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RESEARCH AND DEVELOPMENT CHALLENGES FOR SWEDISH BIOFUEL ACTORS – THREE ILLUSTRATIVE EXAMPLES

Improvement Potential Discussed in the Context of Well-to-Tank Analyses

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This study has been performed as a pilot project in the consolidating phase of developing a Centre of Excellence for renewable fuels, focusing on technology, system aspects and climate impact at the production stage, f3, fossil free fuels.

1 INTRODUCTION

The energy use for Swedish transportation is currently dominated by petroleum-based fuels, mainly gasoline and diesel. Because of climate and energy security of supply issues, the transport sector is now facing major change. Among the renewable fuels, biofuels have currently gained strong political support, both in the EU and Sweden. Since the EU has set a target for the use of renewable fuels in the transportation sector stating that all EU member states should use 10% renewable fuels for transport by 2020 (European Parliament and Council, 2009), there is a potential for an enormous market for biofuels during the coming decade. Though, a significant increase in the production and use of renewable fuels represents a considerable challenge. To avoid increasing production of biofuels based on agriculture crops that require considerable use of arable area, focus is now to move towards more advanced biofuels that can be produced from biomass feedstocks associated with a more efficient land use, so called second generation biofuels

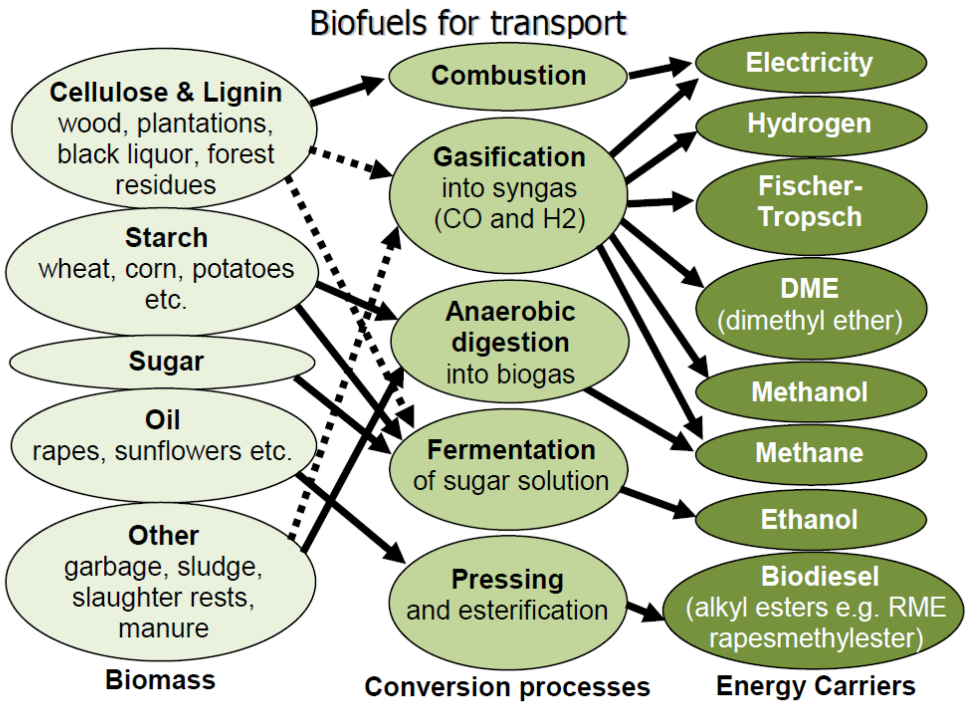

Figure 1. Biomass can be divided into groups depending on chemical composition of the biomass. Different elements are better suited for different processes that convert the biomass into energy carriers useful for the transportation sector. Commercially available options are marked with solid lines, while processes still on demonstration plant level are marked with dotted lines.

In Sweden the conditions for biomass production are favorable and we have promising second generation biofuels technologies that are currently in the demonstration phase.

Climate benefits and greenhouse gas (GHG) balances are aspects often discussed in conjunction with sustainability and biofuels. Every now and then voices are heard in media claiming that biofuels have worse environmental impact compared to diesel and gasoline. This is true for a fraction of the biofuels on the market but not for the majority of the biofuels. The total GHG emissions depend on the entire fuel production chain, mainly from the agriculture or forestry feedstock systems and the manufacturing process. To compare different biofuel production pathways it is essential to conduct an environmental assessment using a well to wheel (WTW) analysis methodology.

This study identifies research and development challenges for Swedish biofuel actors based on literature studies as well as discussions with the researchers themselves. We wanted to learn about ongoing research and find improvement potentials, potential tradeoffs between different improvement options as well as if there are barriers to overcome or technology that needs to be proven in large scale before the fuel production can achieve commercial status. To achieve large scale commercial status key challenges to overcome are (i) the risk connected to scaling up into industrial size and then (ii) in large scale show that the plant can operate according to calculated heat and material balances and (iii) achieve high availability.

2 CASE STUDIES

We have chosen to focus on three biofuel production technology options that are currently in the demonstration phase: cellulose based ethanol, methane from gasification of solid wood as well as DME from gasification of black liquor. This is done with the purpose of identifying research and development potentials that may result in improvements in the well to tank (WTT) emission values. WTT is limited to the fuel cycle, and chosen as the method since the fuel cycle, together with the vehicle operation stages, is the life cycle stage with the greatest difference in energy use and GHG emissions compared to conventional fuels. In addition to the three case studies, we have chosen to discuss improvement potentials for the agriculture and forestry part of the WTT chain.

The overall study aims at, in the context of WTT analyses, (i) identifying and discussing improvement potentials regarding biomass supply, including agriculture/forestry, (ii) increasing the knowledge about the complexity of biofuel production, and (iii) identifying and discussing improvement potentials regarding energy efficiency and GHG emissions for three biofuel production cases. The scope is limited to discussing the technologies, system aspects and climate impacts associated with the production stage.

2.1 POTENTIALS FOR EMISSIONS REDUCTIONS WITHIN THE AGRICULTURE/FORESTRY PART OF THE WTT CHAIN

The agriculture/forestry part of the WTT chain is in general significant, sometimes dominating the emissions from biofuels. The net energy balance and GHG emissions from producing biofuels depend on the amount of, and type of, fuel used in tractors and other machines, the amount of, and type of, chemicals added to the process (e.g. pesticides and fertilizers) as well as the harvest method, soil type and from differences in calculation methodology. Our study shows that changing the use of diesel to low-CO2-emitting fuels, changing to more fuel-efficient tractors, more efficient cultivation and manufacture of fertilizers as well as improved fertilization strategies can lead to emissions reductions. Furthermore, the cultivation of annual feedstock crops could be avoided on land rich in carbon.

New agriculture systems could be introduced that lower the demand for ploughing and harrowing. Recent research indicates that farmers could produce more, and reduce the loss of soil carbon, by using simple techniques of drilling seed into the soil with little or no prior land preparation, a method referred to as “Zero tillage”. The soil carbon will then be protected by the blanket of leaves, stems and stalks from the previous crops. Zero tillage systems provide higher yields at less cost and less emissions, both from less direct CO2 emissions (from the soil) and less use of tractor fuels (FAO, 2001).

Most WTT analyses assume a certain biomass yield per hectare. However, discussions on how to improve the yield from energy crops and the conversion efficiency are ongoing. The construction of, e.g., synthetic genomes, may lead to extraordinary advances in the ability to engineer microorganisms for vital energy and environmental purposes (Venter, 2003). Synthetically produced organisms (cell level bio-factories) will enable new direct methods of bio-engineered industrial production, such as the production of bioenergy, including ethanol and hydrogen as alternative fuels or substitutes for petrochemicals (Synthetic Genomics, 2009).

Another option to reduce GHG emissions from forestry and agriculture includes introducing new types of crops with a higher content of cellulose. In real world, a plant sometimes spontaneously produces 75% cellulose instead of normally approximately 45%. When this gene is identified, it may be possible to use biotechnology on energy crops, increase the crop's cellulose biosynthesis, and thereby improve the area efficiency of for instance cellulosic ethanol (Sundberg, 2002).

As the case study shows there are large uncertainties in the greenhouse gas emissions related to agriculture and forestry used to produce biofuels. Local and specific characteristics such as soil type, (agricultural method) and N2O emissions may have a large impact on the final result. However, radical developments in biomass and biofuel production may occur in the future and consequently reduce the greenhouse gas emissions from the agriculture/forestry part of WTT analyses.

2.2 CASE STUDY: CELLULOSE BASED ETHANOL

We have found that second generation ethanol, with co-production of agriculture based ethanol, biogas, electricity, heat and/or wood pellet, have a promising role to play in the development of sustainable biofuel production systems. The design of optimal second generation ethanol production systems depends on available raw materials, heat sinks, demand for biogas as vehicle fuel and existing agriculture based ethanol plants suitable for integration. Ethanol production systems could thus be far more complex and intelligently designed than previous studies show, depending on the huge number of combinations of process integration options and individual measures. This makes second generation ethanol production systems unique in some way and not directly comparable with other second generation biofuels. This also makes it impossible to draw general conclusions regarding WTT values and GHG balances of second generation ethanol, since the environmental performance of individual systems may vary significantly.

A positive aspect of this complexity, and large number of design options, is that the production system, based on the specific local conditions, could be designed quite differently to optimize the economic conditions and maximize profitability. A negative aspect of the complexity may be that the knowledge, required to develop the most optimal production systems, will be large. Furthermore, several actors from different competence areas are needed and have to be involved in the development of optimally designed second generation ethanol production systems. This may be a potential barrier with similar importance as potential barriers of technical nature.

A more integrated work is needed between different research fields, such as process development and configuration as well as energy and environmental systems analysis to optimize future production systems regarding economical, energy efficiency and environmental perspectives.

2.3 CASE STUDY: METHANE VIA GASIFICATION OF SOLID BIOMASS

Comparing production of methane via gasification with the production of other synthetic fuels, methane has a great advantage of having a high efficiency in respect to biomass converted into methane. The process can, however, be further improved within the gas up-grading section, including gas cleaning and gas conditioning, to obtain an even more efficient process. Catalysts can be improves for selective tar cracking (e.g., it is important not to crack the methane already produced in the syngas), and new gas separation techniques (e.g., aromatic compounds have to be removed) to facilitate the use of air oxidation agent instead of oxygen in the gasifier. There is a need for testing the integrated process under realistic conditions, both at atmospheric and pressurized gasification conditions.

Both the upstream atmospheric steam-blown indirect gasification (e.g., the Güssing and GoBiGas plants) and the direct pressurized oxygen-blown gasification (e.g., the Värnamo plant) with downstream methanation routes are the most promising options for SNG production from biomass. The fact that the indirect technology does not require an oxygen plant is a positive aspect of this technology. In combination with downstream methanation, SNG can reach production efficiencies up to approximately 70% (on lower heating value basis).

The up-scaling potential of the indirect gasification technology is less than the direct pressurized oxygen-blown gasification, due to the complicated heat exchange between the gasifier and the combustor. This makes the indirect technology mainly suitable for decentralized SNG plants (less than 100 MWth). In contrary, the direct pressurized oxygen-blown gasification will be more suitable for centralized applications (larger than 100 MWth).

Apart from high yield and good WTT values another important advantage is the expected high price for synthetic natural gas (SNG).

2.4 CASE STUDY: DME VIA GASIFICATION OF BLACK LIQUOR

Using black liquor as a raw material for DME or methanol production, compared to other biofuel production options, has the advantages of that black liquor is already partially processed and exists in a pumpable, liquid form, and that the process already is pressurized, which enhances fuel production efficiency. Another advantage is that modern chemical pulp mills have a developed infrastructure for handling large amounts of biomass. If black liquor is gasified, and the pulp mill is compensated for the energy loss by a (larger) biomass boiler for steam and electricity production, motor fuels are indirectly produced from low-cost solid biomass.

Although the technology has been proved working in general, and some black liquor gasification processes have reached commercial or near-commercial status, the process can be further improved in e.g., the DME/methanol yield, material and energy savings, and CO2 emissions reductions. However, since the processes are complex most of the improvement potentials also come with technical or economical tradeoffs.

One example of such tradeoff is that the yield of the synthesis gas depends on the dry solids content of the black liquor. Increasing the dry solids content would benefit the DME yield, but high dry solids content is technically challenging since the black liquor still needs to be fluid. The risk of process problems will increase. Another example is that the heat recovery depends on the process pressure. Higher pressure increases the amount of heat that can be recovered as steam, leading to that less imported fuel is needed. It is, however, technically challenging to increasing the pressure and current materials are not tested for that.

Performance of black liquor gasification is also dependent on the characteristics of the host mill and level of process integration.

3 OVERALL DISCUSSION AND CONCLUSIONS

In this study we have focused on three biofuel production technology options, which currently are in demonstration phase (cellulose based ethanol, methane from gasification of solid wood as well as DME from gasification of black liquor), to identify research and development potentials that may result in improvements in the WTT values. We have also discussed improvement potentials for the agriculture and forestry part of the WTT chain.

Although quantitative improvement potentials are given in the three biofuel production cases, it is not obvious how these potentials would affect WTT values. Difficulties are first and foremost related to that the biofuel production processes are complex, e.g. there is not necessarily a linear relation between two parameters. Also, there is no one alone standard method for WTT analysis. It is further challenging how to combine the different improvement potentials, since improvements in one area of the process might increase or decrease the improvement potentials in other areas of the process. Moreover, the improvement potentials depend on which base case you compare with, e.g. if best available technology is assumed. To be able to compare how the improvement potentials affect the WTT-values, completely new WTT-values, taken the entire process into account, needs to be calculated which lies outside the scope of this study. The improvement potentials are instead discussed qualitatively. From the entire study we have come to agree on the following:

- Research and development in Sweden within the three studied second generation biofuel production technologies is extensive.
- In general, the processes within the three cases work well at pilot and demonstration scale, and are now in a phase to be proven in large scale.
- There is still room for improvement although some processes have been known for decades.
- The biofuel production processes are complex and site specific, and process improvements need to be seen and judged from a broad systems perspective (both within the production plant as well as in the entire well-to-tank perspective).
- Enhanced environmental performance can be achieved from energy integration, both within the process as well as from integration with other industries. Such solutions might be unique for each biofuel production plant.
- From the political ambitions (both within EU and Sweden) it is clear that the demand for renewable fuels will significantly increase during the coming decade. This will most likely result in opportunities for a range of parallel biofuel options.
- The studied biofuel options all represent second generation biofuels. The systems are complementary technologies and all three options can be part of the solution to meet the increased renewable fuel demand.
- The process of conducting this study is worth mentioning as a result itself, i.e. that many different actors within the field have proven their ability and willingness to contribute to a common report, and that the cooperation climate was very positive and bodes well for possible future collaboration within the framework of the f3 centre.

Over the past years there has been a discussion whether biofuels should be viewed as an environmental threat or opportunity. From the situation where biofuels were considered to be one of several vital solutions to the climate problem, the view has now shifted into a more complex picture where the use of biofuels also imposes threats of different kinds. All kinds of renewable fuels, biofuels as well as renewable electricity and hydrogen can be produced in many different ways. To bring about a more varied discussion, as well as providing better basic data for various organizations decision-making, more knowledge needs to be developed and disseminated. This study may serve as an example of research that can lead to such improved basic data for decision-making, here coming from refined knowledge about research and development challenges within the complex biofuels production.