Specialist Climate Change Assessment of the Proposed Tshivhaso Coal Fired Power Plant

Produced by Promethium Carbon
for Savannah Environmental
on behalf of Cennergi

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CONTENTS

EXECUTIVE SUMMARY

Cennergi (Pty) Ltd is proposing to construct a 1200MW coal fired power station in two 600MW phases near Lephalale in the Limpopo Province. This specialist climate change assessment explores the project's prospective contribution to climate change through the emission of greenhouse gases such as carbon dioxide.

This assessment focuses on evaluating the alternative technologies and mitigation options available to the project developer and their respective impacts on carbon emissions. The alternatives have been considered in accordance with the technological qualification criteria of the national Coal Baseload Independent Power Producer Procurement Programme. However, for the sake of completeness, this analysis has also considered the incorporation of biomass and solar thermal energy into the stipulated baseload circulating fluidised bed or pulverised fuel combustion technologies as possible future mitigation options.

The carbon footprint presented in this study only accounts for the direct operational emissions from the combustion of fuel within the proposed Tshivhaso Power Plant as the direct combustion emissions typically account for a large majority total lifetime emissions. The greenhouse gas emissions estimated in the carbon footprint are used to assess the impact the power plant will have on the onset of climate change. The project case is also compared against the emissions levels of a forecasted baseline for the national grid as well as other technology alternatives and mitigation options.

From the analysis it is apparent that the proposed project technology (circulating fluidised bed combustor fuelled with 100% coal) is in fact the most intensive project case in terms of carbon emissions. Thus, it is the option that will have the greatest contribution to anthropogenic climate change and its ensuing environmental impacts. The magnitude of this impact will be moderate within the national greenhouse gas inventory while the extent, duration and probability of the plant's greenhouse gas emissions impacts on climate change will be very large. The power plant's overall impact on national emissions and climate change is thus high in significance for a single source as it is likely to become a very large emissions contributor relative to South Africa's national greenhouse gas inventory. As with any issue of common concern to humanity, each actor has an individual responsibility to minimise its own negative contribution to the issue. This is the case despite the impossibility of attributing any particular future climatic changes directly or indirectly to the emissions from the proposed Tshivhaso Power Plant. As such it has been important to explore the possible technological alternatives for the plant as well as mitigation options, such as co-firing biomass.

While the technology alternative, pulverised fuel, will produce marginally less emissions than circulating fluidised bed combustion, both technologies will produce emissions intensities above the forecasted 2025 national baseline, as expected from base load generation. However, the limited water availability and quality of the coal to be supplied to the power station is unlikely to suit a pulverised fuel plant and thus a circulating fluidised bed combustor is expected to be

most viable option considering the procurement program criteria. However, it is still important for the project developer to consider future mitigation options for the power plant.

The ability of circulating fluidised bed combustors to burn a mixture of fuels presents a mitigation opportunity for the plant to co-fire with biomass. The inclusion of 25% biomass into the fuel mix would reduce the emission intensity of the power plant well below the projected emissions baseline of the national grid. While capital intensive the inclusion of solar thermal energy from a concentrated solar power facility can further reduce emissions and offset the increased fuel costs associated with biomass burning. Making provisions for the future addition of carbon capture and storage systems presents another opportunity to reduce carbon emissions.

It is recommend that the project developer seriously considers the future emissions mitigation opportunities related to; co-firing with biomass, incorporation of solar thermal energy and the implementation of an effective monitoring plan.

DECLARATION OF INDEPENDENCE

Robbie Louw, Harmke Immink and Sam Vosper as the authors of this report, do hereby declare their independence as consultants appointed by Savannah Environmental (Pty) Ltd to undertake a climate change assessment for of the proposed Tshivhaso coal fired power station, to be developed by Cennergi (Pty) Ltd. Other than fair remuneration for the work performed, the specialists have no personal, financial business or other interests in the project activity, its application or appeal. The objectivity of the specialists is not compromised by any circumstances and the views expressed within the report are their own.

Robbie Louw

Harmke Immink

Sam Vosper

DETAILS OF SPECIALIST

Promethium Carbon

Promethium Carbon is a South African climate change and carbon advisory company group based in Johannesburg. With a vision to making a difference in climate change in Africa and a focus on technical expertise, our team of climate change professionals assists businesses ranging from small enterprises to multinational entities on their journey towards a low carbon economy. We also assist governments and government institutions in planning for the coming global carbon constrained environment. Through our participation on various working groups and standards boards, we have established ourselves as knowledge leaders in the climate space and act as trusted advisors to our clients.

Promethium Carbon has been active in the climate change and carbon management space since 2004. Our client base includes many of the international mining houses and industrial companies that are operating in and from South Africa. One of our clients was awarded the European Energy Risk Deal of the Year award in 2010 for a carbon credit commercial transaction that Promethium advised the client on. Promethium Carbon also received the Star Excellence Award in recognition of its outstanding contribution to Africa's Economic Growth and Development. This award was received in Abu Dhabi during the World Future Energy Summit 2014. Promethium was furthermore awarded with the Best Project Implementer award by the British High Commission in 2015.

An accurate carbon footprint forms the basis from which an organisation can plan its journey into the low carbon economy. The rules, according to which a carbon footprint is calculated, have been developed at a fast pace over a short number of years, and have reached a level of maturity. Promethium has calculated the carbon footprints and greenhouse gas inventories for numerous companies. Through these carbon footprints and strategy documents Promethium Carbon has helped companies to understand their climate change impacts as well as the associated risks.

Robbie Louw

Robbie is the founder and director of Promethium Carbon. He has over 10 years of experience in the climate change industry. His experience over a period of 28 years covers the chemical, mining, minerals process and energy fields, in which he was, involved in R&D, project, operational and management levels.

Robbie's experience in climate change includes but is not limited to:

- Carbon footprinting: He has extensive experience in carbon footprinting. The team under his leadership has performed carbon footprint calculations for major international corporations operating complex businesses in multiple jurisdictions and on multiple continents.
- Carbon strategy development: He has developed carbon and climate change strategies for major international corporations.

- Climate change impact and risk assessments: He has developed climate change risk assessments for various companies and projects.
- Project development: He has extensive experience in project development in the energy, chemical and mining industries. This covers the scope from project identification, feasibility studies to project implementation. Some examples include carbon sequestration projects focussed on the restoration of impacted grasslands and mining impacted land and greenhouse gas mitigation projects in many industries including farming, mine land restoration and bio-energy production.
- Carbon trading systems: He is the lead author of numerous publications on the design of a potential carbon trading system for South Africa.

Harmke Immink

Harmke is a Director at Promethium Carbon. Her 12 years of climate change expertise is developed from environmental life cycle assessments (LCA), environmental audits and technical performance evaluation. She has a Masters degree in Environmental Measurement Techniques (Sweden), and gained experience across industry sectors through a variety of technical surveys and industry roadmaps.

Harmke's experience in climate change includes but is not limited to:

- South African representative for ISO technical committee 207 on greenhouse gas standards, including eco-labelling and carbon footprint of products;
- Technical assessor for SANAS accredited: ISO 14065 greenhouse gas validation and verification;
- Part of World Resource Institute technical development team for the Greenhouse Gas Protocol standard on accounting for goals and targets;
- Climate change related services include greenhouse gas baseline evaluations, a survey for practical sustainable development indicators for Clean Development Mechanism (CDM) projects, four new or revised methodologies, twelve successful registration of CDM projects as well as three projects assisted with issuance of carbon credits;
- Standardised Baseline Calculations for Grid Emission Factors in Kenya and South Africa;
- Climate change adaptation projects for mining clients, focused on community vulnerabilities and strategically linking with social responsibility;
- Carbon Disclosure Projects (CDP) is a global initiative to collect and distribute high quality information that motivates investors, corporations and governments to take action in the attempt to mitigate climate change. Promethium Carbon CDP clients consistently are in both the top ten disclosure as well as the performance leadership index since 2007; and
- Project leader for the Private Sector Energy Efficiency audits through the NBI.

Sam Vosper

Sam holds the following degrees: Bachelor of Science (Rhodes University), Bachelor of Science (Hons) (Rhodes University), MPhil Environmental Policy (University of Cambridge). He has completed postgraduate courses in: Energy & Climate Change, Environmental Economics, Climate Change Policy, Policy Assessment & Evaluation, International Environmental Law, Ecological Modelling, Climate Change Adaptability and General Linear Models. Sam's undergraduate studies included: Environmental Science, Mathematics, Mathematical Statistics and Economics.
Sam currently works as an environmental consultant specializing in services which include:

- Carbon footprints and Water footprints;
- Researching for South Africa's Third National Communication to the UNFCCC;
- Researching and drafting a measuring, reporting and verification policy for Swaziland to apply to their nationally determined contributions; and
- Energy efficiency and energy management studies.

Sam has previously executed a research project on water supply and catchment sustainability for the town of Mussoorie in the Himalayan foothills. The project involved amalgamating and mapping data on; forest composition, climate change, infrastructural upgrades and land use.

1. INTRODUCTION

Cennergi (Pty) Ltd has tendered to construct a coal fired power station near Lephalale, in the Limpopo Province, as part of the independent power producers baseload programme. The power station would have a maximum generation capacity of 1200MW. The project is proposed to be developed in two phases of 600MW in each phase.

In accordance with the relevant regulations, an Environmental Impact Assessment process must be completed before project development can proceed. As a part of the Environmental Impact Assessment process, Savannah Environmental (Pty) Ltd has appointed Promethium Carbon to undertake a specialist climate change assessment of the project. This involves assessing the project's prospective contribution to climate change through the emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2).

The site for the coal fired power station is located on farmland which falls within the Lephalale Local Municipality, a constituency of the Waterberg District Municipality. The power plant and its associated ash dump, coal stockpile and raw water dam are to be developed over approximately 650ha. The proposed technology for the power plant is a circulating fluidised bed (CFB) combustion facility which will burn coal sourced from a nearby mine.

The contribution of a power plant to global climate change is inherently dependant on the greenhouse gas emissions that the plant will produce as a result of burning coal. However, no specific environmental impacts as a consequence of climate change can be attributed to the greenhouse gas emissions from any individual source. As such, this assessment focuses on exploring the alternative combustion technologies and mitigation options available to the project developer in terms of their respective impacts on climate change through their greenhouse gas emissions.

In seeking to provide the project developer with the best possible information to evaluate the project's environmental sustainability, this approach is aligned with the principles of the National Environmental Management Act 1998. For each technology option considered the project development would include the construction of access roads, storage facilities, water infrastructure, a power line and a substation.

The broad terms of reference and scope of work for this specialist climate change assessment include the following:

1) Calculating the operational carbon footprint of the project with respect to:
   - Direct emissions from fuel combustion;

2) Analysing the project alternatives with regards to:
   - Combustion technologies (pulverised fuel)

3) Reviewing emissions mitigation options with regards to:
   - Supplementary energy sources (thermal energy from CSP);
   - Fuel options (grades of coal and biomass); and
   - Carbon capture and storage.

4) Conducting an impact assessment of the project by:
   - Considering the contribution of the operation to the national emissions inventory and the onset of global anthropogenic climate change;
   - Comparing it against the current Eskom baseline; and
   - Comparing it against the identified alternative and mitigation options.

5) Assessing any greenhouse gas emission management activities for the plant's operations.

2. METHODOLOGY

2.1 Estimating Greenhouse Gas Emissions

The ISO/SANS 14064-1 standard has been used to guide the development of the carbon footprints presented in this assessment. This standard specifies principles and requirements for the quantification and reporting of historical figures of greenhouse gas emissions and removals at the organisation level. The standard also includes the requirements for the design, development, management, reporting and verification of an organisation's greenhouse gas inventory. In this analysis the principles of this standard have been adapted to a project level to calculate the future greenhouse gas emissions of the prospective project

The basic principles of SANS 14064-1 aim to ensure that the greenhouse gas information presented within a carbon footprint is a true and fair account. These principles include:

RELEVANCE: by selecting all the greenhouse gas sources, greenhouse gas sinks, greenhouse gap reservoirs, data and methodologies that are appropriate to the needs of the intended user.
COMPLETENESS: by including all the greenhouse gas emissions and removals relevant to the company.
CONSISTENCY: to enable meaningful comparisons to be made with other greenhouse gas related information.
ACCURACY: by reducing bias and uncertainties as far as is practical.
TRANSPARENCY: by disclosing sufficient and appropriate greenhouse gas related information to allow intended users to make decisions with reasonable confidence.

Following the SANS 14064-1, the carbon footprint of the power plant's direct combustion emissions was developed through the following process:

- Setting the boundaries of analysis;
- Identifying the greenhouse gas sources inside the boundary;
- Establishing the quantification method that will be applied;
- Selecting or developing greenhouse gas emission or removal factors; and
- Calculating the emissions.

In addition to the SANS 14064-1 standard, the Greenhouse Gas Protocol's Corporate Accounting and Reporting Standard was also used as a guide in the carbon footprint calculations. The project boundaries and emissions factors are presented in further detail in the subsequent sections of this report.

2.2 Climate Change Impact of Greenhous Gas Emissions

In following with the EIA reporting requirement the criteria listed below are used to describe and assess the climate change impacts associated with the greenhouse gas emissions from the Tshivhaso Power Plant. The impact of the power plant is interpreted as the plant's contribution to the national greenhouse gas emissions inventory.

Nature: a description of what causes the effect, what will be affected and how it will be affected.

Extent (E): an indication of whether the impact will be local (limited to the immediate area or site of development) or regional, and a value between 1 and 5 will be assigned as appropriate (with 1 being low and 5 being high):

Duration (D): an indication of the lifetime of the impact quantified on a scale from 1-5. Impacts with durations that are; very short (0–1 years) are assigned a score of 1, short (2-5 years) are assigned a score of 2, medium-term (5–15 years) are assigned a score of 3, long term (> 15 years) are assigned a score of 4 or permanent are assigned a score of 5.

Magnitude (M): an indication of the consequences of the effect quantified on a scale from 0-10. A score of 0 implies the impact is small, 2 is minor, 4 is low and will cause a slight impact, 6 is moderate, 8 is high with sizable changes, and 10 is very high resulting drastic changes.

Probability (P): an indication of the likelihood of the impact actually occurring estimated on a scale of 1–5. A score of 1 implies that the impact is very improbable, 2 is improbable, 3 is probable, 4 is highly probable and 5 is definite with the impact occurring regardless of any prevention measures.

Significance (S): a weighting based on a synthesis of the characteristics described above and can be assessed as low (< 30 points), medium (30-60 points) or high (> 60 points). The significance points are calculated as: S = (E + D + M) x P.

The status of the impact will be described as; positive, negative or neutral. Additional details will also be provided on the degree to which the impact can be reversed and the degree to which the impact may cause irreplaceable loss of resources. The extent to which the impact can be mitigated will also be highlighted.

2.3 Comparison with Technological Alternatives and Mitigation Options

Two levels of evaluation are conducted with regards to the power plant's greenhouse gas emissions and climate change impacts. Firstly, a comparison is made between the emissions impacts of the project and the technological alternatives which are set out in the baseload tender requirements. A second analysis compares the project case against potential future mitigation options in terms of their emissions and impacts. These mitigation options are however not within the scope of the tender requirements. South Africa's national inventory and trajectory for greenhouse gas emissions are also considered and give context to both of these evaluations. The functioning of a power plant and its climate change impacts are not affected by seasonality and so this study has not made any special consideration or analysis in this regard.

3. PROJECT DESCRIPTION

Circulating fluidised bed combustors suspend coarse particles of solid fuel on upward blowing jets of air during the combustion process (Utt and Giglio, 2012). It results in a turbulent mixing of gas and solids. The tumbling action of the solid and gas mixture, much like a bubbling fluid, provides an environment for effective chemical reactions and heat transfer. The circulating fluidised bed has a cyclone filter to separate solid material from the hot flue gases which leave the exhaust of the furnace. The solids from the filter are then recirculated into the bed to ensure complete combustion. Circulating fluidised bed plants can be relatively easily calibrated to burn a number of different mixtures of solid fuels. Individual plants have been known to efficiently burn fuel mixes which can vary from 100% biomass to 100% coal (Oravainen and Karki, 2007).

Another technological advantage of a circulating fluidised bed plant is that it can successfully reduce the amount of sulphur emitted in the form of sulphur dioxide (SO_2). This is done though the addition of calcium rich limestone to the combustion bed which reacts and bonds with the sulphur dioxide, thus preventing its release into the atmosphere.

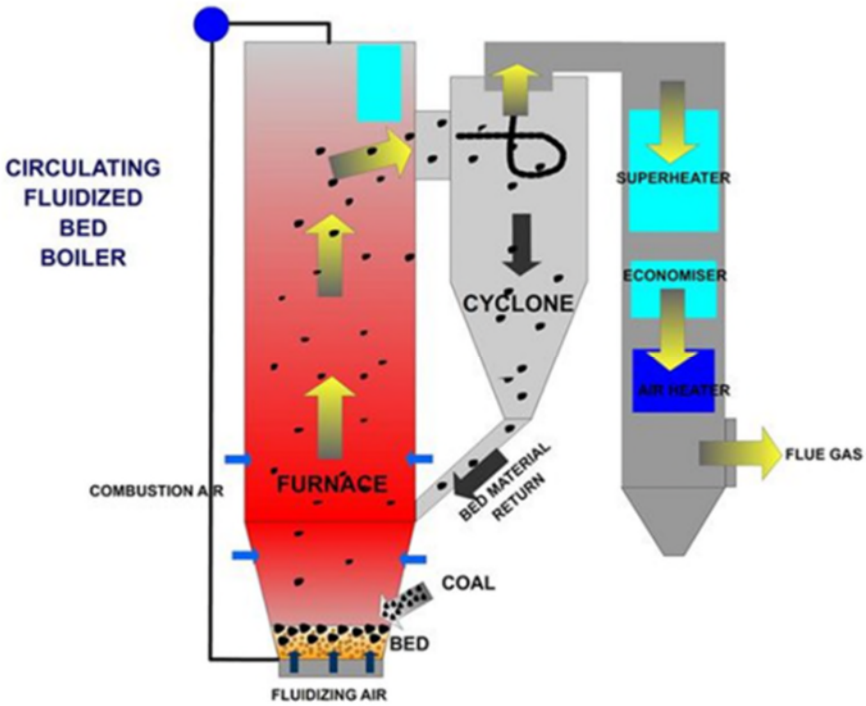

Figure 1: Schematic diagram of a CFB combustor.

Direct dry cooling technology is proposed for use in the project. During this process the steam from turbines goes into a dry-cooling element or a heat exchanger. Fans are used to blow air over a condenser which causes water vapour to change back into liquid. This liquid is then pumped back into the boiler for reuse. This system does not require a cooling tower and therefore evaporation loss is limited. Similarly, a dry ashing approach has been proposed, where the ash waste is to be stored in an above-ground ash dump.

The scale of the Tshivhaso Power Plant requires a sizable area of land upon which to operate. Approximately 50 hectares is required for the power plant alone, with an additional 500 hectares necessary for the ash dump. The project also makes provision for 100 hectares to be used as a strategic coal stockpile and a further 2 hectares has been allocated for use as a raw water dam. The project site alternatives for the power plant are presented in Figure 2 below as adapted from draft scoping report. Since completing the scoping report the selection of sites for the project has been confirmed. Graaffwater Farm (Site Alternative 1) was confirmed as the site for the power plant and Appelvlakte Farm (Site Option 4) was confirmed as the site for the ash dump.

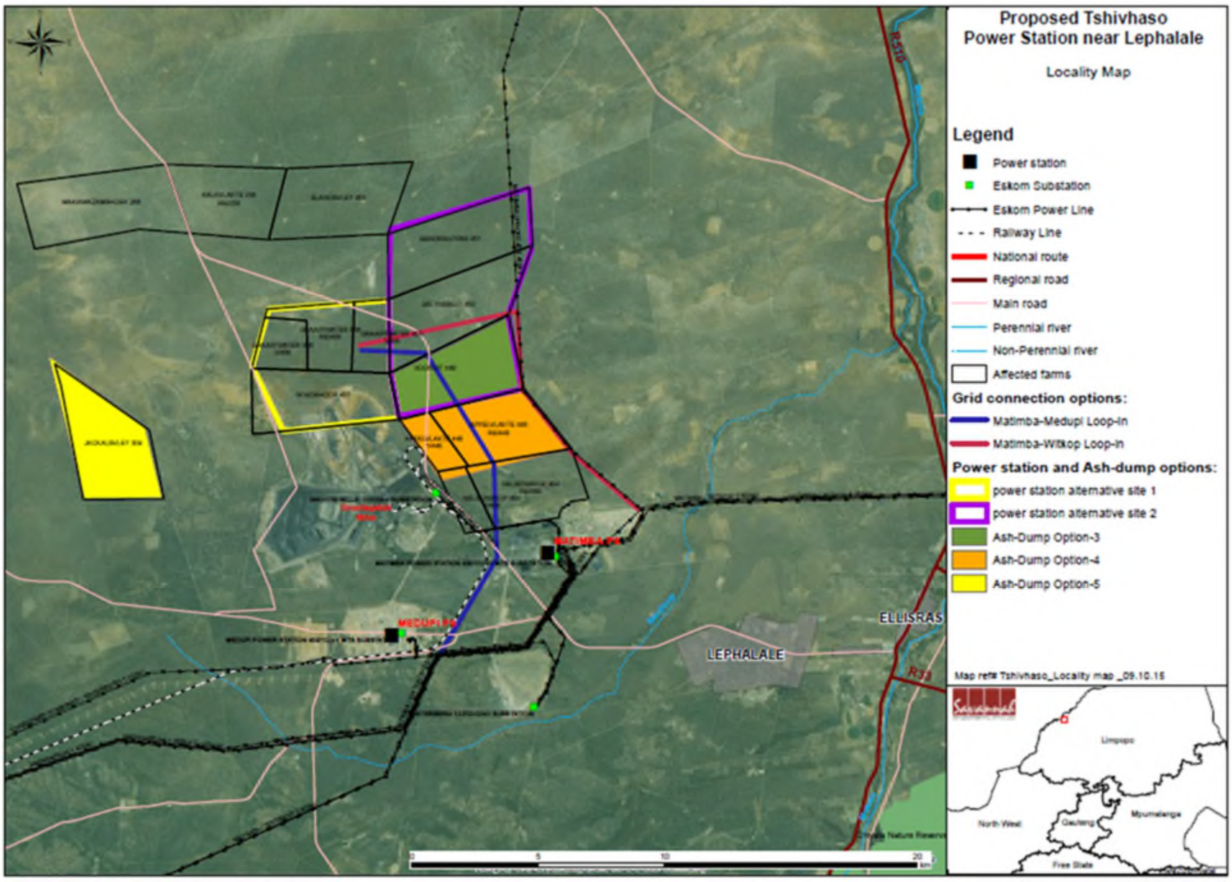

Figure 2: Proposed site alternatives for the Tshivhaso Power Plant.

The project site makes provision for a strategic stockyard to store coal[1]. The strategic stockyard is planned to have a capacity of 700 000 tonnes, which would be able to sustain the plant for approximately 30 days. Coal is expected to be sourced from Thabametsi Coal Mine, which is to be established south east of the proposed sites for the power plant. The coal will be transported by overland conveyors at a rate of 1000 tonnes per hour. Thabametsi Coal Mine is expected to provide coal to the power plant for the lifetime of the plant.

The granular lime stone, to be used for desulphurisation, will be trucked in from the Northern Cape and used at a rate of 64 tonnes per hour. The ash waste, including some used limestone, is to be transported by overland conveyors at a rate of 660 tonnes per hour to the above-ground ash dump. A pipeline is to be constructed to supply the power plant's water needs at a rate of 120 litres per second. This pipeline will connect the source point with a storage reservoir, which will be accompanied by a pump station.

[1] Stockpiled coal in open storage can produce greenhouse gas emissions from low temperature oxidation and even result in spontaneously combustion. The Coaltech Research Association is conducting ongoing studies to quantify these emissions, although they are significantly less than those from combustion. As such this climate change study does not include the greenhouse emissions from this source.

Further water treatment plants will be required to treat process and wastewater onsite. The anaerobic treatment of wastewater is a source of greenhouse gas emissions not included in this study as they are insignificant compared to the combustion emissions. Figure 2 also demonstrates that there are existing access roads that the power plant would be able to make use of. The operation of the Tshivhaso Power Plant will create 239 permanent jobs, onsite, for the duration of the project's lifetime.

3.1 Setting the Boundaries of Analysis

An equity share or operational control approach is used by the ISO/SANS 14064-1 standard to set the boundary of analysis for company based emissions calculations. However, only a project boundary is applied to the emissions calculations of Tshivhaso Power Plant. With this approach, the emissions are recorded from all the facilities, sites or operations within the boundary of the project activities undertaken by the project owner.

Direct combustion emissions can typically account for approximately 90% of the total emissions calculated for the lifecycle of a coal fired power plant (Hondo, 2005). The typical lifetime emissions for a coal fired power plant are presented in Figure 3 below. It is evident that the next largest source of emissions (8.7%) is the indirect upstream emissions which would include the transport of employees, fuel and other inputs. Direct construction emissions account for only 0.4% of total lifetime emissions. Thus, this carbon footprint only accounts for the direct operational emissions from the combustion of fuel within the two 600MW units of the power plant.

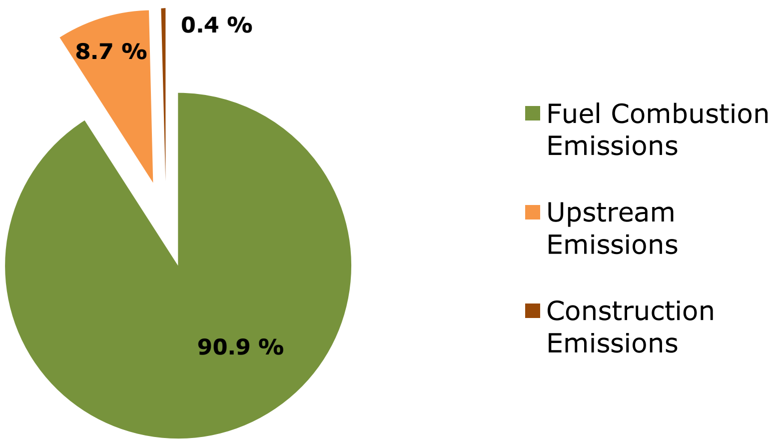

Figure 3: Typical lifetime emissions of a coal fired power plant (Hondo, 2005).

3.2 Emissions Factors

Emissions factors should be appropriate for the local context and relevant to the technology being assess. Local emissions factors, such as the grid emission factor, have been sourced from the reports of local entities such as Eskom as it is the main electricity generator within the country. Additional recognised emissions factors have been sourced from South Africa's Draft Technical Guidelines for Monitoring, Reporting and Verification of Greenhouse Gas Emissions by Industry which is informed by the Intergovernmental Panel on Climate Change's 2006 reporting guidance document.

Emissions factors for the carbon footprint calculations have been sourced from a number of other appropriate entities, including the UK's Department for Environment, Food and Rural Affairs (DEFRA). DEFRA publishes resources annually to assist with company level reporting on greenhouse gas emissions. This assessment makes use of the DEFRA resource published in 2015. It is assumed that these emission factors are representative of the activity data supplied for the project.

Table 1 below provides a detailed list of the emission factors and other factors used in the calculation of the carbon footprints.

Table 1: Summary of emissions factors and key values in the carbon footprint of the Tshivhaso Power Plant.

Emissions Factors and Key Values			
Name	**Value**	**Unit**	**Source**
Coal - Emission Factor	0.096	tonne CO_2e / GJ	Technical Guidelines (2016)
Coal - Calorific Value	11.8	GJ / tonne	Cennergi
Coal - Sulphur Content	1.08	%	Cennergi
Limestone - Emission Factor	0.44	tonne CO_2e / tonne $CaCO_3$	Chemical Equation
Biomass - Emission Factor (sustainable)	0	tonne CO_2e / GJ	DEFRA (2015)
Biomass - Calorific Value	17	GJ / tonne	DEFRA (2015)
Gross electricity produced	10 003 712	MWhs / Year	Cennergi
Parasitic load	1 095 812	MWhs / Year	Cennergi
Net exported electricity	8 911 612	MWhs / Year	Cennergi
Carbon tax effective rate	48	R / tonne CO_2e	National Treasury (2015)

4. TECHNOLOGICAL PROJECT ALTERNATIVES AND MITIGATION OPTIONS

The project alternatives have been considered in accordance with the technological qualification criteria of the national Coal Baseload Independent Power Producer Procurement Programme. This programme requires that bidding power plants (Tshivhaso) be baseload energy generators and thus intermittent renewable energies, such as solar photovoltaics and wind, have not been considering in this analysis. The programme also specifies that the power plants make use of either circulating fluidised bed or pulverised fuel combustion technologies. For this reason the alternative technology assessed in this section will be pulverised fuel.

With the lifetime of a coal fired power plant expected to be reach (or even exceed) 30 years it is also important to consider technological mitigation options that the developer may be able to incorporate at a future stage. This is particularly relevant to the long term lock-in possibilities in fossil fuel combustion technologies. Thus, this analysis has also considered the combining of biomass and solar thermal energy together with the stipulated coal combustion technology to mitigate greenhouse gas emissions while providing base load electricity. Supporting new hybrid coal technologies prevents a lock-in of high emitting fossil fuel technologies. As such, decision makers should be aware of these hybrid options. Much of the information regarding the costs and efficiencies of these technologies was derived from the Electric Power Research Institute (EPRI) 2010 Report titled *Power Generation Technology Data for the Integrated Resource Plan of South Africa*.

In evaluating the combustion technologies and mitigation options, we have assumed that dry cooling and dry ashing processes are applied uniformly for each technology and fuel option. This assumption is based on the limited water availability in the region of operation.

4.1 Technological Project Alternative

As per the bid requirements for the Coal Baseload Independent Power Producer Procurement Programme the alternative technology to circulating fluidised bed is pulverised fuel. Pulverised fuel technology is thus outlined here as the only alternative combustion technology available to the project developer.

4.1.1 Pulverised Fuel

Pulverised fuel is a well-established technology with thousands of plants active worldwide. In pulverised coal combustion, coal is ground (pulverised) into a fine powder with particles smaller than 75 um (Utt and Giglio, 2012). This powdered coal is then blown directly into the burner with a portion of the combustion air. The idea is that fine enough coal particles will burn almost as efficiently as a gas. As such, even the subcritical steam burning plants can have overall thermal efficiencies of 36%.

However, these plants are sensitive to the grade of coal used and typically require bituminous coal with low sulphur contents (Utt and Giglio, 2012). To manage sulphur emissions from the flue gas, these plants require the fitting of additional scrubbing technologies, which incur an additional capital cost and generally requires additional water during operation. The coal to be sourced from the Thabametsi Coal Mine for this project is sub-bituminous coal with a high sulphur content.

4.2 Mitigation Options

The mitigation options presented here are options that could be considered for future inclusion within the power plant. They are not options for the project's initial development as they are beyond the scope of the tender requirements in the baseload independent power producers programme.

4.2.1 Concentrated Solar Power (CSP)

The integration of CSP into conventional thermal energy generation plants offers an elegant solution to the reduction of CO_2 emissions. In the daytime the solar energy can be harnessed through the use of a number of technologies, including parabolic troughs or solar towers, which serve to heat a working fluid such as an oil or molten salt. This heated fluid is then used as a supplementary source of thermal energy to produce steam and power a turbine.

There are examples of hybrid coal fired power plants supplementing a portion of their energy requirements from an accompanying CSP plant, including the Martin Station in Florida (Miller, 2013). While the hybrid plants are more affordable than stand-alone CSP operations, they require significantly more capital expenditure than standard coal fired plants. Furthermore, large areas of land are required for sizable generation capacities, 2.75 hectares per MW of capacity (Miller, 2013). The substitution of coal for sunlight can however reduce fuel costs and buffer the risks associated with changes in the future price of coal while maintaining baseload. The project is located in an area where there are suitable portions of land for CSP deployment and high levels of unemployment.

4.2.2 Coal Grades

Coal can be classified into a variety of grades based on its carbon content, sulphur content and calorific value (Bhattacharya *et al.*, 2013). The burning of higher grade coal, with a higher calorific value, requires the use of less coal for an equivalent energy output. This does not have an impact on the CO_2 emissions directly, as the emissions factor for coal is based on its calorific value. However, as higher grade coal typically has lower sulphur contents and less is required per unit energy produced, less SO_2 is released per unit of energy produced. Consequently, when higher grade coal is burnt there is less SO_2 to capture. In a circulating fluidised bed plant, the SO_2 released during combustion is captured through a lime stone reaction in the furnace. This reaction emits CO_2 as a by-product and thus the use of higher calorific coal will reduce these emissions of CO_2.

The analysis of the coal that is to be sourced from the Thabametsi Coal Mine indicates that the coal has a low calorific value of 11.8 GJ per tonne and a relatively high sulphur content of 1.08%. Higher quality coal will be more expensive and it is unlikely that it can be sourced at a comparable distance from the proposed location for the power plant.

4.2.3 Biomass

Circulating fluidised bed combustors are highly flexible in their use of different fuels such as biomass and refuse derived fuel. The co-firing of coal with biomass is therefore a realistic option. As sustainable locally sourced biomass is effectively carbon neutral, the substitution of coal for biomass presents an opportunity to directly reduce the CO_2 emissions associated with fossil fuel combustion (DEFRA, 2015). The SO_2 emissions from combustion will also be lowered, as there is little sulphur in biomass. This can in turn also reduce the CO_2 emissions associated with desulphurisation of the flue gas.

Biomass can be produced with calorific values up to 18 GJ per tonne however it is more expensive to purchase than coal. The costs of biomass can be significantly reduced through self-cultivation and harvesting where no profit margins are included while creating job opportunities in the area. The quantities of biomass required for combustion in a power plant the size of Tshivhaso would however require significant amounts of farm land, as biomass yields can range from 20-40 tonnes per hectare per year.

4.2.4 Carbon Capture and Storage and Enhanced Coal Bed Methane Recovery

South Africa has established a centre for Carbon Capture and Storage within the South African National Energy Development Institute (SANEDI). The Centre has developed a roadmap for the ultimate commercialisation of carbon capture and storage by 2025. It would be advisable for new power plants to consider making provisions for the future addition of carbon capture and storage technologies to their facilities.

Furthermore, there is potential to use the captured CO_2 for enhanced coal bed methane recovery. This is a method which involves injecting CO_2 into coal beds, where it occupies pore space and absorbs onto the carbon in the coal, thus displacing methane (White *et al.*, 2005). This methane can then be captured and used as a fuel source. The coal beds in the Waterberg region surrounding the Tshivhaso Power Plant present opportunities to make use of such methane recovery (Lephalale Local Municipality, 2015). This technology is still in a research and pilot project phase and is not yet commercially viable.

4.3 Costs of Technological Project Alternatives and Mitigation Options

A cost comparison between circulating fluidised bed combustion, the alternative technology option, pulverised fuel and the mitigation technology, CSP, is presented in Table 2 below. Both the overnight capital costs and fixed operating costs are presented for each technology. The figures have been sourced from EPRI (2010). A visual representation of the comparative overnight capital costs are presented in Figure 4.

Table 2: Comparison of the capital and operating costs of the assessed combustion technologies, adapted from EPRI (2010).

	Technology		
Cost of Technology	CFB	Pulverised Fuel	CFB + 10% CSP
Overnight Capital Costs (Million R/MW)	15.40	19.66	22.36
Fixed Operating Cost per year (Million R/MW)	0.38	0.50	0.49

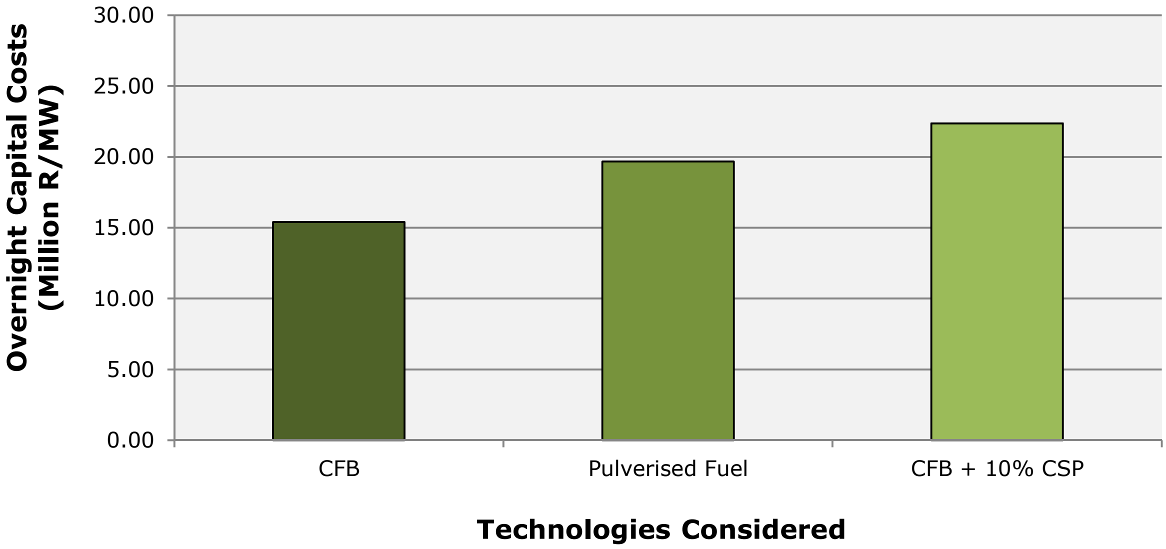

Figure 4: Comparison of the overnight capital costs of the assessed combustion technologies for a 1200MW capacity, adapted from EPRI (2010).

A cost analysis for the project's fuel based mitigation options is presented in Table 3 and Figure 5. A cost comparison between locally sourced coal and locally sourced biomass (low cost and high cost) is presented in Table 3 below. The relative cost disparities appear large when considering the fuel costs per tonne of high cost biomass. However, due to the relatively low calorific values of the proposed low quality coal, these relative cost disparities decrease significantly when considering the cost per unit of stored energy (GJ). The fuel cost per tonne of self-cultivated biomass (low cost) is in fact lower than that for coal and yields far lower costs per unit energy (GJ) due to the higher calorific value of the biomass.

Table 3: Cost comparison for coal and biomass fuels to be used in a CFB.

	Fuel Type	
Cost of Fuel	Coal	Biomass
R/tonne	273.00	200.00 - 700.00
R/GJ	23.14	11.76 - 41.18

The effective fuel costs per MWh of electricity produced for each of the assessed combustion technologies have been calculated using the above fuel costs. The effective fuel costs per MWh are calculated from the relative energy conversion efficiency of the combustion technologies. It is assumed here that pulverised fuel (37% efficiency) is more efficient than circulating fluidised bed combustion (36% efficiency) as per the figures quoted in the EPRI report. The effective fuel costs are calculated for both circulating fluidised bed and pulverised fuel technologies combusting 100% coal. These costs are also estimated for scenarios where the circulating fluidised bed combustor co-fires with 25% biomass (low and high cost) and includes 10% thermal energy from CSP. These assumptions are consistent with the analysis of the mitigation options.

It is illustrated in Figure 5 that under the assumed fuel prices the more efficient fuel to energy conversations achieved by the pulverised fuel result in lower fuel costs than the circulating fluidised bed when firing with coal alone. Expectedly, the effective fuel cost increases with the co-firing with higher cost biomass. However, in the case of low cost biomass the effective fuel cost is reduced. Furthermore there are large potential co-benefits to the creation of jobs and the green economy with the inclusion of biomass. The inclusion of solar thermal energy which has a zero fuel cost can to some degree offset the increased fuel costs of high cost biomass.

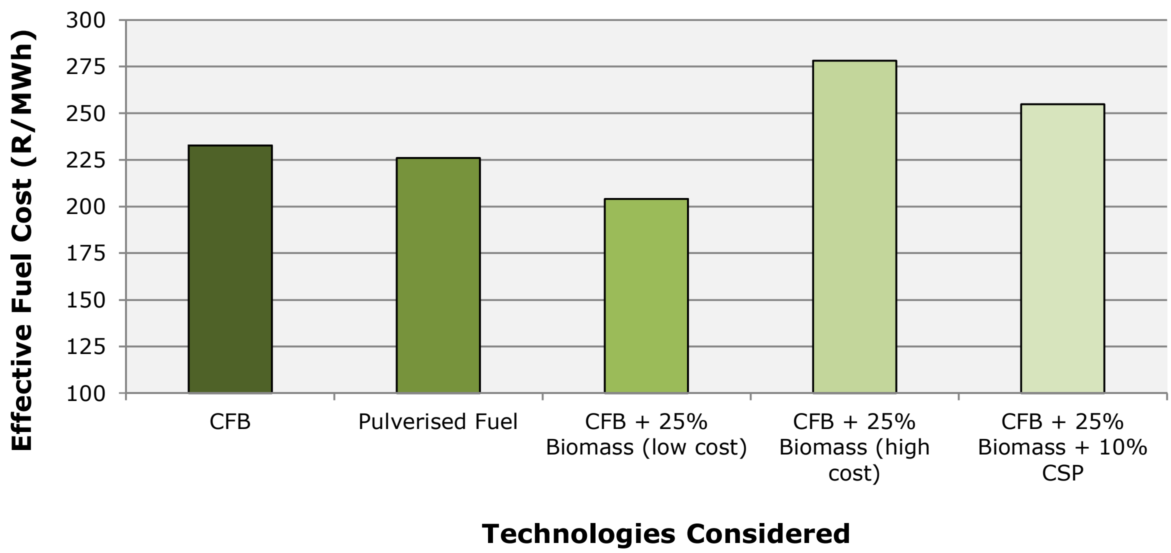

Figure 5: Comparison of the effective fuel costs for the of the assessed combustion technologies for a 1200MW capacity.

An additional factor that should be taken into consideration is the imminent introduction of the nationwide carbon tax. The tax is expected to be effective as of January 2017 and is to be set at an effective rate of R48 per tonne of CO2e emitted. As the tax rate may be revised over time, it is useful to consider how its possible changes may affect the NPV of the cost of the overall power plant. An analysis of the NPV of the costs of the circulating fluidised bed alternative and the biomass (high and low cost) mitigation option are presented in Figure 6. Under current prices adjusted for inflation, biomass (high cost) becomes cost comparable to coal at an effective tax rate of a little over R180 per tonne CO2e. The low cost biomass is cost competitive at current prices and tax rates and will become more competitive as the effective carbon tax rate increases.

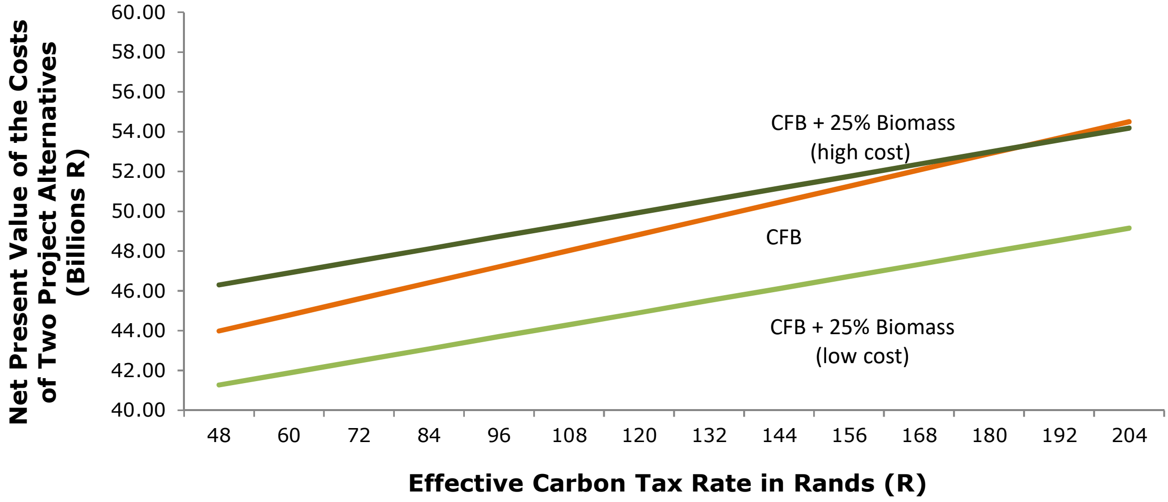

Figure 6: Lifetime cost comparison of the NPV of a CFB combustor burning 100% coal and a CFB combustor co-firing with 25% biomass.

5 PROJECT IMPACTS

The global climate change impacts of a power plant are inherently dependant on the scale of a plant's greenhouse gas emissions. A power plant's greenhouse gas emissions when assessed in the form of a carbon footprint can help to inform the consequent climate change impact of the project and its comparability to other technologies or baselines.

5.1 Carbon Footprint

The estimated carbon emissions from the combustion of fossil fuels for the proposed coal fired power plant were calculated based on the information provided by Cennergi. The results of these calculations are presented in Table 4 below. The emissions are quoted in tonnes of CO_2e per MWh of electricity produced as well as total annual tonnes of CO_2e.

Table 4: Summary of the direct carbon emissions calculated for the fuel combustion for the 1200MW Tshivhaso Power Plant.

	Source of Carbon Emissions		
	Coal Combustion	Limestone Desulphurisation	**Total**
Tonnes CO_2e/MWh	0.97	0.01	**0.98**
Million Tonnes CO_2e/Year	8.61	0.11	**8.72**

The Tshivhaso Power Plant is calculated to produce 0.98 tonnes CO_2e per net MWh of electricity generated. Based on the expected annual MWhs of electricity to be generated by the plant, an estimated 8.72 million tonnes CO_2e will be emitted each year. Assuming a plant lifetime of 30 years, the Tshivhaso Power Plant is expected to directly emit in excess of 261.6 million tonnes CO_2e into the atmosphere over its lifetime. Based on figures published in South Africa's most recent Greenhouse Gas National Inventory Report 2000-2010 (2014) the power plant's annual emissions would equate to 1.6% of South Africa's national emissions (excluding sinks from forestry and other land use).

5.2 Impact of Project Emission for Climate Change

Considering South Africa's emissions trajectory presented in the Intended Nationally Determined Contribution submitted in Paris in 2015 the project's annual emissions would remain within a range of 1.4% - 2.2% of national emissions in the period between 2025 and 2030. However, if the plant is still operational in 2050 it could account for as much as 2.0% - 4.1% of the declining forecasted national emissions. Based on the power plant's generation capacity it is likely to contribute as little as 0.3% of the national electricity supply. This suggests that the plant will become a very large emissions contributor relative to the national greenhouse gas emissions inventory.

Global anthropogenic climate change is caused by the accumulated greenhouse gas emissions from all the world's emitting sources. Considered in isolation, the greenhouse gas emissions from the Tshivhaso Power Plant are likely to have a very small if negligible impact on global climate change. Furthermore, it is not possible to directly or indirectly attribute any climate change effects to the greenhouse gas emissions from the power plant specifically. However, as with any issue of common concern, each actor has an individual responsibility to minimise its own negative contribution to the issue. Thus, the project's environmental impact is considered here in terms of its contribution the national greenhouse gas emissions inventory. The impact summary, presented in Table 5 below, should be understood in light of this consideration.

Table 5: Summary of the climate change impacts of the estimated GHG emissions from the proposed Tshivhaso Power Plant.

Nature: The combustion of coal in the power plant produces greenhouse gas emissions which in turn contribute to the global phenomenon of anthropogenic climate change. Global climatic changes are likely to manifest in numerous global environmental effects although none that can be attributed directly or indirectly to greenhouse gas emissions of the power plant specifically. However, the contribution of the plant to national greenhouse gas emissions is quantifiable and very large.		
	Without Mitigation[2]	**With Mitigation**[2]
Extent	Global (5)	Global (5)
Duration	Long term (4)	Long term (4)
Magnitude	Moderate (6)	Low (4)
Probability	Definite (5)	Definite (5)
Significance	**High (75)**	**High (65)**
Status	Negative	Negative
Reversibility	Low	Low
Irreplaceable loss of resources?	Yes	Yes
Can impacts be mitigated?	Yes	Yes
Mitigation: In order to mitigate the project's contribution to the onset of climate change the power plant would need to mitigate its greenhouse gas emissions. Options for mitigating the power plant's greenhouse gas emissions have been discussed in Section 4.2 and primarily involve substituting the source of thermal energy away from coal towards more carbon neutral sources.		
Cumulative impacts: The greenhouse gas emissions from the power plant are highly cumulative in nature due to the global scope of climate change and the long durations that carbon emission are expected to remain in the atmosphere. As greenhouse gas emissions accumulate in the atmosphere the onset of climate change is likely to be accelerated and then sustained. South Africa's emissions reduction targets are also likely to be impacted by the plant's emissions.		
Residual risks: There are a vast number of other sources of greenhouse gas emissions around the world. Thus, even with efforts to mitigate the project's greenhouse gas emissions the risks associated with the onset of climate change will still be prevalent.		

As climate change is a global phenomenon caused but greenhouse gas emissions that diffuse across the entire atmosphere, the impact of the project's greenhouse gas emissions are considered to be of the largest extent possible. Although the lifetime of the plant is likely to be about 30 years the greenhouse gas emissions produced are typically assessed based on their 100 year global warming potential (GWP). Thus, the

[2] A description of the scoring criteria for the impact table can be found on page 3 of this report.

duration of the impact of the greenhouse gas emissions is considered as long term. Due to the Tshivhaso Power Plant's relatively large contribution to national emissions, its emissions impact is considered to have a moderate magnitude as an individual source. There is a general consensus amongst climate scientists that the probability that greenhouse gas emissions contribute to the onset of climate change is virtually certain and its impact will negatively affect the world's population. The overall significance of the power plant's impact with respect to greenhouse gas emission is high (score >60) based upon the extent, duration, magnitude and probability of the impact. The duration and nature of the impact of anthropogenic climate change will in many cases result in the irreversible loss of resources.

While there are options to mitigate the greenhouse gas emissions from the power plant these options are not able to change the extent, duration or probability of the impact that the greenhouse emissions will have on climate change. The magnitude of the greenhouse gas emissions impact is the only criteria that can be reduced by reducing the quantity of emissions.

The magnitude of the plant's emissions impact in terms of its contribution to the national greenhouse gas emissions can to some degree be reduced by the mitigation options presented in this study. This is represented in the reduced magnitude, and hence reduced significance score, for the project case with mitigation as recorded in Table 5 above. The reduced score do still however qualify the greenhouse gas emissions impact of mitigated project case as high in significance. The cumulative nature of climate change impacts resulting from the greenhouse gas emissions from all the world's sources implies that there will still be risks associated with climate change even if the emissions from the Tshivhaso Power Plant are mitigated. Thus it is instructive to also contrast the impact of the power plant's greenhouse gas emissions (mitigated and unmitigated) against the technological alternative and national baseline.

5.3 Impact Compared Against Baseline

South Africa's Integrated Resource Plan 2010-2030 was brought into effect in March 2011. The updated version is not yet approved and has been subject to intense political debate. It was devised as a 'living plan' for the future generation of electricity in the country. The plan can be used to make projections of the country's future generation capacities and their associated carbon emissions. These figures can be interpreted as a grid emissions factors for each period and present an estimated national baseline of emissions intensity. This presents a useful benchmark from which to compare the intensity of the Tshivhaso Power Plant. The forecasted grid emission factors for the national electricity supply, as estimated from the Integrated Resource Plan, are presented in Figure 7 below. The project's emission factor is also depicted in Figure 7, for ease of comparison.

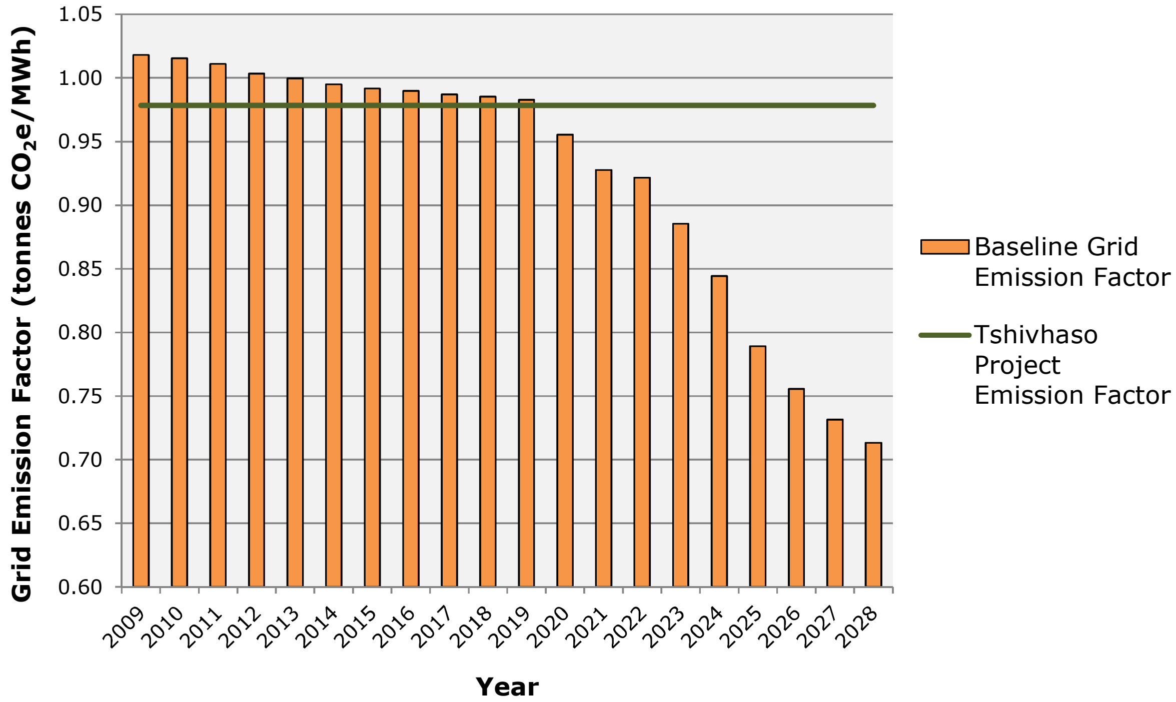

Figure 7: Forecast of the emission factors for the national grid and project in tonnes CO_2e/MWh based on projections in the Integrated Resource Plan for Energy 2010-2030.

The emissions intensity of the Tshivhaso Power plant is 0.978 tonnes CO_2e/MWh. This is comparable to the expected national emissions intensity projected for 2019. The construction of a circulating fluidised bed plant can typically take four years to complete, which suggests that the power plant is likely to have an emissions intensity above the expected national baseline of 0.955 tonnes CO_2e/MWh by 2020.

The national grid's emission intensity will decline as a result of the increasing proportion of renewable energy technologies deployed to produce intermittent power thus diluting the per MWh emissions of the existing base load fleet. Therefore, as a baseload power producer, it is reasonable to expect that the Tshivhaso Power Plant will have a higher emission intensity than the future national baseline. Similarly many of Eskom's other active coal plants have emissions intensities in the range of 0.89 tonnes CO_2e/MWh (Matimba) to 1.26 tonnes CO_2e/MWh (Komati) and will continue to form part of South Africa's base load in the future.

5.4 Impact Compared Against the Technology Alternative and Mitigation Options

It is necessary to consider how the emissions intensities of the alternative combustion technology (pulverised fuel) and the future mitigation options available to the project developer compare against the proposed project. The emissions levels of these options can then also be compared to the forecasted national baseline for emission intensity of electricity generation. Figure 8 below summarises the emissions intensity (tonnes CO_2e /MWh) for the circulating fluidised bed project case, the pulverised fuel alternative and the mitigation options. The baseline national emissions levels for electricity generation for 2020 and 2025 are also presented.

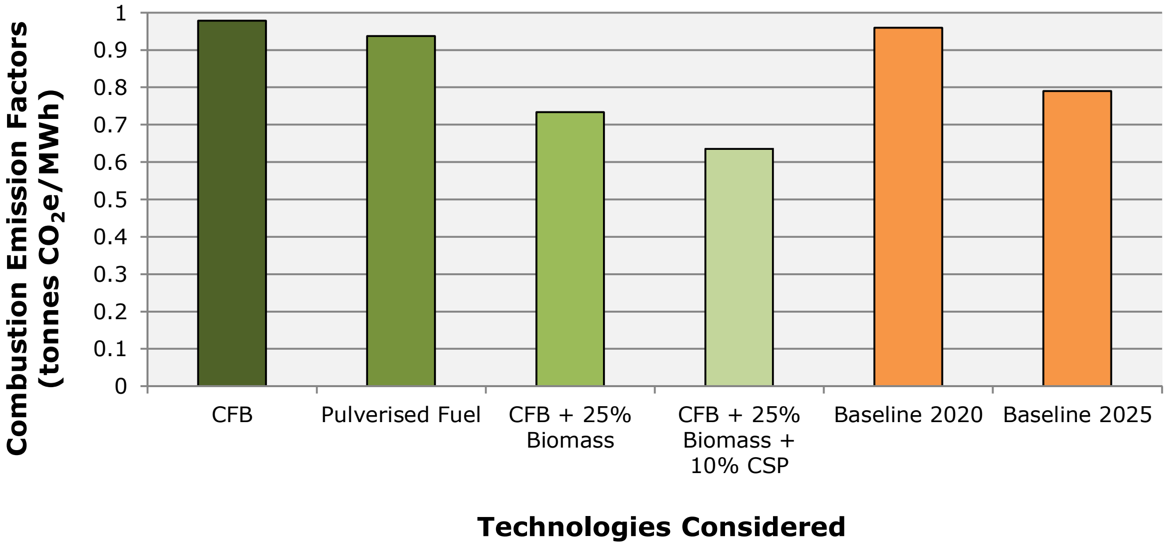

Figure 8: Comparison of the emissions levels of the proposed circulating fluidised bed project case against the technology alternative, mitigation options and the forecasted national electricity generation baselines for 2020 and 2025.

It is evident from Figure 8 that the emissions intensity of the project case is higher than all other cases. At 0.94 tonnes CO_2e per MWh, the pulverised fuel combustion alternative appears to pose a smaller impact, in terms of emissions, than the project case. It also emissions levels slightly below what is projected for the national baseline in 2020, although it exceeds the emissions levels forecasted for 2025.

In terms of the possible future mitigation options, the co-firing of 25% biomass with coal in a circulating fluidised bed combustor results in a significant reduction of emissions below the project case. Due to the carbon neutrality of sustainably harvested biomass that is not transported great distances, the percentage of biomass in the fuel mix directly reduces the emissions. Similarly, the addition of 10% zero emission thermal energy from an additional CSP unit reduces emissions by a further 10%.

The co-firing of 25% in the circulating fluidised bed combustor would produce an emission intensity of 0.73 tonnes CO_2e per MWh. This figure is 7.2% below the projected emission intensity for the national grid electricity for 2025. The addition of 10% solar thermal energy reduces this figure to as low as 19.5% below the 2025 forecasted baseline. The emissions impacts for the selection of circulating fluidised bed combustion technology are presented below in Figure 9 as a causal chain.

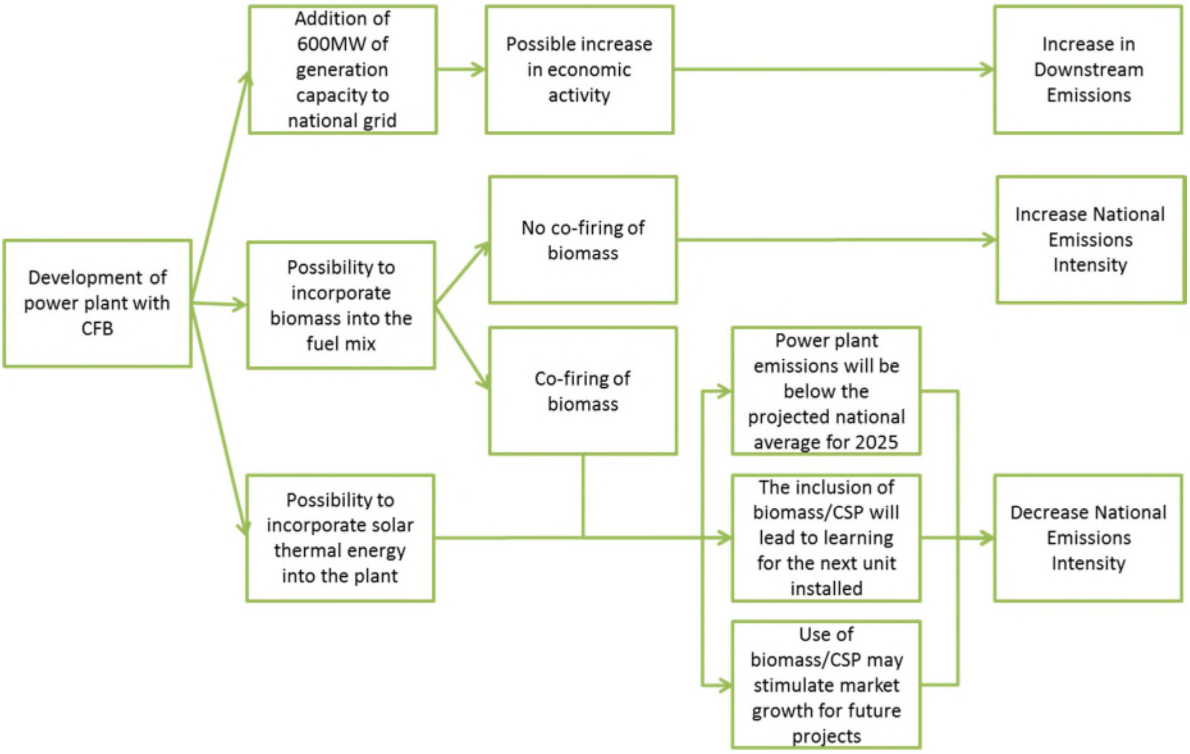

Figure 9: Flow diagram of the causal chain of emissions impacts resulting from the development of the Tshivhaso Power Plant.

6 OPERATIONAL EMISSIONS MANAGEMENT

The emissions trajectory for the power plant will essentially be locked-in once the final decision regarding the combustion technology is made. Once operational there will be limited potential for the plant to reduce its emissions over its lifetime other than the gradual addition of hybrid technologies such as biomass or solar thermal energy as detailed in the mitigation options.

Beyond this the state of the coal used in a circulating fluidised bed combustor can affect the heat output of the furnace which in turn affects the boiler and then the energy produced by the turbine. Wet coal has a high moisture content and thus burns less efficiently due to energy being consumed by evaporation (Bhattacharya *et al.*, 2013). Similarly the size of the coal particles used in a Circulating fluidised bed combustor can affect the completeness of fuel burning and heat generation. Coal that has become wet or crushed to the incorrect size may lead to the consumption of larger quantities of coal per MWh electricity produced. Consequently the burning of more coal per MWh leads to the emission of more CO_2 per MWh.

Therefore, the management of coal stockpiles and maintenance of coal crushers are important areas for operational emissions management. It would be advisable to include these facilities as core areas within a Carbon Management Plan for the power plant. Such a plan could be modelled on the Plan Do Check Act (PDCA) approach within the ISO

9001 Quality Management System Requirements. Beyond the two priority areas mentioned, the plan should aim to incorporate carbon management into the everyday organisation practices of the power plant. In general a good governance structure with high level responsibility for carbon emissions and climate change assist in effectively implementing such management plans.

Specifically, it is recommended that the management plan ensure that coal be stored appropriately so as to protect it from unnecessary moisture exposure. The storage and transportation of coal must also be managed in such a way that it does not crush the coal beyond its useful size. Maintaining the coal crushers will further ensure that the coal particles are optimally sized.

Monitoring is essential to track the effectiveness of any carbon management plan. Monitoring of the moisture content and size of the coal particles supplied to the furnace will be of particular interest for circulating fluidised bed combustion. This information should be supported by the monitoring of the coal storage conditions, transport systems and crusher performance. Furthermore, it will be valuable to monitor the on-site electricity demands as these form part of a plant's parasitic load requirements and effectively reduce the amount of exportable electricity per tonne of CO_2 emitted. The specific monitoring of carbon dioxide, methane and nitrous oxide will become a requirement as part of the Draft Mandatory Greenhouse Gas Reporting Regulations and may even require Tier 3 direct emissions measurement in the future. Thus is may be advisable to consider the inclusion of systems for emissions monitoring via direct measurement.

While highly recommended, the authorisation of the plant's construction is not conditional on the inclusion of the carbon management approach described above.

7 OPINION ON PROJECT

It is apparent that the proposed project technology (circulating fluidised bed combustor fuelled with 100% coal) is in fact the most alternative in terms of carbon emissions. Thus, it is the option that will have the greatest contribution to anthropogenic climate change and its ensuing environmental impacts. The magnitude of this impact will be moderate within the national greenhouse gas inventory while the extent, duration and probability of the plant's greenhouse gas emissions impacts on climate change will be very large. The power plant's overall impact on national emissions and climate change is thus high in significance for a single source. Despite the presence of residual risks even if mitigation efforts are made high emitting sources such as Tshivhaso fall within the collective responsibility to minimise individual negative contribution to the issue.

From the perspective of the national greenhouse gas inventory the plant will be a relatively large source of greenhouse gas emissions, accounting for 1.6% of the most recent national inventory and possibly contributing as much as 4.1% of the forecasted national inventory for 2050. These emissions are proportionally large when considering that the power plant is likely to only supply 0.3% of South Africa's future electricity demand. As such it has been important to explore the possible technological alternatives and mitigation options for the plant.

From the analysis of the circulating fluidised bed and pulverised fuel technologies available to the project developer under the Coal Baseload Programme, it is evident that the emissions intensities of both technologies will be higher than the national baseline of emissions intensity from electricity generation forecasted for 2025. However, the quality of the coal that can be sourced from the Thabametsi Coal Mine is not likely to be suitable for a pulverised coal combustor. Similarly the limited water resources in the area of operation are likely to inhibit the wet scrubbing systems required for pulverised fuel combustion. Unless the project developer is able to source higher grade coal and additional water supplies it is unlikely that pulverised fuel will be a feasible technological option despite being marginally less carbon intensive. Based on resource availability and the need to produce baseload power it is reasonable to pursue circulating fluidised bed technology. This technology is however more emissions intensive than the national baseline, which includes intermittent renewable energy.

Due to the scale at which the power plant will produce greenhouse gas emissions it is important that the emissions be mitigated where and when possible. This analysis has demonstrated that there are options to improve the emissions intensity of circulating fluidised bed combustion. While these options are beyond the scope of the bid requirements, they present useful insight for the project developer. These options include the future incorporation of biomass into the fuel mix of the circulating fluidised bed combustor and supplementing the combustors energy supply with solar thermal energy from CSP units.

The inclusion of biomass into the fuel mix for the circulating fluidised bed combustor appears to be the most effective technological option to reduce the power plant's carbon emissions and impact on climate change. The inclusion of thermal energy from an additional CSP plant is similarly effective, although comparatively expensive in capital terms. The inclusion of 10% of thermal energy would require a 152MW plant to be built (without storage facilities). While there may be land available, the suitability of the topography may be another limiting factor.

The inclusion of 25% biomass into the fuel mix would reduce the emission intensity of the power plant well below the projected national baseline of emissions intensity for electricity generation. Circulating fluidised bed combustors can be calibrated to use varying mixes of fuels. As such the incorporation of biomass into the fuel mix could be done in such a way so as to gradually decrease the plant's emissions below the projected national grid baseline or in line with other emissions obligations.

Furthermore, the net present value (NPV) of the cost of co-firing with 25% biomass (high cost) in the circulating fluidised bed plant is only 5.3% higher than a circulating fluidised bed plant without co-firing. While the purchase costs of biomass are typically higher than that of coal, costs can be significantly reduced through self-cultivation and harvesting, where third-party profit margins are avoided. Co-firing with low cost biomass (self-cultivated) could actually recue the NPV of the plant's costs by up to 6.2%. The inclusion of biomass into a large power plant such as Tshivhaso may also help to stimulate growth in the biomass market and encourage the uptake of biomass based combustion technologies for other future power plants. In this way, the Tshivhaso Power Plant would indirectly assist in the lessening of the emission intensity associated with the national energy generation. Similar benefits are derived from the inclusion of solar thermal energy from CSP.

By making provisions for the future instalment of CCS technologies, the Tshivhaso Power Plant will maintain the opportunity to significantly reduce its future carbon emissions and climatic impact. Having an effective carbon management plan and emissions monitoring system will assist in tracking and minimising greenhouse gas emissions on a daily basis.

It is concluded that the Tshivhaso Power Plant is likely to produce a significant amount of greenhouse gas emissions and account for a relatively large proportion of South Africa's greenhouse gas inventory. The overall significance of its impact on the national inventory is high and thus mitigation options must be pursued as part of a shared responsibility to the global issue of climate change. In meeting this objective it is suggested that the development of circulating fluidised bed combustion technology in the Tshivhaso Power Plant is expected to be the most suitable option based on the technological requirements of the Coal Baseload Programme. While it is expected to have comparable climatic impacts, in terms of carbon emissions, to pulverised fuel technologies, circulating fluidised bed technology has greater opportunities for emissions reductions through the future co-firing of biomass. It is recommended that the project developer seriously considers future opportunities related to the; co-firing with biomass, incorporation of solar thermal energy and the implementation of an effective monitoring plan.

REFERENCES

Bhattacharya, C., Banerjee, N. and Sadhan Sarkar, H. 2013. Economics of Removal of Coal Moisture in Thermal Power Generation with Waste Heat Recovery. International Journal of Emerging Technology and Advanced Engineering **3**(3): 22-28.

Department of Energy. 2014. Integrated Resource Plan for Electricity 2010-2030 [Online]. Available at: http://www.energy.gov.za/IRP/irp%20files/IRP2010_2030_Final_Report_20110325.pdf (Accessed: 01/07/2016).

Department of Environmental Affairs. 2015. South Africa's Intended Nationally Determined Contribution (INDC) [Online]. Available at: https://www.environment.gov.za/sites/default/files/docs/sanational_determinedcontribution.pdf (Accessed: 20/07/2016).

DEFRA. 2015. Greenhouse gas reporting - Conversion factors 2015 [Online]. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2015 (Accessed: 15/06/2016).

EPRI. 2010. Power Generation Technology Data for Integrated Resource Plan of South Africa [Online]. Available at: http://www.energy.gov.za/IRP/irp%20files/Tech_Data_for_Integ_Plan_of_South_Africa_July_08_2010_Final.pdf (Accessed: 12/06/2016).

Eskom. 2011. COP17 Fact Sheet [Online] Available at: http://www.eskom.co.za/OurCompany/SustainableDevelopment/ClimateChangeCOP17/Documents/Air_quality_and_climate_change.pdf (Accessed: 17/08/2016).

Eskom. 2015. Eskom Fact Sheet [Online]. Available at: http://www.eskom.co.za/IR2015/Documents/Eskom_fact_sheets_2015.pdf (Accessed 18/07/2016).

Hondo, H. 2005. Life cycle GHG emission analysis of power generation systems: Japanese case. *Energy* **30**: 2042–2056.

International Organization for Standardization. 2015. *ISO 9001:2015 Quality Management System Requirements*. Geneva: International Organization for Standardization.

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy [Online]. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf (Accessed: 15/06/2016).

Lephalale Local Municipality. 2015. Final Integrated Development Plan [Online]. Available at: http://www.lephalale.gov.za/docs/SDBIP/Final%20%20IDP%202015-2016%20Lephalale..pdf (Accessed: 13/07/2016).

Miller, K. 2013. Hybrid Solar Thermal Integration at Existing Fossil Generation Facilities [Online]. Available at: www.eskom.co.za/.../RenewableEnergy/.../G3CSP_FossilHybridMillerFINAL.pptx (Accessed: 13/07/2016).

Mining Weekly. 2015. S African coal exports unsustainable at long-term prices – Prevost [Online]. Available at: http://www.miningweekly.com/article/s-african-coal-exports-unsustainable-at-long-term-prices-prevost-2015-11-04 (Accessed: 15/06/2016).

Maurstad, O. 2005. An Overview of Coal Based Integrated Gasification Combined Cycle (IGCC) Technology [Online]. Available at: https://sequestration.mit.edu/pdf/LFEE_2005-002_WP.pdf (Accessed: 07/07/2016).

National Treasury. 2015. Draft Carbon Tax Bill [Online]. Available at: http://www.treasury.gov.za/public%20comments/CarbonTaxBill2015/Carbon%20Tax%20Bill%20final%20for%20release%20for%20comment.pdf (Accessed: 13/07/2016).

Oravainen, H. and Karki, J. 2007. Co-firing Techniques for wood and Coal: Review of the Various Co-firing Concepts in Europe [Online]. Available at: https://www.unece.org/fileadmin/DAM/timber/workshops/2007/belgrade/Presentations/oravainen2.pdf (Accessed: 12/07/2016).

SACCCS. 2010. CCS Roadmap and Strategy [Online]. Available at: http://www.sacccs.org.za/roadmap/ (Accessed: 13/07/2016).

Standards South Africa. 2006. *SANS 14064-1:2006 Greenhouse Gases Part 1: Specification with guidance at the organisational level for the quantification and reporting of greenhouse gas emissions and removals*. Pretoria: Standards South Africa.

Utt, J. and Giglio, R. 2012. Technology comparison of CFB versus pulverized fuel firing for utility power generation. *The Journal of The Southern African Institute of Mining and Metallurgy* **112**: 449-454.

White, C., Smith, D., Jones, K., Goodman, A., Jikich, S., LaCount, R., DuBose, S., Ozdemir, E., Morsi, B. and Schroeder, K. 2005. Sequestration of Carbon Dioxide in Coal with Enhanced Coalbed Methane Recovery A Review. *Energy & Fuels* **19**(3): 659-724.