Design of novel DME/methanol synthesis plants based on gasification of biomass - DTU Orbit (30/04/2019)

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A way to reduce the CO2 emissions from the transportation sector is by increasing the use of biofuels in the sector. DME and methanol are two such biofuels, which can be synthesized from biomass, by use of gasification followed by chemical synthesis. This method of producing biofuels is shown to be more cost-effective, less energy consuming and less CO2 emitting, when considering the total well-to-wheel processes, than first generation biofuels and second generation ethanol produced by biological fermentation. It is also shown that trustworthy sources in literature (the IPCC and IEA Bioenergy) estimate the global biomass resource to be sufficiently great to allow the use of biomass for fuels and chemicals production. IEA Bioenergy even indicate that it might be more appropriate to use biomass for fuels and chemicals production than for electricity production because few and expensive renewable alternatives exists for biomass in the fuels and chemicals sector, but many cost effective renewable alternatives exists for biomass in the electricity sector. The objective of this study was to design novel DME and methanol plants based on gasification of biomass, with a main focus on improving the total energy efficiency of the synthesis plants, and lowering the plant CO2 emissions - but also try to improve the DME/methanol yield per unit biomass input, and integrate surplus electricity from renewables in the production of DME/methanol. This objective lead to the design of the following plants: 1. Large-scale DME plants based on gasification of torrefied biomass. 2. Small-scale DME/methanol plants based on gasification of wood chips. 3. Alternative methanol plants based on electrolysis of water and gasification of biomass. The plants were modeled by using the component based thermodynamic modeling and simulation tools Aspen Plus and DNA. The large-scale DME plants based on entrained flow gasification of torrefied wood pellets achieved biomass to DME energy efficiencies of 49% when using once-through (OT) synthesis, and 66% when using recycle (RC) synthesis. If the net electricity production was included, the total energy efficiencies became 65% for the OT plant, and 71% for the RC plant (LHV). By comparing the plants based on the fuels effective efficiency, it was concluded that the plants were almost equally energy efficient (73% for the RC plant and 72% for the OT plant). Because some chemical energy is lost in the biomass torrefaction process, the total efficiencies based on untreated biomass to DME were 64% for the RC plant and 59% for the OT plant. CO2 emissions could be reduced to 3% (RC) or 10% (OT) of the input carbon in the torrefied biomass, by using CO2 capture and storage together with certain plant design changes. Accounting for the torrefaction process, which occurs outside the plant, the emissions became 22% (RC) and 28% (OT) of the carbon in the untreated biomass. The estimated costs of the produced DME were $11.9/GJLHV for the RC plant, and $12.9/GJLHV for the OT plant, but if a credit was given for storing the bio-CO2 captured, the cost became as low as $5.4/GJLHV (RC) and $3.1/GJLHV (OT) (at $100/ton-CO2). The small-scale DME and methanol plants achieved biomass to DME/methanol efficiencies of 45-46% when using once-through (OT) synthesis, and 56-58% when using recycle (RC) synthesis. If the net electricity production was included, the efficiencies increased to 51-53% for the OT plants (LHV) - the net electricity production was zero in the RC plants. The total energy efficiencies achieved for the plants were 87-88% by utilizing plant waste heat for district heating. The reason why the differences, in biomass to DME/methanol efficiency, between the small-scale and the large-scale plants, showed not to be greater, was the high cold gas efficiency of the gasifier used in the small-scale plants (93%). By integrating water electrolysis in a large-scale methanol plant, an almost complete conversion of the carbon in the torrefied biomass, to carbon in the produced methanol, was achieved (97% conversion). The methanol yield per unit biomass input was therefore increased from 66% (the large-scale DME plant) to 128% (LHV). The total energy efficiency was however reduced from 71% (the large-scale DME plant) to 63%, due to the relatively inefficient electrolyser.