Zdravko Kravanja, Miloš Bogataj (Editors), Proceedings of the 26th European Symposium on Computer Aided Process Engineering – ESCAPE 26
June 12th -15th, 2016, Portorož, Slovenia
http://dx.doi.org/10.1016/B978-0-444-63428-3.50368-4

A Study on the Endogenous Symbiosis of First and Second Generation Biorefineries: Towards a Systematic Methodology

Aikaterini D. Mountraki,[α,b] Bouchra B. Mlayah,[b] Antonis C. Kokossis[α*]

[a]*National Technical University of Athens (NTUA), Address, Athens and Postcode, Greece - akokossis@mail.ntua.gr*

[b]*Compagnie Industielle de la Matière Végétale (CIMV), Address, Toulouse and Postcode, France*

Abstract

To date, first and second generation processes have been integrated by the adoption of grassroots design methodologies while, in reality, their coupling is far more complex. The integration of first and second generation biorefineries is a combined grassroots–retrofit design problem that hides endogenous symbiotic options and proves the deficiency of present-day practices in proposing realistic designs for such mixed design problems. This work studies the different symbiotic options in the integrated pair of first and second generation biorefineries, scoping for the development of a new systematic methodology which can combine different process systems engineering tools for the integration of grassroots-retrofitted problems. Preliminary results indicate a significant potential in internal trade-offs savings, both in operating and capital cost. The framework advocated by this work can be applied to general applications with the use of combined thermodynamic and mathematical programming methods.

Keywords: Biorefinery, Retrofit, Integration, Optimization, Endogenous Symbiosis.

1. Introduction

Second generation (2G) biorefineries can be used to upgrade, rather than eliminate existing first generation (1G) plants. As they process different feedstock, the integration of different generation biorefineries has attracted attention recently. Researchers have integrated the two technologies by using conventional methods (Dias, 2008; Naik et al., 2010; Palacios et al., 2012; Dias et al., 2014; Lennartsson et al. 2014). Nevertheless, existing studies undertake the problem as a grassroots design problem. While first generation installations are nascent plants, still possible to amend and modify, second generation upgrades account for new technology and investment very flexible to adjust so that the upgrades are best. An additional challenge with the particular integration is that first and second generation technologies hide inner trade-offs. There is significant potential to exchange (by-)products and not only to integrate energy. Bagasse can be used as a feedstock in the second generation process, and, similarly, lignin can be used as fuel for the co-generation unit. Moreover, the processes may utilize common sections, like sharing the same dehydration section. Finally, the co-generation (CHP) unit, after modifications, can support both plants. That implies a retrofit problem that is much larger and complex than most conventional applications. A systematic retrofit approach is possible to scale-up by using thermodynamics and mathematical programming (Briones & Kokossis, 1996; Smith et al., 2010) and has been advocated by the work presented here.

2. Methodology for mixed retrofit - grassroots designs

The framework introduced in this paper is an extension of the methodology proposed by Kokossis and Yang (2010) and is capable to address mixed grassroots-retrofit design problems. This approach involves hierarchical layers as shown on Figure 1.

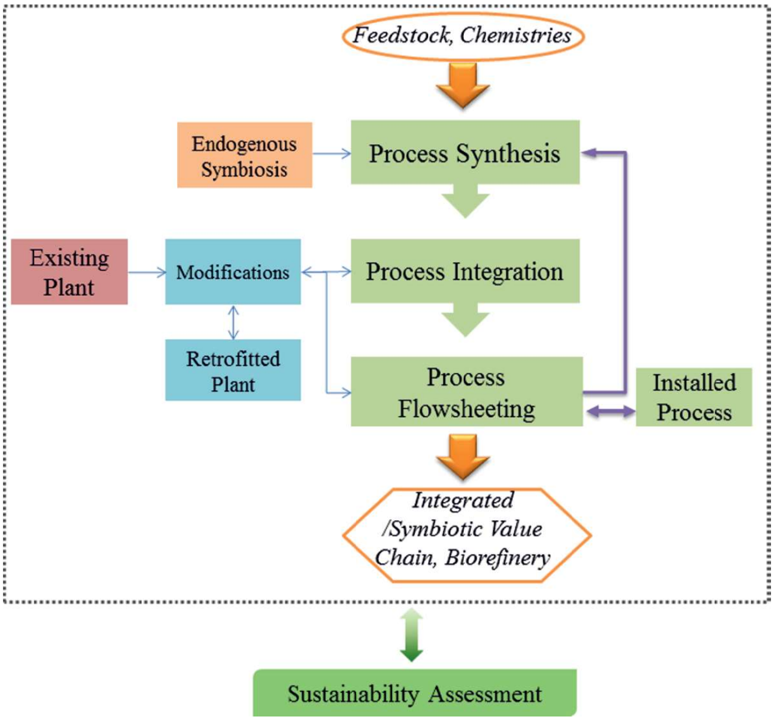


Figure 1. The three layer approach for mixed grassroots - retrofit problems

Tasks follow in a bottom-up approach whereby the lower layer (Process Flowsheeting) is the initial stage and validation check-point. The initialization stage includes data generation though the development of process flow diagrams. The new process (Installed Process) is receptive to design suggestions and data available concern mainly the main equipment. In the case of the Existing Plant, every design detail is available, but as the process equipment is already installed, all this investment cannot be disregarded. The checkpoint includes control of the modifications applied in the Existing Plant. The modifications can be considered as additional cost for re-piping, pressure drops, and auxiliary equipment and need to be restricted to minimum necessary, making sure that the existing investment is maximally exploited. Finally, the flowsheets are evaluated. The lower layer validates the achievement of targets set in Process Integration layer and asses the sustainability of the project. Different software can be used for the Process Flowsheeting, like Aspen, ProSim, gproms, or even Excel sheets, reflecting the different levels of detail in data availability.

Process Synthesis is used to systematically sift different options depending on different Feedstock, Chemistries, and Endogenous Symbiosis. At this layer, the capacity, the raw material, and the value chain are under evaluation. The Existing Plant has an entrenched supply and distribution chain, but it is an opportunity to re-evaluate its position on the market. Depending on the existing demand, it might be profitable to invest on a bigger capacity and/or a new product. The case of the Installed Process, on the other hand, stands an open challenge. Furthermore, it would be negligence not to search for internal trade-offs. Are there any industrial sectors in common? Can the CHP be modified so as to be adequate for both processes? Can they exchange (by-)products? Process Synthesis can go through internal product exchange options. The great number of alternatives imposes the use of a systematic screening tool that can treat complicated interconnections. The use of graph tools proposed by Kokossis et al. (2015), is suitable to systematically screen among numerous options.

Depending on the configuration selected at the Process Synthesis stage, Process Integration also needs to systematically tackle with big data. One option is to handle the two processes as one, fully integrating one to another. This approach uses process integration analysis and is how this problem is managed, so far: combining any stream of one process with any stream of the other, with no restrictions. Another option is to integrate them as different processes by using Total Site Analysis (TSA) tool. TSA is more appropriate for this case since the heat exchange between processes is indirect, by exploitation of excess steam, allowing the consideration of the retrofit problem. Modification options in the Existing Plant include changes for the reduction in the use of utilities, appropriate structural modifications, number and type of equipment to be purchased, changes in the installed heat transfer area, re-piping and reassignment of streams. These decisions can be addressed by using thermodynamic-heuristic and mathematical programming methods. (Briones & Kokossis, 1996; Smith et al. 2010). Retrofit integration tries to eliminate the heat transfer crisscrossing by making the maximum use of the existing equipment. If the integration imposes the replacement of a heat exchanger, does the old equipment fit with a one foreseen for the new process?

In brief, the combined grassroots - retrofit problem imposes different handling than the ordinary design problems. The proposed framework uses Process Synthesis to screen decisions, Process Integration to combine TSA with combined process integration and retrofit tools, and Process Design to evaluate the economic feasibility and the environmental sustainability of the project. The first step of the framework studies endogenous symbiosis, as illustrated in the next section.

3. Endogenous Symbiosis: Opportunities in integrated first and second generation biorefineries

It is selected to integrate a sugarcane bioethanol process with a lignocellulosic biorefinery. Simulation models in Aspen Plus are produced for each case. The design of the autonomous distillery (Figure 2a) is based on literature (Dias, 2008; Dias et al., 2011) and follows four main steps. At first, sugarcane is cleaned upon reception in the factory to remove part of the dirt. Extraction of sugars is done by using mills, where sugarcane juice and bagasse are separated, driving the juice to fermentation. Finally, fuel ethanol is produced. The design of the lignocellulosic process (Figure 2b) is based on the organosolv biorefinery of CIMV Process^{TM} (Delmas, 2008; Mountraki et al., 2011) and is consisted of six major sections, which involve extraction and delignification of the feedstock, de-acidification of the cellulosic pulp, concentration of the extraction liquor, treatment of lignin, concentration of the sugar syrup, and the recuperation of the solvent by distillation. With the intention to build a benchmark and to keep the same basis of comparison, it is postulated that the conventional distillery burns 1/3 of the trash, and that all bagasse produced feeds the 2G process. Feed flows are kept steady in all cases.

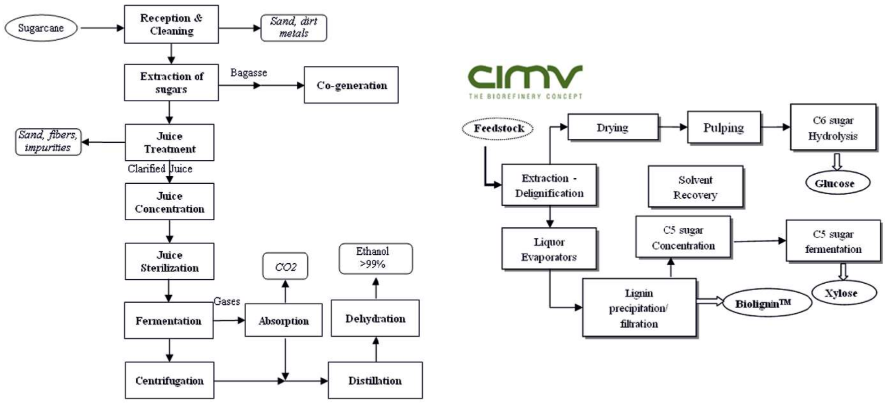
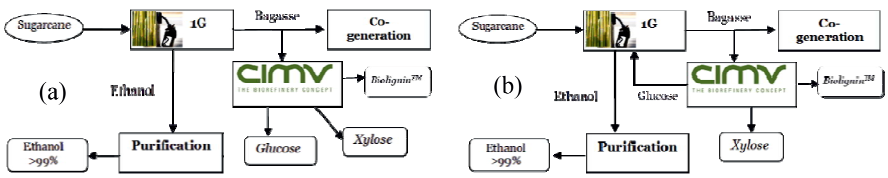


Figure 2. Block Flow Diagram of a) 1G plant and b) CIMV Process™ (Permission CIMV, 2015)

The base case assumes that each process is individually integrated, setting a benchmark for profitability. Options to expand include the use of bagasse as feedstock (Scenario1, 2, and 3), the increase of 1G capacity by taking in the 2G glucose (Scenario 2), and the purification of 2G ethanol in the existing purifying section (Scenario 3). In the first case, CIMV minimizes the transportation cost for the bagasse feedstock. Scenario 2 allows to increase the production of 1G ethanol, without modifying the previous sections and without aggravating the supply chain. In Scenario 3 both plants produce ethanol, so they can share the distillation equipment. Finally; CHP section, which is designed to support only 1G, can be retrofitted to support also 2G. If both processes manage to decrease their energy consumption, small modifications in the CHP unit may cover their thermal needs. The results of the unconstrained total site integration are illustrated on Table 1.



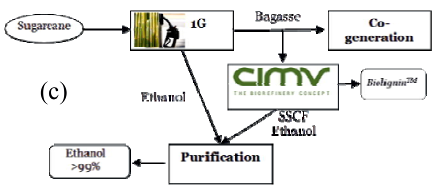


Figure 3. Schematic representation of (a) Scenario 1, (b) Scenario 2, and (c) Scenario 3

In Reference Case, the individually integrated 1G ethanol process burns the exact quantity of bagasse produced to cover its thermal requirements, while CIMV requires the 85%. Even though 2G process requires more energy per tonne of dry biomass, it produces the same amount of fuel ethanol (10 t/h) with less feedstock, by co-fermenting the C5 and C6 sugars. In Scenario 1, both processes are thermally integrated by unrestricted TSA. In that case, the amount of energy required per ton of dry biomass is even lower than the stand alone integrated 1G plant. Furthermore, apart from fuel ethanol, all three 2G key products are produced, which can be further valorised and contribute to a fully developed multi-product biorefinery. In Scenario 2, the capacity of 1G ethanol is increased by fermenting the 2G glucose, while xylose and Biolignin^{TM} can be differently valorized. The heating requirements in that case are a lower than the summation of both processes. Finally, in Scenario 3, both processes are oriented towards ethanol production, and, in that case, the profit of the TSA integration is not obvious. On the other hand, capital investment is saved.

Table 1. Summarized Results

	Reference Case		**Scenario 1**	**Scenario 2**	**Scenario 3**
	1G	2G	1G - 2G	1G - 2G	1G - 2G
Heating [MW/t dB*]	2.5	4.2	2.3	2.8	3.0
Cooling [MW/t dB*]	2.0	3.8	1.5	1.9	2.1
Ethanol 99.5% [t/h]	10.0	10.0	10.0	16.8	20.0
Clucose 80.0% [t/h]	-	-	34.3	-	-
Xylose 80.0% [t/h]	-	-	9.3	9.3	-
Biolignin^{TM} dry [t/h]	-	11.1	11.1	11.1	11.1
Bagasse to CHP**	99.9 %	85.4 %	140.5 %	172.7 %	192.0 %

*dry Biomass/ **compared to 2G feed

4. Conclusions

To sum up, the integration of first and second generation biorefineries is not a straight forward integration problem, but it hides endogenous symbiotic options. The unconstrained results of symbiotic scenarios (Table 1) show that the integrated scheme can be beneficial for both processes. The case of Scenario 3, which is actually the summation of the individual processes, saves supply chain expenses the new process and has lower energy consumption per ton of dry biomass compared to the autonomous distillery. A step further, Scenario 2 increases the capacity of the conventional distillery without the need of modifications in the pre-treatment section and keeps total energy consumption low. Finally, Scenario 1 allows the lignocellulosic biorefinery to produce other products by valorising its key products (glucose, xylose, and lignin). All three scenarios save capital investment by sharing common sections. This study of internal trade-offs unveils the complex nature of the integrated problem. The 1G process is a retrofit while 2G is a grassroots case. The existing plant imposes minimum modifications while the new technology has no limitations. The existing approaches are not able to combine grassroots and retrofitted design. The framework proposed in this paper lays the groundwork for coping systematically with complex design problems. Process Synthesis can screen paths and symbiotic options, Process Integration combines grassroots integration with retrofitted in a TSA approach, and finally Process Design evaluates the project and provides all the necessary details for economic and environmental evaluation. Future work includes the implementation of the systematic steps described and the detailed economical investigation, scoping for the development of a systematic methodology.

Acknowledgment

The financial support from Marie Curie European Research Program, RENESENG (FP-607415) is gratefully acknowledged.

References

A. Kokossis and A. Yang, 2010, On the use of systems technologies and a systematic approach for the synthesis and the design of future biorefineries, Computers & Chemical Engineering, 34, 1397-1405.

A. Kokossis, M. Tsakalova, and K. Pyrgakis, 2015, Design of integrated biorefineries, Computers and Chemical Engineering, 81, 40–56.

A. Mountraki, A. Nikolakopoulos, B.B. Mlayah and A. Kokossis, 2011, BIOCORE–A systems integration paradigm in the real-life development of a lignocellulosic biorefinery, 21st European Symposium on Computer Aided Process Engineering–ESCAPE, Vol. 21, pp. 1381-1385.

M. Delmas, 2008, Vegetal Refining and Agrichemistry, Chemical Engineering Technology, 31(5), 792-797.

M. Dias, 2008, Simulation of ethanol production processes from sugar and sugarcane bagasse, aiming process integration and maximization of energy and bagasse surplus [Simulação do processo de produção de etanol a partir do açúcar e do bagaço, visando a integração do processo e a maximização da produção de energia e excedentes do bagaço] (in Portuguese), MSc Dissertation (Chemical Engineering), School of Chemical Engineering, University of Campinas.

M. Dias, M.P. da Cunha, R. Maciel Filho, A. Bonomi, C.D. Jesus, and C.E. Rossell, 2011, Simulation of integrated first and second generation bioethanol production from sugarcane: comparison between different biomass pretreatment methods. Journal of industrial microbiology & biotechnology, 38(8), 955-966.

M. Dias, O. Cavalett, R. Maciel Filho, and A. Bonomi, 2014, Integrated first and second generation ethanol production from sugarcane, Chemical Engineering Transactions, 37, 445-450.

P.R. Lennartsson, P. Erlandsson, and M.J. Taherzadeh, 2014, Integration of the first and second generation bioethanol processes and the importance of by-products, Bioresource technology, 165, 3-8.

R. Palacios-Bereche, A. Ensinas, M.Modesto, and S. Nebra, 2012, Ethanol production by enzymatic hydrolysis from sugarcane biomass–the integration with the conventional process. In Proceedings of the Ecos 2012–25th international conference on efficiency, cost, optimization, simulation and environmental impact of energy systems (pp. 26-29).

R. Smith, M. Jobson, and L. Chen, 2010, Recent development in the retrofit of heat exchanger networks, Applied Thermal Engineering, 30(16), 2281-2289.

S.N. Naik, V.V. Goud, P.K. Rout, and A.K. Dalai, 2010, Production of first and second generation biofuels: a comprehensive review, Renewable and Sustainable Energy Reviews, 14(2), 578-597.

V. Briones and A. Kokossis, 1996, A new approach for the optimal retrofit of heat exchanger networks, Computers & chemical engineering, 20, S43-S48.