The Refinery of Today, Tomorrow, and the Future: The Role of CO_2 Capture

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The hydrocarbon processing industry is in the midst of a major shift in feedstocks, structure, and products in response to rapidly changing energy sources and external driving forces associated with greenhouse gas emissions. Even amidst this rapidly changing landscape, fossil-based feedstocks, processing, and products will continue to be the status quo for the foreseeable future due to extensive existing investment. However, existing fossil-based plants with compatible equipment will begin the externality-induced transition over to bio- and e-refinery formats to leverage this existing infrastructure and logistical connections. Advanced separations play a role in this transition in several ways. First, modern separations can partner with existing technologies (e.g., distillation) to extend the time in which fossil-based processing remains competitive under modern externalities (e.g., CO_2). Moreover, energy- and capital-efficient separation technologies can reduce the effect of CO_2 and other emission mandates on fossil-based refining returns on energy invested. While bio- and e-refineries are often thought of as a “blank slate” for advanced separations technologies (thus bypassing the problem of working, amortized capital in existing plants), in fact, the adaptation of existing fossil-based refineries to renewable feedstocks suggests that the “hybrid” separation system paradigm is likely to be the standard for years to come. Nevertheless, these “green refineries” introduce many new separations challenges that are poorly addressed by conventional technologies. There are several unifying themes from a separations perspective in all three refinery archetypes (i.e., fossil, bio-, e-). Two themes that will be discussed in this seminar are “countering complexity” and “combatting dilution”, which represent perennial and emerging separations challenges, respectively. These themes are meant to highlight real-world deviations from the commonly thought of “binary” separation problems that the separations community typically grapple with. “Combatting dilution” will be the theme for this lecture, with a specific focus on CO_2 capture from dilute sources including ambient air, exhaust gases, and flue gases.

Modern and futuristic refinery archetypes (carbon-constrained, bio-, and e-) all must grapple with the critical issue of dilute feedstocks and products, especially CO_2. A clear issue with dilute CO_2 feedstocks is that it is unlikely that these molecules can be catalytically upgraded or converted when in a sea of similar compounds and diluents. This reality provides an economic driving force for improvements in separation systems capable of handling these dilute systems. Unfortunately, existing large-scale separations equipment can often consume more energy than the energy content of the dilute molecule – a showstopper if fuels are the final product for the captured CO_2. Our calculations indicate that it is ultimately adsorption-based separations processes that provide the path forward for this class of separations. A key challenge – which will be the focus of the talk – is how to scale up (or “number up”) adsorption-based systems by 2-3 orders of magnitude. This level of scale-up is necessary for the CO_2 footprint from the chemicals and petrochemicals sector to be addressed – another 1-2 orders of magnitude of scale-up beyond this are needed to address emissions from the transportation sector and power generation sector! This enormous task – coupled with the short time frames left available to stay under global carbon budgets – suggests that simplicity of materials and manufacturing will be critical for success. Manufacturing platforms based on fiber spinning – an eminently scalable process – will be discussed and compared to existing and emerging CO_2 capture approaches. The talk will conclude with a discussion on the intersection of fuels, power, chemicals, water, and carbon and the roles that engineers will play during the major transitions that are likely to occur in global energy systems over the next twenty years.