INVITED SPEAKER

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REVISITING CONTAMINANT BIODEGRADATION CONCEPTS & REASSESSING TOOLS FROM SYNTHETIC MICROBIAL ECOLOGY & BIOENGINEERING

Over many decades, industrial waste and hazardous pollutants have been continuously generated posing serious threats to environmental and human health. Large amounts of toxic contaminants such as persistent organic pollutants (POPs) are released into the environment by mining, industrial, agricultural, and urban activities from point sources, forming groundwater plumes with high pollutant concentrations (μg/L to mg/L range), whereas the continuous discharge of various bioactive molecules in the environment from agriculture or from sewage treatment into surface waters introduces pesticides, pharmaceuticals, or consumer care products from nonpoint sources in low concentrations (micropollutants in ng/L to μg/L range).

Although effective in some contexts, chemical and physical methods for managing industrial waste often tend to suffer from high costs, incomplete degradation, and the generation of secondary pollutants. As a result, biotechnology is offering alternatives for the effective clean-up of contaminated sites via microorganisms that can oxidize/reduce, bind, immobilize, volatilize, or transform contaminants. Despite the progress achieved and the successfully established practice of bioremediation in a variety of cases, its application to clean up contaminated sites has shown different and occasionally contradictory results. Therefore, there is a need to take a critical look at mainstream concepts including redox zonation and steady-state transport assumptions for assessing biodegradation rates. In addition, the observation of low biodegradation rates and extents may not necessarily indicate an absence or low occurrence of specific degrader microorganisms.

Recently proposed conceptual tools, such as the plume fringe, local transport limitations, and transient conditions may be useful in understanding the processes affecting biodegradation and in rationally intervening to enhance its application. Combining new subsurface oxidation-reduction potential (ORP) sensors with DNA and RNA sequencing-based microbiome analysis could help elucidate the processes of biostimulation with alternative e-acceptors in contaminated soils in relation to active microbial communities, revealing the spatial and temporal granularity of the biodegradation data.

Additional concepts from microbial physiology and molecular microbial ecology, including the notions of microbial syntrophic metabolism as well as substrate-concentrating strategies at both the cell and aggregate levels, could help explain field observations in bioremediation projects and lead to new approaches for sustainable management of low-concentration contaminants such as micropollutants. Finally, through ecological bioengineering, a given microbial community can be manipulated in engineered, open ecosystems in which operational parameters and process configuration can act as selective forces on the community.

Granular sludge (GS) technology for wastewater treatment is a prime example of such a community. These granules are dense and compact engineered microbiomes typically generated from stress-induced microbial self-immobilization. Although the precise mechanisms involved in the formation of distinct granule types (e.g., methanogenic, aerobic, or anammox) are still not fully grasped, several common aspects are emerging, including the role of extracellular polymers and operational parameters like upflow velocity and shear force. These, together with a dissection of structural features and microbial community interactions, including single-granule microbiome sequencing could serve as a unifying blueprint to guide the future precision engineering of such complex yet efficient and reproducible microbial waste management systems.