Multi-stage Pyrolysis for Biofuel Production: A Life Cycle Evaluation of Energy Consumption and GHG emissions

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Abstract: Thermochemical conversion of biomass via fast pyrolysis and catalytic upgrading of resultant product streams has gained interest as a technologically and economically viable option for producing renewable transportation fuel. Prior research has investigated the conversion of biomass via a single stage fast pyrolysis reactor operating in a temperature range of approximately ~500 C^0. However, single stage fast pyrolysis constrains the quantity of liquid transportation fuel that can be produced from biomass; a multi-stage process in which input biomass undergoes thermal decomposition with varying temperature and residence times can maximize the overall carbon yield of the fuel system. Thermal fractionation of the biomass produces product streams with varying chemical compositions, which can be catalytically upgraded to produce useful transportation fuel(s) as well as fuel additives. The goal of this research is to evaluate the potential life cycle environmental impacts of multi-stage *pyrolysis* for conversion of biomass to liquid transportation fuel, and compare the results in regards to a single-stage fast pyrolysis platform.

A life cycle assessment (LCA) model was developed to quantify the environmental impacts of producing drop-in replacement biofuels derived by thermochemical conversion of biomass via multi-stage pyrolysis. Life cycle assessment is performed to track the environmental impacts of producing pyrolysis-derived fuels for each stage in the process chain and is utilized to compare the environmental sustainability of multi-stage pyrolysis in regards to several key performance metrics including: Energy Return On Investment (EROI) and life cycle greenhouse gas (GHG) emissions. The aim of this research is to compare the environmental tradeoffs between different fuel processing options, reactor configurations, co-product scenarios, and biofeedstocks. .

Process inventories for the production of several biofeedstocks including: miscanthus, switchgrass, and Oak were developed based on peer-reviewed and technical literature as well as laboratory scale and experimental data. Process level data for multi-stage pyrolysis were constructed based on a combination of ASPEN simulation, experimental data, peer-reviewed literature,, and best available engineering knowledge. Detailed literature review was conducted to develop probability distribution functions for key input parameters (fertilizers, fossil energy consumption, etc.) for each stage in the process chain as well as life cycle impact factors. These probability distributions are utilized to conduct Monte Carlo simulation to capture uncertainty in the Life Cycle Inventory (LCI)

and Life cycle impact assessment (LCIA). Addressing uncertainty in a stochastic manner allows for a broader understanding of the expected range for key sustainability and performance metrics. Life cycle data was obtained from the United States Life Cycle Inventory (USLCI) and EcoInvent databases. Synthesizing life cycle data with the developed agricultural and fuel conversion/upgrading modules, the environmental impacts of different combinations of pyrolysis reactor configurations and biofeedstocks are quantified and benchmarked. The results of the analysis are compared with leading 2nd generation and advanced biofuels as well as the Environmental Protection Agency's (EPA) Renewable Fuel Standard for cellulosic biofuels (i.e. 60% reduction in overall life cycle GHG emissions relative to baseline petroleum fuels).