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Beyond ethanol - a process and systems engineering approach to the design of advanced biofuels

1-2 pm PST Monday July 26th, 2021
Zoom link is provided via email, or
contact dyss@uw.edu

Bio

Juan Manuel Restrepo-Florez is a post-doctoral associate at the University of Wisconsin-Madison. His current work focuses on the application of process and systems engineering techniques to the design of integrated biorefineries for the production of advanced biofuels. Before accepting his position in Madison, he was a Ph.D. candidate at the Georgia Institute of Technology. During his Ph.D. he pioneered the use of metamaterials theory in mass diffusion and membrane applications. He holds a bachelor's degree in biological engineering from the National University of Colombia, and a master's degree in Chemical and Biochemical Engineering from the University of Western Ontario.

Abstract

Currently, U.S. consumption of liquid transportation fuels is close to 14 million barrels per day, accounting for nearly 28% of the nation's greenhouse gas emissions. Most of this demand is satisfied by fossil fuels. In this context, the large-scale deployment of biofuels, may help to mitigate the negative impacts of uncontrolled fossil fuel consumption. However, the most common biofuels (i.e., ethanol and biodiesel) can only be blended at a limited fraction (usually below 10%). This limitation has motivated the search for biomass-upgrading strategies toward advanced fuels that can be blended at a higher level. A promising avenue for producing advanced biofuels relies on ethanol upgrading. In this approach, ethanol is transformed into a blend of components with similar or superior properties, compared to fossil fuels. This platform has three major advantages: (1) It can use the available infrastructure for ethanol manufacturing, which is capable of producing 1.1 million barrels per day in the U.S. This advantage becomes more significant if we consider that the domestic demand is already satisfied, and it is expected to decrease, impacting those rural communities structured on the current market. (2) The ethanol-upgrading platform enables the production of fuels across the whole distillation spectrum, from gasoline to middle distillates. (3) Upgrading strategies can exploit developments in ethanol chemistry to tailor the fuels produced to achieve properties superior to those of fossil fuels.

Advances in this field have been significant on the chemical side.[1,2] Currently, a large number of chemistries and catalysts exist for the transformation of ethanol into a broad palette of components. Despite these advances, a systematic analysis of the problem has barely been attempted. Consequently, ethanol-upgrading strategies have been conceived based on engineering judgment, and they often fail to detect trade-offs and synergies. Therefore, a systematic exploration of the different alternatives for ethanol upgrading is critically needed, and it may be instrumental for the rapid development and deployment of advanced biofuels.

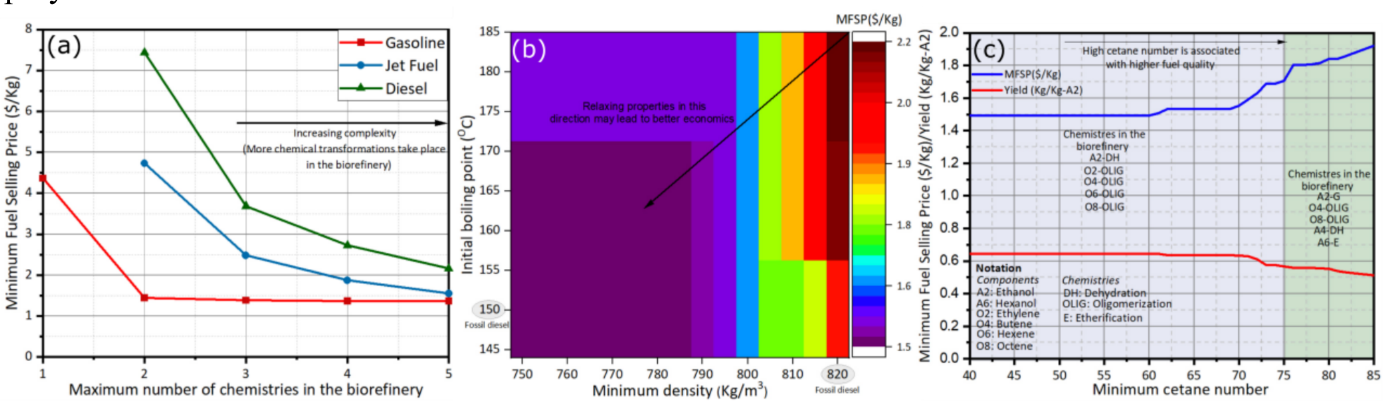

Figure 1. (a) Effect of complexity on the process economics; (b) Interplay between fuel properties and the Minimum Fuel Selling Price (MFSP) in a diesel biorefinery; (c) MFSP and yield as a function of cetane number (higher values are desired, the reference value for a fossil fuel is 40) in a diesel biorefinery.

In this work,[3] we present the first systematic analysis of ethanol upgrading. We identify optimal biorefineries for the production of gasoline, jet fuel, and diesel. We also present a comprehensive analysis of the relation between fuel properties and biorefinery profitability; and we establish the role of biorefinery complexity (measured as the number of chemical transformations used) in the production of advanced biofuels from ethanol (see Figure 1 for representative examples; in Panels b and c, results correspond to a diesel production biorefinery). We clearly show the possibility of producing fuels with properties superior to those of fossil fuels, and we discuss the upgrading strategies that can be used to produce them. To represent and solve this problem, we have developed a superstructure-based optimization framework that makes use of mixed integer nonlinear programming. This framework allows us to find the optimal sequence of upgrading reactions while simultaneously considering the processing costs and the properties of the fuels produced. In our work, we consider a state-of-the-art design space for ethanol upgrading, both in terms of the chemistries and catalysts available. The use of a system-level analysis has allowed us to identify non-intuitive processes for ethanol upgrading and to clearly characterize relevant trade-off relations.

1. Eagan, N. M., et al. Nat. Rev. Chem. 3, 223–249 (2019).
2. Sun J & Wang Y. ACS Catal. 4, 1078−1090 (2014)
3. Restrepo-Flórez, J.M. & Maravelias, C. T. Energy Environ. 1, Sci. 9–19 (2021)