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Process Synthesis for the Sugar Sector – Computer Based Insights in Industrial Development

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Abstract

The application of process synthesis to the European sugar industry is a valuable support for decision-making in an industry severely hit by deregulation of agrarian markets. The paper offers a broader view on possible pathways for utilizing sugar beet. Results of sensitivity analysis using the P-graph approach and a branched and bound MINLP optimization method reveal the impact of price variations for ethanol and sugar on the core structure of sugar plants. This information may help to set the strategy for the sugar sector in Europe in the years following deregulation of the market.

Keywords

Sugar production, bio-fuels, process synthesis, bio-refineries

1. Introduction

Increasing prices for crude oil and the resulting high energy prices have made alternative, bio-based processes attractive from an economical point of view. Ecological considerations, especially the threat of global warming due to high green house gas emissions, have added to this renewed interest in processes utilizing biogenic raw materials and wastes from agriculture, forestry and aquaculture. Although there is a long history of utilizing biogenic raw materials, their conversion to modern-day bulk and fine chemicals as well as the large-scale provision of energy carriers from these raw materials calls for a large number of genuinely new and innovative processes and completely new "utilization networks". The next decades will therefore see a dramatic restructuring of process industry, both in terms of new technologies as well as new logistical concepts that allow the utilization of de-centrally provided raw materials from agriculture as opposed to centrally provided fossil resources.

Process synthesis has proven its value in many applications in conventional process industry. However, these applications were more often than not restricted to single plants and had in many cases focused on retrofit cases. The application to cases dealing with renewable resources poses special challenges, as de-central production and closing of material cycles requires to include logistics in the synthesis (1). Another aspect of the application of process synthesis to renewable resources cases is that these processes may be still in their infancy and heuristics to build up viable process structures may be hard to come by. The combinatorial P- graph approach, combined with a branched and bound MINLP optimization method (2,3,4,5,6), has been successfully used in this context (7,8). This method will therefore be used in this paper in order to gain insight into the development dynamics of the European sugar sector as it adapts to the new regulatory and economic boundary conditions.

2. Forces Driving the European Sugar Sector

The sugar industry in Europe is faced with considerable challenges linked to the new sugar regime implemented by the EU triggered by WTO consultations. The European Commission directive regulating the future sugar market will cut the prices for sugar by 36 % from 631,9 €/t now to 404,4 in the 2009/2010 campaign and an average cut in sugar beet production of about 19%, which varies widely across the member states (9). It is clear from these numbers that the European sugar sector faces dramatic changes. These changes affect the efficiency of the sector, the optimal size of the sugar sector as well as the sugar beet growing area and the range of products that may be provided while utilising sugar beet.

The challenges facing the sugar sector from re-structured markets coincide with a considerable increase in demand for bio-fuels. The driving force for this increase is concern about global warming. This concern is politically translated again via European Commission directives, now regulating the fraction of bio-fuel required to be mixed to conventional fossil gasoline and diesel. This fraction has to reach 5,75 % in 2010 (10). Ethanol, which may be readily produced based on sugar beet, will carry a large part of this burden. Besides this a renewed interest in bioplastics may also prove to become a competitive pathway to utilise sugar beet.

The questions to be answered therefore are:

- What does the competition between sugar production and the production of ethanol mean for the internal structure of sugar processing?
- What, if any, possibilities exist to more fully utilise sugar beet and what does this mean for the sugar sector in future?

These questions will be (at least partially) answered in this paper.

3. Investigating future structures of the sugar sector by process synthesis

A crucial and pressing question to be answered is the integration of the ethanol pathway into the sugar sector. Sugar beet is a prime resource for the provision of ethanol for fuel, as its yield per hectare (with regard to ethanol) is almost three times that of corn.
In order to investigate the structural influence of falling sugar prices and possible rising ethanol prices on the structure of utilizing sugar beet the "core" sugar process is combined with the ethanol pathway (see figure 1).

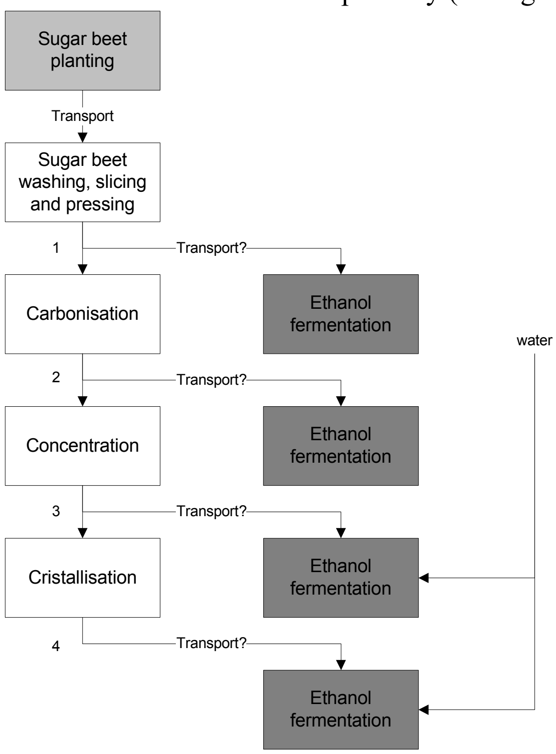

Fig. 1: Integration of ethanol production in the sugar process

One can see from figure 1 that there are different possible points to integrate ethanol production into the core sugar process. At point 1 the raw juice (with a sugar content of appr. 14%) is used as a raw material for fermentation. Point 2 indicates the use of purified raw juice. Point 3 utilizes a higher concentrated molasses (with 60% sugar) and point 4 uses the highest concentrated molasses (> 80 % sugar). In the last two alternatives, water has to be added for fermentation. The volume of the molasses however is small and transport to ethanol plants outside the sugar factory is therefore cheaper.

At current prices (631,9 €/t white sugar) the production of sugar is still more profitable compared to ethanol (with a world market price of 330 €/t). However the margin between the production of sugar and utilizing sugar beet for ethanol production is slim. If the price of sugar falls to the level required by the EC directive for the campaign 2009/2010 (404,4 €/t) ethanol production will be preferable at current world market prices. Process synthesis reveals that in this case the alternative to draw all juice towards fermentation at point 1 is the most preferable if the fermentation can handle the impurities at this point. Otherwise the utilization of the juice at point 2 is the next best solution. It is notable that under this price ratio no sugar production is recommended! This indicates that the sugar production is gradually supplanted by provision of fuel, making large-scale fermentation plant investments close to sugar factories a very promising alternative.

Interestingly enough the price ratio for the switch to fuel production is relatively insensitive to the development of energy prices. This comes from the fact that both the ethanol production as well as the sugar process is relatively energy intensive. Higher energy prices make the products more expensive in general but do not favor one pathway over the other.

4. Transforming sugar factories to bio-refineries

The competition between fuel production and sugar processing is however only the most basic question faced by sugar industry in the next years. As a matter of fact the low prices of both commodities will force the sector to investigate new pathways to fully utilize the potential of their raw material, the sugar beet. This crop proves to be very versatile and powerful: besides providing a high content of sugar, this plant has yields of up to 60 t/ha (fresh crop) of which up to 10 t/ha are sugars and on top of that provides a harvest of green leaves that competes acre for acre with the yield of turnips.

The versatility of sugar beet as raw material is on the one hand a tremendous chance for the sugar sector to branch out into other product markets and to establish itself as a major player in a general development towards a more sustainable industry. As no other sector with the exception of the pulp and paper industry, the sugar sector has experience in the raw material logistics of renewable resources at the large scale. On top of that this sector has already running plants in the best locations for the utilization of high yield agricultural crops.

On the other hand this versatility complicates the decision about the future structure of the sugar sector considerably. Fig. 2 shows a very simplified "super structure" of the utilization of sugar beets.

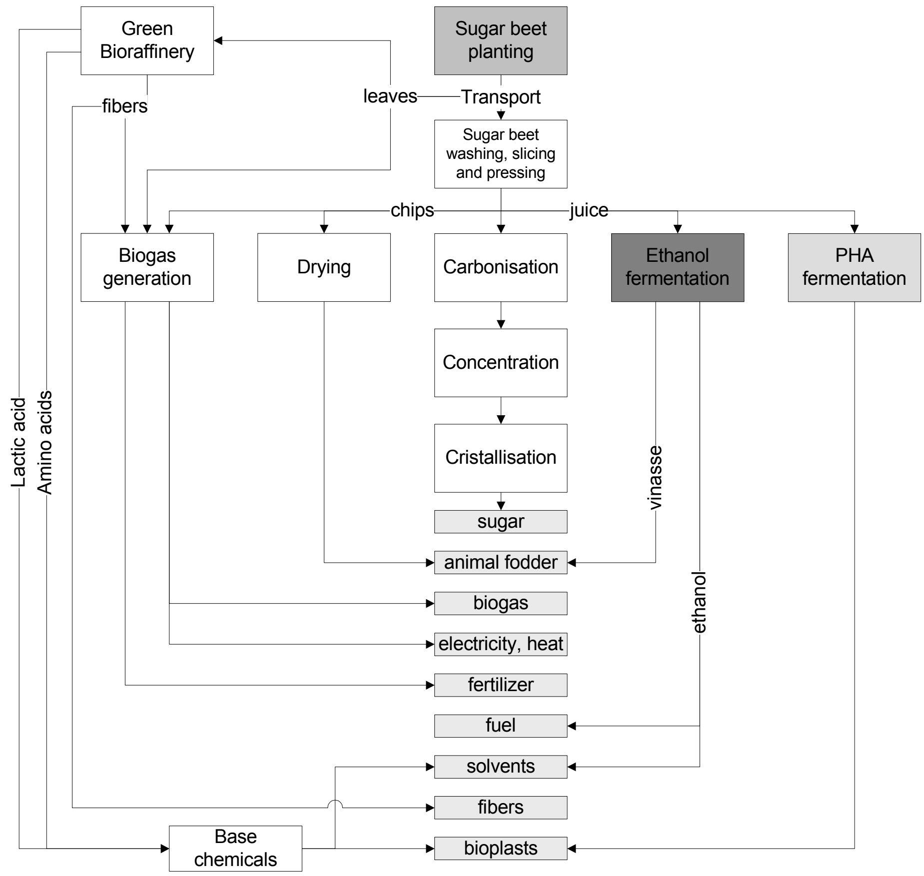

Fig. 2: Possible pathways of sugar beet utilization

5. Conclusions and future work

This figure clearly indicates the complexity of the optimization task at hand. Some of the pathways indicated in fig. 2 are additive to the sugar/ethanol system (as the utilization of leaves), but may feed competing processes (the green biorefinery or the biogas plant). Some lead to comparable products via different pathways (e.g. the solvent production). Some are directly competitive (e.g. the utilization of biogas in a co-generation vs. the injection of biogas into the grid). This complicated network of pathways, that depend on various markets and price ratios will become a real testing ground for process synthesis as a tool to support strategic decisions in the sugar sector.

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