circular food system consisting of four "crops" grown in individual production units and controlled to their optimal environments, thus establishing a continuous series of food products at one location.

Their research established separate, but adjacent, CEA rooms to grow mushrooms, leafy greens, fish and beetles. The expectations were that the beetles feed on spent mushroom substrate and then themselves become fish feed; the hydroponically grown green plants gain fertilizer from the fish water and reduce the harmful nitrogen returning to the aquaponic system; the plants consume CO_2 from the mushroom production room during critical stages of that cycle and use spent substrate for propagation. The benefits are year-round harvests of plants, fish and mushrooms, as well as the occasional insect barbeque!

Consider the ultimate circularity challenge demonstrated by Kai Staats and his team of researchers at the University of Arizona Biosphere 2 facility, where SAM (Space Analog for the Moon and Mars) has been created as a high-fidelity replica of a planetary habitat. On another planet, all resources for life (oxygen, water and food) must be created, then utilized and their byproducts (carbon dioxide, waste liquids and solids, and inedible foods) must be recycled. The closed habitat of SAM contains all resources and utilizes edible plants (dwarf peas) to regenerate oxygen and fresh water, plus compost processes to decompose solid waste into fertilizer, water and CO_2. To date, one person remained hermetically sealed in SAM for 14 days by successfully and safely breathing oxygen and exhausting CO_2 in biological exchange with the pea plants.

The fresh thoughts of a recent doctoral student sums this up with a dissertation including research demonstrating the potential of employing effluents from hydroponic and aquaponic systems as nutrients for sustainable crop production of strawberry, lemon grass and mushroom grown within CEA:

“Sustainable agricultural practices must overcome the immense pressure on traditional food production systems given the politics, global population growth, resource scarcity and the escalating impacts of climate change. Controlled Environment Agriculture will be a vital component of the solution, offering unparalleled potential for efficient, year-round cultivation of high-quality crops in diverse and often resource-limited environments.”—Dr. Myles Lewis, 2025. **IG**

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