Life Cycle Assessment of Renewable Diesel using Catalytic Pyrolysis and Upgrading

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Background

Advanced biofuels are under development to meet policy objectives to for diversifying energy supply and reducing the carbon-intensity of the transportation sector. Countries around the world have developed renewable and low carbon fuel policies to incentivize bringing transport fuels derived from biomass to the market. At present biochemical and thermochemical conversion technologies are under development at laboratory and pilot scale to investigate the technological needs and economics of scaling biofuels and value-added co-products. Among the technologies that have the same goal of optimizing biorefinery economics to produce low carbon fuels and value added co-products, such as chemicals and polymers. Within the thermochemical conversion platform is a set of pyrolysis and upgrading methods that hold much promise for reducing the greenhouse gas (GHG) intensity of drop-in transport fuels, including aviation fuel (Sorunmu *et al.* 2017) and fast pyrolysis with catalytic upgrading of bio-oil produced from forest residues to produce renewable diesel. Our objective is to develop life cycle assessment models from material and energy balances developed from chemical process simulation models based on experiments (Mullen *et al.* 2011; Carassco *et al.* 2017).

Methods

Life cycle assessment (LCA) and techno-economic analysis (TEA) were used to evaluate two fast pyrolysis and upgrading pathways to produce renewable diesel from forest residues in the U.S. Northeast. Life cycle inventory (LCI) models were developed from mass balances generated from of biomass chemical conversion computer simulations. One configuration employed fast pyrolysis and catalytic upgrading (Carassco *et al.* 2017) and the second employed catalytic pyrolysis with one-step upgrading (hydrotreating with a zeolite catalyst). In both cases the co-produced biochar is assumed to either replace coal in power generation or be amended to land to replace soil organic carbon (Pourhashem *et al.* 2013). We evaluate these alternative pathways using the life cycle impact assessment metric, the 100-year global warming potential (GWP). The functional unit defined is 1 MJ of renewable diesel product.

Findings

Figure 1 shows graphic results on the contribution of life cycle inputs, credits and the net life cycle GWP, respectively. Two co-product credit scenarios taken from the work of (Pourhashem *et al.* 2013) were evaluated for the bio-char co-product; one in which the biochar is used as a coal substitute in power generation, and the other in which the bio-char is land-amended to replace soil organic carbon (SOC). Figure 1 shows the effects of a +/-20% change in all input contributions towards GWP. In each case, system expansion was used to treat the effects of co-products. In all cases, the pathways would meet U.S Renewable Fuel (RFS2) guidelines for renewable fuels, with a 50% reduction in life cycle GWP relative to a baseline fuel.

Renewable diesel produced from catalytic pyrolysis had slightly higher GHG emissions (25 g CO₂e/MJ) compared to that produced from fast pyrolysis (19 g CO₂e/MJ) with catalytic upgrading due to its lower yield (116 versus 196 L/dry metric ton) and thus incrementally greater GHG emission contributions from feedstock collection and transport, but also due to differences in input utilities, chemicals, and catalyst regeneration. The catalytic upgrading process considered a case in which hydrogen for upgrading the bio-oil is produced from the biochar co-product and non-condensable gases, which required greater electricity input compared to the catalytic pyrolysis process but no additional hydrogen. On the other hand, catalytic pyrolysis required purchase of hydrogen, which we assume was produced from catalytic cracking; however, it may also be sourced also from steam reforming of natural gas. Daily catalyst regeneration was a significant process input, contributing sizably to net GHG emissions, amounting to 33% of the GHG intensity of the catalytic upgrading process, and 12% for catalytic pyrolysis process. For the systems studied herein, the catalytic upgrading process requires three catalysts, Ni/ZSM-5, Co/Mo, and

Ru/C catalysts, whereas catalytic pyrolysis assumes use of only Ni/ZSM-5. Although the contribution of the catalyst to GWP is higher for catalytic upgrading, low product yield and higher co-product quantity for catalytic fast pyrolysis either results in a higher GWP if the biochar co-product is co-fired with coal or a much negative result if land amended for carbon sequestration. However, product yield along with meeting GHG emissions reduction targets suggest that catalytic pyrolysis could be more favorable as a commercial process.



Figure 1. Life cycle greenhouse gas emissions measured as the 100-year global warming potential (GWP) for four fast pyrolysis pathways that include catalysts in upgrading and/or fast pyrolysis.

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