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Best Practices for Small-scale Biomass Based Energy Applications in EU-27: The Case of Fermentative Biohydrogen Generation Technology

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A holistic approach for the optimum exploitation of biomass resources for food, energy and other products will provide the key for a sustainable bio-based future in EU. The small and medium scale applications are expected to play a crucial role in this direction in the future, due to their flexibility and adaptability to the regional and local conditions. The increasing biomass demand and socio-environmental concerns for bioenergy applications require the development of a framework of "Best Practices" for any new application entering the system, in order to ensure its techno-economic feasibility and socio-environmental sustainability. In the present work such a framework will be developed and presented, and it will be specified for the two-step fermentative biohydrogen generation technology. Under this point of view, a "Best Practice" guide is developed for each of the 4 previously selected, most suitable for the examined technology feedstocks, i.e. sugar beet, potato steam peels, barley straw and wheat bran. An outline with main points referring to both sugar beet and barley straw is presented in this work.

1. Introduction

One of the major challenges confronted by EU member countries, in order to attain the 20-20-20 target, is the acceleration of the implementation of biomass based energy applications (McCormick and Kaberger, 2007). The integration of such applications into the European energy system will rely on their techno-economical feasibility and socio-environmental sustainability. A holistic approach for the optimum exploitation of biomass resources for food, energy and other products will provide the key for a sustainable bio-based future in EU.

$C_6H_{12}O_6 + 6\ H_2O \rightarrow 6\ CO_2 + 12\ H_2$	$\Delta G_0' = +3$ kJ
$C_6H_{12}O_6 + 2\ H_2O \rightarrow 2\ CO_2 + 2\ CH_3COOH + 4\ H_2$ ***(hyper)thermophilic bacteria***	$\Delta G_0' = -206$ kJ
$CH_3COOH + 2\ H_2O \rightarrow 2\ CO_2 + 4\ H_2$ ***Photosynthetic bacteria***	$\Delta G_0' = +104$ kJ

Figure 1: Two step biomass to biohydrogen conversion process (Claassen, 2008)

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The increasing biomass demand and socio-environmental concerns for bioenergy applications require the development of a framework of "Best Practices" for any new application entering the system. The efficient system design will be presented in this study, as well as, the crucial point identification, through the application of this approach on a specific technological pathway, which is considered as suitable for small scale applications, i.e. 8000 dry t biomass/y. More specifically, the efforts which took place in this direction, within the framework of FP6 Integrated Project "HYVOLUTION (2006-2010)", where the biological production of hydrogen was studied (see Figure 1), will be summarised (*Claassen, 2008; Claassen et al., 2010*). Under this point of view, a "Best Practice" guide is developed for each of the 4 previously selected, most suitable for the examined technology feedstocks, i.e. sugar beet (SB), potato steam peels (PSP), barley straw (BS) and wheat bran (WB). The selection criteria and process were presented elsewhere (Diamantopoulou et al., 2007; Diamantopoulou et al., 2011; Diamantopoulou, 2012). In the present work the results for SB and BS are reported.

2. Methodology

Data which was either experimentally produced in lab scale or collected both at EU and regional level, for a series of crucial factors of implementation is summarized and presented for two of the promising feedstocks, i.e. sugar beet juice and barley straw, under the following 8 headlines:

- Potential – Geographical Distribution
- Typical plant type
- Logistics – Supply Chain
- Technology of pretreatment/hydrolysis
- Economics (biomass, pretreatment)
- Sustainability (environmental, social)
- Role of co-products
- Other key parameters

Multiple decision making and technological pathways assessment tools, which were developed throughout the project duration, were applied for mapping the optimum operation scenarios for each raw material as far as the techno-economic feasibility and socio-environmental sustainability dimensions are concerned. Throughout this process the driving forces and barriers for the implementation of the specific technology is identified, and the competition with other biofuel and biohydrogen generation technologies for feedstock availability is discussed. The regional application dimension, as well as the resource exploitation approach was assessed through the "South vs. North Europe" and "Best Practice vs. Maximum Resource Use" scenarios.

3. Results and discussion

3.1 Sugar Beet

Given that the specific biohydrogen generation system can be considered as being in direct competition with the sugar production industry (food supply), the potential estimation was based on the assumption that 10 % of the current production potential of EU-27 can be allocated to the 2-step biohydrogen generation plants. The beet composition for two typical EU beet producing countries is presented in Table 1 (Panagiotopoulos et al., 2010a):

Table 1: Composition of sugar beet

Component	Dutch (% Dry basis)	Greek (% Dry basis)
Sucrose	67	64
Cellulose	4	4
Hemicellulose	5	5
Lignin	0.9	1

Potential – Geographical Distribution. While considering the potential availability of sugar beet, the EU sugar regime, according which 7 to 10 % of the current sugar beet production is expected to be lost due to EU sugar reform should be also taken into account as a crucial factor increasing its future availability. The available biohydrogen generation potential based on the maximum pretreatment and conversion efficiency of the sugar beet sucrose content, under the above set conditions, is assessed as about 170 kt H_2/year for EU27 (Karaoglanoglou et al., 2008). The respective feedstock potential is dispersed throughout EU, around the area of the 106 currently operating sugar production plants. However, the competition by the bioethanol and biogas generation industry, which is based on a currently better established technology should be considered as a potential resource limiting factor. It should be noted that there are already 21 sugar beet based bioethanol plants in EU27, whereas the gradual introduction of small scale biogas generation plants is also expected (CEFS, 2012).

Typical plant type. The suggested plant type for this category of feedstock is the **add-on plants**, where the biohydrogen unit will be placed next to the sugar production unit, operating on a symbiotic basis, and fed by only a small portion of the sugar beet juice processed by the sugar unit. This approach will decrease the operational and supply chain costs of the biohydrogen generation units by allocating part of them to the main activity of the sugar industries.

Logistics – Supply Chain. The installation of the biohydrogen unit as an add-on one, next to the already existing sugar plant will exploit the already existing supply chain network of this plant. Furthermore, even in the regions where the sugar production unit was shut down due to EU sugar policy, the installation of larger stand-alone plants can benefit from the “know-how” of previously operating sugar production units, and the relevant agricultural background of the regions.

Technology of pretreatment. The recovery of the fermentable carbohydrates, which for the specific feedstock is mainly sucrose, requires the simple and well established technology of water extraction. As a consequence, the optimization of the fermentability of the obtained juice is the main technological target.

Economics (biomass, pretreatment). In the case of sugar beet, high biomass and low pretreatment cost is observed. The potential exploitation of economy of scale, of the sugar production plant for pretreatment/supply chain cost should be considered for the more efficient plant operation.

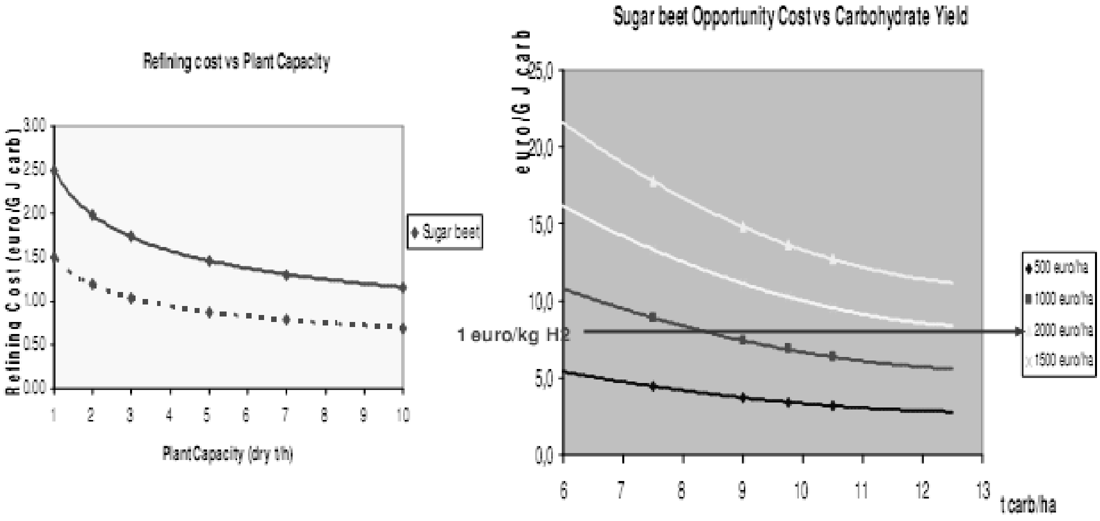

Figure 2: Optimization of the financial feasibility (Diamantopulou, 2012)

Sustainability (environmental, social). A large variation in the relevant index (BSI) can be observed depending on the regional conditions and agricultural practices. The targeted optimization objectives will define the configurations of the overall biohydrogen generation chain.

Role of co-products. The role of the co-products is crucial for the feasibility and sustainability of the system, given that a large part (weight base) of the initially produced beet is collected either as field (leaves) or process co-product (pulp). Besides the already existing application fields which exploit the respective co-products produced by the sugar industry, there is a large number of potential applications with high added value, which can contribute to the improvement of feasibility and sustainability indices of the hydrogen plant.

Other key parameters. Further points which should be concerned during the design and operation of a sugar beet-to-hydrogen supply chain and production plant follow:

- Irrigation requirements in sugar beet production,
- Social impact through the employment and the replacement of the currently closed down sugar factories throughout EU,
- Seasonality and short time window for the beet collection, handling and respective plant supply.

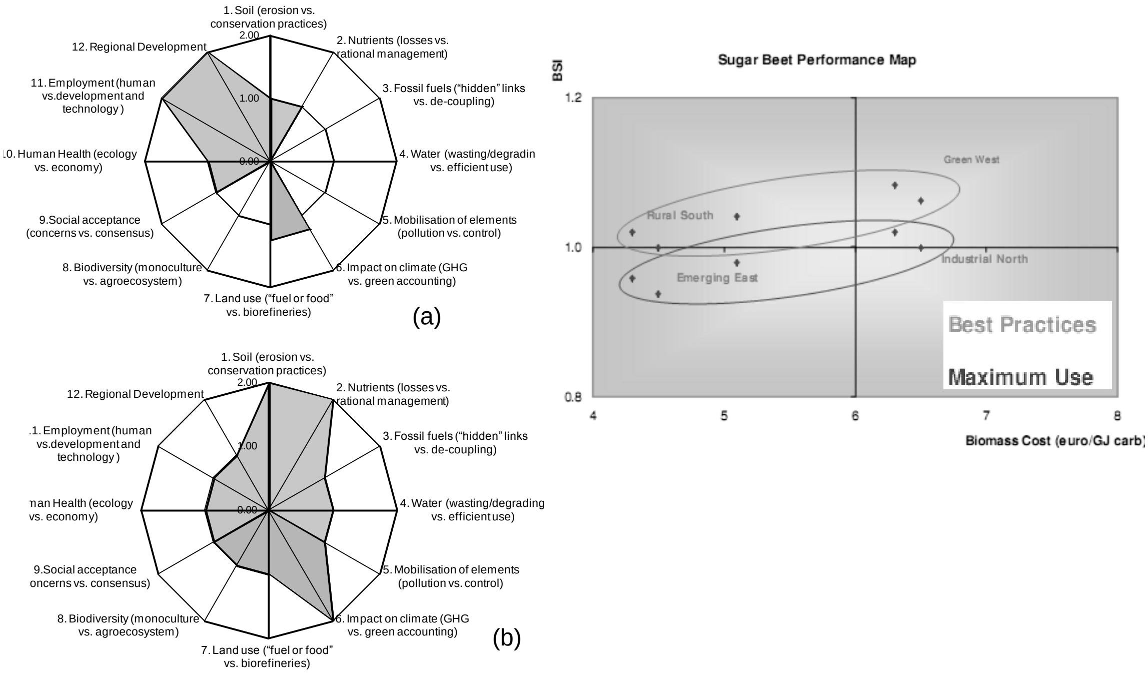

Figure 3: Biomass sustainability index for “Maximum use” (a) and “Best Practices” (b) scenarios; and its correlation with biomass cost and regional conditions (Diamantopoulou, 2012)

3.2 Barley straw

The use of this feedstock can be considered as being in competition with animal feed and other energy technology markets (e.g. gasification, pellets etc.), and its availability will depend on the demand and accessibility. Furthermore, straw of different origin (from wheat or other cereals, which is largely produced) should be considered as potential future candidate feedstock which will benefit from the infrastructure built for barley straw. It should be noted that barley straw as a feedstock for Hyvolution technology, has the most complex composition (see Table 2), among the selected feedstocks since it is composed by cellulose and hemicellulose which have to be hydrolysed, and lignin which should be removed (due to its inhibitory activities).

Table 2: Composition of barley straw (Panagiotopoulos et al., 2010b)

Component	Amount % (Dry basis)
Cellulose	37.2
Hemicellulose	24.4
Acid-insoluble lignin	16.1
Ash	6.4

Potential – Geographical Distribution. Maximum annual hydrogen generation potential, based on the EU27 barley production and the overall carbohydrate content of barley straw is about 2.8 Mt H_2/year. The actually available potential, based also on the current technology level for the pretreatment and conversion technology is assessed to be about 1/3 of this amount. It presents the largest dispersion, among the four selected Hyvolution feedstocks, both at country level and within the regions, since it is usually available at farm level.

Typical plant type. The above mentioned large dispersion of the feedstock sources and its availability at farm-site favors the stand alone plant for decentralized, rural applications. Larger centralized plants should not be excluded, due to the low moisture content of the feedstock and economy of scale benefits of the rather complicated pretreatment process, especially at “Rural South” regions.

Logistics – Supply Chain. It should be treated as an independent, energy crop, since its separation from the main farm product (barley grain) takes place in the farm and it can follow a separate and independent handling and logistics route in case it will be utilized in biohydrogen generation.

Technology of pretreatment/hydrolysis. Mild acid pretreatment/mild-alkaline pretreatment and subsequent enzymatic hydrolysis are the pretreatment processes applied to this feedstock. Some of the experimental results concerning the carbohydrate recovery through the pretreatment processes, as well the effect of the potential inhibitors, are provided in Figure 4 *(Panagiotopoulos et al., 2010b).*

Component	(g/l)
Glucose	11.8
Xylose	4.7
Arabinose	0.7
Acetic acid	1.2
Hydroxymethylfurfural (HMF)	0.1
Furfural	0.2

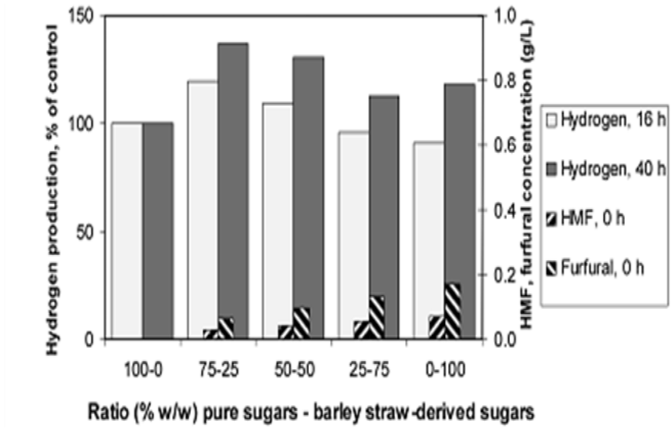

Figure 4: Hydrolysate composition and effect of the concentration of HMF and furfural on the fermentability of barley straw. The data on HMF and furfural are based on measurements of the concentration in the culture media at the start of the fermentation. The data on hydrogen are based on measurements of its concentration in the headspace of the flasks after 16 and 40 h of fermentation.

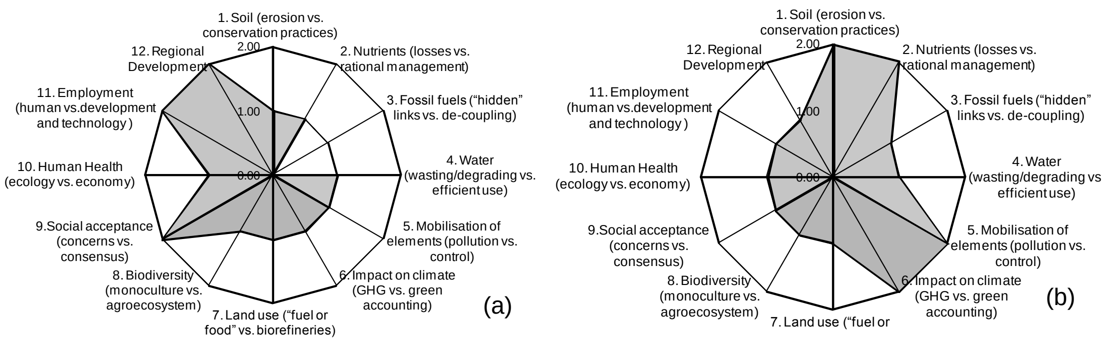

Figure 5: Biomass sustainability index for “Maximum Use” (a) and “Best Practices” (b) cases

Economics (biomass, pretreatment). Low biomass, quite high pretreatment cost, mainly due to the cost of enzymes, chemicals & energy needs, characterize the specific feedstock. Furthermore, the handling and transportation costs are quite low due to the low moisture content of the feedstock and the suggested proximity of the pretreatment/conversion plant to the farm site.

Sustainability (environmental, social). According to the assessment of the sustainability index BS-to-biohydrogen plants tend to increase the overall system sustainability, when it is compared with the non-use alternative, in both Best Practice and Maximum Use options.

Role of co-products. The application of pulp either as animal feed substitute or additional energy resource will play a crucial role in the further improvement of the plant's performance, given that both the lignin, recovered through the pretreatment, and non hydrolysed carbohydrate constitute a large portion of the initial dry biomass. .

Other key parameters. The reduction of enzymatic load, chemicals and energy needs, with simultaneous increase of the hydrolysis efficiency and fermentability is crucial for the feasibility of the system. With respect to the fermentability of the hydrolysates, the limitation of the release of fermentation inhibitors during pretreatment is of major importance for good fermentability.

4. Conclusions

SB as a readily available, due to the conditions created by the EU sugar reform, and efficiently fermentable raw material is expected to play a crucial role in the short term introduction of the examined hydrogen generation technology. Its already existing supply chain and handling infrastructure will further favour its potential exploitation. BS, on the other hand, being a farm residue, with more demanding pretreatment and conversion technology, should be seen as a medium to long term option, under the condition that both efficiency and co-product value addition will be improved. The application of the holistic approach presented above, provides the necessary methodological tools for the assessment and selection of the optimum raw material, technology and resource exploitation combinations under regional conditions.

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