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BIOSYNFUEL PRODUCTION VIA SLOW OR FAST PYROLYSIS? A LIFE-CYCLE ENERGY DEMAND AND GLOBAL WARMING APPROACH

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ABSTRACT

Two pyrolysis-based biosynfuel pathways are compared via life cycle assessment regarding their cumulative non-renewable energy demand (CED) and global warming potential (GWP). An avoided burden approach is used for dealing with the different products. Biosynfuels are produced by slow or fast pyrolysis of short-rotation poplar followed by hydrotreating of the obtained bio-oil. Key inventory data of both energy systems are derived from Aspen Plus® simulations. The fast pyrolysis-based system shows higher fossil energy savings but lower GWP reduction, indicating a trade-off situation between the two impact categories. Overall, biosynfuel production by slow pyrolysis is found to be competitive under CED and GWP aspects and can be considered as an alternative to fast pyrolysis systems.

INTRODUCTION

Second generation biofuels permit the use of residues and lignocellulosic energy crops as feedstock and are therefore seen as an appropriate alternative to conventional biofuels (EC, 2012). Thermochemical decomposition by pyrolysis is one of the available options for processing lignocellulosic biomass (Venderbosch & Prins, 2010). The pyrolysis products are char, bio-oil and gas, with the obtained amounts of each fraction varying with feedstock type and process conditions (slow pyrolysis maximizing char and gas or fast pyrolysis maximizing liquid yields). The liquid fraction, the bio-oil, can be upgraded to high-quality biofuels by hydrotreating in biorefineries (Bridgwater, 2012).

Few publications on the environmental performance of pyrolysis-derived biofuels can be found in literature (Han et al., 2011, 2013; Hsu, 2012; Iribarren et al., 2012a, 2012b; Kauffman et al., 2011). Furthermore, existing studies of slow pyrolysis (SP) focus on heat and electricity generation or on charcoal production (Brown et al., 2011), while biofuels are produced exclusively via fast pyrolysis (FP). However, SP can be an option for biosynfuel production if a profitable use can be given to the co-produced char.

MATERIALS AND METHODS

In this work, two biorefinery scenarios for the production of synfuels via FP and SP are contrasted by means of life cycle assessment (LCA). Bio-oil is produced via fast and slow pyrolysis of hybrid poplar and then upgraded to gasoline and diesel in the biorefinery. The considered impact categories are cumulative non-renewable energy demand (CED) and global warming impact potential (GWP) according to the IPCC guidelines for a 100-year time horizon. An input-oriented functional unit (FU) is defined: 1 kg of poplar wood chips with 50% moisture content.

Inventory data for the conversion processes are derived from Aspen Plus® simulations. The pyrolysis process includes biomass pre-treatment, pyrolysis, product recovery, and gas combustion to produce the heat required by the pyrolysis reactor. The upgrading process contains a two-stage hydrotreatment (HT), product separation and distillation, hydrocracking (HC) of the heavy oil fraction, and steam reforming of light off-gas and natural gas to produce the hydrogen required by HT and HC. Remaining inventory data concerning cropping and transport are taken from earlier works (Iribarren et al., 2012a, 2012b), while background data come from the ecoinvent® database. Table 1 presents a selection of key inventory data of both systems. The assessment follows a cradle-to-gate approach, covering from the production of the feedstock to the refinery gate. Capital goods are excluded from the study.

Table 1. Selected inventory data of the two pyrolysis-based systems for biosynfuel production (values per FU).

Selected inputs	FP-based	SP-based	Selected outputs	FP-based	SP-based
Poplar chips (kg, wet)	1	1	Gasoline (kg)	0.075	0.023
Transport (t·km)	0.210	0.179	Diesel (kg)	0.071	0.026
Electricity (kWh)	0.229	0.183	Char (kg)	0.040	0.147
Natural gas (MJ)	1.576	0.604	Steam (MJ)	0.523	0.120
			CO_2 to air (kg, direct)	0.249	0.295

Both the pyrolysis and the upgrading processes are multifunctional. Four different products are obtained: gasoline, diesel, pyrolysis char, and process steam (the latter produced by cooling the hydrotreating reactors). In order to account for all products, a system expansion approach based on avoided burdens is used. As the evaluation of the global impact avoided by the processes is of principal interest for an input-related assessment, this is considered the most coherent method. The main challenge is the identification of the product that most probably would be replaced. This is easy for mass products with an existing market, but difficult for niche products such as pyrolysis char. In this work, biosynfuel is supposed to substitute fossil gasoline and diesel, steam substitutes process steam produced in a heat plant with natural gas, and the pyrolysis char is assumed to be used for energy purposes substituting fossil coal.

RESULTS

Figure 1 shows the GWP and CED results of both pyrolysis-based systems. The biofuel scenarios show GWP reductions of 0.549 kg CO_2 eq (SP-based) and 0.503 kg CO_2 eq (FP-based) per FU. Negative values are obtained as a result of the system expansion approach used through this study, where the products derived from the biomass all replace energy products from fossil origin.

While SP is found to give better GWP results, FP shows a more favourable performance in terms of CED. The differences between FP and SP systems stem principally from the external inputs required by the processes, with the most important contributors being electricity consumption, transport and natural gas consumption. Nevertheless, no key contributor with a decisive impact on the differences can be identified.

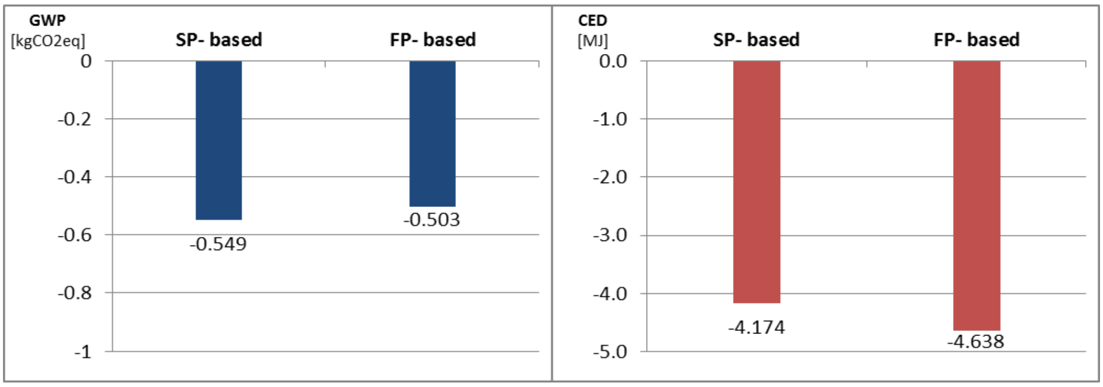

Figure 1. GWP and CED results of the two pyrolysis-based systems (values per FU).

DISCUSSION

The results obtained for the two assessed categories lead to opposite recommendations on the best-performing system. The FP-based system shows higher CED savings, but lower GWP reduction when compared to the SP-based system. This results in a trade-off between fossil energy savings and GWP reduction, which impedes the unambiguous identification of the best pathway under environmental aspects.

The SP-based system shows a surprisingly good performance in spite of the much lower synfuel yields achieved. This can be explained by the lower input required for the upgrading process. Lower bio-oil yields per FU lead to a lower amount of bio-oil to be upgraded and hence to lower overall inputs required for the processing plant. The SP plant itself is on the other hand less energy efficient than the FP plant and leads to a reversed picture under CED aspects. Nevertheless, although environmentally recommendable, the feasibility of a biofuel process based on SP can be questioned, as normally economic aspects would favour the FP process due to its much higher synfuel yields.

The system expansion approach gives comprehensive results for the given assessment and avoids the problem of assigning a common value to the different products as required for allocation. Nevertheless, the choice of the substituted product is often difficult and can be rather arbitrary, especially if no established market exists for the co-product (e.g., pyrolysis char). Using the char for substituting other products such as conventional charcoal could change the results significantly, as the GWP savings attributed to the avoided production of coal and steam make up significant shares of the overall GWP reduction. An assessment of the impacts of different substitution assumptions could be interesting in this regard.

CONCLUSIONS

Both biofuel processes show similar results in the two assessed categories. The FP process requires more external inputs and hence shows slightly lower GWP reduction, while the SP process scores worse under CED aspects due to the lower efficiency of the SP plant.

Although yielding much less biosynfuel per unit of biomass processed, SP-based systems can compete with FP-based ones under environmental aspects. They could hence be considered an environmentally favourable alternative for biofuel production.

REFERENCES

Bridgwater, A. V. (2012). Review of fast pyrolysis of biomass and product upgrading. *Biomass and Bioenergy*, 38(null), 68–94. doi:10.1016/j.biombioe.2011.01.048

Brown, T. R., Wright, M. M., & Brown, R. C. (2011). Estimating profitability of two biochar production scenarios: Slow pyrolysis vs. fast pyrolysis. *Biofuels, Bioproducts and Biorefining*, 5(1), 54–68. doi:10.1002/bbb

EC Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (2012). Brussels: European Commission.

Han, J., Elgowainy, A., Dunn, J. B., & Wang, M. Q. (2013). Life cycle analysis of fuel production from fast pyrolysis of biomass. *Bioresource Technology*, *133C*(null), 421–428. doi:10.1016/j.biortech.2013.01.141

Han, J., Elgowainy, A., Palou-Rivera, I., Dunn, J. B., & Wang, M. Q. (2011). *Well-to-wheels Analysis of Fast Pyrolysis Pathways with GREET*. Oak Ridge.

Hsu, D. D. (2012). Life cycle assessment of gasoline and diesel produced via fast pyrolysis and hydroprocessing. *Biomass and Bioenergy*, 45(null), 41–47. doi:10.1016/j.biombioe.2012.05.019

Iribarren, D., Peters, J. F., & Dufour, J. (2012a). Life cycle assessment of transportation fuels from biomass pyrolysis. *Fuel*, 97(null), 812–821. doi:10.1016/j.fuel.2012.02.053

Iribarren, D., Peters, J. F., Petrakopoulou, F., & Dufour, J. (2012b). Well-to-Wheels Comparison of the Environmental Profile of Pyrolysis-Based Biofuels. *20th European Biomass Conference and Exhibition*. doi:10.5071/20thEUBCE2012-5AV.1.7

Kauffman, N., Hayes, D., & Brown, R. (2011). A life cycle assessment of advanced biofuel production from a hectare of corn. *Fuel*, 90(11), 3306–3314. doi:10.1016/j.fuel.2011.06.031

Venderbosch, R., & Prins, W. (2010). Fast pyrolysis technology development. *Biofuels, Bioproducts and Biorefining*, 4(2), 178–208. doi:10.1002/bbb.205