SWEDISH KNOWLEDGE CENTRE FOR RENEWABLE TRANSPORTATION FUELS

# ETHANOL PRODUCTION IN BIOREFINERIES USING LIGNOCELLULOSIC FEEDSTOCK – GHG PERFORMANCE AND ENERGY BALANCES

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## INTRODUCTION

Current trends in the development of biofuel production systems are towards maximization of high-value product output as well as an increased focus on the sustainability of biomass feedstock production. Co-production of products such as energy, food and chemicals in so called biorefineries is a promising alternative for optimized utilization of biomass. Lignocellulosic materials such as straw and other agricultural or forestry residues have been identified as attractive alternatives feedstock because of their high availability and lower resource demand. In Sweden both ethanol and biogas are used as transportation fuels, co-production of these fuels increases the biofuel conversion efficiency compared to separate production systems.

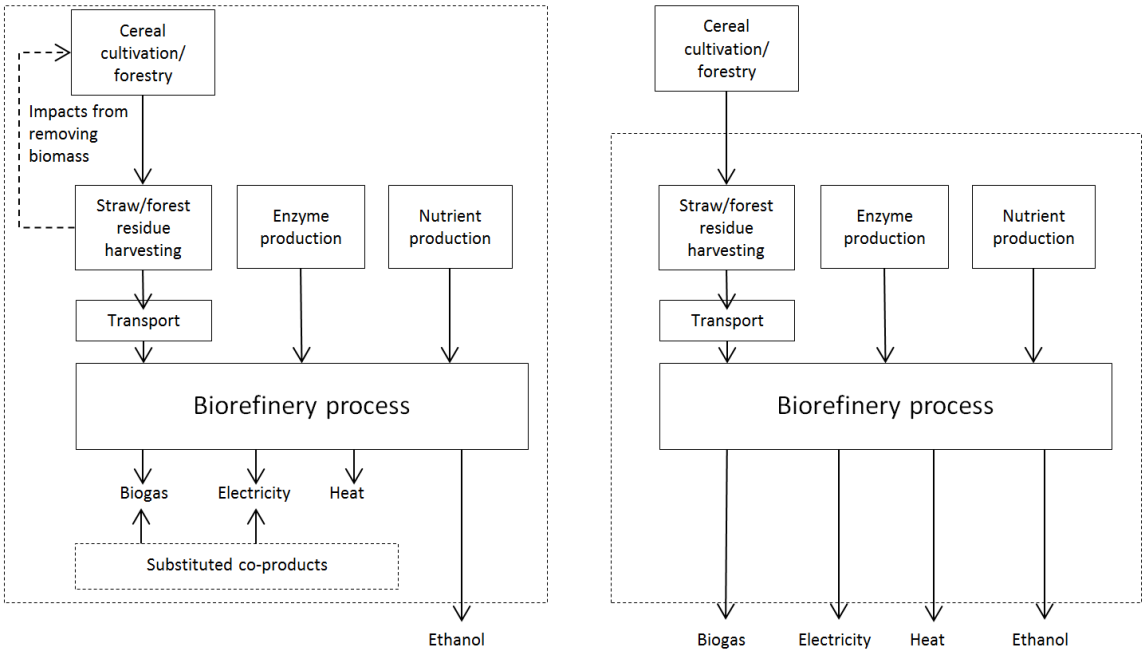
Biorefineries producing a variety of high-value co-products, pose particular challenges for sustainability assessment methodologies including handling of co-products and definition of functional unit. Therefore there is a need for a discussion on critical methodological issues in LCA, for biofuels in general and specifically for biorefinery systems. Further, LCA as an environmental evaluation tool is increasingly used in policies, with methodological rules for the calculations e.g. as in

the EU Renewable Energy Directive (RED). Using different type of methodology can give large variation of results. With a predicted increasing share of biofuels produced in biorefineries, these methodological challenges needs to be addressed.

This project is a continuation of the f3 project *Sustainable performance of lignocellulose-based ethanol and biogas co-produced in innovative biorefinery systems* in which the greenhouse gas (GHG) performance of ethanol and biogas co-produced in biorefineries from a lignocellulosic feedstock were calculated, applying the RED methodology. In the present project we expand the analysis and compare the methodology to the standard ISO LCA-methodology.

## AIM

The aim of the present study was to analyze the GHG performance and energy balance of ethanol co-produced with biogas and electricity in a biorefinery. Two lignocellulosic materials relevant for the Swedish context, straw and forest residues, were considered. Results from the GHG balance are discussed in relation to the GHG performance of the fuels calculated using the RED methodology. Additionally, analyzes were performed to examine the importance of significant methodological choices and critical parameters, with the objective to contribute to the discussion about the LCA practice for assessing environmental performance of energy production from lignocellulosic biomass and co-production in biorefineries.




**Overview of the system studied with the system boundaries of Method I (ISO) to the left and the system boundaries of Method II (RED) to the right.**

## METHOD

Life cycle assessment was used to evaluate two large-scale hypothetical biorefinery systems, one utilizing straw as feedstock (the straw scenario) and one using forest residues (the forest residue scenario). Two calculation methods have been used. Calculation Method I (ISO), where ethanol is considered to be the main product, system expansion is used to allocate the impact between co-

products this is following the recommendations in the ISO standard of LCA (ISO, 2006). Calculation method II (RED) follows the calculation procedures in the RED with energy allocation based on lower heating value (LHV). System boundaries differed between the studies, Method I (IOS) included soil organic carbon (SOC) changes due to residue removal, while this was not included in calculation Method II (RED) since according to the RED environmental impact from using residues from agriculture and forestry could only be included from collection and onwards. The functional unit was 1 MJ ethanol in Method I (ISO) and 1 MJ ethanol, biogas or electricity in Method II (RED). In the RED methodology the same results are achieved for all energy carriers since energy allocation is used.

## RESULTS

The GHG performance of 1 MJ ethanol was found to be 43.6 g $CO_2$e and 15.6 g $CO_2$e using Method I (ISO) for straw and forest residues respectively. Using Method II (RED) the GHG performance was 17.4 g $CO_2$e and 16.1 $CO_2$e per MJ ethanol produced, for the straw and forest residue scenario respectively. SOC changes hade the largest impact in Method I (ISO), while the impact from the use of enzymes and were most significant in Method I (RED). The energy balance shows MJ primary energy ($MJ_{prim}$) used per MJ ethanol or bioenergy produced. Using Method I (ISO) the energy use was low for the straw scenario, 0.046 $MJ_{prim}$ per MJ ethanol, for the forest residue scenario the energy use was even negative -0.693 $MJ_{prim}$ per MJ meaning that for every MJ ethanol produced 0.693 MJ fossil energy is "saved". These low values for the energy balance is due to co-product substitution. When the energy balance was calculated with Method II (RED) the straw scenario uses 0.22 $MJ_{prim}$ primary energy per MJ ethanol produced, the corresponding value for the forest residue scenario was 0.21 $MJ_{prim}$.

## DISCUSSION AND CONCLUSIONS

Co-production of fuels such as ethanol and biogas can improve biomass use efficiency and lead to environmental gains. This study assessed the GHG performance and energy balance of ethanol co-produced with biogas using two different calculation methods. The results varied depending on calculation method, where the co-product handling and the inclusion of upstream impact from residue harvesting explain most of the differences. Important life cycle steps were process inputs, in particular enzymes as well as SOC changes while harvesting and transports of the feedstock had minor importance.

The results show that the choice of allocation method was important and significantly altered the results. Generally system expansion can result in large credits especially when high value co-products such as upgraded biogas are produced. Ultimately the importance of the substitution effect will depend on the production mix in the biorefinery. With the introduction of biorefineries with diverse sets of co-products, there might be a need to reconsider the use of energy allocation as the default method in the RED. Energy allocation does not show the benefit of the co-products, which is especially true for products that not are energy carriers. There are examples of other greenhouse gas accounting methods such as the North American Renewable Fuel Standard (RFS) and the Californian Low Carbon Fuel Standard (LCFS) that uses system expansion instead of energy allocation for allocating impacts. This might be a viable alternative for assessing biorefinery products.

The results indicate that if SOC changes were included in Method II (RED), the ethanol would only meet the current target of 35% reduction from a fossil fuel reference set in the RED. Although, SOC change rates are uncertain and depend on factors such as local conditions and time aspects, this is also true for other SOC changes, currently included in the RED. Therefore, we believe that including upstream impact from residue harvesting in in the RED would be favourable, and to carefully consider including SOC changes due to residue recovery.

Several sensitivity analyses were performed. These analyses showed that input data hade great impact on the total results. However, it was only in one case that the total GHG emissions per MJ ethanol were higher than a fossil fuel reference (83.8 g $CO_2$-eq $M^{-1}$). This was for Method I (ISO) when a time perspective of 20 years, the short-term perspective, was used for the SOC changes. Further, the results sensitivity analysis indicate that if SOC changes of 75 g and 90 g C $kg^{-1}$ DM straw and forest residues, respectively were included in Method II (RED), the ethanol in both scenarios would only meet the current target of 35% reduction from a fossil fuel reference set in the RED and not the forthcoming targets. The real enzyme dose for ethanol production from straw and forest residues in these kind of large scale biorefineries is not known. A doubling of the dose increased the GHG emissions from 100-36%. It is clear from the present study that enzyme production is a significant contributor to the GHG and energy balance of lignocellulosic ethanol. Improved enzyme technology to lower the enzyme doses is therefore desirable, for large scale plants on-site production of enzymes to enable the use of bioenergy in the manufacturing could be one option.

## PROJECT OUTCOMES

A manuscript based on the results of this project has during spring of 2014 been accepted for publication in **Journal of Cleaner Production**.

Conference presentation of parts of the results: Karlsson, H., Ahlgren, S., Börjesson, P., Hansson, P-A. Comparison of LCA methods for evaluating biorefinery products. Abstract and poster in 19th SETAC LCA Case Study Symposium, 11-13 November 2013, Rome, Italy. http://www.eventure-online.com/eventure/publicAbstractView.do?id=230347&congressId=7224