AIChE JOURNAL Highlight

Chemical Engineering Opportunities in Ecological Engineering and Sustainability

In its short history, chemical engineering has moved far beyond bulk chemical production. Through identification of fundamental unit operations, chemical engineers could see the underlying similarity of separating alcohol from water in a fermenter and separating gasoline from diesel in a refinery. This allowed the discipline to focus on processes as opposed to products, thereby moving in a multitude of new directions.

Particularly successful has been the application of chemical engineering principles to biological processes at the cell-to-tissue scale. Yet the research emphasis remains largely focused on the smallest biological scales, missing the opportunity to tackle the most important biological system on Earth — the biosphere.

Daniel Stouffer (Doñana Biological Station, Seville, Spain), Carla Ng (ETH Zürich, Switzerland), and Luis Amaral (Northwestern Univ.) explain that chemical engineers are well-positioned to contribute significantly to conceptual transitions occurring in ecology, and that ecological knowledge is of fundamental importance to engineers interested in sustainability research. Their Perspective article, "Ecological Engineering and Sustainability: A New Opportunity for Chemical Engineering," appears in the December issue of the *AIChE Journal*.

A typical large chemical plant contains reactors, separation units, heat exchangers, and miles of pipes. To the untrained eye, it appears exceedingly complicated. Yet analysis of this system is well within the bounds of traditional chemical engineering — indeed, it provides the foundation of its core curriculum.

Now consider a chemical plant in which the units represent species and pipes represent predator-prey interactions, transferring biomass and energy throughout the environment. On an abstract level, it seems hard to justify why the study of these two systems would require different approaches. Chemical engineering conceptually spans the entire range of energy, mass and time scales relevant to ecosystem dynamics. Considering important and timely ecological problems such as diversity loss, it becomes clear that chemical engineers can make important contributions to this field, the authors say.

In ecology, research remains largely restricted to the study of one to a few species within an ecosystem. The reach of such studies is naturally limited, because it is unclear how knowledge about one ecosystem extends to others. This is similar to the early history of chemical engineering and independent industries. Do ecological unit operations exist that will allow us to simplify the analysis of these complex systems?

Recent research on food-web structure is providing a definitive answer to this important question. The central conclusion of this research is that, despite all the aspects unique to each ecosystem, there exist a number of universal features that hold for a large number of ecosystems. This hypothesis is based on the principle that there are emergent properties in complex systems that arise from constraints acting upon it. For example, species' bio-energetic constraints may determine aspects of ecosystem structure, such as number of autotrophic species and of top predators.

Ng and colleagues recently followed an interdisciplinary approach to describe contaminant accumulation. Their model captures the complexity of contaminant-biota interactions in a food web affected by multiple human-induced stressors, illustrating how inclusion of more detail at the species level, and integration of techniques from chemical engineering, statistical physics, and traditional ecology, can help to explain environmental signals that, at the food web scale, seem hopelessly complex.

They explain that "ecosystems are complex systems. We cannot hope to understand them by studying the components in isolation, just as we cannot optimize the output of a chemical plant without a systems perspective. It is also in the best interest to keep the biosphere operating properly. However, before we can effectively manage fisheries (food production), prevent accumulation of toxins (quality control), or reduce species extinctions (operate sustainably), we must work to develop unifying frameworks just as chemical engineering did nearly a century ago. The question is, are we open to the challenge?"

Mass and energy transfer of ecological processes are similar to crude oil processing. Photos courtesy of Emerson Process Management and U.S. Dept. of Agriculture Natural Resources Conservation Service.