A Cost Analysis of a Biomass Supply Chain for Sustainable Aviation Fuel in South Africa

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Abstract

The aviation industry has experienced high growth in recent years and is projected to continue to increase rapidly in the future. As a result, it is also one of the world's fastest growing sources of greenhouse gas (GHG) emissions. Whilst this industry has focused on fuel and operational efficiency, more still needs to be done to further limit the negative impact it is having on the planet. Sustainable aviation fuel (SAF) is being investigated as an alternative fuel and uses sources like biomass, which have lower GHG emissions. In South Africa, there exists an opportunity for organic waste and invasive alien plants (IAPs) to be used as a biomass source for SAF. However, no research on the establishment of a supply chain for using biomass to produce SAF in this country could be located. A supply chain design and cost analysis was undertaken to ascertain whether biomass, to produce SAF, is feasible in South Africa

Keywords
Sustainable aviation fuel (SAF), Biomass,

1 Introduction

Prior to the Covid 19 pandemic, air travel was one of the safest, fastest and more profitable modes of transport in modern history. "Flights are energy-intensive and depend on fossil fuels. Subsidies from fuel taxes give the airline industry an unfair advantage over other transportation modes. While many sectors are beginning to reduce their emissions, aviation's have continued to grow" (Green, 2020). As a result, it has been one of the world's fastest growing sources of greenhouse gases like carbon dioxide, which cause climate change. In 2019, flights globally produced 915 million tonnes of carbon dioxide (CO_2) per annum which is 12% of all transport sources CO_2 emissions. "Carbon emissions from the airline industry grew by 75 per cent from 1990 to 2012. It's expected they will continue to grow rapidly until 2050. If left unchecked, they could consume a full quarter of the available carbon budget for limiting temperature rise to 1.5 C" (Green, 2020).

Net carbon emissions from international aviation will be capped through carbon neutral growth from 2020 (ATAG, 2020). As a result, the world is turning to governments and business to reduce the impact that all transportation modes, especially the aviation industry, have on climate change. Whilst the aviation industry has focused on fuel and operational efficiency, which has helped the industry limit its emissions, more still needs to be done to further limit the impact it is having on the planet. Sustainable aviation fuel (SAF) is, therefore, being investigated and is crucial to providing a cleaner source of fuel to power the world's fleet of aircraft (ATAG, 2020; ATAG, 2017). Whilst there has been some progress in the aviation industry with regards to fuel and operational efficiency, more still needs to be done to further reduce the impact that the airline industry is having on the environment

Sustainable Aviation Fuel (SAF) is not derived from fossil fuels, but rather from sources like biomass, and as such, is an attractive alternative due to its lower Greenhouse gas (GHG) emissions. Its production is not limited by the geographical constraints of fossil fuels, thus allowing for a more diverse environmental supply (ATAG, 2017). SAF can also provide economic benefits for developing countries that have large amounts of unviable land for food crops, but are suitable for growing SAF crops, or which have other sources of biomass such as municipal and animal waste. Whilst there exists no fully functional commercial supply chain for SAF, many of these developing countries could benefit in both economic development and growth from the new industry that SAF would provide without negatively impacting their local food production ability (ATAG, 2017).

South Africa is one such country that could greatly benefit economically from the use of biomass for SAF; this is due to several factors. South Africa either uses crude oil or coal to produce jet fuel. In the case of crude oil, South Africa currently imports most of its required crude oil (used for making jet fuel amongst other fuels), making it particularly susceptible to price fluctuations (Nkomo, 2009). The coal to liquid (CTL) production process provides relief from the crude oil demand and could lower the high demand for coal through cofiring coal with biomass i.e. partially replacing coal with waste biomass in existing gasification installations (Publishers, 2015). A large petroleum-based organisation in South Africa has the capability of completing the biomass to liquid (BTL) conversion and can therefore be processed with coal to produce a virtually zero net green gas house effect (Williams, et al., 2006).

Although South Africa has a limited potential in bioenergy when considering rainfall constraints, food security and variability of supply, there does exist opportunity for organic waste and invasive alien plants (IAPs) as a biomass source for SAF (SAEON, 2017). Further motivation for this is the international aviation hub of O.R Tambo International Airport, which would drive the demand for SAF for both local and international airlines. Thus, gaining an understanding of the biomass footprint, the associated supply chain network and feasibility would prove paramount in establishing whether South Africa is indeed a viable candidate in using biomass to produce SAF.

Currently, there exists little to no research on the establishment of a supply chain for using biomass to produce Sustainable Aviation Fuel (SAF), which would assist in greatly reducing the GHG emissions in the aviation industry, should it be a viable option. A supply chain design and cost analysis must therefore be completed to ascertain whether biomass to produce SAF is feasible in South Africa.

The objective of this study was to establish the feasibility of the biomass supply chain network in South Africa This was achieved by determining the raw material (biomass) supply footprint in South Africa and the links (modes of transport) and nodes (stops between raw material and customer) within the biomass supply chain network concerned with moving the raw material at source to the customer (processing plant). The lowest cost of the biomass supply chain network was then established and compared to the cost of the coal supply chain network in South Africa.

2 Methodology

2.1 Research Design

An investigation was conducted to establish if the biomass footprint is large enough to meet the required demand from the processing plant and if the biomass supply chain is feasible. This was accomplished by designing a supply chain network with associated costs. Once completed, biomass supply cost curves were compared to coal supply cost curves. Due to the low calorific values of biomass, this feedstock was processed into a form that exhibited a higher calorific value so that it can be compared to coal. To do this, the biomass needed to be chipped/shredded, transported to a special facility (densification centre) where it would densified into a pelletized product (thus increasing the calorific value), which would then be transported to a processing plant in Secunda. It was assumed that both the pelletized product and coal undergo similar processes to be converted into liquid, which include both gasification and Fischer Tropsch processes. This allowed pelletized product to be used in place of coal for fuel generation without the need for any equipment changes at the processing plant in Secunda. To accomplish the objectives of this analysis, a quantitative research methodology was employed.

2.2 Data Collection and Analysis

Data pertaining to the availability, seasonality and type of biomass was collected by an external environmental organisation, which was an indicative measure of the biomass measurement per annum for the next 20 years. A biomass supply chain establishment and analysis were subsequently undertaken and completed separately for three pelletized products, which included white pellets, black pellets and fuel rods (for a conservative and an optimistic scenario), which were formed (densified) from various shredded/chipped biomasses. This involved obtaining the optimum (lowest) cost option for moving the biomass, for each type of pelletized product, from various source points nationally to a processing plant in Secunda. It considered the availability, seasonality and extraction methods and costs of the various biomass types, identification of appropriate primary and secondary transport and establishment of associated costs and considered the best placement of densification centres to optimize costs.

A macro enabled Excel spreadsheet to run the Excel Solver using linear programming techniques, in order to establish the biomass supply cost curves. This was completed to ascertain the lowest cost pellet option and to obtain the best placement and number of densification centres (for the lowest cost pellet option) required to meet the demand for the pelletized product. Once completed, this was compared to a calculated coal supply curve derived from literature to ascertain the feasibility of the biomass supply chain in South Africa.

The following graph illustrates a high-level representation of the research methodology that was conducted:

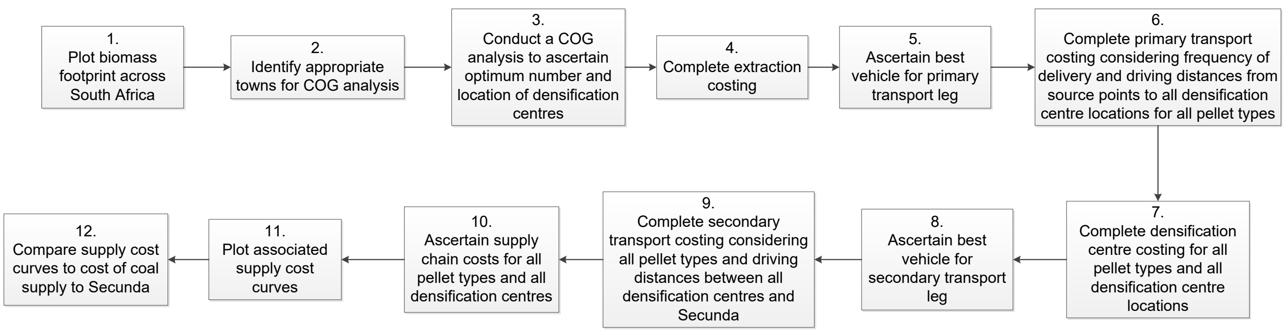

Figure 1: High level view of research methodology

3 Results and Discussion

There were five types of viable biomass identified for pelletisation. These consisted of (1) Alien Invasive Plants which includes biomass types such as eucalyptus, pine, acacia, prosopis and willow alien invasives, and is mainly located across KwaZulu Natal, Gauteng, Mpumalanga and some parts of the Limpopo province; (2) Agricultural Residue that includes soya, maize, sunflower and sugar cane residues, and is mainly located across the Gauteng and Free State provinces and parts of the Mpumalanga province; (3) Forestry that includes commercial eucalyptus and pine plantations, and is mainly located across the Mpumalanga and KwaZulu Natal provinces; (4) Organic Waste which is made up of services and un-serviced organic waste and is mainly conglomerated across part of the Limpopo province and showed scattered dispersion across the Mpumalanga, KwaZulu Natal and Eastern Cape provinces; (5) Sawmill and Paper which includes black liquor reside from paper mills and bark residues from sawmills and is conglomerated only across the Gauteng province. All these biomass types are seasonal and ranges from one quarter per annum availability or year-round availability. The conservative biomass availability scenario only had four of the above five biomass available, as organic waste did not feature in this scenario.

The first objective was to ascertain if there was enough biomass availability to meet the required demand for a pelletized product type year-round. The processing plant in Secunda communicated that the biomass requirement per annum would range from 500 000 tonnes dry mass to 5 000 000 tonnes dry mass per annum. A Centre of Gravity (COG) analysis (steps 1, 2 and 3 of Figure 1) was conducted twice using the biomass availability to identify the optimal set of towns that would be used to establish the best placement of densification centres for optimizing the total cost of the biomass supply chain. The Figure 2 and Figure 3 below provide a graphical representation of the towns identified during the second and final COG analysis and the amount of biomass conglomerated within each.

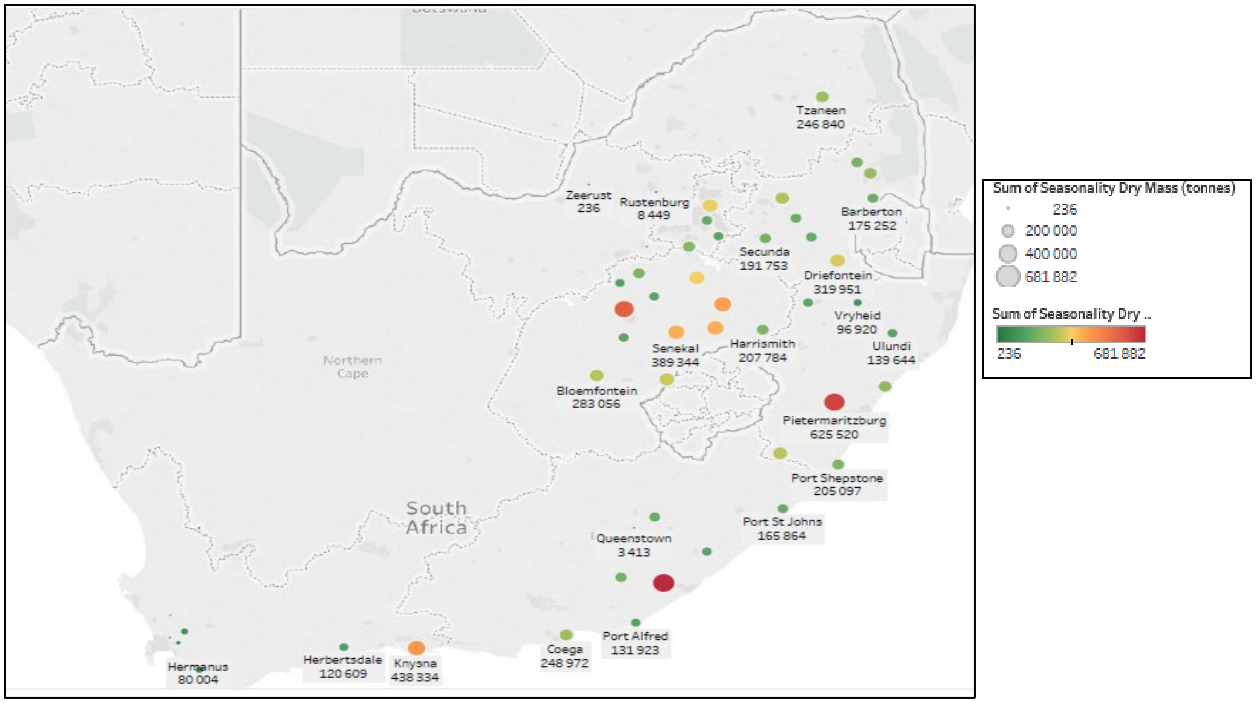

Figure 2: Second Round COG for optimistic biomass availability (Conservative scenario)

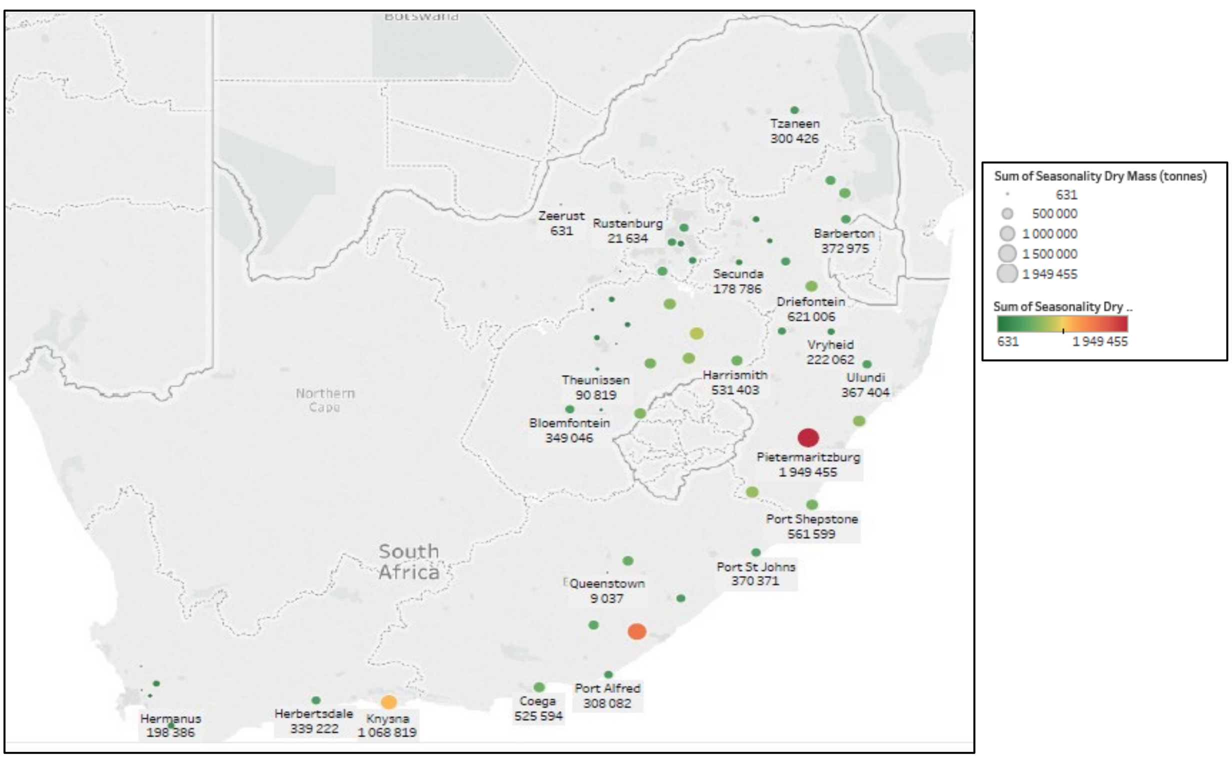

Figure 3: Second Round COG for optimistic biomass availability (Optimistic scenario)

A biomass supply chain establishment and analysis were subsequently undertaken and completed separately for three pelletized products, which included white pellets, black pellets and fuel rods (for a conservative and an optimistic scenario), which were formed (densified) from various shredded/chipped biomasses. Figures 4 and 5 below illustrate the densification process options available to each biomass type and the process options for each pellet type respectively. All these scenarios needed to be considered when calculating the feasibility of the biomass supply chain.

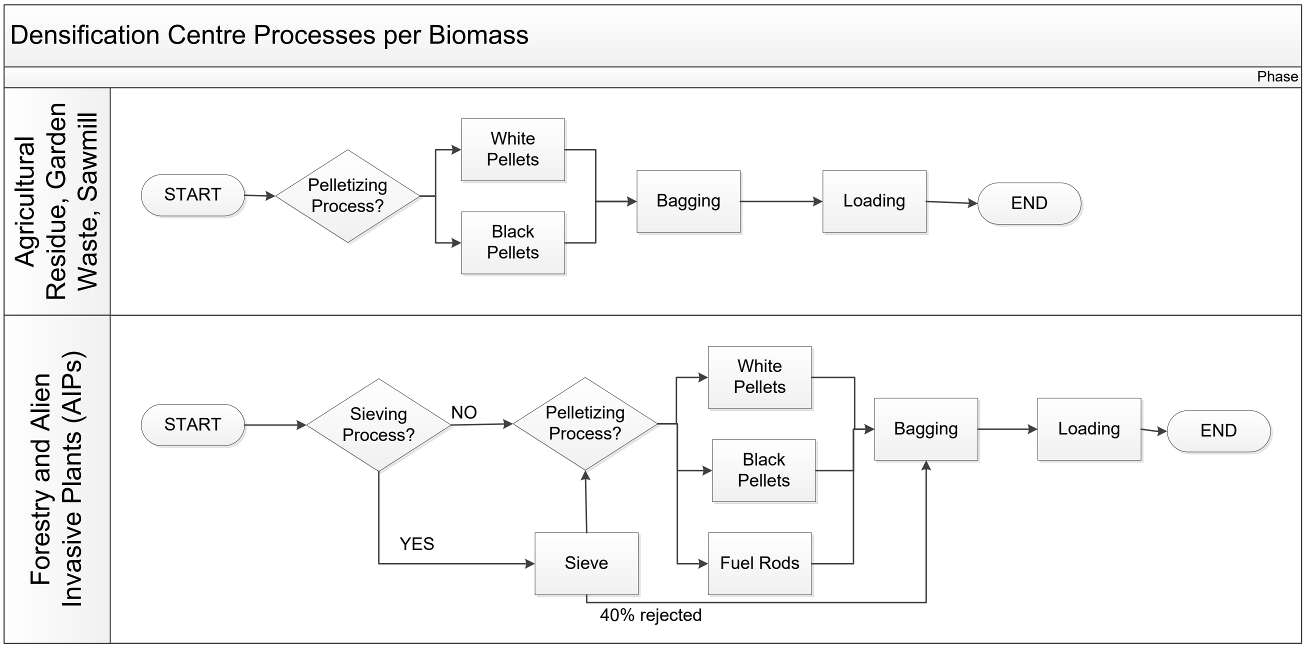

Figure 4: Densification Process per Biomass Type

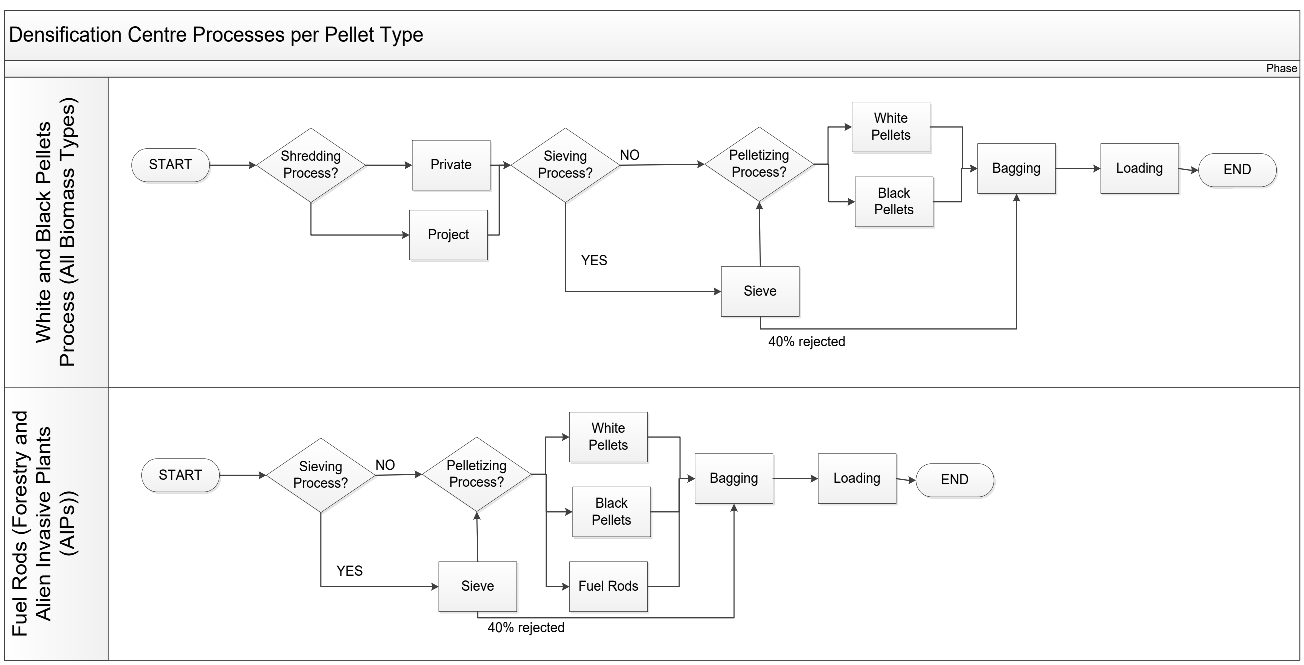

Figure 5: Densification Process per Pellet Type

To establish the total cost of the supply chain of the various pellet products for the two scenarios, (and hence identify the lowest cost option) costs associated with extraction of the biomass at source, primary transport of biomass from source to identified densification centres, densification processes, secondary transport from the densification centres to Secunda were aggregated. This was completed separately for 20 different processes for the conservative and optimistic scenario.

When considering the primary transport leg, economies of density were considered when transporting wood chips, and the walking floor vehicle was selected as it exhibited the highest volume capacity from the options considered, whereas when the secondary transport was considered, economies of weight was the optimal choice for transporting the pelletized product from the densification centres and as a result, the tautliner was selected as the most feasible choice due to its high availability on a national level. Rail was also considered as part of the secondary transport leg; however, the COG analysis was completed before the rail siding areas could be obtained and as a result, not many towns with rail sidings were selected in the COG analysis.

The processing plant also communicated that standardization of the pellet type would be the best option to test, which was due to the different chemical properties that each pellet type would exhibit during processing. Also, each different pellet type required an associated type of densification centre, with different set up costs and different output rates. Thus, to make the project feasible, it was decided that only one type of densification centre would be set up nationwide.

This meant that the scenarios would be tested for black pellets or white pellets or fuel rods individually. Once the supply curves were generated, the cost curves of each process for each pellet type were generated and they would be compared to each scenario within each pellet type to ascertain which pellet type was the most feasible option. The optimal biomass supply cost curve was subsequently compared to the coal supply cost curve. This enabled the viability and feasibility of a biomass supply chain to be established.

3.1 Conservative Scenario

The total amount of biomass available per annum for this scenario amounted to approximately 10 million tonnes dry mass. Figure 6 below illustrates the lowest cost options obtained from white pellets, black pellets and fuel rods for the conservative biomass availability scenario.

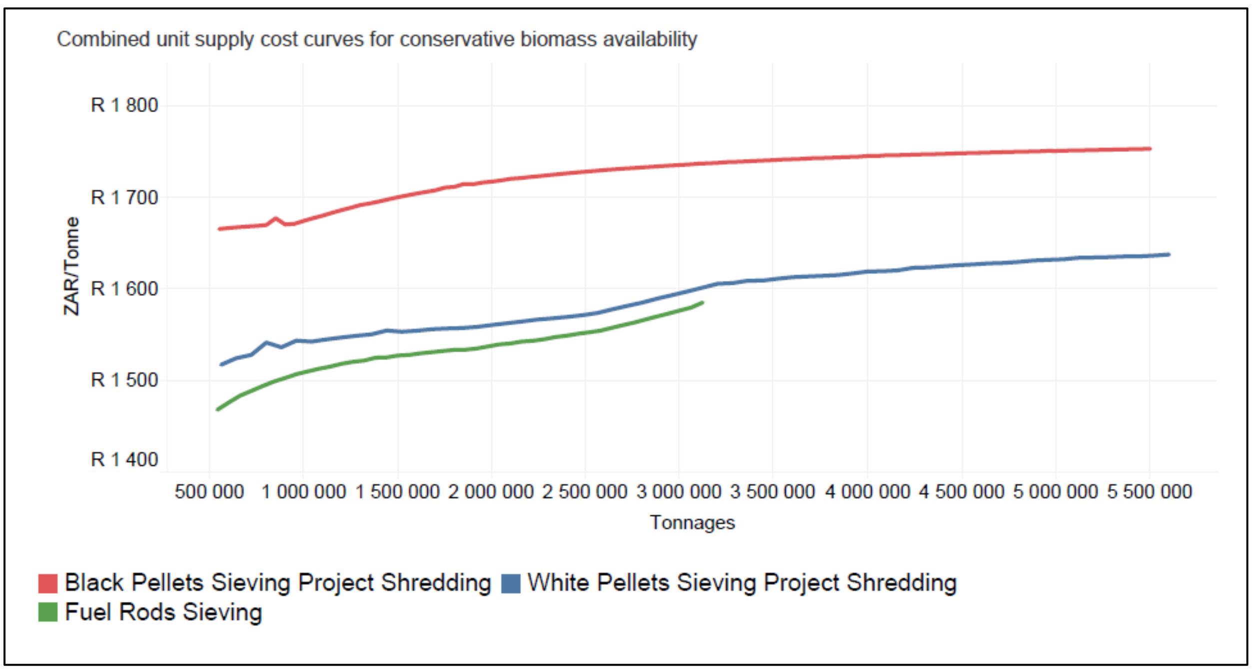

Figure 6: Lowest unit supply cost curves from biomass processes

When all the options were considered, the sieving option across all pellet types proved to be more feasible than the non-sieving options. Project shredding for black and white pellets proved to be more affordable than private shredding. Fuel rods did not exhibit any shredding option as agricultural residue was not a compatible biomass type to develop this pelletized product.

Ultimately, the lowest cost option was the sieving for the fuel rods, which was 4% cheaper than the sieving, project shredding white pellet option, and 13% cheaper than the sieving black pellet option. This result is not surprising as agricultural residue could not be used for this pellet option, which displayed a cost of R409/t for project shredding, and R608/t for private shredding. These were 136% and 203% more expensive than Forestry (which had the second highest extraction cost) respectively. However, whilst fuel rods were the most feasible option, the pelletized output was not enough to meet the maximum demand requirement of 5 000 000 tonnes from the processing plant. The highest tonnage output of fuel rods were 3 060 000 tonnes, which again is not surprising as only AIPs and Forestry biomass types could be used to create fuel rods. This combined with the fact that fuel rods are a newer and relatively untested technology (even though they had a higher calorific value) made white pellets (sieving and project shredding) the optimal solution. As a result, the densification centre allocation per town was run for the sieving, project shredding white pellet scenario.

These were allocated to the availability of biomass type in the COG towns (towns with a high availability of sawmill, AIPs and Forestry has a larger number of densification allocations due to the low extraction costs), the secondary costing (associated with the distances travelled from the densification centres to Secunda), the primary transport (associated with the distances travelled from source to densification centres) or a combination of the above. As the supply of the white pelletized products increased, so did the number of required densification centres, especially in the towns that exhibited high availability of biomass. The number of densification centres posited for areas like King Williams Town and Pietermaritzburg grew to seven and six densification centres in these towns respectively for more than 1 920 000 tonnes of supply. This number of densification centres within one town is not practical and it is therefore recommended that King Williams Town and Pietermaritzburg biomass supply be split into other towns and the model to be run again with these new towns added in.

While fuel rods (sieving) and white pellets (sieving and project shredding) exhibited the lowest biomass cost supply curves, they were still higher than the coal cost curves by 670% and 699% respectively. The coal cost curves were calculated by using the figures gained from literature in 2009 and were adjusted to account for inflation to obtain 2019's coal pricing. Figure 7 below illustrates the difference between the biomass supply cost curves and the coal cost curve:

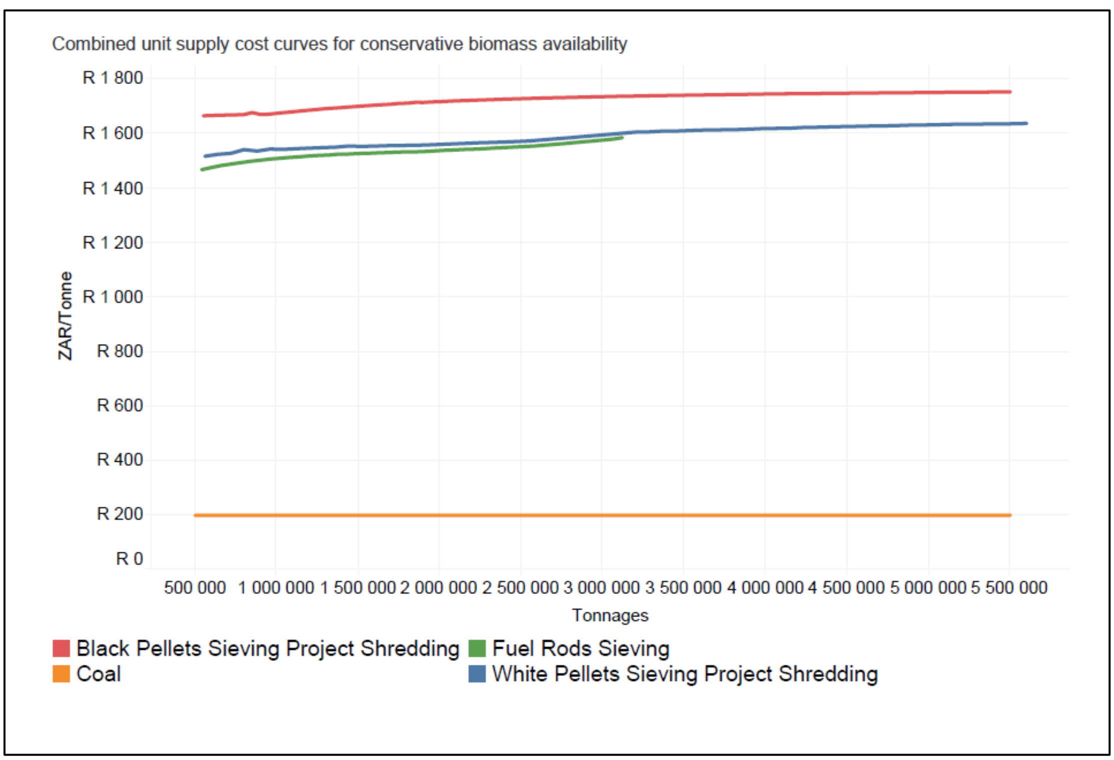

Figure 7: Biomass unit supply cost curves compared to coal supply cost curves

3.2 Optimistic Scenario

The total amount of biomass available per annum for this scenario amounted to approximately 20 million tonnes dry mass. Figure 8 below illustrates the lowest cost options obtained from white pellets, black pellets and fuel rods for the optimistic biomass availability scenario.

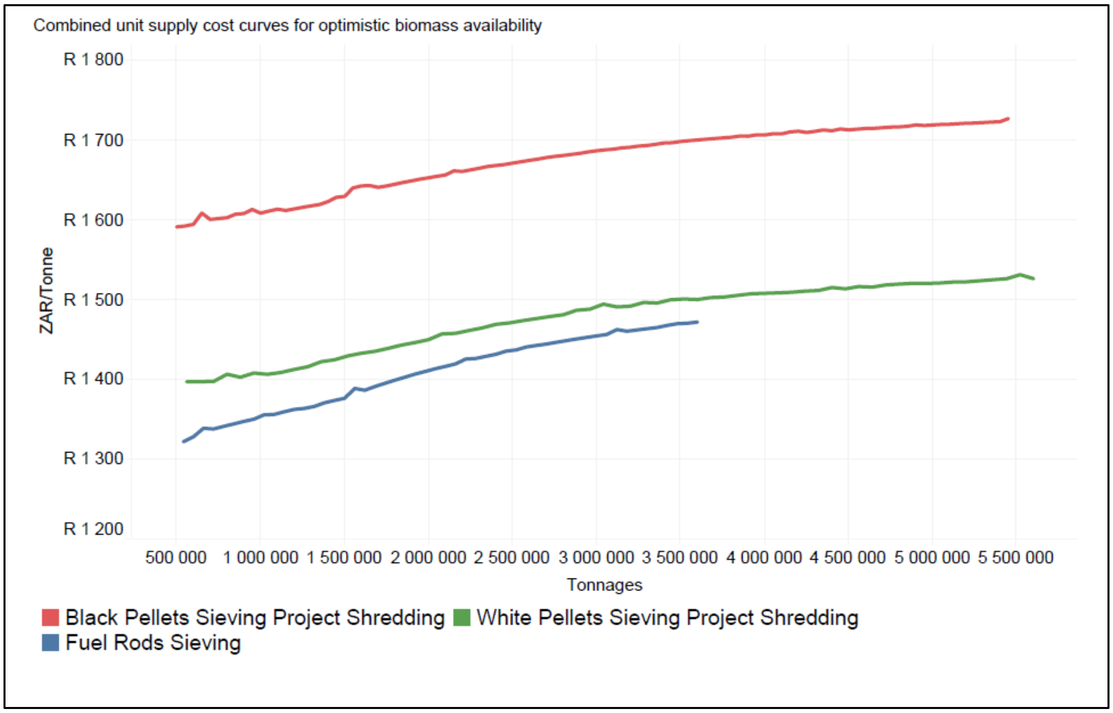

Figure 8: Lowest unit supply cost curves from biomass processes

Sieving again proved to be the more feasible option when compared to non-sieving options. Project shredding also proved to be more affordable than private shredding for the optimistic scenario. Once again, the lowest cost option was sieving for fuel rods, which was 5% cheaper than the sieving, project shredding white pellet option, and 19% cheaper than the sieving black pellet option. However, whilst fuel rods were the most feasible option, the pelletized output was not enough to meet the maximum demand requirement of 5 000 000 tonnes from the processing plant. The highest tonnage output of fuel rods were 3 120 000 tonnes and based on the challenges discussed for fuel rods in the previous section, white pellets for sieving and project shredding was selected as the best option.

Densification centre allocation was then run for this scenario and was subject to the same criteria as discussed in the previous section and exhibited similar pattern as the previous section where supply of the white pelletized products increased, so did the number of required densification centres, especially in the towns that exhibited high availability of biomass, which became impractical as the supply grew.

While fuel rods (sieving) and white pellets (sieving and project shredding) exhibited the lowest biomass cost supply curves, they were still higher than the coal cost curves by 608% and 642% respectively. This is shown in Figure 9 below.

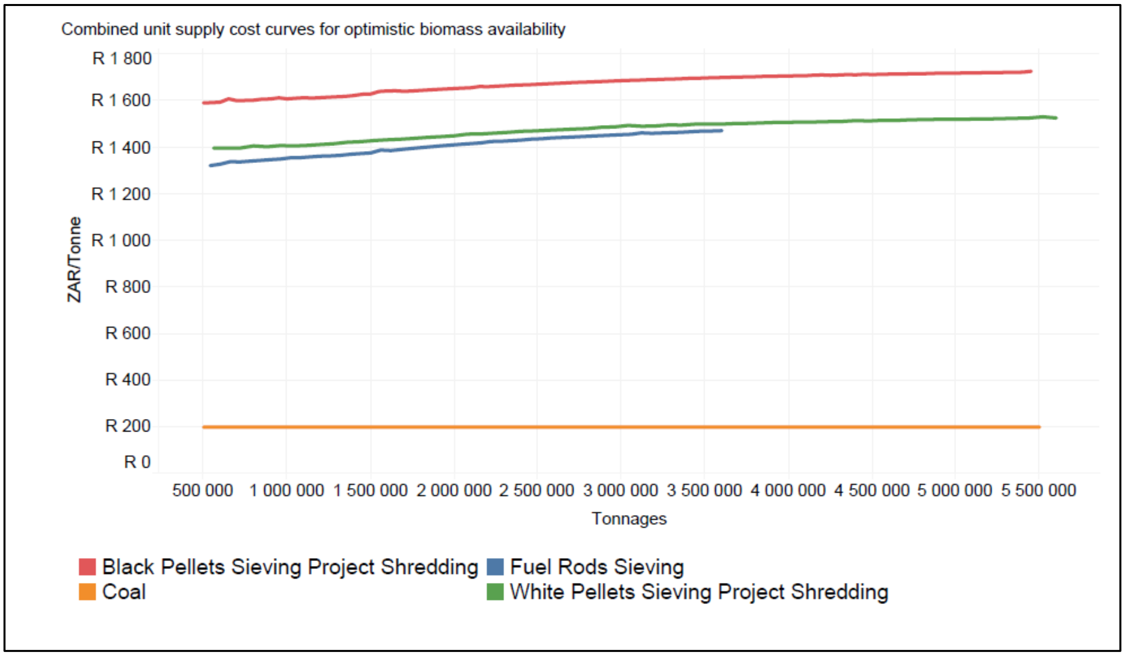

Figure 9: Biomass unit supply cost curves compared to coal supply cost curves

4 Conclusions

Due to the high and increasing GHG emissions from the aviation industry, which is detrimental to the environment, an alternative fuel with a less negative impact on the environment needed to be investigated. This involved investigating a fuel derived from biomass, namely, Sustainable Aviation Fuel (SAF). In order to gauge whether SAF was a viable alternative to conventional aviation fuel, an investigation into a biomass supply chain needed to be completed. South Africa displayed several biomass types that could be harvested for SAF, but this supply chain would need to be understood, designed, costed and compared to the coal supply chain cost. To properly compare the biomass supply chain to the coal supply chain, the harvested biomass (which had very low calorific values) would need to be processed into a form that exhibited calorific values that were closer to that of coal. This process was densification and involved compressing chipped/shredded biomass into wood pellets. Three types of pelletized products supply chains were analysed, namely white pellets, black pellets and fuel rods for a conservative biomass availability scenario and an optimistic biomass scenario. This involved completing analyses for 20 different processes separately for the conservative and optimistic scenario. Fuel rods with sieving came out to be the most feasible option across both scenarios but did not have enough supply to meet the maximum required demand of 5 000 000 tonnes per annum. This, coupled with the relatively new technology of fuel rods, made white pellets, sieving with project shredding the next best option.

The optimal biomass supply cost curves were over 600% more expensive than the coal supply cost curve. Based on this alone, it can be ascertained that the biomass supply chain is indeed infeasible. However, the biomass supply chain costs could be further reduced if the COG analysis was run again, with the towns with rail sidings as priority, as some rail sidings were more affordable than road transport.

Furthermore, the need for GHG emission reduction and the imposed carbon tax liability could make the biomass supply chain for SAF viable. This, coupled with the fact that SAF is created from a renewable feedstock; is categorized as a drop-in fuel, which can be blended with conventional aviation fuel to varying degrees with no impact on the infrastructure whilst still meeting the aviation's industry safety and quality requirements would make SAF a serious consideration in future.

It is therefore recommended that further investigations pertaining to the negative financial impact that carbon tax liability will have on the aviation industry as well as the potential price that SAF could yield considering the increase in demand due to the depletion of coal and natural gas in future and the carbon tax liability be conducted as these criteria could not only make SAF (and thus the biomass supply chain) viable but profitable.

5 Recommendations

The following studies are recommended to ascertain the viability of the biomass supply chain in South Africa in future:

- Complete this COG analysis again with rail sidings as a priority. This will allow more towns with rail sidings to form part of the study, which may lower the supply chain costs and will lower the potential impact on road congestion and environment.
- Conduct a COG analysis again after areas that exhibited very high biomass availability have been split out to include more towns in proximity with less biomass.
- Conduct a study to ascertain the impact the primary and secondary transport will have on the roads in terms of traffic congestion.
- Conduct a GHG emission analysis on the primary and secondary transport for the biomass supply chain as well as the transport used to move coal to Secunda and compare the two emission profiles..
- Investigate the negative impact that the carbon tax liability will have on the aviation industry as well as the potential price that SAF could yield considering the increase in demand due to the depletion of coal and natural gas in future.

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