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## Biobased Chemicals in a Carbon-Restricted World

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In the quest for a more sustainable society, researchers, policy makers, and businesses are looking for options to reduce the use of fossil resources. Replacing these with renewable resources is a way to both ensure long-term material and energy security and reduce CO<sub>2</sub> emissions.<sup>1</sup> Biomass based products are relevant in this context, but it is important to select the routes that are most beneficial in the context of an integrated energy and materials system. In such an integrated system biomass should be used primarily to produce “drop-in” chemicals for the petrochemicals industry like ethylene, propylene, methanol and benzene, toluene and xylene (BTX). To study the sustainability of biobased BTX a complex life cycle analysis was conducted looking at several products from woody biomass.<sup>2</sup> In this paper we argue that production of biobased BTX yields good economic and environmental benefits for the following reasons:

- Applicability of alternative sources
- The “drop-in” property
- CO<sub>2</sub> emission savings

Energy and materials should be viewed as an integrated system because while oil can fulfill a large range of human needs, most renewable resources are limited in the function they can provide. Heat, a low value but high volume product, is a side-product of all physical and chemical processes. The ability to use any renewable resource for heat is only limited by logistic problems, since there is more than enough incoming solar energy to theoretically supply all heat needs. The same

goes for electricity, also a very high volume but low value product, which can be produced with all renewable resources. Electricity can, in turn, be used for transport via electric or hydrogen-powered vehicles, although heavy duty vehicles and aviation are still dependent on liquid fuel. But for the most high value products from fossil resources, chemicals, materials and pharmaceuticals, only biomass is an alternative.

Since biomass is only available in limited amounts at a time it is essential that we learn how to produce biobased chemicals and materials efficiently, as they are the only alternative we have for those fossil resource products where carbon is an essential component. Providing heat, electricity and transport can largely be done with the more ubiquitous renewable resources such as solar and wind power, or by reusing/recycling biobased materials and chemicals in their waste phase to get additional use from the input biomass. The latter would also not be possible if the biomass was used for fuel or power directly, since it is consumed in those cases.

But within biobased chemicals and materials there also needs to be a selection based on economic viability and environmental desirability to ensure that a biobased society is actually sustainable in the widest sense of the word. We argue that benzene, toluene, and xylene are prime examples of desirable biobased chemicals.

Benzene, toluene, and the xylenes (BTX) are petrochemicals produced in vast quantities (ca. 60 Mt/year) and form the basis of a large variety of products. They can be produced from woody biomass through catalytic pyrolysis with a relatively high efficiency (ca. 35% on a higher heating value basis). Because biobased BTX are identical to fossil-based BTX, they are so-called “drop-in” chemicals: they can be put into the market immediately, replacing the fossil-based product.<sup>3</sup>

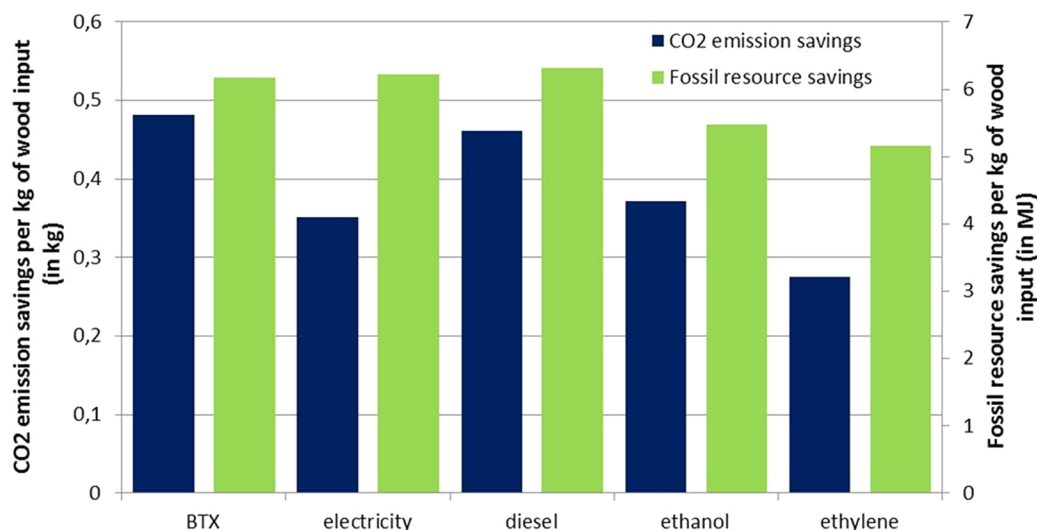
The “drop-in” attribute comes with several big advantages: a fast transition is possible, there is virtually no new infrastructure necessary and existing high performance materials can be made with them. The fast transition of drop-in chemicals results in the environmental benefits being available directly. Such is not the case for some new products that take decades to penetrate the market, like polylactic acid (PLA). Continued use of existing infrastructure saves materials, energy, and money. The ability to make high performance materials means that over their lifetime, biobased BTX can make a big difference by the environmental merit of the products they are used for, such as lighter vehicles.

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**Figure 1.** Fossil resource and CO<sub>2</sub> emission savings from biobased BTX and other biobased products per kg of wood input into each process (after ref 2).

It should be noted that many of the advantages mentioned above are applicable to all drop-in sustainable alternatives to less sustainable, mature products. But BTX are particularly attractive chemicals since they show little demand fluctuations and their price is expected to increase. Since the number of products made from BTX is enormous, demand will not come down significantly in the foreseeable future. Price fluctuations have existed historically because in the petrochemical process production is difficult to regulate, but with decreasing fossil resources the price of BTX is expected to increase in the long run. The rise of shale gas as a fossil resource is also expected to increase the price of BTX, since a transition to shale gas results in lower BTX production from naphtha.

So BTX are attractive chemicals to make from biomass and therefore a fast transition with relatively small investments in materials and energy can be accomplished, leading to environmental benefits in a relatively short-term.

The environmental benefits of biobased BTX were explored by comparing biobased BTX with biobased electricity, ethylene, ethanol, and Fischer–Tropsch diesel production from 1 kg of wood. The fossil resource and CO<sub>2</sub> savings that can be achieved by spending 1 kg of wood on any of these products and thereby replacing the fossil product can be seen in Figure 1. It is clear that BTX and FT diesel offer bigger savings than the other products, but as mentioned above, biobased chemicals like BTX is a preferable use of biomass over fuel since other renewables than biomass can power transport.

Another important environmental and societal benefit of bioBTX is that it can be made from woody and waste biomass, rather than oil or starch crops that require more material and energy inputs and compete with food supplies.<sup>4</sup>

So producing drop-in chemicals from biomass offers a sustainable and economically interesting solution to the pending shortage of carbon as fossil resources are depleting. Biobased BTX is an excellent example of a good choice for biobased drop-in chemicals and also has the advantage of offering relatively good CO<sub>2</sub> and fossil resource savings compared to other biobased products and their fossil counterparts.

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### Notes

The authors declare no competing financial interest.

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