BIOREFINERY DESIGN AS A CASE STUDY IN CHEMICAL ENGINEERING DESIGN

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ABSTRACT

Increasing global demand for improved product and process functionality requires higher quality, lower costs, product customization, conservation of natural resources, reuse and recycling of materials, and meeting new energy and environmental challenges. To respond and stay competitive internationally, from a manufacturing perspective North America must be more innovative and responsive – and currently the biorefinery represents one important potential opportunity to pursue these design objectives. This paper describes (a) an overview of the biorefinery industry context, and (b) how work in the NSERC Design Chair in this area is being used as a case study in courses in the Chemical Engineering undergraduate and graduate programs at Ecole Polytechnique.

INTRODUCTION

Contrasting approaches have been used to develop the design competency, which depend on many factors including in particular the previous industrial design experience of the instructor highlighting the empirical nature of design. Furthermore, teaching the engineering design competency can involve various methods such as project-based learning and interdisciplinary approaches.

The definition and description of design and design processes have been given considerable attention in the literature. Crain et al (1995) describe the TIDEE initiative (Transferable Integrated Design Engineering Education), which was aimed at developing and integrating design education in the first two years of the engineering curriculum. The NSERC Chairs in Design Engineering (2004) also developed a definition of the engineering design competency. Engineering design has been characterized in many ways, including the following:

- (1) Creative process. Design is supported by knowledge and methods as well as by analysis and synthesis capabilities.
- (2) Iterative. Designers need to access different sources of information during the design process and this information must be refined by negotiations, clarifications, discussions and evaluations until the information and context are appropriate for the design problem.
- (3) Interactive and social. Interaction between experienced designers and teamwork are critical for design, regarding in particular the information acquired through case-based and problem-based learning. This reflects to some extent the empirical nature of design.
- (4) Open-ended. Questions that are posed in design situations typically have no unique answer. Design questions solicit divergent thinking, based on deduction incorporating facts and extending these to the possibilities that can be created from them (Dym et al, 2005).
- (5) Multidisciplinary. The design competency is considered by some to be similar for different engineering disciplines. One key to improved technology development and innovation lies in cooperation amongst disciplines in order to identify unique designs.

At many universities these skills are being incorporated in courses across the engineering undergraduate curriculum. However this emphasis on multidisciplinary synthesis and design coupled with a greater emphasis to deeper inquiry and open-ended problem solving, development of management and communication skills, international exposure and preparation for continuing professional development and career-long learning are all mounting pressures on already overburdened engineering curricula (Fromm, 2003).

METHODS

One important strategy for addressing the engineering design competency is to incorporate industry-based case study learning into the engineering curriculum. In the NSERC Design Engineering Chair at Ecole Polytechnique, numerous Product and Process Design projects addressing biorefinery case studies are underway with forestry company industry partners.

This presentation presents (a) foundation ideas behind the biorefinery design engineering research program, and (b) how these are being incorporated into courses in the Chemical Engineering curriculum at Ecole Polytechnique. The case studies inspire design work in the

capstone design course, as well as a graduate-level course where Process integration design tools are introduced.

RESULTS

In the 27 January 2006 Science Magazine, Art Ragauskas and his colleagues at Georgia Institute of Technology introduced a new state-of-the-art biorefinery concept stating that “in essence, the modern biorefinery parallels the petroleum refinery: an abundant raw material consisting primarily of renewable polysaccharides and lignin enters the biorefinery and, through an array of processes, is fractionated and converted into an array of products including transportation fuels, co-products, and direct energy”. Already today, several forestry companies are considering its implementation in the coming years despite the fact that no commercial scale biorefinery has yet been implemented producing chemicals from second generation biomass. Developing innovative biorefinery solutions that are unique to the North American competitive landscape in a global economy will require bold fast-track research into new conversion processes, coupled with innovative design techniques.

The so-called forest biorefinery can be defined in economic terms, and this can provide the basis for the design problem definition. Various case studies using this problem definition are being addressed in the NSERC Design Chair at Ecole Polytechnique. Techno-economic assessment of different embryonic and emerging biorefinery processes is critical during the early stages of design, and at the same time not obvious due to several complicating factors such as scale of technology development, scarce information from technology developers due to intellectual property concerns, future price volatility and uncertainty, and others. Traditional techno-economic assessment and techno-economic risk analysis methods that are used in early stage biorefinery process design are critical, and overviewed in this presentation. Key methods are used for capital and operating cost estimation, profitability analysis and suitable risk analysis methods for these techno-economic analysis methods. Primarily the focus is on conceptual level process design.

There are many process-product combinations possible for the biorefinery, and this has emphasized the importance of product design in the applied methodologies, so that process/technology strategies “serve” business/product strategies leading to profitable transformation.

DISCUSSION

The open-ended and multidisciplinary issues associated with the biorefinery must be addressed in a creative and iterative process, by students involved in design teamwork.

In the Chemical Engineering capstone design course, in recent years we have incorporated a wide range of problem definitions that are inspired by our case study work in the NSERC Design Chair. The emphasis in this course is on process design, and the management of technology and market uncertainty in the elimination of biorefinery process options.

In the Chemical Engineering Advanced Design and Process Integration course, in recent years we have imported the methods we have developed in energy (pinch) analysis, life cycle assessment etc, but in particular, have emphasized the complex aspect of product design for the biorefinery.

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