Feasibility study for maize as a feedstock for liquid fuels production based on a simulation developed in Aspen Plus®

MSc Research Dissertation

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EXECUTIVE SUMMARY

South Africa's energy sector is vital to the development of its economy. Instability in the form of disruption in supply affects production costs, investments, and social and economic growth. Domestic sources are no longer able to meet the country's demands. South Africa must find a local alternative fuel source in order to reclaim stability and encourage social and economic development.

Biomass is one of the most abundant renewable energy sources, and has great potential as a fuel source. Currently biomass contributes 12% of the world's energy supply, while in some developing countries it is responsible for up to 50% of the energy supply. South Africa is the highest maize producer on the African continent. Many studies carried out indicated that maize, and its residue contain valuable materials, and has the highest lower heating value in comparison to other agricultural crops. This indicates that maize can be a potential biomass for renewable energy generation in South Africa.

A means for energy conversion for biomass, is the process of gasification. Gasification results in gaseous products H_2, CO and CO_2. Since the process of biomass gasification involves a series of complex chemical reactions involving a number of parameters, which include flow, heat transfer and mass transfer, it is very difficult to study the process of gasification by relying on experimentation only. Numerical simulation was used to provide further insight on this process, and accelerate development and application of maize gasification in a cost effective and efficient manner. The objective of this study was therefore, to verify and evaluate the feasibility of maize gasification and liquid fuels production in South Africa from an economic and energy perspective.

The simulation model was developed in Aspen Plus® based on two thermodynamic models specified as Soave – Redlich – Kwong and the Peng Robinson equation of state. All binary parameters required for this simulation were available in Aspen Plus®. The gasification unit was modelled based on a modified Gibbs free energy minimization model.

Gasification of maize and downstream processing in the form of Fischer-Tropsch (FT) synthesis and gas to liquids (GTL) processing for liquid fuels production was modelled in Aspen Plus®. Sensitivity analyses were carried out on the process variables: equivalence ratio (ER), steam to biomass ratio (SBR), temperature and pressure, to obtain the optimum gasification conditions. The optimum reactor conditions, which maximized syngas volume and

quality was found to be an ER of 0.22 and SBR of 0.2 at a temperature of 611°C. An increase in pressure was found to have a negative effect; therefore atmospheric conditions of 101.325 kPa were chosen, in order to maximize CO and H_2 molar volumes. Based on these conditions the produced syngas consisted of 35% H_2, 16% CO, 24% CO_2 and 3%CH_4.

The results obtained from gasification, based on a modified Gibbs free energy model, show a closer agreement with experimental data, than other simulations based on the assumption that equilibrium is reached and no tar is formed. However, these results were still idealistic as it under predicted the formation of CO and CH_4. Although tar was accounted for as 5.5% of the total product from the gasifier (Barman *et al.*, 2012), it may have been an insufficient estimation resulting in the discrepancy in CO and CH_4.

The feasibility of maize as a feed for gasification was examined based on quality of syngas produced in relation to the requirements for FT synthesis. A H_2/CO ratio of 2.20 was found, which is within range of 2.1 – 2.56 found to support greater conversions of CO with deactivation of the FT catalyst (Lillebo *et al.*, 2017). The syngas produced from maize was found to have a higher H_2/CO ratio than conventional fossil fuel feeds; implying that maize can result in a syngas feed which is both renewable and richer in CO and H_2 molar volumes. Liquid fuels generation was modelled based on experimental production distributions obtained from literature for FT synthesis and hydrocracking. The liquid fuel production for 1000 kg/hr maize feed, was found to be 152 kg/hr LPG, 517 kg/hr petrol and 155 kg/hr diesel. The simulation of liquid fuels production via the Fischer-Tropsch synthesis and hydrocracking process showed fair agreement with literature. Where significant deviations were found, they could be reasonably explained and supported. This simulation was found to be a suitable means to predict liquid fuels production from maize gasification and downstream processing.

The feasibility of liquid fuels production from maize in South Africa was examined based on the country's resource capacity to support additional maize generation. It was found that based on 450 000 hectares of underutilized land found in the Homelands, an additional 1.216 billion litre/annum of synthetic fuels in the form of diesel and petrol could be produced. This has the potential to supplement South African liquid fuels demand by 6% using a renewable fuel source. This fuel generation from maize will not impact food security due to the use of underutilized arable land for maize cultivation, or impact water supply as maize does not require irrigation. In addition, fuel generation in this manner supports the Biofuels Industry Strategy (2007) by targeting the use of underutilized land, ensuring minimal impact on food security, and exceeds its primary objective of achieving a 2% blending rate from renewable sources.

The economic feasibility of liquid fuels derived from maize was determined based on current economic conditions in 2016. Based on these conditions of 49 $/bbl Brent Crude, 40 $/MT coal and 6.5 $/mmBTU of natural gas at a R/$ exchange rate of R14.06 per U.S. dollar, it was found that coal, natural gas and oil processing are more economically viable feeds for fuel generation relative to maize. However, based on projected market conditions for South Africa, the R/$ exchange rate is expected to weaken further, the coal supply is expected to diminish and supply of natural gas is expected to be a continued issue for South Africa. Based on this, maize should be considered as a feed for fuel generation to reduce the dependency on non-renewable fossil fuel sources.

The energy feasibility of liquid fuels produced from maize was only evaluated from a thermal energy perspective. It was found that maize gasification and FT processing requires 0.91 kg steam/kg feed. This 0.91kg of steam accounts for the raw material feed, distillation and heating required for every 1kg of maize processed. It was found that 2.56 kg steam/kg feed was generated from the reactor units. This was assumed to be in the form of 10 bar steam, as in this form it can be sent to steam turbines for electricity generation to assist with overall energy efficiency for this process. In addition, the amount of CO_2 (kg/kg feed) produced, was examined for maize processing in comparison to fossil fuel feeds: natural gas and coal. The CO_2 production from liquid fuels processing based on a maize feed, was found to be the highest at 0.66 kg/kg feed. However, a coal feed has higher ash and fix carbon content indicating greater solid waste generation in the gasifer. While dry reforming of natural gas is a net consumer of CO_2, but had significantly higher steam requirements in order to achieve the same H_2/CO ratio as maize. This indicates that although maize results in more CO_2/kg feed, it is 88% more energy efficient than dry methane reforming.

Additional experimental work on FT processing using syngas derived from maize is recommended. This will assist in further verification of liquid fuels quantity, quality and process energy requirements.