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Biofuels: From Viability to Pilot Projects

Deliverable 2:

Assessment of Process Options for Triticale Fermentation to Ethanol in the Western Cape

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EXECUTIVE SUMMARY

In South Africa there is a growing interest in the construction of bioethanol plants to produce biofuel that will reduce the environmental impact of fossil fuels used in road transport. The present project investigated one option for biofuel production in the Western Cape, i.e. conversion of triticale (small grains) for conversion to bioethanol. As indicated elsewhere in this report, triticale is suitable for cultivation on marginal lands in the Western Cape, which are drylands with limited rainfall that are not economically suitable for wheat/barley production, and is presently cultivated at small scale for animal feed. It is estimated that approximately 370 000 tonne/y triticale can be produced on marginal land in the Western Cape , as described in the Deliverable 1 section of this report). A bioethanol-triticale plant using 370 000 tonne/y triticale has a production capacity of 160 Ml ethanol/y.

This report considered the impact of process technology selection for triticale-ethanol production on the conversion efficiency, economics and environmental benefits (with greenhouse gas emissions used as a proxy) derived from biofuels production. Three alternative process technologies for conversion of triticale to ethanol were compared through detailed modelling of process steps, energy balances, economics, CO_2 emissions and water requirements. The three processes were (1) the conventional dry grinding process with higher temperatures in mashing ("Warm" process), (2) the conventional dry grinding process with lower mashing temperature ("Cold" process) and (3) processes with dry grinding that include Pre-fractionation for removal of the hull from triticale prior to fermentation (Pre-fractionation processes). An economic sensitivity analysis was done to determine the influence of input variables on financial viability, while environmental impacts of alternative processes were determined through calculation of CO_2 gas emissions and water requirements.

The report covers: the background of the project, the aims and methodology, and the technical, economic and environmental assumptions. The modelling outcomes in terms of conversion efficiency, economic and environmental results were compared between the three processes. Also an economic sensitivity analysis was done with the input parameters to the models, i.e. Basic Fuel Price (BFP), triticale price, DDGS price, electricity price and the use of biomass to replace coal for process energy. Processes that are less sensitive in terms of economic viability to fluctuations in market prices were deemed as being more robust investments. All of the economic modelling was done using the approach recommended by the national Department of Energy, i.e. a producer incentive (subsidy) based on a 15% Return on Asset for the biofuels producer, and an ethanol selling price that is linked to the BFP.

The financial viability of bio-ethanol production from triticale was mostly sensitive to the BFP, as BFP represents the largest source of revenue to the biofuel producer. Because the bio-ethanol price is linked to the BFP, any change in BFP will directly affect revenue and

financial viability of the biofuel producer. Furthermore, fluctuations in the triticale feedstock price also had a strong impact on the profitability of the plant, since feedstock purchasing represents approx. 70% of the operational costs of a triticale-ethanol plant. The Pre-fractionation processes produced animal feed by-product (DDGS) with significant increases in market value, compared to DDGS from processes without Pre-fractionation. The reason for this is that Pre-fractionation reduces the fibre content of the DDGS, thus increasing the protein content, both of which will increase the price per tonne for DDGS. The increases in market prices for DDGS from the Pre-fractionation processes significantly improved the economic viability and robustness to fluctuations in BFP and triticale price of these processes compared to conventional dry grinding options. Increased DDGS prices could thus offset some of the potential negative economic effects caused by price variations in triticale and ethanol sales (BFP). For the conventional dry grinding processes, DDGS made a minor contribution to the economic value, compared to the Pre-fractionation process options.

The required subsidy to ensure profitability of triticale-ethanol production was based on a return on assets of 15%, as defined in the policy set out by the national Department of Energy. The required subsidy to achieve this level of economic returns was mostly determined by the BFP and triticale prices, while in some cases co-production of high-value DDGS could reduce the subsidy required. The combined effect of fluctuations in BFP and triticale warrant a subsidy mechanism to protect biofuel producers, and ensure ongoing economic viability of biofuel production throughout the 20-year lifespan of these projects.

The triticale-ethanol production plant has the potential to produce significant amounts of surplus electricity, for sale to the national grid. The ethanol process has certain steam and electrical energy requirements, which can either be met by installing a Combined Heat and Power (CHP) plant adjacent to the ethanol process, or by installing a low pressure boiler to provide process steam and purchasing power from Eskom instead of own generation via CHP. In order to meet the process requirements for steam, the CHP plant will automatically produce a surplus of electricity, since the ratio between steam and electricity production is dictated by the application of energy efficient generation methods. The surplus electricity, beyond the requirements of the ethanol process, for the size of triticale-ethanol plant considered here, would be approx. 23-24MW.

Process energy to the triticale-ethanol factory could be supplied by coal, or locally available plant biomass as the energy source, used as fuel source in the CHP plant or boiler described above. The use of coal instead of biomass for process energy will impact CO_2 emissions by 66.4%, as a result of which the life cycle CO_2 balances for the agriculture-transport-production-application value chain for the biofuels will only provide marginal environmental benefits. Although coal may represent the lowest cost option for the energy demands of the triticale-ethanol factory, it is recommended that locally available biomass sources (e.g. invasive alien plants, appropriate agricultural residues) be used to substitute coal, to ensure that significant environmental benefits are realised with triticale-ethanol production. Biomass may cost more per unit of energy, compared to coal, although this is somewhat offset in the

Western Cape by the transport costs associated with coal from up-country, compared to shorter transport distances for locally available biomass, i.e. alien and invasive plants from Working for Water clearing activities.

Onsite production of (surplus) electricity (by installation of the CHP plant, and sales of the electricity to the national grid) did not improve the economic viability of the triticale-ethanol process, compared to the alternative where only low pressure steam is generated onsite, and process electricity demands are provided by Eskom. The process options with surplus electricity production and sales provided Internal Rate on Returns (IRR) of 30% to 70%, for electricity sales prices up to R1.2/kWh. These IRRs by themselves were attractive to the private investor, but still lower than the 38% to 117% IRRs predicted by economic models for triticale-ethanol processes without a CHP plant installed, primarily due to the large capital cost of the CHP plant. The (approximate) additional capital cost of the CHP plant, in comparison to the triticale-ethanol process without onsite electricity production, ranged between R51,000 to R58 000 per kW of installed capacity. Thus CHP, at electricity prices of R1.20/kWh, reduces the IRR compared to the no-CHP cases which use coal-based Eskom power. However, the case for CHP is strengthening as the Eskom electricity tariffs continue rising and the electricity supply-demand situation worsens.

Regarding differences between the Warm, Cold and Pre-fractionation process alternatives: the Cold process was more profitable than the Warm process, mainly due to much lower capital costs and energy savings, thus requiring lower subsidies. However, the Pre-fractionation process was the most profitable of all the options considered, due to a 10.6% reduction in the required capital costs, lower operational cost (lower energy consumption), and increased revenue (higher DDGS market value). The reduced capital cost of the Pre-fractionation was achieved through smaller processing equipment (fermentation, distillation, drying) subsequent to the Pre-fractionation step, compared to the conventional dry grinding. Such capital cost savings were larger than the additional capital cost of Pre-fractionation and bran hydrolysis equipment, giving the net Capex benefit of 10.6%. The Pre-fractionation process was economically the most robust triticale-ethanol production, thus also requiring the smallest subsidy for viability (only needs subsidisation for BFP below R5.50/l to achieve an ROA of 15% even without a market for surplus electrical energy). At the current BFP the Pre-fractionation process is economically viable with an IRR of 18.75% and a subsidy requirement of R0.70/l (first year) ethanol to achieve the desired ROA of 15%.

Thus a key recommendation regarding process technology is that triticale-ethanol producers should be encouraged to apply the optimum technological options, and, as demonstrated by the case studies considered in this report, this is Pre-fractionation, in order to maximise the economic viability of the process. The Pre-fractionation process will also provide high quality animal feed (DDGS) to replace imports of soya oilcake.

Furthermore DOE support for co-generation is under way as part of the Integrated Resource Plan 2010-2030, which allocated 800 MW for industrial co-generation products. This will improve the business case for electricity co-generation.

The potential for electricity co-production with triticale-ethanol stems from the high energy (process steam) demands for conversion of triticale grains to ethanol. Primary consumption of process energy lies with distillation of ethanol and drying of the DDGS animal feed by-product. Electrical process demands are significantly smaller than typical steam process demands, thus resulting in a potential for production of surplus electricity in a CHP system. The process demands of triticale-ethanol production, should, as far as possible be met with bio-based energy sources, which requires a sustainable supply of local biomass (e.g. invasive alien plants from clearing). An intermediate solution with an onsite biomass-boiler for steam and buy-in of limited amounts of Eskom power could still provide attractive environmental benefits. For the process with a CHP plant, the potential contribution of 23-24 MW of power to the economy of the Western Cape can only be realised if the Biofuels framework of national government allows for sales of both ethanol (biofuel) and electricity. Security of feedstock (biomass) and market access for ethanol and electricity will be essential in order to mitigate the financial risk of the substantial capital outlay required for such electricity production. As per Deliverable 1, the support and development of emerging farmers will be key to achieving the agricultural development, job creation and social development objectives of triticale-biofuel production, which should be strongly supported by local government.

The results in the report are based on process simulation and assumptions regarding process parameters, utilities and feedstock prices. It is further recommended to develop stochastic methods of sensitivity analysis, to assess technical and economic feasibility in more detail. The simulation models can be updated as market and legislative information becomes available to assess and enumerate overall technical and economic feasibility on an ongoing basis. This information should include prices for triticale and DDGS, and experimental work done on yields of enzymes.

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ABBREVIATIONS

ABBREVIATION	WORD
BFP	Basic Fuel Price
CHP	Combined Heat and Power
DDGS	Dried Distillers Grains and Solubles
GHG	Greenhouse Gas
IRR	Internal Rate of Return
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
ROA	Return on Assets
SSF	Simultaneous Saccharification and Fermentation
WDG	Wet Distillers Grains

ASSESSMENT OF PROCESS OPTIONS FOR TRITICALE FERMENTATION TO ETHANOL IN THE WESTERN CAPE

1. INTRODUCTION

The focus of this project (which satisfies Deliverable 2) was to investigate the potential production of bioethanol from triticale in the Western Cape from an economic and environmental perspective. Selected conversion processes for triticale-ethanol production were evaluated to determine the contribution of process technology and process design options to the economic viability and environmental benefits.

1.1 Background

Fossil fuels used in road transport cause environmental pollution. Due to climate change-related risks, carbon dioxide emissions need to be reduced. Renewable fuels such as bioethanol and biodiesel may contribute to reducing carbon dioxide emissions. Carbon dioxide from the atmosphere is transformed into plant biomass via photosynthesis. Biomass can be used for bioethanol production and can therefore contribute to a reduction in net carbon dioxide emissions. The use of fossil fuels does not provide such a "closed carbon cycle," but rather results in a net increase in Greenhouse Gas (GHG; e.g. CO_2) concentrations in the atmosphere. Furthermore, fossil fuels are likely to become more scarce and expensive in the long term, whereas biofuels are inherently renewable and sustainable. Bioethanol is also cleaner-burning compared to fossil fuels, as it has low sulphur and low heavy metal content. It is also an oxygenate, which means that more complete combustion takes places and thus less carbon monoxide is emitted (Balat et al., 2008).

South Africa has very little bioethanol production for use as biofuels at the moment – most likely due to concerns about their economic feasibility, increasing food prices, and the food vs. fuel debate. Current bio-ethanol production is focussed exclusively on the potable and beverage grade markets, using conventional feedstock produced on arable land. There is, however, the potential to expand bioethanol production in the Western Cape through the cultivation of triticale as feedstock, using marginal lands, especially when sufficient subsidy support is available from national government, to ensure economic viability of biofuels production.

Triticale is a hybrid between wheat and rye and is presently used as an animal feed. It is a viable biofuel crop, particularly because it can be cultivated on marginal lands. The drylands area under small grains cultivation has decreased significantly in recent decades, due to changing market conditions and a preference for high-yielding soils. Large areas of drylands previously under wheat cultivation are currently not being used for this purpose, as the wheat yields on these soils do not warrant economically viable agricultural practices. However, advantages of triticale include the fact that the grain is drought tolerant, more pest and disease resistant, needs less input cost and produce higher yield, making it a more profitable crop to grow. Triticale production on marginal lands will significantly limit the potential impact on food production.

It has been estimated that 370 000 tonne per year of triticale can be produced on such marginal lands (see Deliverable 1 of this report), providing a production capacity for bioethanol-triticale of 160 million litres of ethanol per year. Furthermore, triticale produced in the Western Cape for ethanol production and local use will avoid the "transport differential" penalty of approximately R600/tonne, paid by local farmers for the "export" of grains to inland markets (national grain prices are determined in Gauteng). The agricultural potential of triticale as a biofuel crop therefore warrants further investigation to consider the economic and environmental potential of triticale-ethanol production plants. This is the focus of this report.

1.2 Aim

The aim of this project is to identify the preferred industrial process for conversion of triticale to ethanol in the Western Cape, taking both economic and environmental considerations into account. The three processes considered are:

- The conventional warm dry grinding process ("warm" process);
- The conventional dry grinding process but with lower mashing temperature ("cold" process); and
- "Warm" dry grinding to include Pre-fractionation, for removal of the fibrous hull from grains prior to fermentation.

1.3 Methodology

To achieve the above-mentioned aim, the three alternative processes for conversion of triticale to ethanol are compared through detailed simulations of conversion process steps, energy balances, economics, and CO_2 emissions. All the processes were modelled in *Aspen version 8.3*. An economic and economic sensitivity analysis was done on these three processes to determine how robust they are against variations in economics, while environmental impacts were determined through calculation of CO_2 emissions.

In all instances the base case model was taken to be the Warm process that includes the Combined Heat and Power (CHP) plant, for production of process steam and electricity, as well as the production of surplus electricity for potential "export" to the national grid. In the base case, the CHP plant is operated with coal as the energy source, meeting both the process energy requirements (steam, electricity) and providing surplus electricity for "export" from the plant. The Steering Committee for the project noted the uncertainty in terms of the accessibility of the electricity markets created by the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) of national government. In the scenario where the production plant produces both ethanol and electricity, the commercial project developer will be tasked with two separate and distinctly cumbersome processes to be able to sell the ethanol, via the relevant biofuel regulations and markets, and the electricity, via the REIPPPP process.

As a result of the inherent risk of not being able to sell the electricity, due to REIPPPP market constraints, the base case was taken as the economically worst case scenario, where the additional Capex of the CHP plant is included in the construction of the plant, but where the project owner is unable to sell the surplus electricity produced. In the economic assessments this was augmented by two alternatives, i.e. either where surplus electricity could be sold, or where the CHP plant is excluded from the initial capital outlay. In the latter case, the CHP plant is replaced with a lower pressure boiler, providing only the steam required by the process, while the electricity requirements are met by purchasing power from Eskom. The impacts of replacing coal as a process energy source with locally-available plant biomass were also assessed (in terms of economics and environmental benefits).

Assumptions

A basic process description and variations to this basic process (including newer, alternative process technologies) are discussed in this section. The economic and GHG assumptions are also presented. The combination of technical, economic and environmental (GHG emissions) data discussed in this section forms the basis of all subsequent simulation/modelling work for comparison of conversion processes.

Technical assumptions

In this section the three process descriptions and associated flow sheets are presented.

1.3.1 *The Conventional Warm Dry Grinding Process*

The base case model was taken to be the Conventional "Warm" Dry Grinding process, which is the conventional process for industrial production of ethanol from starch grains. Figure 1 presents the process description.

Triticale is ground and mixed with water to a solids loading of 30%. The next stage is liquefaction, where the mixture is heated up to 60°C for approximately 60 minutes. Pejin et al. (2009) point out that α-amylase (see "Liquefaction" reactor - Figure 1) and glucoamylase (see "SSF" reactor - Figure 1) enzymes are added for the warm process. The conversion of starch to glucose is assumed to be 98% of the theoretical yield, based on starch content of the raw material. The mixture is then sent to Simultaneous Saccharification and Fermentation (SSF) reactors, where the operating temperature is 35°C (Balcerek and Pielech-Przybylska, 2013). The residence time of the mash in the SSF reactors is 48 hours (Wang et al., 1997). The yield of the SSF reactors is 95% of the theoretical maximum, based on sugars released by enzymatic hydrolysis. Carbon dioxide (CO_2) produced by the fermentation of glucose to ethanol is removed from the SSF reactors in a vapour stream outlet. This stream also contains some ethanol that requires removal in a scrubber. The scrubber recovers 99% of ethanol vapour and the resultant liquid is sent back to the Beer column. Two knock-out drums remove the excess carbon dioxide from the liquid stream before distillation. The first knock-out drum is operated at 86 °C and 0.85 atmospheres and largely vaporises carbon dioxide, some water and ethanol. The second knock-out drum is operated at 70°C and 1 atmosphere and condenses most of the ethanol vapours, while most of the carbon dioxide remains in the vapour phase. The two knock-out drums thus remove 99% of the carbon dioxide in the liquid stream from the scrubber, with the residual liquid sent back to distillation for ethanol recovery.

The fermented liquid mixture from the SSF reactors is sent to the distillation columns, in combination with the CO_2–free liquid from the vapour scrubber. The first distillation column (Beer column) removes solids and reduces the amount of water, prior to feeding to the second column (Rectifier column). The mass fraction of ethanol in the distillate from the Beer column is 35%. The Beer column contains only a re-boiler and not a condenser, as the distillate is sent to the Rectifier column in vapour phase. The distillate from the Beer column is sent to the Rectifier column in vapour form, where the mass fraction of ethanol in the final product stream is 91% wt. (Amigun et al., 2012). The ethanol condensate from the Rectifier column is further dehydrated by a molecular sieve system to achieve a final ethanol concentration of 99.9%. Denaturant is subsequently added to the purified ethanol to make it unfit for human consumption, prior to storage and sale.

The solids (bottoms) from the Beer column are sent to a solid-liquid separator. The moisture content of the resulting solid product is 65 wt%, which is called Wet Distillers Grains (WDG). The water in the liquid stream from the solid-liquid separator is processed through vacuum evaporation, to decrease the moisture content to 60 wt%. The resulting evaporated liquid stream (syrup) and the WDG are mixed and further dried in a rotary drum to a moisture content of 12 wt%. This product is then called Dried Distillers Grains and Solubles (DDGS), which is an animal feed by-product of the process. DDGS, as produced by all of the triticale-ethanol processes considered here should fulfil the market for animal feed demands that triticale presently provides for.

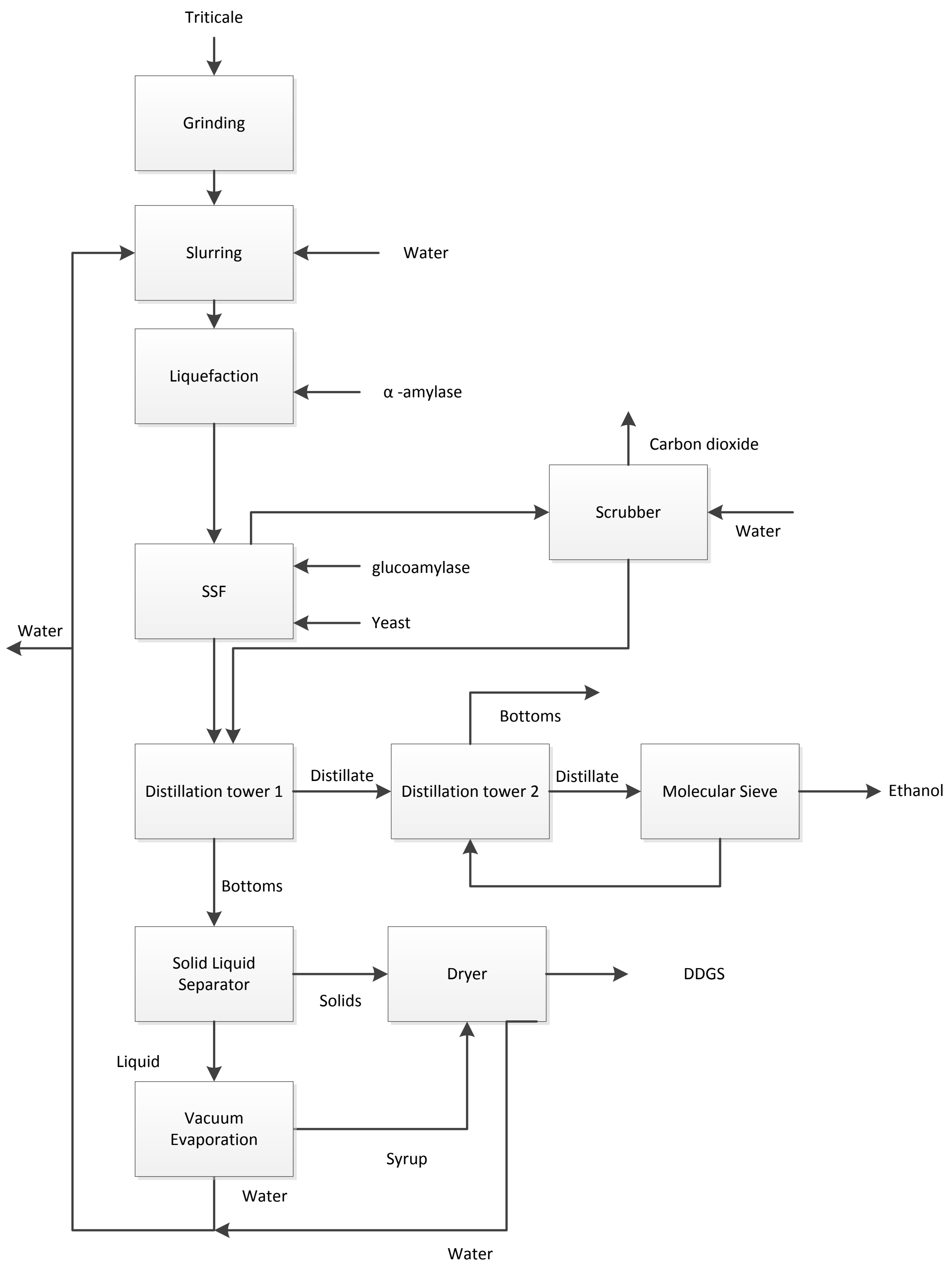

FIGURE 1: BLOCK FLOW DIAGRAM OF CONVENTIONAL DRY GRINDING PROCESS WITH WARM ENZYME PROCESS.

1.3.2 The Cold Dry Grinding Process

The cold process (Figure 2) differs from the warm process because the enzyme cocktail which is used in mashing (such as Stargen 002 from Genencor) is capable of performing hydrolysis at a lower temperatures (30ºC) than the warm process (60ºC). The “cold” enzyme cocktail has a lower hydrolysis efficiency (90%), compared to the warm enzymes (98%), but requires lower energy inputs for starch conversion to fermentable sugar. The cold enzymes do require a pre-saccharification step to improve the hydrolysis efficiency: Pre-saccharification is performed with an amylase product like Optimash, at a temperature of 57ºC with a residence time of 120 minutes.

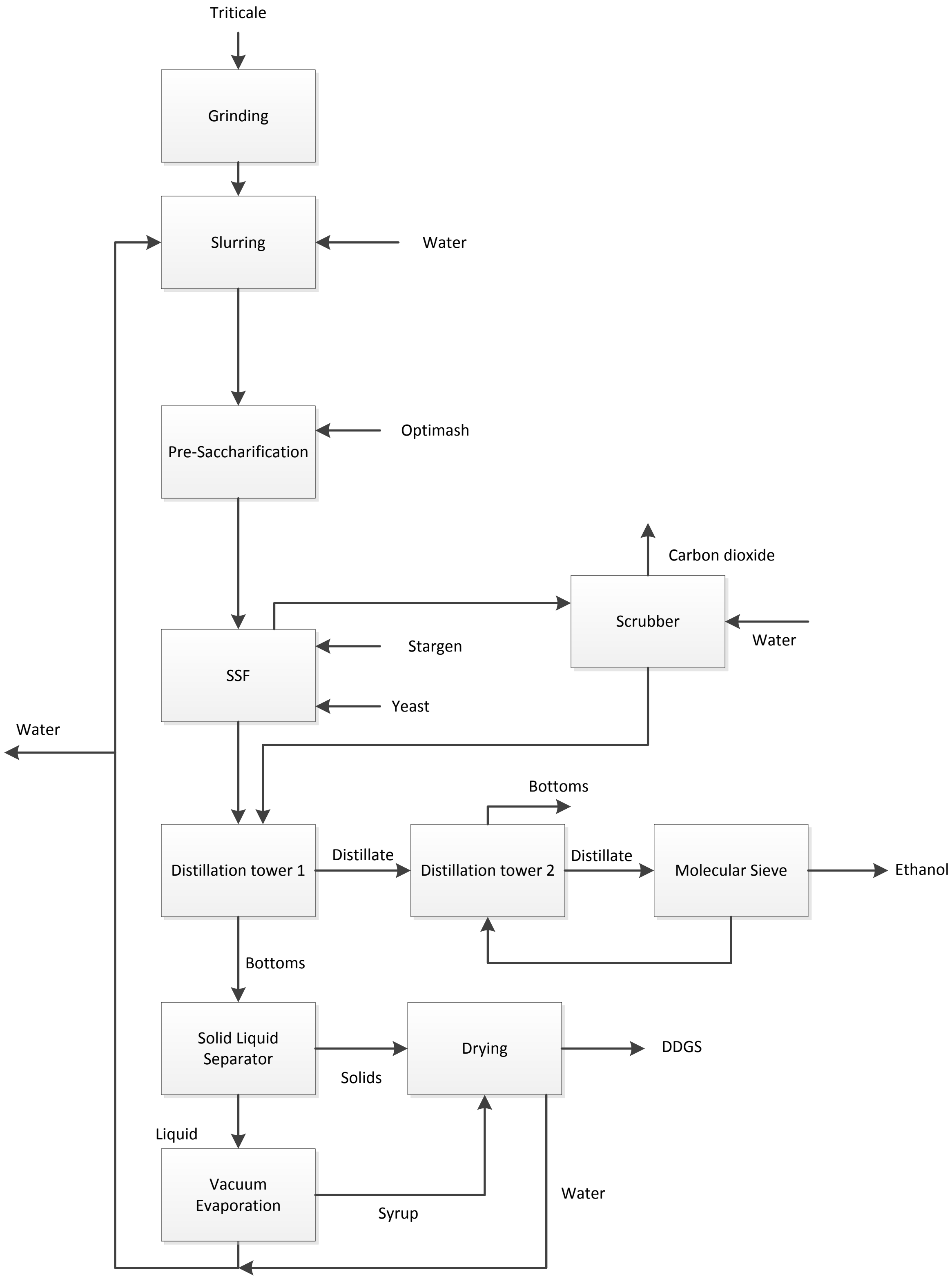

FIGURE 2: BLOCK FLOW DIAGRAM OF CONVENTIONAL DRY GRINDING PROCESS WITH COLD ENZYME PROCESS.

1.3.3 The Pre-fractionation Dry Grinding Process

The Pre-fractionation Dry Grinding Process (Figure 3) is similar to the conventional dry grinding process, but differs in that the bran is removed from the triticale grain prior to final grinding for hydrolysis-fermentation. The bran separated from the triticale grain is enzymatically treated to hydrolyse the residual protein and starch contents. This occurs in the Bran Hydrolysis reactor, operated at a temperature of 30ºC and with a residence time of 6 hours. The liquid from the Bran Hydrolysis reactor is separated from the solids through a solid-liquid separator and used as make-up water in the SSF reactor. This liquid product is combined with the starch-rich solids from Liquefaction to form a combined feed to the SSF reactor. This ensures that protein and residual starch in the bran are recovered as raw materials for fermentation (nutritional source for the yeast; additional carbon for ethanol). The spent bran, consisting mostly of fibrous lignocellulose, is used as an energy source in the boiler, where process steam is produced.

The Pre-fractionation Dry Grinding process significantly decreases DDGS fibre (bran) content and thus lowers the mass yield of DDGS. As a result, DDGS with higher protein content, compared to the “Warm” and “Cold” Dry Grinding process, is produced. Although a lower quantity DDGS is produced, it has significantly higher market value due to the higher protein content. The Pre-fractionation Dry Grinding process also offers capital cost savings as smaller equipment is required with the same feed capacity, compared to processes without Pre-fractionation, where the bran is present as “dead weight” in the hydrolysis-fermentation-distillation-drying process stages. Thus, Pre-fractionation significantly reduces the amount of thermal energy required for fermentation, distillation and DDGS drying, thereby also reducing the overall energy demand of the process. Finally, the Pre-fractionation Dry Grinding process provides bran as an energy source in the boiler, which marginally reduces the demand for external energy sources, such as coal or biomass (Amigun et al., 2012, 2011).

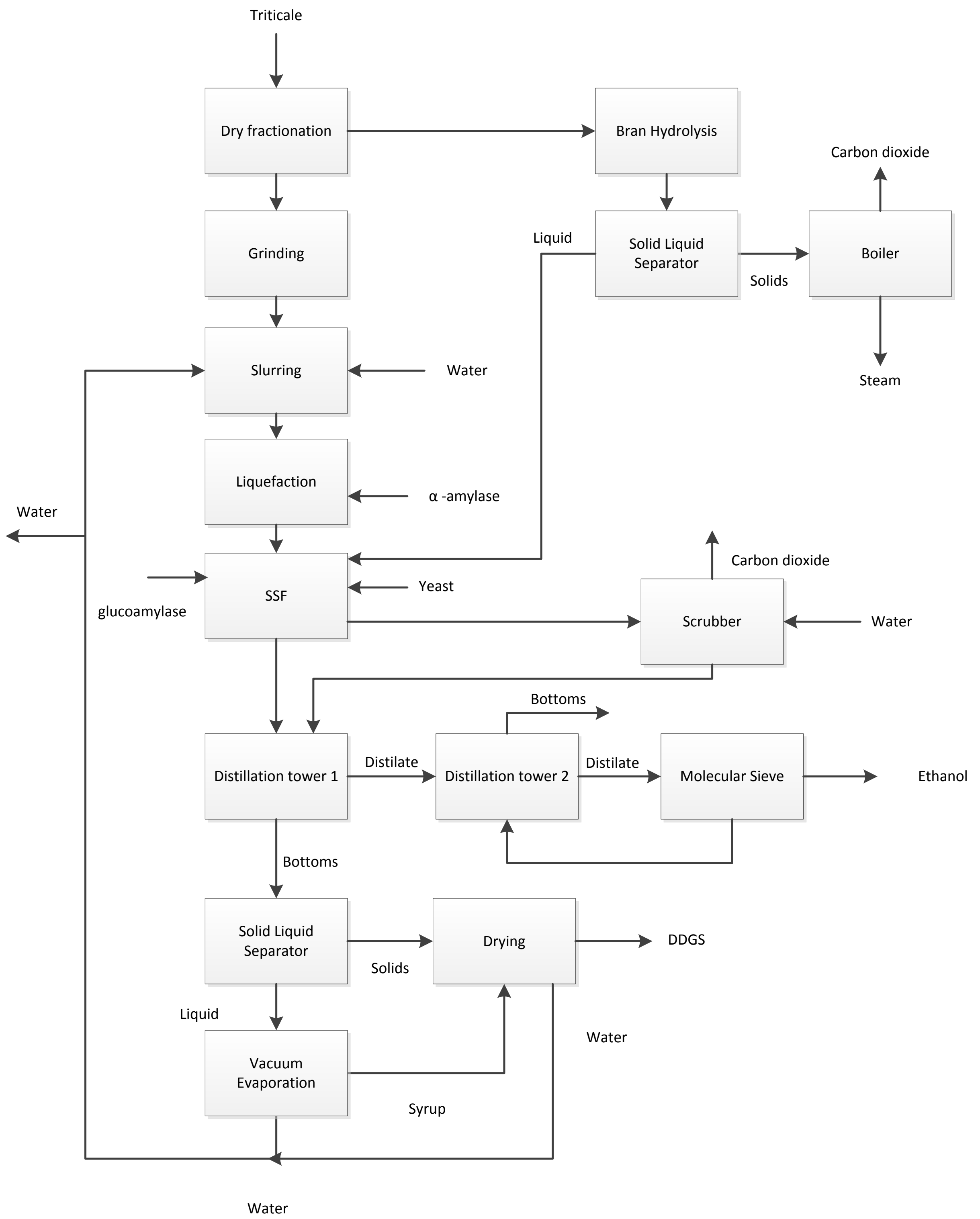

FIGURE 3: BLOCK FLOW DIAGRAM OF DRY PRE-FRACTIONATION GRINDING PROCESS WITH WARM ENZYME PROCESS.

1.4 Economics assumptions

It is assumed that ethanol can be sold at the Basic Fuel Price (BFP) for petrol, provided it is blended at no more than 2% with petrol, which is the mandatory blending and subsidy support in South Africa. The BFP saw a drastic reduction in recent months, to values as low as R4.40/l for February 2015. However, for the baseline of this economic analysis the average BFP over the last 14 months of R7.59/l was used. The DDGS price was assumed to be R1800/tonne for the warm and cold processes, after consultation with the (ruminant) animal feed industry. The DDGS from the Pre-fractionation Dry Grinding process could be sold at a price of R7000/tonne. This price is motivated by the significantly higher protein and lower fibre content, making it suitable for feeding to non-ruminant animals (e.g. poultry, pigs) - the largest animal feed market in South Africa (conventional high fibre DDGS can only be consumed by ruminants).

Although there is uncertainty regarding the market for, and price of carbon credits, this report assumes a price of R132/tonne CO_2 equivalent. The sales price of electricity is taken as R0.67/kWh, the minimum value at which it could be sold into the electricity grid. Economic simulations for a CHP plant were done where surplus electricity is produced, and is either sold to the grid, or cannot be sold due to market constraints. Economic evaluations included a scenario in which a CHP plant was built, but the surplus electricity not sold, to determine the robustness of the process economics against the inherent uncertainty and risks with electricity sales through the REIPPPP. Furthermore, the economic implications for a process without using a CHP plant were also considered.

The triticale feedstock price was assumed to be R2 00/tonne, based on consultation with representatives from the Department of Agriculture in the Western Cape. This factory gate price considers the avoided “transport differential penalty” by farmers, due to grains being marketed locally, rather than being “exported” north. The local market therefore makes triticale the lowest cost starch grain available in the Province, with a significant cost-advantage compared to grain sorghum, which is frequently considered as feedstock for ethanol production elsewhere in SA.

The price of yeast is R150/kg, while the price of conventional “warm” enzymes is assumed as R115/tonne. The price of Stargen 002, the enzyme for the cold process, is assumed as R96/kg, although it is required in approximately double the dosage as the conventional warm enzymes.

The cost of coal is assumed as R500/tonne, delivered to the factory gate. Biomass price was taken as R362/tonne, delivered to the factory gate. The price of water for the process is assumed as R12/kl.

Energy cost (including electricity) is assumed to increase by 10% a year, while ethanol and chemicals prices are only assumed to increase by 8% a year. Salary cost is assumed to increase by 7% a year.

In this report:

- The "subsidy" was calculated as the rand per litre ethanol (R/l) amount required from government for bioethanol producers to achieve a 15% Return on asset (ROA).
- "Economically viable" is when a positive Internal Rate Return (IRR) achieved at a 15% ROA, with the latter provided by the subsidy support where necessary.

1.5 Environmental assumptions

For this report a cradle-to-grave CO_2 emissions approached was considered. In this cradle-to-grave cycle it is assumed that most of the GHG emissions will be CO_2, which is as follows.

- Agriculture: Triticale production produces 0.2kg of CO_2/tonne of grain, based on emissions data collected by GreenCape.
- Triticale and biomass transport: It is assumed that a truck runs on diesel and uses 30l/100km. The load capacity of a truck is assumed as 40 tonne. It is assumed that 1 L diesel produces 2.68kg CO_2. All biomass and triticale used for the plant is located within a 100 km radius of the plant.
- Coal Transport: The sea freight emissions of coal is 124g CO_2/tonne nautical mile (from Richards bay to Saldanha Bay is 990 nautical miles) and rail freight is 0.026kg CO_2/tonne mile (Saldanha Bay to Swellendam for 332km).
- Production Process: Emission factor is 0.94g CO_2/kg coal.
- Ethanol/petrol balance: A car uses 9l/100 km and produces 2.35kg CO_2/l petrol and 1.5kg CO_2/l ethanol.

2. RESULTS

In this section the results of the three processes, namely Conventional Warm Dry Grinding process (the "Warm process"), Cold Dry Grinding process (the "Cold process") and Pre-fractionation Grinding proses (the "Pre-fractionation process") are presented.

In all instances the base-case model was taken to be the Warm process and reference to any process or economic indicators refers to coal as energy source, unless indicated otherwise in brackets.

2.1 Technical

Error! Reference source not found. presents the amount of triticale used and resultant ethanol, DDGS and CO_2 produced. At a triticale base feed rate of 370 000 tonne/y for each process, the Pre-fractionation process produces the most ethanol at 161 000 000 l/y, followed by the Warm and Cold processes, at 160 000 000 l/y and 155 000 000 l/y, respectively. This is expected, as the Pre-fractionation process has two hydrolysis steps, which would give a higher yield of glucose available for conversion to ethanol. The difference in ethanol produced by the Warm and the Cold process can be attributed to the inefficiency of the enzymatic conversion of starch to glucose in the Cold process.

TABLE 1: PRODUCTS AND FEEDSTOCKS

Models	Warm Process	Cold Process	Pre-Fractionation Process
Triticale (ton/y)	370 000	370 000	370 000
Ethanol (L/y)	160 000 000	155 000 000	161 000 000
DDGS ton/y	124 600	132 350	91 800
CO2 (ton/y)	122 500	116 000	122 500

In terms of DDGS produced, the Cold process produces 132 350 tonne/y which is more than the Warm process (124 600 tonne/y), as the enzymes are less efficient at converting starch to glucose at cold temperature. The Pre-fractionation process produces the least mass of DDGS at 91 800 tonne/y, because the bran is removed from the process; however, the DDGS is of a higher quality (higher protein content, less fibre), thus likely to fetch a higher price.

Both the Warm and Pre-fractionation processes produced the same amount of CO_2, namely 122 500 tonne/y. As would be expected, the Cold process produced less CO_2, 116 000 tonne/y, due lower starch conversion.

Table 2 shows the energy, heating and cooling utility demands for the 3 processes, based on a triticale feed rate of 370 000 tonne/y for each process. The Pre-fractionation process uses the least amount of heating duty (87 MW), with both the Cold and Warm processes requiring 92 MW. The difference is attributed to the smaller mass throughput in the hydrolysis-fermentation-distillation-drying sections of the Pre-fractionation process, compared to processes without Pre-fractionation. The specific energy use (J/l ethanol) was lowest for the Pre-fractionation process is 0.540 (J/l), while the Cold process (0.594 J/l) was less efficient than the Warm process (0.575 J/l), due to lower ethanol yields.

For both coal and biomass the annual energy requirements are: Pre-fractionation **>** Warm process **>** Cold process (See Table 2 for values). The process that has the highest electricity demand is the Cold process at 12 MW, which is due to the higher solids loading in the SSF reactors. The electricity demand is the Pre-fractionation and Warm process is 10 MW and 11 MW, respectively. The cooling duty follows the following trend: Pre-fractionation **>** Warm process **>** Cold process (80 MW, 87 MW and 88 MW respectively).

Whereas the heating demands of the conversion processes are always met by steam produced onsite in a boiler, the electricity demands can either be met by Eskom-supplied power, or by onsite electricity generation. Table 2 indicates that total amount of electricity that can be produced onsite for the various process scenarios, which will provide the process energy demands and surplus electricity for export to the national grid (CHP plant included). The amount of (surplus) electricity that can be produced in the processes follows the same trend as the heating duty, because steam and electricity are always co-generated in a CHP plant: More heating demand will require more steam and thus automatically produce more (surplus) electricity. The amount of surplus electricity for export to the national grid (23-24 MW), could make a significant contribution to development of the Green Economy in the Western Cape, but only when biomass is used as the energy source, rather than coal.

TABLE 2: UTILITIES

Models	Warm Process	Cold Process	Pre-Fractionation Process
Coal (ton/y)	198 000	190 500	188 000
Biomass (ton/y) wet	425 000	422 000	402 000
Heating Duty (MW)	92	92	87
Cooling Duty (MW)	88	87	80
Electricity Needed (MW)	11	12	10
Electricity Produced (MW)	35	35	33

2.2 Economics

The capital (Capex) and operating (Opex) costs of the three processes, including the CHP plant for onsite electricity generation, are given in **Error! Reference source not found.**. Capex, in increasing order, is as follows: Cold process (R2 083 M) **<** Pre-fractionation (R2 146 M) **<** Warm process (R2 400 M). The above Capex can be evaluated by the Capex requirement per litre ethanol produced annually. Capex for the Warm process is R15/l, while for the Cold and the Pre-fractionation processes it is R13.4/l and R13.3/l, respectively. This compares well to an oil refinery that has a value of about R15/l.

The Capex of the plant is decreased by approximately 57% if a CHP plant for onsite electricity production is excluded. The additional Capex for the CHP plant, in comparison to the triticale-ethanol process without onsite electricity generation, ranged from R58 125 to R51 261 per kW installed capacity, which compared well with other types of renewable energy, but only if plant biomass is used as energy source for the process. The process without onsite electricity production will still utilise an onsite boiler for generation of steam at the pressure required by the process, and will purchase the required electricity from Eskom. The economic impacts of electricity production onsite, with export of surplus electricity to the national grid, are discussed in the report sections below.

TABLE 3: CAPITAL (CAPEX) AND OPERATIONAL (OPEX) COSTS

Models	Warm Process	Cold Process	Pre-Fractionation Process
CAPEX (R Million)	R 2 400	R 2 083	R 2 146
CAPEX (R Million) without CHP	R 1 005	R 889	R 967
CAPEX/L ratio	15.0	13.4	13.3
OPEX (R Million)	R 1 107	R 1 455	R 1 076
OPEX with Biomass (R Million)	R 1 172	R 1 140	R 1 125
OPEX/L ratio	6.92	9.39	6.68

Annual Opex in increasing order, is as follows: Pre-fractionation (R1 125 M) **<** Warm process (R1 140 M) **<** Cold process (R1 172 M).

To put Opex into perspective, the Rand per litre ethanol price compares as follows: R6.68/l for the Pre-fractionation, R6.92/l for the Warm process and R9.39/l for the Cold process. The base case is taken at a BFP of R7.59/l, as a representative value over the last 14 months. The current BFP value of R4.40/l results in a situation where input costs exceeds the sales revenue for both Warm and Cold processes, which does not justify ethanol production, nor the allocation of subsidy to support such ethanol production.

The Opex when using biomass instead of coal for process energy/electricity is as follows: Pre-fractionation (R1 125M) **<** Cold process (R1 140M) **<** Warm process (R1 172M). There is an increase in Opex using biomass, which is mainly due lower energy density of biomass compared to coal, resulting in a higher cost per unit energy.

In all cases the IRR (see Table 4) for the Pre-fractionation process is much better than both the Warm and Cold processes. This marked difference is mainly attributed to the much higher premium for the DDGS sold for the Pre-fractionation compared to the Warm and Cold processes (R7 000/tonne vs R1 800/tonne), as well as significant savings in Capex and Opex due to smaller equipment and reduced process energy. The marginal difference in IRR between the Warm and Cold process is attributed to the Cold process' lower Capex, being offset by the Warm process' higher ethanol production capacity.

TABLE 4: IRRS FOR DIFFERENT SCENARIOS

Models	Warm Process	Cold Process	Pre-Fractionation Process
IRR (Base Case, CAPEX included CHP plant, coal as energy source with no sales of electricity)	21.3%	22.6%	51.7%
IRR(Base Case, CAPEX included CHP plant, coal as energy source with sales of electricity)	29.0%	31.3%	61.9%
IRR (CHP plant not included in CAPEX, using coal as energy source)	38.8%	41.0%	116.5%
IRR (Base Case, CAPEX included CHP plant, biomass as energy source with sales of electricity)	25.7%	27.5%	57.7%
Note: The OPEX of the IRR (without CHP) is the same as that of the base case OPEX			

It should be noted that the base case scenario refers to all processes with a CHP plant, but where no sales of surplus electricity (production beyond process requirements) are realised. Coal is also used as energy source in the base case. This definition of the base case was applied to determine the robustness of process economics against uncertainty concerning the sales of electricity on to the national grid via the REIPPPP.

The slightly higher IRR for the Base Case (Capex included CHP plant with sales of electricity) with coal as an energy source, compared to the use of biomass (Capex included CHP plant with electricity sold) is due to the higher cost per unit energy for biomass compared to coal (Table 4). The IRRs for processes including a CHP plant, but where sales of surplus electricity could not be realised (21.3%, 22.6% and 51.7%) were obviously lower than process options with a CHP plant where sales of the surplus electricity production could be realised (29.0%, 31.3%, 61.9% for the same processes). The Pre-fractionation process could provide an attractive return to investors when CHP is included, irrespective of whether surplus electricity sales could be realised. Even with sales of surplus electricity, the process options including a CHP plant still provided lower IRRs (29.0%, 31.3%, 61.9%) than process options where the CHP plant is replaced with onsite generation of low pressure steam and buy-in of process electricity requirements from Eskom (IRRs of 38.8%, 41.0%, 116.5%, for the same process options). The highest IRRs were consistently achieved with processes that do not have a CHP plant, due to the high capital cost of the CHP plant.

Table 5 shows the required subsidies for all processes and different scenarios. Note that the "subsidy" was calculated as the rand per litre ethanol (R/l) amount required from government to achieve a 15% ROA. For all cases the Pre-fractionation process does not require any subsidy. The rest of the subsidies are shown in Table 5. This subsidy is highly dependent on the BFP, for which an average value over the last 14 months was taken.

TABLE 5: SUBSIDIES

Models	Warm Process	Cold Process	Pre-Fractionation Process
Subsidy (Base Case, CAPEX included CHP plant, coal as energy source with no sales of electricity)	R 0.59/L	R 0.44/L	R 0.00/L
Subsidy(Base Case, CAPEX included CHP plant, coal as energy source with sales of electricity)	R 0.00/L	R 0.00/L	R 0.00/L
Subsidy (CHP plant not included in CAPEX, using coal as energy source)	R 0.00/L	R 0.00/L	R 0.00/L
Subsidy (Base Case, CAPEX included CHP plant, biomass as energy source with sales of electricity)	R 0.84/L	R 0.69/L	R 0.00/L

The base case is taken at a BFP of R7.59/l. Given the current (February 2015) BFP of R4.40/l of the three processes considered, only the Pre-fractionation process is economically viable with an IRR of 18.75% and a subsidy requirement of R0.70/l (first year) ethanol to achieve the desired ROA of 15%.

2.3 Environmental

Table 6 shows CO_2 emissions per year for the three processes using a cradle to grave approach. Table 6 should be read as follows:

- Row 1: Shows the CO_2 emissions produced by each process using coal as energy source;

- Row 2: Shows the CO_2 emissions produced by each process; using biomass as energy sources;
- Row 3: Shows the saving in CO_2 emissions should ethanol be used as fuel instead of petrol;
- Row 4: Shows the difference in CO_2 emissions should ethanol be used as fuel instead of petrol; in other words the nett savings in CO_2 emissions with coal as energy sources;
- Row 5: Shows the difference in CO_2 emissions should ethanol be used as fuel instead of petrol; in other words the nett savings in CO_2 emissions with biomass as energy source.

The total amount of CO_2 produced over the cradle-to-factory-gate section of the triticale-ethanol value chain, was compared for the alternative process technologies. This includes all emissions in agriculture, harvesting, transport and grain conversion to the final ethanol product. In this comparison the Pre-fractionation process produced the least amount of CO_2at 115 100 tonne/yr, followed by the Cold process at 116 700 tonne/yr. and the Warm process at 117 200 tonne/yr. Using biomass to replace coal significantly reduced CO_2 emissions over the cradle-to-factory-gate, due to it being carbon neutral and the smaller impact of biomass transport compared to coal (see row two, Table 6).

TABLE 6: CO_2 BALANCE

Models	Warm Process	Cold Process	Pre-Fractionation Process
Nett CO2 (ton/y)	117 200	116 700	115 100
Nett CO2 Biomass (ton/y)	79 590	79 570	79 420
CO2 replaced by bioethanol (ton/y)	136 200	131 900	136 800
Coal CO2 reduction (ton/y)	19 000	19 500	21 100
Biomass CO2 reduction (ton/y)	56 610	56 630	56 780

The benefit of using ethanol to replace petrol is illustrated by the saving in CO_2 emission shown in row three in Table 6, which represents the GHG benefit of ethanol consumption, which should be compared to the negative environmental impacts of CO_2 emissions in ethanol production (rows one and two). The Pre-fractionation process has the greatest reduction in CO_2 emissions at 136 800 tonne/y followed by the Warm process at 136 200 tonne/y and the Cold process at 131 900 tonne/y As a consequences, the nett savings in CO_2 emissions, as the difference between CO_2 savings due to ethanol use and CO_2 emissions due to ethanol production, for processes using coal as energy source, were 21 100 tonne/y, 19 500 tonne/y. and 19 000 tonne/y for the Pre-fractionation Warm and the Cold processes, respectively. The savings in CO_2 emissions using biomass are shown in row five in Table 6 (56 610 to 56 780 tonnes/y), and were significantly larger than when coal is used as process energy source.

Table 7 and Table 8 show the break-down of CO_2 emissions for coal and biomass for each process (i.e. breakdown of rows one and two in Table 6). In both cases, agriculture is the main contributor to CO_2 emissions.

TABLE 7: CO_2 BREAK-DOWN USING COAL

Models	Warm Process	Cold Process	Pre-Fractionation Process
Argiculture (ton/y)	74 000	74 000	74 000
Process Plant	13 700	13 650	13 000
Triticale Transport (ton/y)	2 800	2 800	2 800
Coal Transport (ton/y)	27 100	26 700	25 700

There is a marked difference in transport-related emissions when locally sourced biomass is used instead of coal. Table 8 does not contain CO_2 emissions from the process plant as the emissions produced for heating is carbon neutral when biomass is used.

TABLE 8: CO_2 BREAK-DOWN USING BIOMASS

Models	Warm Process	Cold Process	Pre-Fractionation Process
Argiculture (ton/y)	74 000	74 000	74 000
Process Plant	-	-	-
Triticale Transport (ton/y)	2 800	2 800	2 800
Biomass Transport (ton/y)	3 240	3 220	3 060

The nett input of fresh water required for each plant is given in Table 9, taking into consideration the maximum amount of recycling of process water that can be achieved in the triticale conversion process. Notwithstanding a 97% recycling of all process waters, the nett water requirements are significant for all processes. The cooling water requirement is the main contributing factor, due to evaporation of process water to provide cooling, which for the Warm process is 24.5l/l (litre water/litre ethanol), for the Cold process 15.5l/l and the Pre-fractionation process 23.5l/l. Currently, the simulation model accepts a 3% loss of cooling water to atmosphere. At these consumption rates, the cooling cycle needs further investigation, to find options with lower water-demands.

TABLE 9: WATER BALANCE

Models	Warm Process	Cold Process	Pre-Fractionation Process
Make up Process (ton/h)	7.5	7.4	7.6
Make up Steam (ton/h)	5.6	4.5	4.5
Make up Cooling water (ton/h)	433	274	429

3. SENSITIVITY ANALYSIS

Different factors may have an effect on the profitability of the triticale-ethanol production process, as investigated through a sensitivity analysis. These factors include BFP, Triticale cost , DDGS price, CO_2 tax , electricity price and biomass cost , together with the potential for co-production and sales of surplus electricity, as discussed below. The latter option is addressed in the "Without Electricity" scenarios and results are presented below, (base case plant, including CHP plant that produces surplus electricity beyond the process requirements, but where no sales of the surplus generated electricity are realised, due to market constraints).

3.1 Basic Fuel Price

In Figure 4 it can be seen that the highest IRR is achieved by the Pre-fractionation process, ranging from 14% at a BFP of R4.00/l to 69% at a BFP of R9.00/l. For the Pre-fractionation process, as for all other processes, the sale of surplus electricity produced onsite by the CHP plant improved the profitability of the process, compared to scenarios where the surplus electricity is produced but not sold. The IRRs increased from 14% to 23.0% at a BFP of R4.00/l, and showing similar increases at higher BFPs, due to such electricity sales, rather than wastage. The Cold process performed better than the Warm process in terms of IRR, which means the Cold process requires less subsidy. Note however, that for threshold BFP values of R6.00/l and R5.00/l, below which, the Cold and Warm processes have negative IRRs irrespective of selling electricity or not. This indicates that fluctuations in BFP may result in situations where triticale-ethanol production is not viable, and should be suspended for a particular period of time – according to the national biofuels legislation, such shutdowns will not negatively affect the 15% ROA proposed as a basis for calculating the required subsidy support.

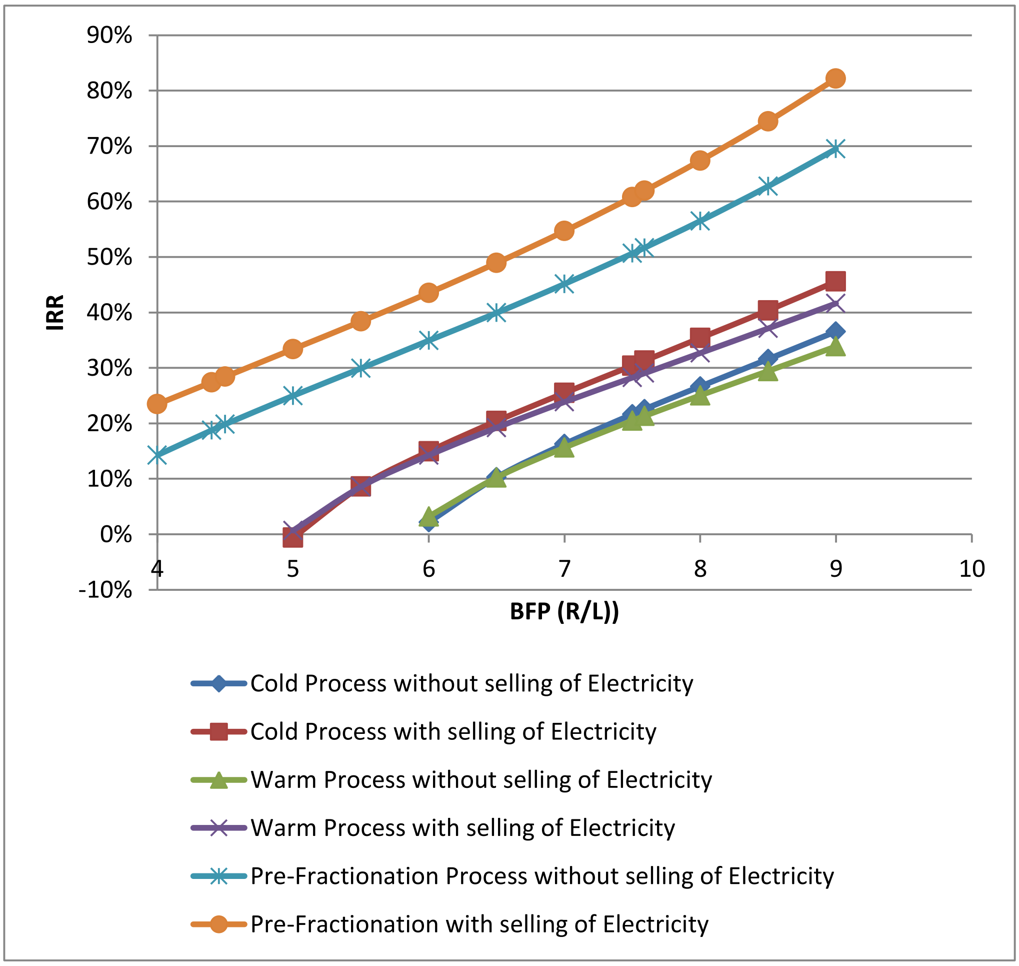

FIGURE 4: BFP VS IRR. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

From Figure 5 it can be seen that the Pre-fractionation process only needs subsidy below a BFP of R5.50/l (to ensure a 15% ROA), even without revenue being generated from the selling of surplus electricity production. However, with the selling of surplus electricity, a subsidy is only required with a BFP of below R4.50/l. The Warm and Cold processes were less robust to changes in the BFP, compared to the Pre-fractionation process, requiring subsidy below a BFP of about R7.50/l and about R8.50/l, respectively.

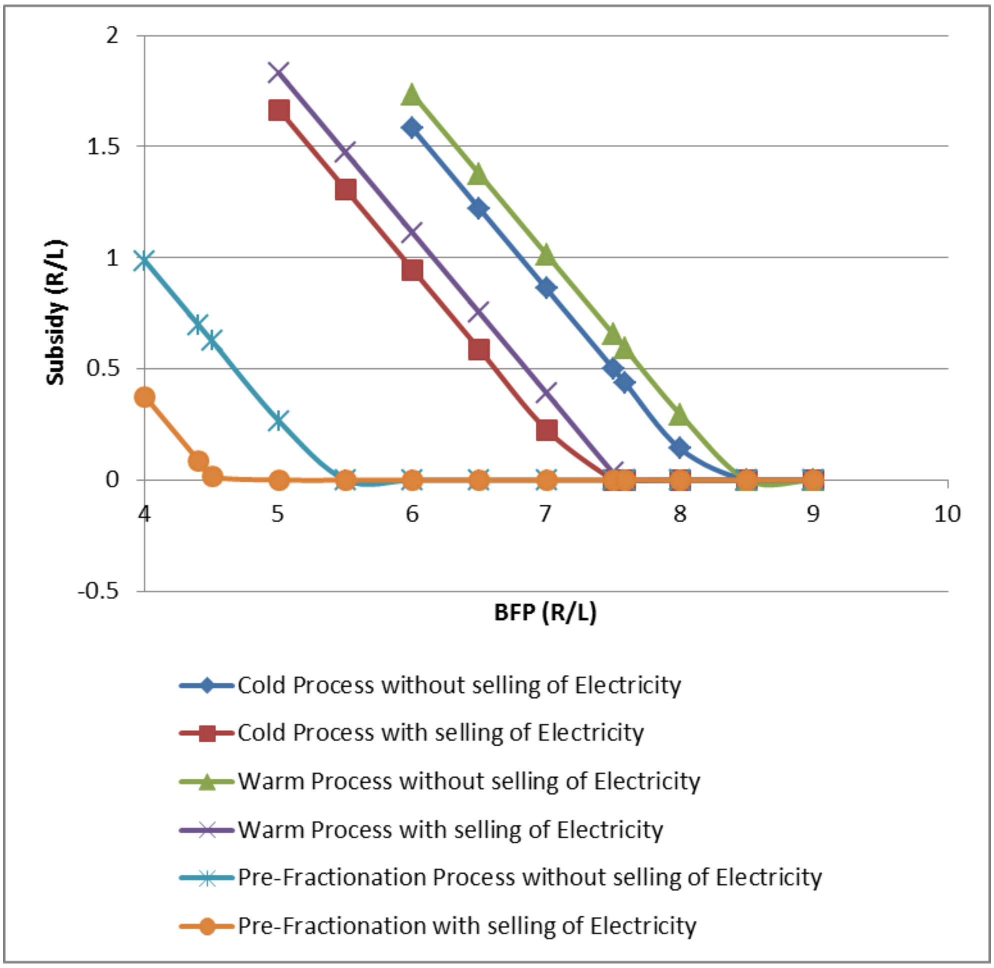

FIGURE 5: BFP VS SUBSIDY. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

3.2 Triticale Price

Figure 6 shows an overall downward trend in IRR and economic viability as the price of triticale increases, which is expected as triticale feedstock represents approximately 70% of the Opex of ethanol production. The "Without Electricity" options in Fig 6 refer to base case plant, which includes CHP plant for electricity production, but where no electricity sales are realised. Selling surplus electricity, rather than wastage, improved the profitability of each plant. The most profitable process from Figure 6 is the Pre-fractionation process with the selling of electricity, followed by the Pre-fractionation process without selling electricity, the Cold (with electricity sales), Warm (with electricity sales), the Cold (without electricity sales), and finally, the Warm (without electricity sales) processes.

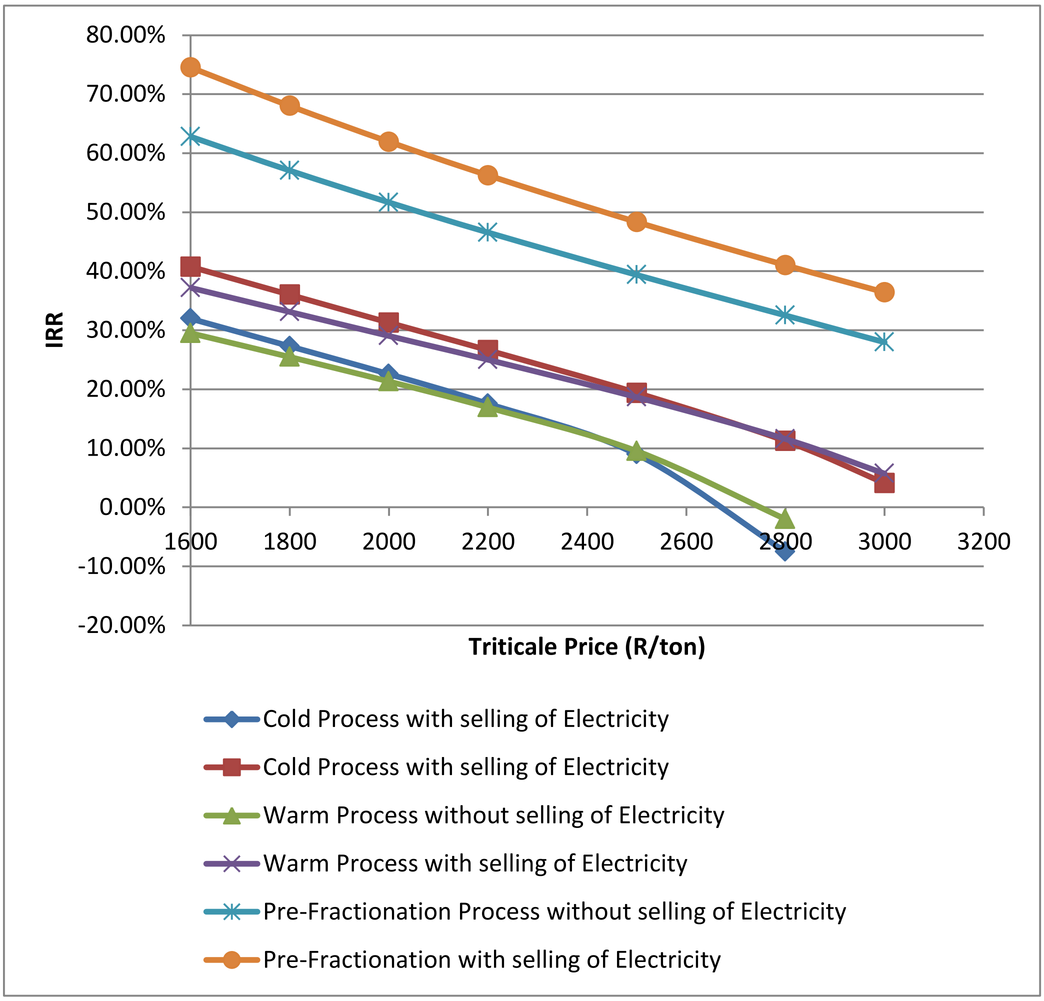

FIGURE 6: TRITICALE PRICE VS IRR. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

The required subsidy for a 15% ROA was very sensitive to variations in the price of triticale grain, evident by the upward trend in the graph in Figure 7. The Pre-fractionation process required almost no subsidy, except at the maximum price applied (R3000/tonne for triticale required subsidy of R0.05/l). The Cold process required less subsidy than the Warm process, and should therefore be economically more robust to feedstock price variations. The Pre-fractionation process should be the preferred process based on variations in the price of triticale.

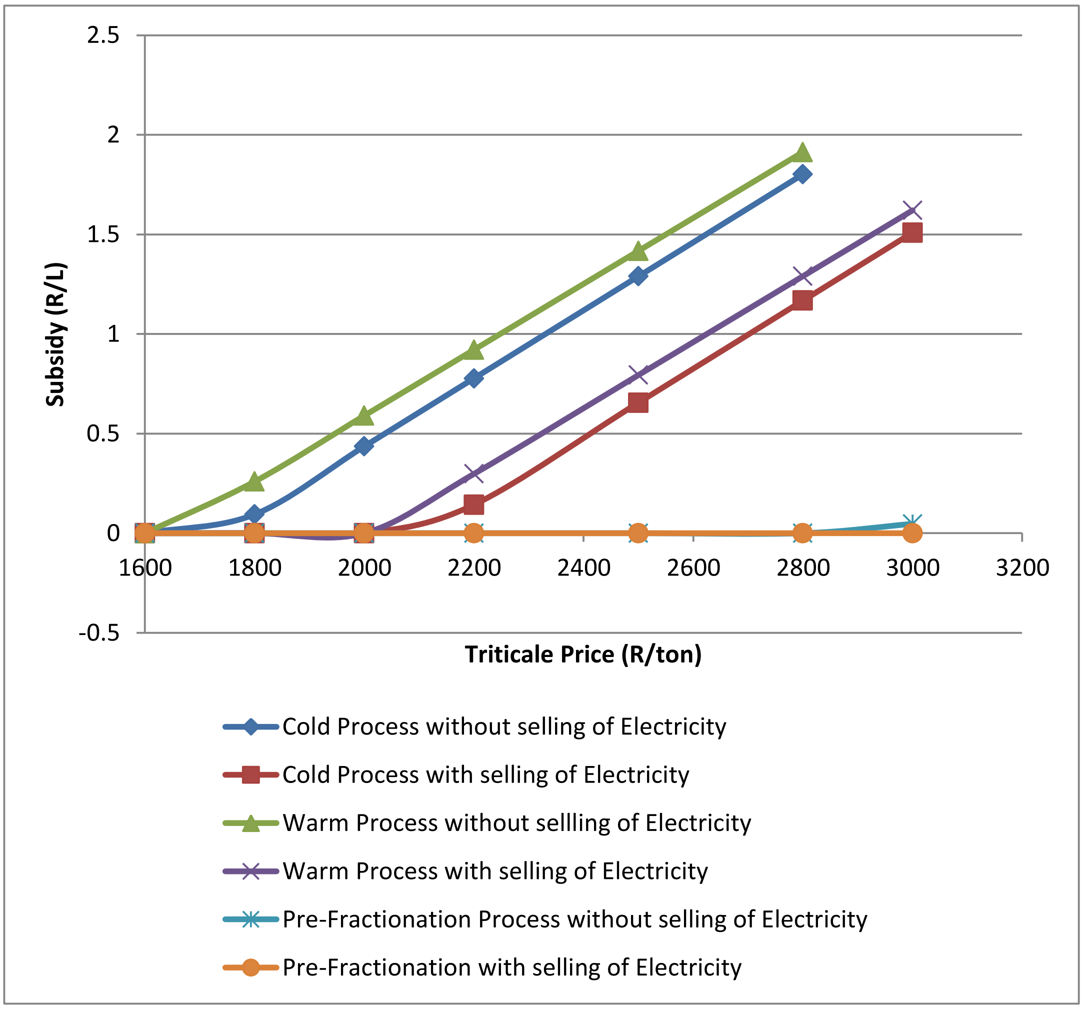

FIGURE 7: TRITICALE PRICE VS SUBSIDY. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

3.3 DDGS Price

Figure 8 shows an upward trend in the economic viability (measured as IRR) as the price of the DDGS increased; the profitability of the plant increased with an increase in DDGS price. The "Without Electricity" options in Fig. 8 refer to base case plant, which includes CHP plant for electricity production, but no electricity sales are realised, due to market constraints.

A noticeable difference in the IRR can be observed between the Pre-fractionation process and the Warm and Cold process (contributed by the difference in DDGS price of R7 000/tonne vs R1 800/tonne). This is due to the fact that the Pre-fractionation process produces a higher quality animal feed demanding a higher price (R7 000/tonne vs R1 800/tonne), resulting in substantially higher economic returns.

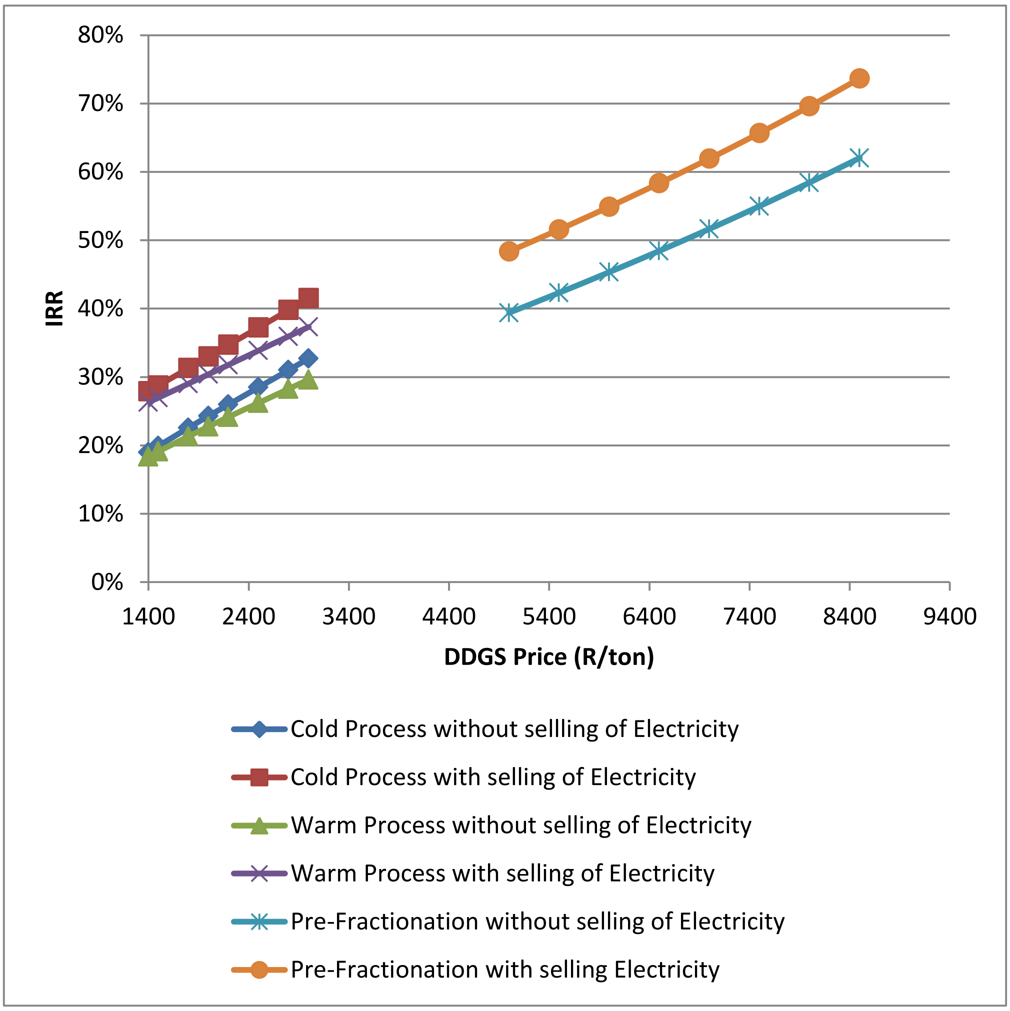

FIGURE 8: DDGS VS IRR. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

In Figure 9 it can be noted that the economic viability of the Pre-fractionation process is not dependent on subsidy in the DDGS prices ranges tested. Hence the Pre-fractionation process profitability is independent of subsidy in the range of DDGS prices specified. For the Warm and Cold processes, DDGS price is more dependent on subsidy (without selling electricity), but less so when electricity is sold. The Cold process is more robust to changes in DDGS price than the Warm process. DDGS price does influences the subsidy needed, although to a lesser extent than the BFP and feedstock prices.

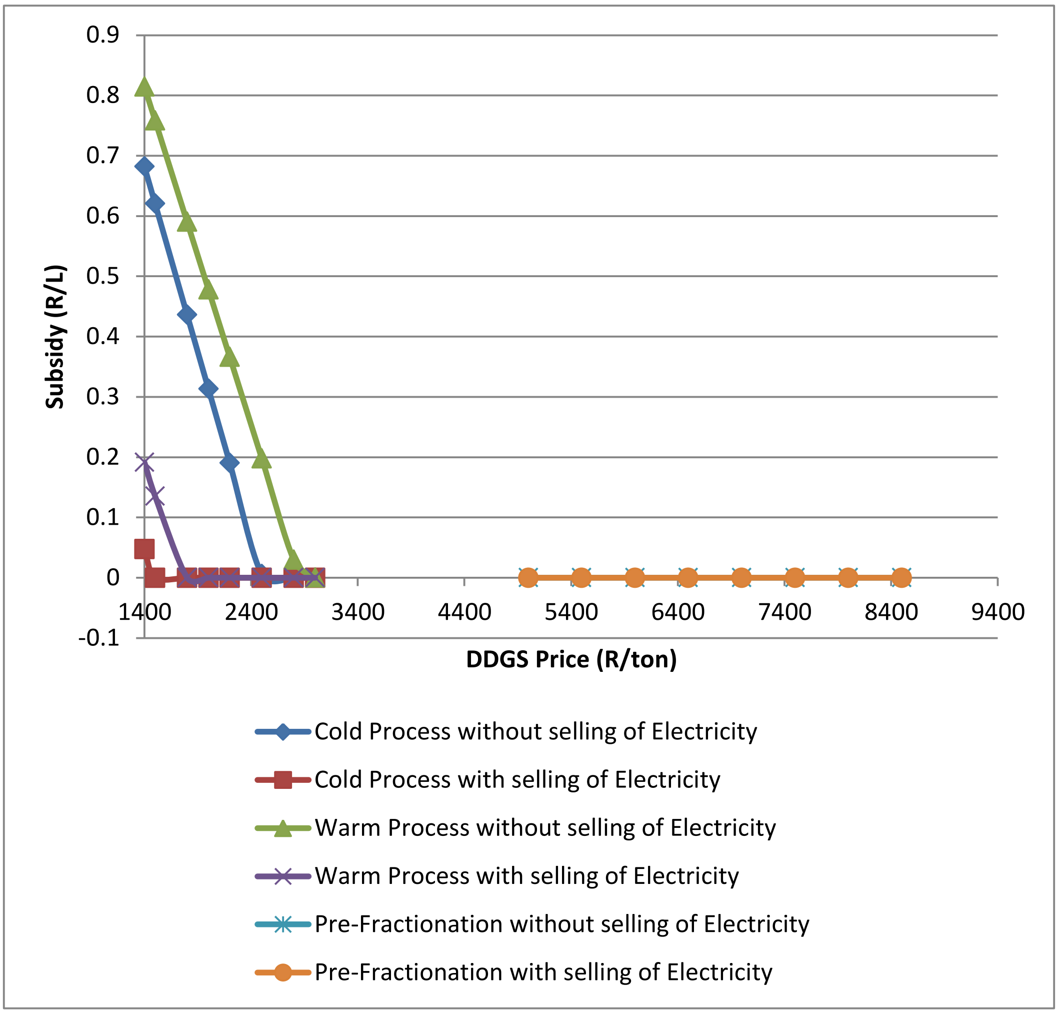

FIGURE 9: DDGS PRICE VS SUBSIDY. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

3.4 CO_2 Price

The CO_2 price in Figure 10 show very little effect on the IRR of any of the processes (with our without electricity sold), hence it can be concluded that the selling of CO_2 will have very little effect on the process profitability. The IRR is more dependent on the process choice that the CO_2 price, with the Pre-fractionation process outperforming all the other processes. The "Without Electricity" options in Fig 10 refer to the base case plant, which includes a CHP plant for (surplus) electricity production, but no electricity sales are realised. Figure 11 confirms the similar trends as Figure 10, showing an almost insignificant decrease in subsidy needed as the CO_2 price increased for all of the processes.

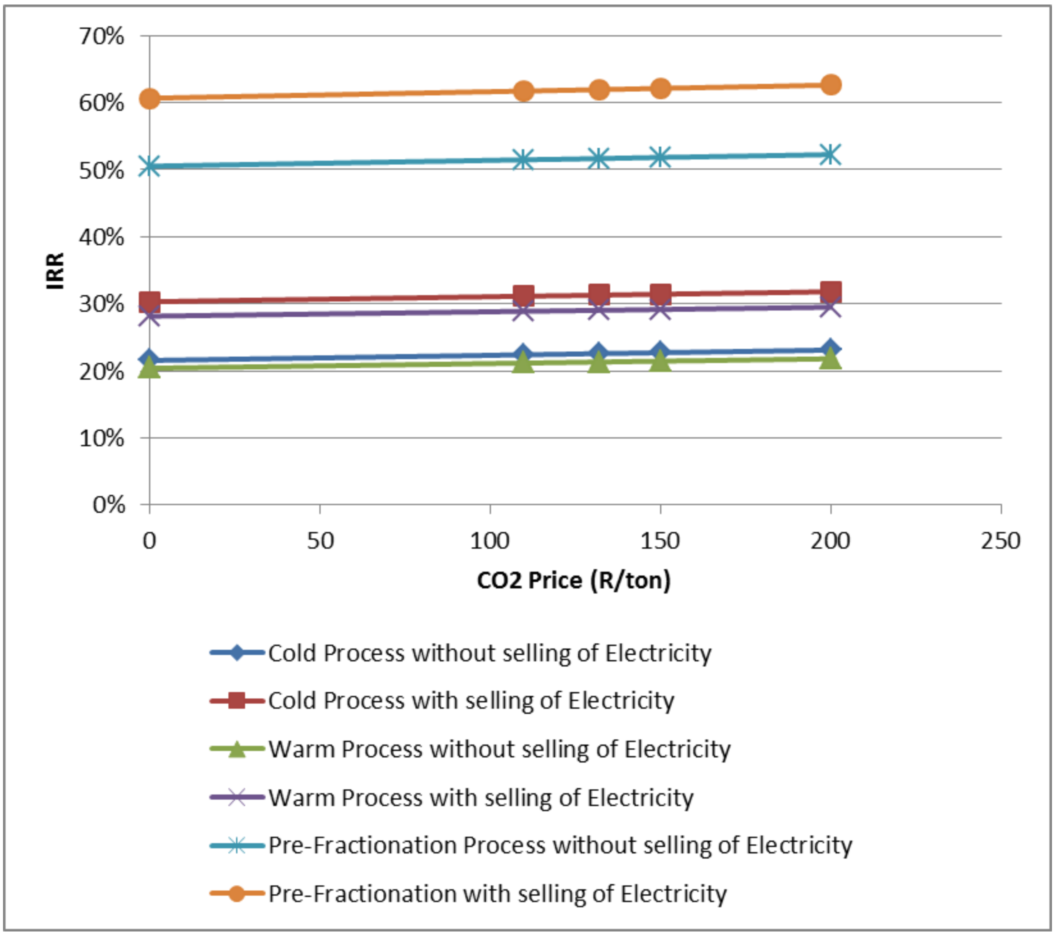

FIGURE 10: CO_2 VS IRR. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

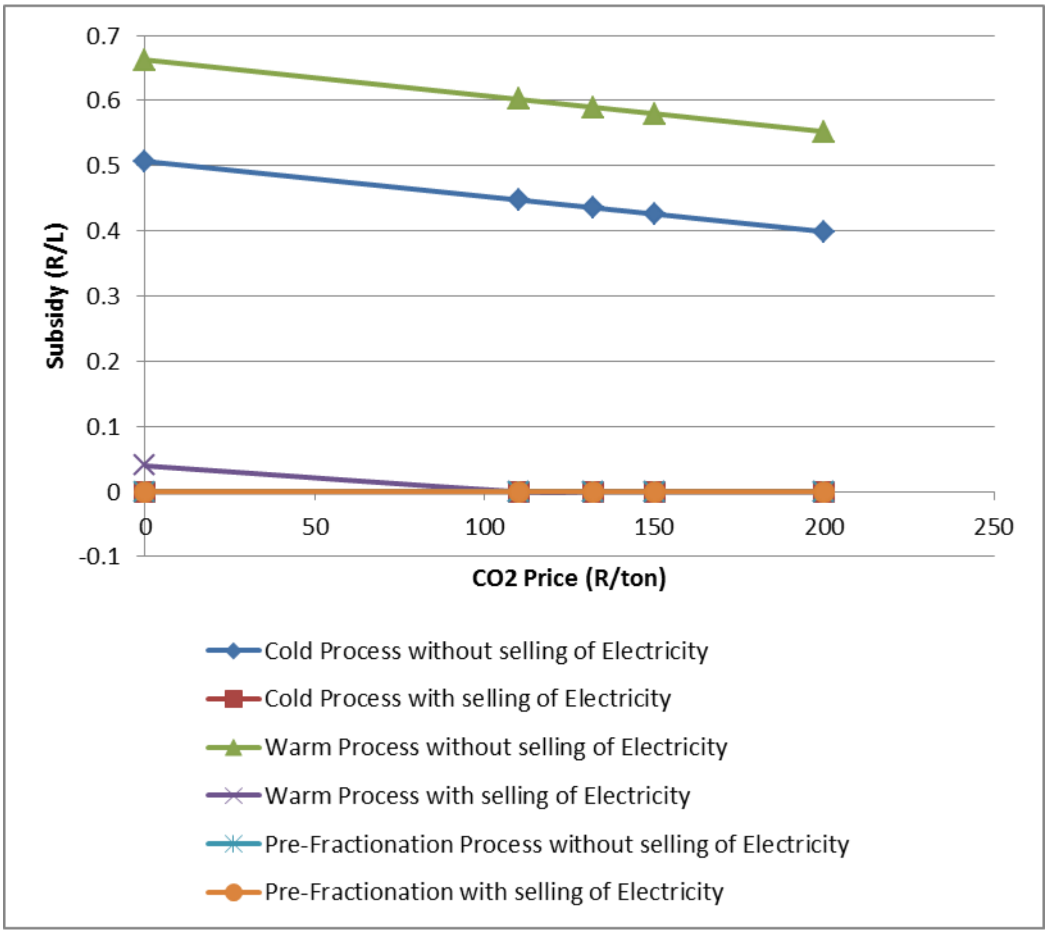

FIGURE 11: CO_2 PRICE VS SUBSIDY. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

3.5 Electricity Price

An increase in the selling price of electricity, in the scenario where surplus electricity is produced and sales thereof are realised, improved the IRR of the plant as shown in Figure 12. The Pre-fractionation process achieves a higher IRR than the Warm or the Cold process, and is therefore more profitable. The Cold process preforms marginally better than the Warm process and thus is preferred above the Warm process, but the Pre-fractionation process outperforms the former two. However, despite increases in the profitability of the processes producing and selling surplus electricity, at higher electricity prices, the IRRs presented in Fig. 12 are still lower than the corresponding IRRs for processes where no CHP plant is built and electricity is not produced onsite (Tables 4 and 5). The latter processes consistently provided better economic returns, than their corresponding processes with electricity production and sales of surplus electricity.

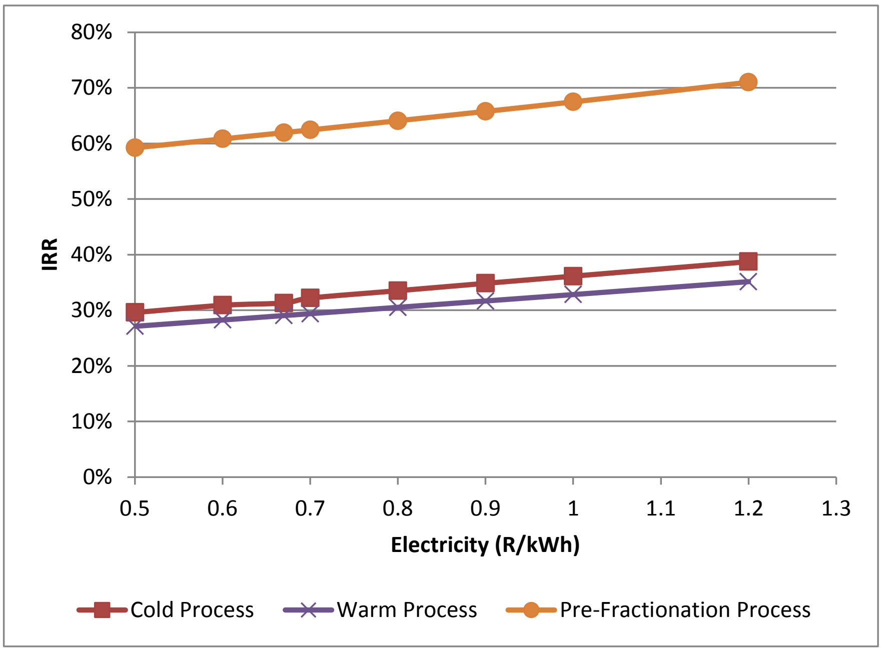

FIGURE 12: ELECTRICITY PRICE VS IRR

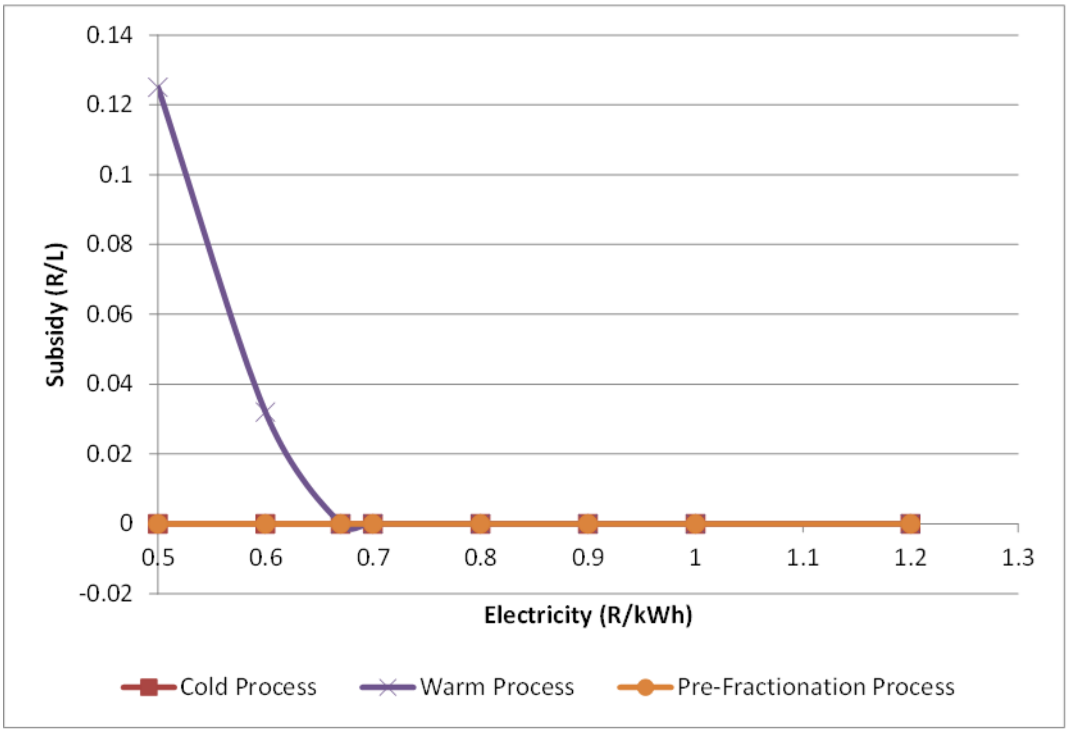

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Figure 13 it can be seen that the only process that needs a subsidy at lower electricity selling prices is the Warm process. Accordingly it is the least robust of the three processes in terms of electricity selling price. The Cold and the Pre-fractionation processes do not need a subsidy in the specified price ranges.

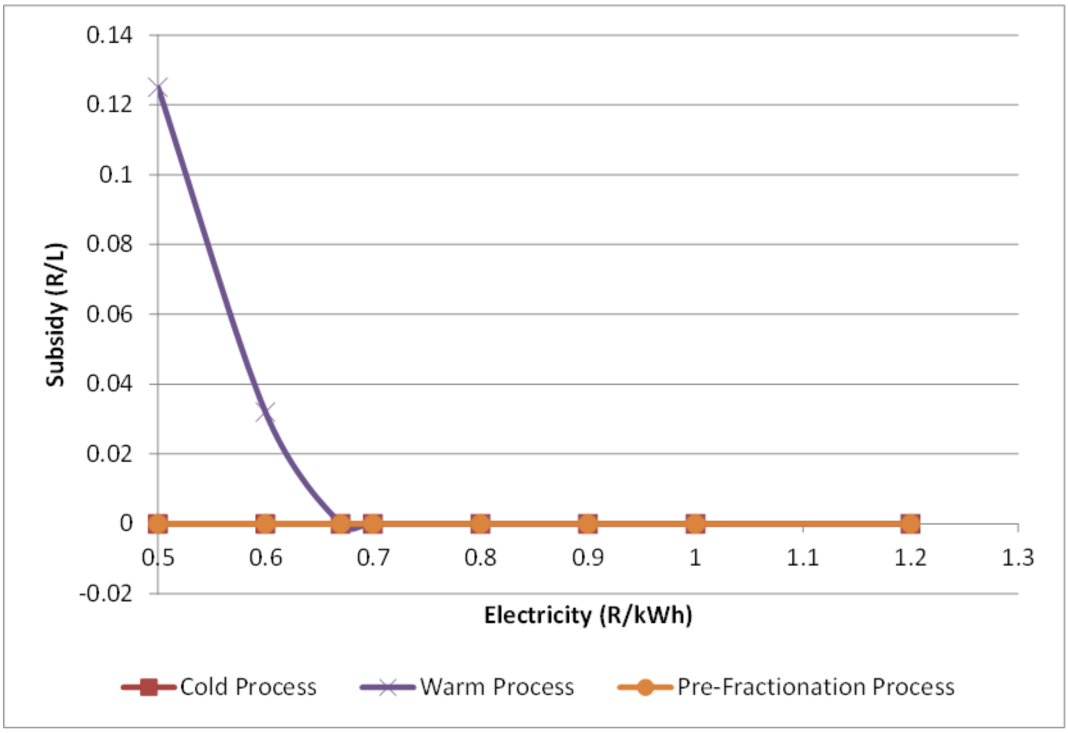

FIGURE 13: ELECTRICITY PRICE VS SUBSIDY

3.6 Biomass Price

From Figure 14 it can be seen that an increase in biomass price adversely affected the IRR of all processes. The Pre-fractionation process profitability is the least affected by the increased in biomass price. The "Without Electricity" options in Fig. 14 refer to base case plant, which includes CHP plant for electricity production, but no electricity sales are realised.

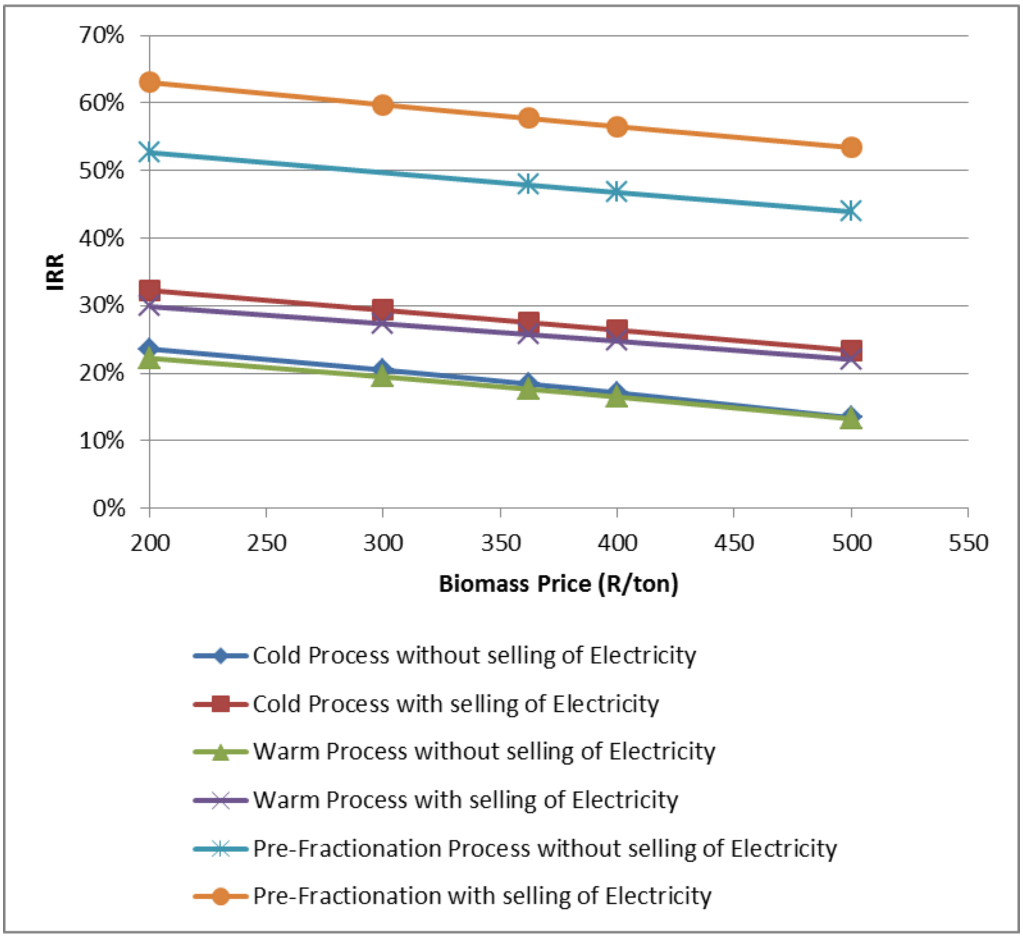

FIGURE 14: BIOMASS PRICE VS IRR. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

The required subsidy to achieve a ROA of 15 % is affected by an increase in biomass price, as shown in Figure 15. The Warm and Cold process, without the selling of electricity, is the most affected by the biomass price. The Warm process also preforms worse than the Cold process in terms of the subsidy needed to render the plant profitable. The Pre-fractionation process subsidy does not seem to be affected by the biomass price increase (hence the higher IRR) and thus is the most robust process in terms of biomass price.

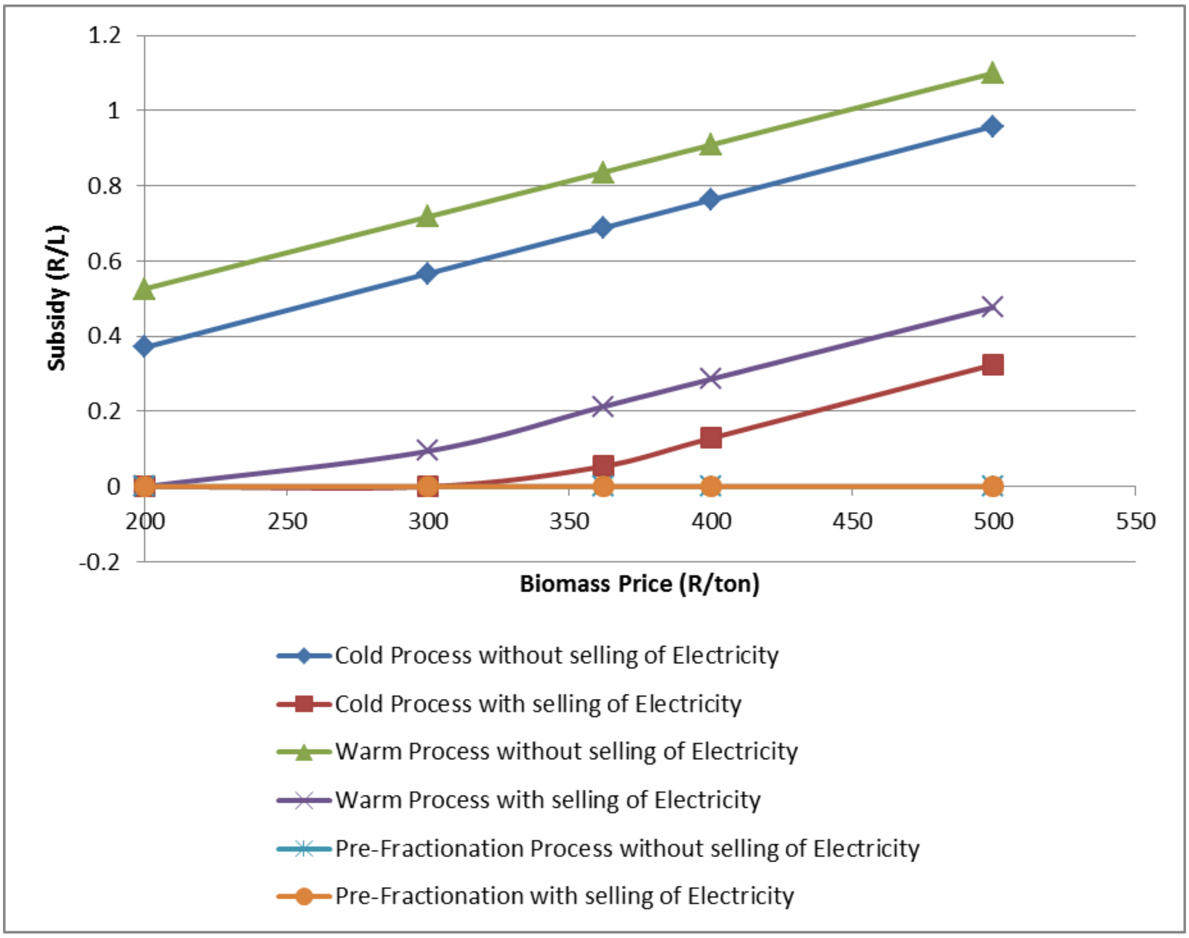

FIGURE 15: BIOMASS PRICE VS SUBSIDY. "WITHOUT ELECTRICITY" REFERS TO BASE CASE PLANT, WHICH INCLUDES CHP PLANT FOR ELECTRICITY PRODUCTION, BUT NO ELECTRICITY SALES ARE REALISED.

4. CONCLUSION

From this report the following conclusions and recommendations can be made:

- The BFP is the predominant factor influencing the profitability of the triticale-ethanol plant. To maintain profitability the subsidy should be re-evaluated preferably monthly, to mitigate the financial risks of BFP price variations for the biofuel producer.
- Triticale Price fluctuations have a strong effect on profitability of the plant and hence the subsidy should be revised regularly according to any change in feedstock prices.
- In the range considered, the DDGS sales price has an effect on the subsidy needed, but to a lesser extent than the BFP and Triticale Price. Pre-fractionation significantly adds value to DDGS and the overall profitability of the process.
- CO_2 price has an insignificant effect on the subsidy and the profitability of the plant.
- The selling of surplus electricity produced onsite improved the profitability of the plant, compared to the scenario where surplus electricity is produced onsite, but sales thereof are not realised. However, onsite electricity production with sales of surplus electricity

provided lower economic returns than processes without onsite electricity production, due to the high capital cost of the CHP plant for electricity production.

- Electricity selling price variations do not have a major effect on the subsidy needed to render the plant profitable.
- Biomass replacement of coal will have a negative effect on the plant's profitability, but will improve the CO_2 balance of the plant significantly.
- The Cold process needs less subsidy than the Warm process and the former is preferred should it be required to choose between the two.
- The Pre-fractionation process is the process that is the most robust to changes in prices and the most profitable, and is therefore recommend as the best process to produce bioethanol from triticale.
- The cooling water requirements for each process requires further investigation, to reduce the amount of water lost due to evaporation in cooling. Options to be considered includes operating at a higher solids loading, considering alternative separation technologies, alternative removal (evaporation) technologies.
- It should be noted the results of this report are based on a theoretical simulation and assumptions regarding processes parameters, utilities and feedstock prices. It is recommended to develop a robust Monte Carlo simulation to assess technical and economic feasibility in more detail. Furthermore, process parameters need to be confirmed by experimental work and pilot plant testing, while price assumptions need to be evaluated by more detailed economic studies. During the process, the simulation model could be updated as information becomes available to assess and enumerate overall technical and economic feasibility on an ongoing basis.

5. REFERENCES

Amigun, B., Petrie, D., Görgens, J., 2011. Economic risk assessment of advanced process technologies for bioethanol production in South Africa: Monte Carlo analysis. Renew. Energy 36, 3178–3186. doi:10.1016/j.renene.2011.03.015

Amigun, B., Petrie, D., Görgens, J., 2012. Feedstock and Technology Options for Bioethanol Production in South Africa: Technoeconomic Prefeasibility Study. Energy Fuels 26, 5887–5896. doi:10.1021/ef3008272

Balat, M., Balat, H., Öz, C., 2008. Progress in bioethanol processing. Prog. Energy Combust. Sci. 34, 551–573. doi:10.1016/j.pecs.2007.11.001

Balcerek, M., Pielech-Przybylska, K., 2013. Effect of simultaneous saccharification and fermentation conditions of native triticale starch on the dynamics and efficiency of process and composition of the distillates obtained: simultaneous saccharification and fermentation of native triticale starch. J. Chem. Technol. Biotechnol. 88, 615–622. doi:10.1002/jctb.3873

Pejin, D., Mojović, L.J., Vučurović, V., Pejin, J., Denčić, S., Rakin, M., 2009. Fermentation of wheat and triticale hydrolysates: A comparative study. Fuel 88, 1625–1628. doi:10.1016/j.fuel.2009.01.011

Sea route & distance - ports.com [WWW Document], n.d. URL http://ports.com/sea-route/#/?a=16689&b=3848&c=Richards%20Bay,%20South%20Africa&d=Port%20of%20Saldanha,%20South%20Africa (accessed 2.22.15).

Wang, S., Thomas, K.C., Ingledew, W.M., Sosulski, K., Sosulski, F.W., 1997. Rye and triticale as feedstock for fuel ethanol production. Cereal Chem. 74, 621–625.