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Economic Assessment of Biorefinery Processes: The Case of Bioethanol

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Bioethanol gained growing attention as biofuel in the recent past. Its production steadily increased over the years attesting on 87.2 billion liters worldwide in 2013, with the United States as the top producer (ca. 60%), followed by Brazil.

Ethanol is mainly produced from sugar cane (Brazil) and corn or other cereals (US), but these sources induced criticisms as for social sustainability, being directly competitive with the food and feed chain. Therefore, a second generation concept was introduced for biofuels, by developing processes for their production from waste biomass or energy crops not competitive with agriculture. However, currently in the US and Europe most bioethanol is still produced as first generation. For example, it was estimated that in 2011, 40% of corn harvested in the US was used as a feedstock for bioethanol production, compared to just 7% a decade earlier.

Early examples of second generation bioethanol production are available, such as the Proesa process developed by Mossi & Ghisolfi group in Italy [1]. This process commercially operated since 2013 for the production of 40 kton/year of bioethanol (60 kton/year at full capacity) starting mainly from Arundo Donax, a common cane which can be harvested locally with good yield. The same technology has been exported in Brazil (65 kton/year, from sugar cane transformation wastes) and US (60 kton/year from non-food competitive biomass). In April 2013, a commercial ethanol plant started being built in Florida using sweet sorghum as a feedstock. The plant is being built by Southeast Renewable Fuels LLC using the process technology of Uni-Systems do Brasil Ltd.

In spite of these emerging commercial experience in biorefinery, a consolidated expertise is still lacking. In particular, in developing countries it will be a challenge to balance large-scale industrial development with small-scale local value chains, which would be required to ensure environmental, economical and social sustainability. Therefore, to become a viable alternative, biofuels should be economically competitive, show environmental benefits, and provide a high net energy gain.

On the other hand the research is very active in the biorefinery field. Simple queries on Scopus reveal that the word “biorefinery” is included in 3,646 references, “biofuels” in 37,193 documents and “bioethanol production” returns 4,859 references. As for bioethanol uses, the commercial practice is presently focused on the use of bioethanol as blend for gasoline or directly as fuel, to meet the most recent regulations on the fuel pool quota from renewable sources. Also in this case the research broadens the application potential of bioethanol, focusing mainly on hydrogen/syngas production by thermocatalytic processing (e.g., steam reforming) or on chemicals such as diethyl ether or ethylene.

To date, comprehensive information on the economic sustainability of these ethanol conversion processes is still lacking. Indeed, in spite of huge efforts in developing materials and innovative ideas, the economical assessment of the proposed solutions is fundamentally lacking and this prevents the analysis on the real breakthrough potential of these technologies. Furthermore, no idea on the size of possible plants is given, to assess their real sustainability and possibility of integration in the social framework of different countries. Only few reports address bioethanol production (mainly first generation) and much less its transformation into hydrogen through steam reforming. Some of the most recent examples of techno/economic assessment of bioethanol production/exploitation are described in the following.

Brunet et al. described process simulation and optimised heat integration of bioethanol production from corn (40 million gal/year) [2]. Life-cycle analysis is also included. The estimated total capital investment of a dry-grind bioethanol production from corn was 60.5 million $, the operating cost was 67.4 million $/year. The most significant parameter was the cost of the (92.96% of the raw materials), while the cost of utilities was 15.1 million $/year. As for LCA, most of the environmental impact comes from the use of the corn (74.6%), followed by utilities. The energy required to obtain one gallon of bioethanol is estimated ca. 25 BTU, ca. 40% attributed to the reboiler of the beer column, rectifier and stripping.

The most developed processes for the production of lignocellulosic bioethanol are based on biomass pretreatment by dilute acid treatment, steam explosion or similar thermomechanical processes. Typically, in these cases lignin is recovered and valorised as fuel as a mean to economically sustain the process. A different concept is at the basis of the “Organosolv” process, which dissolves lignin in a proper organic solvent in order to recover it in pure form to be valorised as chemical or additive[3]. Some demonstrative scale processes have been developed and reviewed by Kautto et al. [3] with attention to the minimum ethanol selling price resulting from different technologies. Capital costs, annual cash flows and sensitivity analysis towards different parameters (technical and market-related) have been considered. Higher capital costs are associated to the organosolv process due to more complex layout. Therefore, profitability is excluded if lignin does not find a suitable market with much higher revenue than as fuel.

A systematic framework for the design and assessment of bio-based chemical processes was proposed by Nguyen et al. [4] for the production of three commodity chemicals form ethanol: ethylene, acetic acid and ethylacetate. The starting biomass was also varied, including sugarcane, corn and corn stover. The paper interestingly compares not only the total production costs of the proposed commodities, but also the environmental impact and safety analysis.

Different retrofit cases have been analysed considering a 40 kton/year ethanol production facility from corn, including fluctuating price of the raw material [5]. The results suggest that grain price is

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fundamental to determine the profitability of the plant. Decreasing the ethanol price below 702 US$/ton led to non profitable scenarios as well as reducing the plant size to less than 75,000 tons grains/year. Energy integration has been also proposed, considering an anaerobic digester for biogas production to partially sustain the utilities demand of the process. The effect of final bioethanol purity has been also taken into account [5-8].

In order to compare different scenarios and strategies for the deployment of biomass potential, a systematic approach has been proposed, to develop minimised cost functions in a life-cycle cost analysis through interval linear programming techniques [9]. A mixed integer linear programming technique was also used to forecast price scenarios for bioethanol. This analysis was used to compare different solutions for the bioethanol supply chain in Northern Italy (based on corn or mixed lignocellulosic biomass) [10,11].

A bioethanol production route different from the enzymatic hydrolysis has been proposed, consisting in the biomass gasification followed by the catalytic conversion of syngas to ethanol [12]. A combined LCA and economic analysis compares four process configurations, each using a different light hydrocarbon reforming technology: partial oxidation, steam methane reforming, tar reforming and autothermal reforming. The most profitable configuration appeared the one based on partial oxidation.

Besides these examples, the examination of the literature in the field suggests the need of increasing attention to the economical and lifecycle assessment of the proposed solutions. Furthermore, the integration of this analysis with downstream ethanol conversion technologies is quite completely lacking. This is an emerging important research field where much has to be done.

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