Design of integrated biorefineries

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ABSTRACT

The design of biorefineries from pilots and installed facilities bears tremendous social and economic benefits. By 2020, Bloomberg predicts that, only in Europe, there would be around 1,000 of such new units bringing €32.3 trillion revenues and 1 million new jobs. Process systems engineering has a pivotal and critical role in the development of biorefineries. The general view is increasingly supported by results and analysis that prove the significance of systems engineering in future developments. The design and synthesis of biorefineries constitutes a complex problem challenged to cope with the large and unknown product portfolios as they arise from different chemical itineraries and processing paths (value chain analysis) as well as process engineering options to select units and integrate them into a plant (process synthesis, process integration). In all cases, the designs are required to match maximum efficiencies in the use of materials/energy and to assess uncertainties in processing and economic parameters that may affect the selected designs and the level of integration. The presentation explains a systems framework tested on real-life applications. The work combines methods in process synthesis and integration, optimization and process modelling. At a conceptual level, process synthesis determines process and products to use, enabling a systematic screening with a simultaneous approach and the systematic use of optimization. Process integration, integrates for maximum efficiency in raw materials and energy, as well as for the maximum performance against environmental targets. Process flowsheeting validates with process simulation and enables improvements with parametric optimization. The coordinated use of the systems methods constitutes a significant advancement in the state of the art, currently relying on case-by-case analysis (flowsheeting) or the experimentation with commercial simulators.

The systematic methodology is already applied to several real-life biorefineries that include lignocellulosic and oleochemical biorefineries, halophytic algo-biorefineries and, more recently, waste biroefineries. The lignocellulosic applications involve chemistry paths with 70-odd chemicals that include basic intermediates (sugars, lignin, ethylene, oils), bulk chemicals (ethanol, butanol, propanol, isopropanol), bio-based polymers (PVC, resins, polyamides, PEIF, polyacrylates, PUs), and a wide range of chemicals (xylitol, xylonic acid, itaconic acid, sorbitol, isosorbide, hydrogel etc). Preliminary results are often impressive. Other than systematically screening and scoping integrated paths for the plant, the analysis reduces energy by 70% and the water use by 50-60%. Research is strongly coordinated with LCA. Results demonstrate that, unless fully integrated, biorefineries remain unsustainable. Instead,

fully integrated biorefineries stand as viable and operational options, offering a strong promise to the development of sustainable industries in the future.

The development of the system framework relied on a new generation of methods that combine synthesis and process integration at different levels, further building high-throughput capacities using ontology engineering. Semantics and ontology engineering are intended to compound the screening of engineering options with a parallel screening for materials, strains, resources, and chemistries (biology, biochemistry node). They are also intended to capitalize and link the systems methodology with other systems methods around the world. Design work is being recently extended to address retrofit applications with a purpose to upgrade first generation plants into second (or higher generation) biorefineries. The methodology is also tested in the context of Industrial Symbiosis where the biorefineries are deployed to explore links (mass and energy exchanges) between industries and resources available at urban sites. Results and applications in that context will be presented from recent work to evaluate the bioenergy potential at four different EU ports. Other work in progress includes data modelling to develop Class 4 and Class 5 estimates for CAPEX and OPEX, data modeling to calculate LCA metrics at early stages, and the extension of FineChem to biorenewables.