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Editorial: Editors' showcase: fuels and chemicals

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Editorial on the Research Topic
Editors' showcase: fuels and chemicals

Throughout its history, industrial microbiology has answered many challenges; food and beverage, antibiotics, pharmaceuticals, nutraceuticals, biomaterials, fuels, and chemicals, often with billions of dollars of impact on markets and society. But these efforts pale in comparison to the challenge of planetary-scale carbon management, which must balance the circularity of a carbon economy with the sequestration of excess environmental carbon. Biorefineries, integrating carbon capture with diverse bioproduct markets, offer our best route to stabilizing an unbalanced global carbon cycle while powering a robust and equitable bioeconomy.

The Earth's responses to changing carbon fluxes take place over geological timescales. Human activity is a more acute and impactful perturbation of this cycle and the planet's adaptation is clearly lagging. Fossil fuels have driven human advancement, but no matter how beneficial, this scale of influence has significant impacts. Greenhouse gases, climate change, ocean acidification, microplastics, soil depletion, aquatic eutrophication, air quality, water pollution, and acid rain are all linked to fossil fuel use. Wealth and power are concentrated along with fossil fuel reserves at the national, regional, corporate, and individual levels. The non-uniform distribution of these resources stresses energy justice and equity. Social, political, and economic divisions are created and reinforced by access to and availability of fossil energy.

Advances in microbiology offer accelerated routes to adapt biology to new and rapidly changing carbon compounds. Molecular biology, genetic engineering, and all -omics provide opportunities to fundamentally change the way carbon cycles through our world. Coupling carbon management into a circular bioeconomy is driven by combined economics. As carbon credits and carbon valuation routes develop, economy will tilt toward a circular bioeconomy based on a balance of products vs. sequestration and away from fossil fuels. Biorefineries, powered by industrial microbiology, offer an alternative to fossil-based industries while managing carbon on a global scale. A broad portfolio of conversion processes applicable to a variety of feedstocks and a range of bioproducts will ensure that biorefinery options are available across all social, political, and geographic landscapes.

In the inaugural Frontiers in Industrial Microbiology – Fuels and Chemicals Editors Showcase, four articles highlight the importance and potential of industrial microbiology to enable advanced biorefineries.

In Perspectives on biorefineries in microbial production of fuels and chemicals, Decker et al. summarize biorefinery efforts and indicate key learnings and crucial opportunities to expand from a narrowly focused, single-product-centric process to a cascading biorefinery approach where carbon management and bioeconomy markets drive the utilization of diverse feedstocks by multiple processes. A true biorefinery should balance carbon management with providing biofuels and bioproducts for a robust bioeconomy. A broader portfolio of bioproducts provides a more adaptable market economy. Having a range of conversion technologies available that can be tailored to local feedstocks and advantaged markets will broaden bioconversion and expand the bioeconomy, leading to increased opportunities and more equitable generation and distribution of energy, fuels, and bioproducts.

Wei and Himmel offer insight into more efficient industrial microbiology in Continuous multimodal technologies in industrial microbiology: potential for achieving high process performance and agility. They detail how disconnecting biocatalysis steps that are normally carried out simultaneously in fermentation into discrete unit operations can improve efficiency and yield while reducing costs. Enabled by advances in membrane separation and solvent extraction, discrete steps can be optimized by chemical, electrochemical, or biological catalysis. Temperature, pH, and redox can be adjusted separately for each step to increase overall efficiency while reactor size and flow rate can be adjusted to accommodate differences in the flux of the unit operations. Immobilized enzymes, whole-cell catalysis, and cell-free systems can be designed with state-of-the-art tools for processes ranging from single-step transformations to entire metabolic pathways.

Lignocellulosic biomass has been touted for decades as a renewable, low-carbon alternative to fossil fuels. Pretreatments to obtain the polysaccharides often result in degradation and inhibitor formation, limiting the fermentability of the hydrolysate. This often requires additional processing steps to detoxify and clean up the resulting sugars, which increases costs. In Metabolic engineering in lignocellulose biorefining for high-value chemicals: recent advances, challenges, and outlook for enabling a bioeconomy, Lama et al. provide a comprehensive review of alternative biochemicals from lignocellulose that have been enabled by metabolic engineering. The authors point to key advances in genetic tools that have advanced microbial tolerance of hydrolysate, co-utilization of various sugars, and expanded microbial conversion of multiple hydrolysate components into different products. Having multiple options for products and conversion paths for varied monomers is essential for flexibility in adapting to changing markets and different feedstocks.

Biorefineries are not just for carbon. Hydrogen has long been considered an "ideal" fuel, but production is challenging. In Biohydrogen: prospects for industrial utilization and energy resiliency in rural communities, Mandalika et al. discuss opportunities to decarbonize industrial processes and provide energy security and resiliency when traditional energy sources are too expensive or lost due to infrastructure failure. The authors clarify the decarbonization advantages of biohydrogen produced through dark fermentation or steam reforming of biomethane in terms of avoided carbon by displacing fossil fuel feedstocks and through biological generation routes. By proposing to couple bioH_2 production from local waste feedstocks with the production of fertilizer and sequestered carbon, the authors provide yet another option for biorefineries to impact markets by tackling energy justice and carbon management while stimulating a local bioeconomy and improving local ecosystems.

Future biorefineries will look very different from today's linear operations. Advances in industrial microbiology developed through new genetic tools, novel operational paradigms, stepwise process optimization, better models and artificial intelligence, broadening of feedstocks, integration of carbon management and sequestration, and market advantages through diverse product portfolios will transform the biorefinery landscape. New configurations hold the promise to break the fossil fuel dependency on energy and economic availability and affordability, directly impacting the lives of everyday people and the global ecology. As global society comes to terms with our influence on the carbon cycle, biorefineries offer a clear route to economically co-manage carbon and a circular bioeconomy while promoting energy justice and equity. This vision is going to take commitment and effort to develop, with industrial microbiology as the critical technology for its success.

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