



STUDY ON NAMIBIAN BIOMASS PROCESSING FOR ENERGY PRODUCTION



Conducted by

STEAG Energy Services GmbH, Essen, Germany

In cooperation with

Transworld Cargo (Pty) Ltd., Windhoek, Namibia

Date: 15 October 2013

This study has been supported through a Private Public Partnership fund (PPP) via the *Namibian Employers Federation (NEF)* and *Global Compact Network Namibia (GCNN)* that is financed through the *Deutsche Gesellschaft für Internationale Zusammenarbeit* and supported by the German Government.

Supported by:



Global Compact Network
Namibia



giz

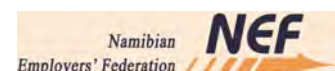


Table of Content

1 Executive Summary	1
2 Introduction.....	5
3 Analysis of the Current Power Supply Situation	7
4 Analysis of the Current Biomass Situation	13
5 Basic Investigations for an Energy Concept Development.....	17
5.1 Harvesting Options.....	17
5.2 Biomass based Products, Production Technologies and Marketing Op- portunities.....	20
5.2.1 Biomass Chips.....	20
5.2.2 Biomass Briquettes/Logs	23
5.2.3 Biomass Pellets	26
5.2.4 Bio-coal Pellets/Torrefied Biomass Pellets	32
5.2.5 Comparison of different Biomass based Products.....	38
5.3 Logistics and Infrastructure	39
5.3.1 Point of Departure	39
5.3.1.1 Biomass and Supply Chain	39
5.3.1.2 Namibia Transport Infrastructure and Capacities	40
5.3.1.3 Implications of Transport Infrastructure provision on Bio- mass Bulk Transport	41
5.3.1.4 Assumption/Model.....	42
5.3.2 Biomass Value Chain and Supply Chain	42
5.3.2.1 General	42
5.3.2.2 Local Level from Farm to Processing Plant.....	43
5.3.2.3 Regional Level from Plant to Site	44
5.3.2.4 International Level from Plant to International Port Destina- tions	45
5.4 Levelled Costs of Electricity	46

6	Concept Development for Future Utilization of Namibian Biomass	48
6.1	Construction of Decentralized Biomass Power Stations.....	48
6.1.1	Plant Description	49
6.1.2	Resource Supply Situation	51
6.1.3	Economic Analysis	53
6.2	Construction of Decentralized Hybrid Power Stations on the Basis of Biomass and Solar Heat.....	55
6.2.1	Plant Description	55
6.2.2	Resource Supply Situation	57
6.2.3	Economic Analysis	57
6.3	Production of Biomass based Fuels for the National / Foreign Markets	58
6.3.1	Plant Description for White/Black Pellets.....	59
6.3.2	Resource Supply Situation	61
6.3.3	Economic Analysis	64
7	List of Figures.....	69
8	List of Tables	73
9	List of Acronyms.....	76
10	Reference List	77

1 Executive Summary

Namibia is challenged by a massive bush encroachment problem that affects meanwhile 26 - 30 million ha of farmland. Numerous studies give evidence of the negative environmental and economic effects of this phenomenon for the farming community, and the country at large. It has been estimated that through loss of agricultural productivity, the bush encroachment results in overall economic losses of 1.6 billion N\$ per year.

At the same time the bush encroachment constitutes an immense economic opportunity and energy asset. Effective counter measures through debushing programs and supporting value chains have the potential to mobilize the inherent development potential. Direct effects include but are not limited (a) to increase agricultural productivity, (b) to develop new economic value chains with benefits for the national economy, (c) to create new employment opportunities in rural environments and (d) to improve the national energy supply base. The latter has the potential to increase self sufficiency of energy and, importantly, to bridge a demand gap of energy provision to be expected to take effect as from 2016 at latest.

The latter requires swift measures in support of utilization of Namibian biomass for power generation. The enhanced know how based on extensive research being conducted over the past years, the availability of technical expertise and the commitment of national and international stakeholders support the realization of pilot investments, with the potential to subsequent roll out.

The identified biomass utilization options focus on local consumption and, as second priority only, on export opportunities. The local utilization of biomass for power generation is based on favorable "leveled costs of energy production" in the range of 1.0 - 1.1 N\$/kWh. That value is close to the respective costs of conventional energy, and considerably lower than previous estimates. It corresponds however to international benchmarks of biomass power plants and power generation. That cost level qualifies biomass to be a future complementary energy source as a base load provider specifically at decentralized locations.

Export opportunities for processed biomass in the form of biomass pellets ("white pellets") or bio-coal pellets ("black pellets") exist worldwide. Obvious opportunities for Namibian biomass are in South Africa and Europe. In both regions it is the policy/regulatory environment that determines the current and future biomass demand. Given such policy support, which is the case for major European countries and a future

option for South Africa, both regions are facing an increasing demand in industrial biomass fuels and a corresponding undersupply out of own biomass resources. The demand gap needs to be met by imported biomass fuels. While the current demand is primarily on white pellets, there are good reasons to assume that the future biomass demand for co-combustion in coal fired power plants will shift towards bio-coal. That likely development would allow Namibian production to benefit from lower supply chain costs which result from material qualities of black pellets as compared to white pellets (e.g. higher bulk and energy densities; hydrophobic nature).

The proposed biomass utilization strategy focuses on the combination of various utilization options, e.g. by combining local strategies (e.g. wood chip production for decentralized biomass/hybrid plants) with regional/international strategies (e.g. pellet/bio-coal production for coal-fired power plant supplies). The combined production strategies will allow for the utilization of technology and operational synergies, and will have an increased impact on bush encroached areas.

Priority utilization options identified by this research include the following:

1 – Decentralized biomass power plants

The concept of decentralized biomass power plants is based on low biomass energy production costs in the Namibian context. They are fed by unprocessed and cost effective wood chip fuel of high quality and calorific value. Their location is in proximity to supply and demand area ensuring minimal transport costs and energy transmission losses. Initial/pilot plants are recommended to be of 5 MW capacities which accommodate energy demand profiles of medium sized towns as well as regulatory authorization requirements.

2 – Decentralized hybrid power plants based on biomass and solar heat

The concept of decentralized hybrid power plants is as per above but additionally utilizes the high irradiation conditions in Namibia. The hybrid plant allows for biomass based base load power generation and solar based peak load power generation during day time. The development of hybrid technology would position Namibia at the forefront of energy technology innovation in Africa, and beyond.

3 – Biomass based fuel supply including wood chips, white pellets and bio-coal for industrial and power generation applications

The principle preference concerning the three considered biomass fuels depends (a) on the combustion technologies and corresponding fuel requirements and (b) on the transport distances and supporting supply chain requirements. The profitability analysis shows that, from a pure cost point of view, the Windhoek region is best to be supplied by wood chips, further away destinations such as the Erongo region by biomass pellets (“white pellets”) while international destinations are best served by bio-coal (“black pellets”).

Wood chips would be for local consumption only due to their low bulk and energy density alone. However, there are ample consumption opportunities ranging from biomass power plants to boilers in industrial applications of the food industry. As compared to other biomass products, the production of wood chips is capital extensive and has the potential to promote large scale decentralized de-bushing activities of farmer’s and/or service providers.

The production of white pellets meets a demand in industrial applications that require long distance transport, such as the mining sector or the fishing industry in the Erongo region. White pellets are also supported by an increasing global demand as primary biomass resource. Of particular relevance for Namibia is an increasing supply-demand gap in Europe that need to be met by pellet imports from overseas. The same principles apply to South Africa provided, however, policy support from Government and Eskom: increasing biomass demand, lack of own biomass resources and resulting import requirements preferably from the region. Namibia would be in a very competitive situation to supply the South African market.

Bio-coal pellets or black pellets are superior to white pellets with regard to bulk and energy density and overall transportability. Its material quality similarity to fossil coal favors bio-coal for future co-combustion in coal-fired power plants both globally and locally. With regard to the latter perspective, NamPower is committed to co-fire the rehabilitated van Eck power station with biomass, preferably with bio-coal. In an international perspective, it must be noted that the bio-coal fuel is still in its development stage, with very few operational plants worldwide. This infant stage of bio-coal development allows considering to develop a bio-coal pilot plant in Namibia which would further support the position of Namibia as an innovation hub. Such an investment, however, would require some reliable commitment of potential industrial consumers, be it in Namibia, in South Africa and/or overseas.

The success of pilot plant investments including harvesting, processing and power generation critically depend on the full utilization of local advantages of respective sites. These need to provide optimum conditions as regards resource supply, availability of logistics infrastructure and proximity to consumers, and synergies thereof. Thus, the selection of the initial production site both under resource supply, local power demand and national and international supply chain perspectives will be critical for the success of the pilot plant investment. It seems that Okahandja in the [Otjozondjupa](#) region provides such optimum conditions and could thus serve as model for later roll out to other locations in the central northern and eastern part of the country.

It is recommended to proceed with the development of biomass utilization by promoting decentralized biomass power plants. Here we propose to conduct a full feasibility study which considers site evaluation, technologies, biomass sourcing, employment effects and economics. The study will result in a realistic project scheme.

Besides, in order to progress with other immediate opportunities, further investigations are required into (a) detailed parameters for biomass-solar hybrid power plants and (b) confirmed local and international market opportunities for bio-coal.

STEAG Energy Services GmbH in cooperation with Transworld Cargo Pty Ltd is interested in actively participating in the process of enhancing the utilization of Namibian biomass for power generation, be it as a technical or consulting partner, as a project developer, as an independent power producer and/or an investor for biomass based power generation projects.

2 Introduction

Namibia has a country side of approximately 820,000 km² and is located north/south of the tropic of Capricorn. Its natural vegetation is dry savannah with biomass productivity increasing parallel to annual rainfall from south to north. The area is primarily used for extensive cattle farming with commercial land rights in the southern and central part and communal rights in the north.

Namibia's farmland is burdened by a massive encroachment of bush species. It is estimated that approximately 26 million hectare of Namibia's farmland is affected by the encroachment of invader bush. The process of bush encroachment is said to be caused primarily by range management problems such as overgrazing, preventing of natural fires and reduction of browsers. Since the beginning of the last century a significant decrease of agriculture productivity through reduced carrying capacity of land has been observed. Meanwhile bush encroachment is a national challenge that starts to mobilize both public and private sector responses.

The energy demand and the target of CO₂-reduction of energy generation worldwide emphasize the role of biomass as CO₂-neutral fuel. This makes biomass from bush encroachment a perspective fuel source in Namibia combining natural sourcing by saving of fossil fuels, securing of agricultural productivity and natural conservation. Utilization for energy generation beginning at domestic needs over decentralized power generation up to co-combustion in large coal-fired power plants open a wide-range of opportunities for biomass utilization from bush encroached areas. Both the scope of the bush encroachment problem as well as the potential benefits of debushing to utilization of the biomass resource for future energy generation is of national interest. Any related initiatives meet a very supportive public and private sector environment in Namibia.

According to the terms of reference, a pre-feasibility study on biomass generation and treatment in Namibia shall be conducted, targeting international markets for bio energy utilization. The treatment shall consider pelletizing as well as processing biomass to bio-coal. The main focus is on logistics and treatment in Namibia. The overall objective is the development of a business model for biomass generation through pelletizing and torrefaction technology under consideration of environmental, technological, logistics and business parameters. In the course of the study implementation, additional biomass perspectives were identified and taken on-board. That includes the utilization

of wood chips in industrial and power generation applications, and the design of biomass-solar hybrid generation plants.

3 Analysis of the Current Power Supply Situation

The national energy generation capacity in Namibia totals up to approximately 500 MW. Namibia's state-owned electricity generation and transmission entity NamPower is the main power producer in Namibia, producing nearly all grid electricity. The electrical energy, which is fed into the transmission grid by NamPower, is generated at four local power plants, shown in table 3.1.

Tab. 3.1: Main national power plants for current energy supply in Namibia

Power Station	Energy Source	Power Capacity	Commissioning	Operation Mode
Ruacana (Kunene River)	Water	249 MW (till 2012) 332 MW	1972 (2012 upgraded)	Base Load
Van Eck (Windhoek)	Coal	120 MW (4 x 30 MW)	1972	Peak Load
Paratus (Walvis Bay)	Heavy Fuel Oil	24 MW (4 x 6 MW)	1976	Peak Load
Anixas (Walvis Bay)	Heavy Fuel Oil	22,5 MW	2011	Peak Load

Ruacana is a hydro-electric power station at the Kunene River at the Namibian Angolan border. The commissioning was in 1972 with a generation capacity of 249 MW. In 2012 the power station was upgraded to 332 MW. The power generation of Ruacana depends on the river's water flow. There is no big water dam at or near Ruacana, only a small reservoir is available to manage water storage for 24 hours. This is not an effective buffer that ensures water availability or can be used to regulate flow during the dry period. Thereby, in the dry season Ruacana cannot achieve complete capacity and reduce the feeding of electrical energy into the national grid.

Van Eck is a coal-fired power station in the north of Windhoek and has a total capacity of 120 MW, which is separated into four boilers with a capacity of 30 MW of each boiler. The used technology is travelling grate and the fuel is lumpy chestnut coal. The power plant was commissioned in 1972 and is now only used as peak load power plant to overcome short-term supply gaps because of high fuel and operating costs. Furthermore, Van Eck is no longer able to produce electricity at rated capacity due to plant obsolescence.

Paratus power station in Walvis Bay uses heavy fuel-oil and was commissioned in 1976. The power station has 4 separate boilers with a total electrical generation capacity of 24 MW. Anixas power station in Walvis Bay, which is also based on heavy fuel-oil, was commissioned in 2011 and has an installed capacity of 22.5 MW. Similar

to the Van Eck power station, Paratus and Anixas are mainly used as peak load power plants to match short term demand peaks due to high fuel and operating costs.

Figure 3.1 shows the percentage distribution of the energy supply generated at the four Namibian power plants.

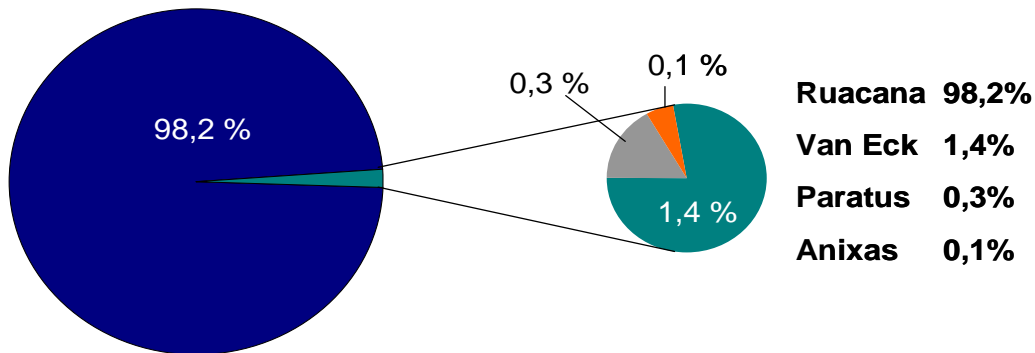


Fig. 3.1: Percentage distribution of local electricity generation (based on [8])

More than 98 % of the electricity generations from Namibian power plants are from the hydro-electric power station Ruacana. This underlines the strong role played by the Ruacana power station as base load power plant. The other three fossil-fired power plants generate only 2 % of the total national energy supply. The corresponding workload of Namibia’s power plants is shown in figure 3.2.

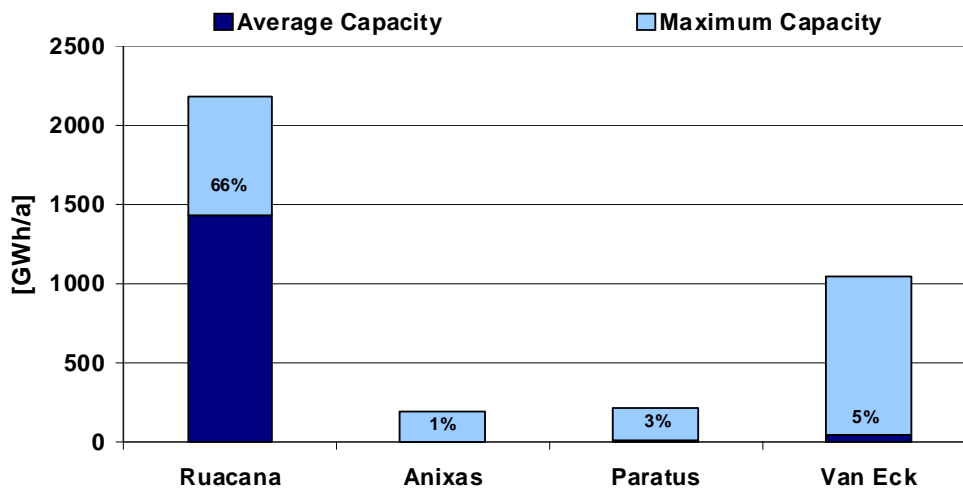


Fig. 3.2: Workload of Namibia’s power plants during the last decade 2001-2011 (based on 7500 operating hours per year)

Although the Ruacana power station plays a central role in the local power generation of Namibia the average reached power capacity of Ruacana is only approximately 66 % due to different river flows during dry and rainy periods. But in 2012 the power station was upgraded from 249 MW to 332 MW, so that the maximum and the average reached power generation of Ruacana will probably be higher in future. The other three

fossil-fired power plants Anixas, Paratus and Van Eck are used as peak load power plants for matching of short term demand peaks. The average capacity related to the maximum capacity of these power plants is in each case lower than 5 %.

Figure 3.3 shows the electricity demand in the years 2001-2011 splitting in self production and import.

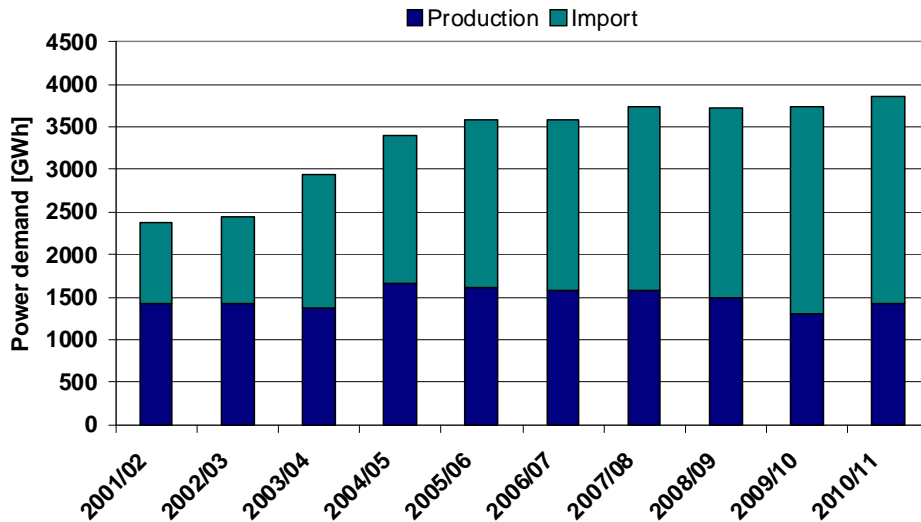


Fig. 3.3: Power demand energy production and import [18]

It can be seen that Namibia’s self production of power is not sufficient for the total Namibian power demand. Although the local power plants are not operating at maximum capacity, as shown in figure 3.2, a high power amount is imported from neighboring countries. Considering these facts the power import from neighboring countries seems to be cheaper than the self production in Namibia due to high specific power production costs. Figure 3.4 shows Namibia’s dependence on energy suppliers from neighboring countries like South Africa, Zimbabwe and Zambia.

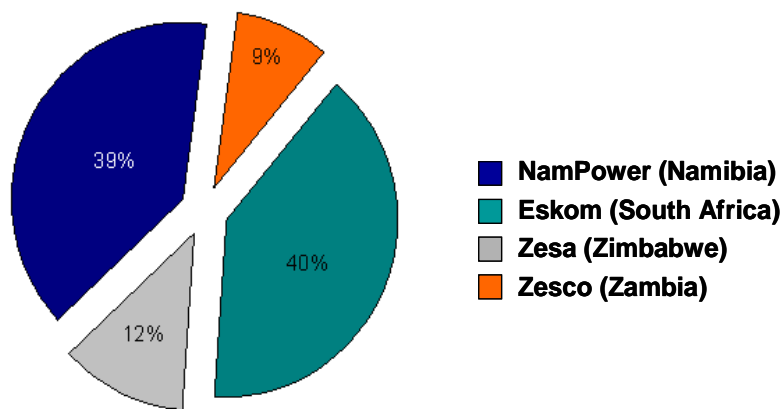


Fig. 3.4: Percentage distribution of Namibia’s energy supply in 2012 (based on [18])

Meanwhile more than 60 % of the local energy demand in Namibia has to be imported. Especially Eskom, a South African energy supplier, plays a central role as a supply partner who will provide electricity for Namibia. Approximately 40 % of the local energy demand is supplied by Eskom. Other important suppliers are Zesa from Zimbabwe (12 %) and Zesco from Zambia (9 %). Small importers from Mozambique and the South African power pool are not listed, because they currently do not play a significant role. For the power import a network of high voltage transmission lines is available with two main power lines. On the one side it is the north-south transmission line with a capacity of about 600 MW that connects Namibia with South Africa. And on the other side it is a route through the Caprivi Strip in north-eastern Namibia, which secures a link to countries like Zambia or Zimbabwe. The Caprivi interconnector has a capacity of 300 MW and can possibly reduce the dependency towards South Africa and increase the trade with SAPP (South African Power Pool) [27].

Namibia’s Integrated Resource Plan assumes for electrical energy for the period between 2011 and 2031 an annual growth rate of 4.25%. With the energy of the present situation and the assumed further increase of the Namibian electricity demand, the energy market will be increasingly dependent on the import, if no new strategies will be developed in Namibia’s energy supply system. Furthermore, there is the danger of having a demand gap in the energy supply on the Namibian electricity market, because the increasing demand for electricity could exceed the local and the external power supply. Figure 3.5 represents a forecast for possible power consumption and an illustration of the different sources of electricity supply.

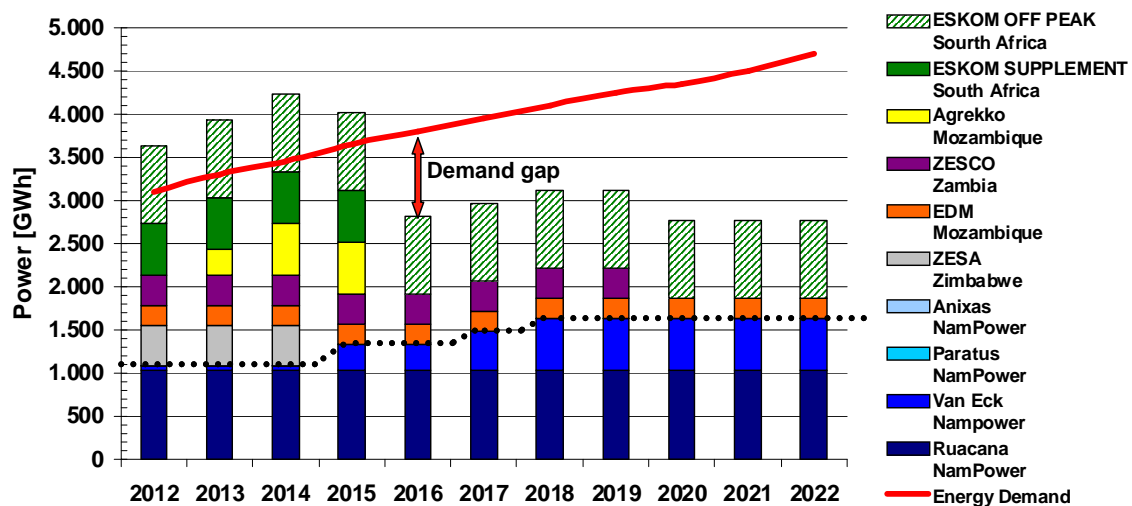


Fig. 3.5: Forecast of power consumption and supply in Namibia including peak demand (based on [8], [14], [28])

The current power supply will completely cover the energy demand until 2015. But from 2016 a national undersupply is expected. The future power supply is currently not secured from 2016. Long term contracts with suppliers from neighboring countries will expire. A trade agreement with Eskom is expanding every year and was extended until 2015. The share of the South African power utility Eskom is currently at approximately 40 %. But due to higher requirements and more stringent restrictions with respect to timing, quantity, cost and seasonal peak loads, the energy supply of Eskom for Namibia will decrease in future. Zesa at least still provides power until 2014 from the Hwange Power Station and Zesco with a commitment of 50 MW until 2020.

To avoid a possible demand gap from 2016 new power generation capacities have to be realized in Namibia. First of all Van Eck power station represents a significant component of Namibia's generation capacity. A rehabilitation of the power station can be an important step to minimize the demand gap for the next years and extend the life time of the power station. Constructions for the rehabilitation have started and it is expected to complete in 2014/2015. Additionally a high efficiency of the operated units should be endeavored in order to achieve additional power. In future, NamPower plans to use bio-coal as fuel for the power station Van Eck. Besides the rehabilitation of Van Eck several other energy projects are in discussion or in planning. Table 3.2 gives an overview of currently known energy projects in Namibia, which are discussed or planned, whereas no guarantee of completeness will be given.

Tab. 3.2: Overview of discussed or planned energy projects in Namibia (based on [1], [12], [14], [15], [18], [22], [23])

Project	Energy Source	Capacity	Commissioning
Kudu Gas to Power Project	Natural Gas	800 MW (400 MW for Namibia)	probably in 2018 (planned since 1996)
Coal-fired Power Station, Walvis Bay	Coal	414 MW	?
Gecko Power Station, Swakopmund	Liquid Natural Gas or Heavy fuel Oil	400-600 MW (in several steps)	first step (100-150 MW) planned in 2016
Arandis Power Station	Heavy Fuel Oil	120 MW	planned in 2014
Baynes Hydro Power Station	Water	600 MW (300 MW for Namibia)	? (constr. start 2015)
Popa Falls Hydropower (Okavango River)	Water	20 MW	?
Orange River Small Hydro Stations	Water	72 MW (12 x 6 MW)	?
Diaz Wind Farm Lüderitz	Wind	20-44 MW	?
Wind Parc Walvis Bay Area	Wind	50 MW	?
Tsumkwe	Solar	30 MW (3 x 10 MW)	?
CBEND Bush to Electricity Project	Biomass (Invader Bush)	0.25 MW	2012?

On the basis of these energy projects the demand gap could be closed and new power imports from neighboring countries could be avoided, but currently unsure, if these energy projects will really come, because most of these energy projects are only in discussion or in the planning phase. Furthermore, the assumed demand gap could probably be closed at the earliest from 2018 onwards.

Conclusion:

Namibia's power supply is facing considerable challenges in the near future. Specifically the period until the scheduled Kudu gas power plant will come online as from 2018/2019, will be challenged by a national power demand that exceeds supply. In the last years the share of imported power increased continuously, so that Namibia's power supply is currently dependent on neighboring countries like South Africa, Zimbabwe and Zambia. In the past, specifically South Africa's huge power capacities helped to maintain the energy supply in Namibia. However, this external power supply will decrease with time due to overall lower excess power capacities in South(ern) Africa. Rising electricity costs are likely to influence the economic performance of Namibia, particularly in energy-intensive areas such as manufacturing and mining. This future scenario requires innovative policy and strategic measures. Specifically, own power generation capacities suitable for base load provision with low specific production costs are to be mobilized in order to maximize a sustainable energy supply out of own resources. Against this background, biomass as a national energy source has great potential to play a major future role in the national energy supply of Namibia.

4 Analysis of the Current Biomass Situation

Namibia's north is to a great extent covered with invader bush, a mixture of various kinds of bushes. It is estimated that currently about 26 Million hectare of agricultural land is moderately or highly covered with invader bush [7]. The amount of biomass per hectare varies between 8 and 20 tons and depends on the local vegetation and weather conditions [7]. In the North of Namibia the conditions of growth are better than in the South of Namibia. So the vegetation density rises from South to North, whereas Windhoek represents the southern vegetation border. Figure 4.1 shows the biomass distribution and the biomass density in Namibia.

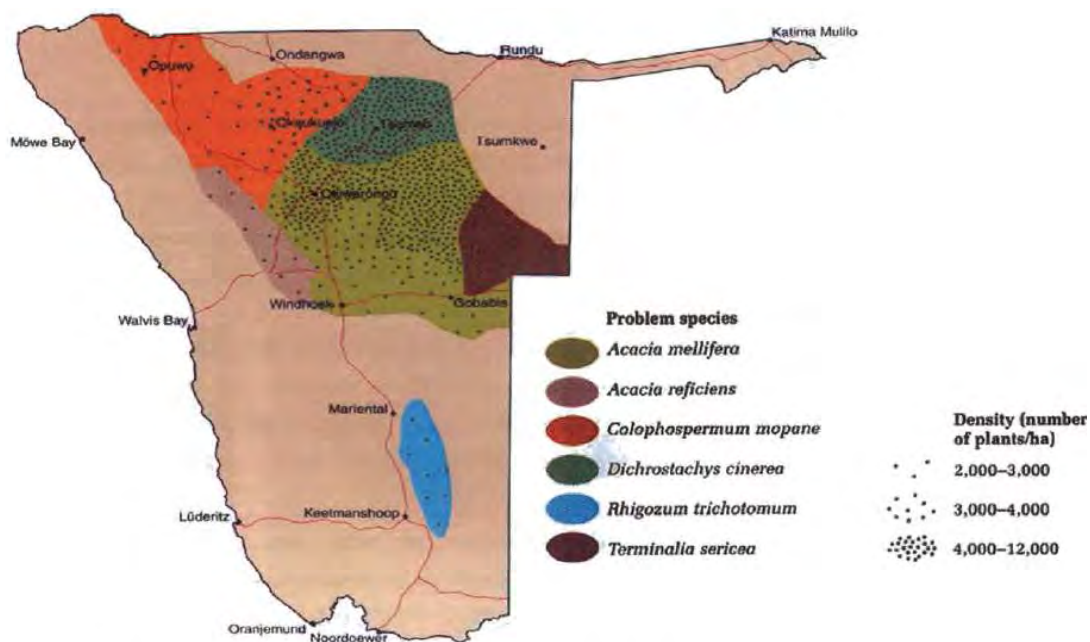


Fig. 4.6: Invader bush distribution in Namibia [27]

The productivity of the Namibian savannah and farmland is largely determined through the soil water balance. Increased droughts are direct results of bush encroachment and endanger strongly the Namibian economy as well as the botanic and fauna diversity. Bush encroachment is recognized as a form of land degradation that reduces the livestock capacity of rangelands due to the loss of grazing land for cattle or decrease of domestic vegetation. This observation leads to serious economical drops in Namibia concerning both the commercial and the urban farmer regions. Thus farmers have to face up to financial damages.

Removing the invader bush is cost-intensive and often uneconomically implemented. Therefore different thinning and removing options were developed to increase the usable area of graze land for cattle breeding and hence the economic efficiency of the

land. But mostly the removing of invader bush leads only to higher costs for the farmers and not to higher incomes due to the creation of bigger rangelands. Currently the invader bush is felt by the farmers only as disturbing factor for the cattle breeding. Figure 4.2 shows two examples for Namibian rangeland. On the left side a typical example for unwanted bush encroachment without launch of countermeasures, on the right side wanted rangeland with launch of countermeasures.

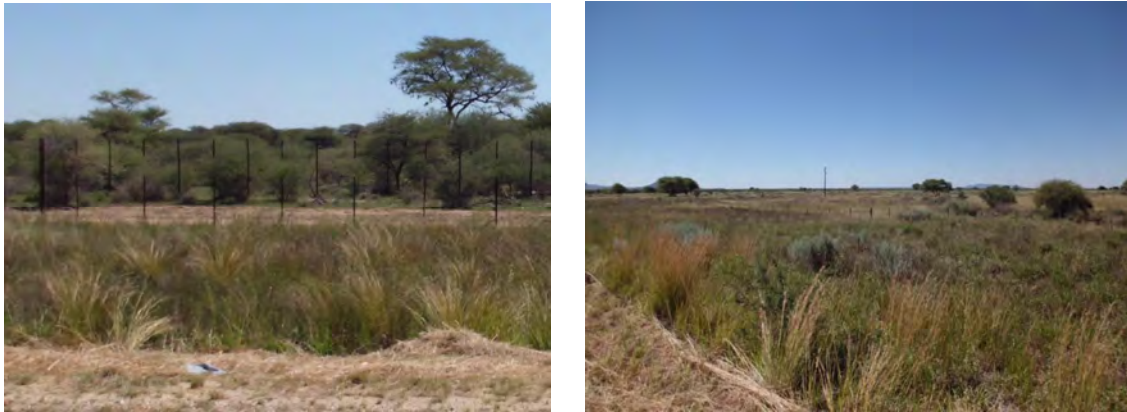


Fig. 4.7: Namibian rangeland with and without bush encroachment

Otherwise, bush encroachment/bush harvesting could offer a long term economical and ecological use as a resource for different application options. Currently, several companies are using the invader bush already for industrial applications, producing bush-briquettes or bush-chips as biomass based fuel products. Other companies are using the invader bush directly as fuel substitute for conventional fuels like coal in existing combustion systems. One example is the use of invader bush in the cement industry by the company Schwenk Cement. Therefore invader bush seems to be a promising and convenient raw material for energy production by direct combustion, pyrolysis or gasification. Figure 4.3 gives an examination of the current utilization of invader bush.

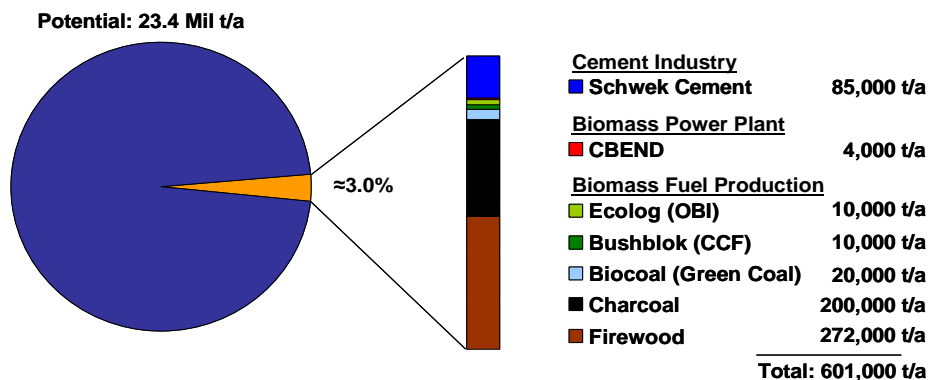


Fig. 4.8: Examination of the current utilization of invader bush

It can be seen that there are already biomass based applications in Namibia, but mainly limited to small production of biomass based fuels for the use in Namibian households like bush-briquettes, charcoal or lumpy firewood. The existing applications of Namibian biomass amount to a total of about 600,000 t/a. This means only 3 % of the possible annual use potential of Namibian biomass. The biomass use potential of approximately 23.4 million t/a results from an estimated rangeland of 26 million hectares with an average bush density of approximately 10 t/ha, whereas 50 % of the biomass can be harvested every ten years (data obtained from [7]).

Approximately 60,000 tons per year of charcoal (base year 2008) was produced on the basis of invader bush [3], [9]. This means a biomass raw material demand of approximately 180,000 – 220,000 t/a because of the material loss during the charcoal production process. The production capacity of the two Namibian bushblok/ecolog producers CCF and OBI is approximately 10,000 t/a for each production plant [20], [29]. The torrefied biomass production of Greencoal close to Omaruru is in the range of 10,000 t/a with an estimated raw material demand of 20,000 – 25,000 t/a due to the material loss of the torrefaction process. Beyond these biomass treatments there is also a pilot plant of the company CBEND, which is currently in operation and uses invader bush by gasification with subsequent combustion and power generation. The power output of this power plant is 0.25 MW with an estimated raw biomass demand of approximately 3,000 – 4,000 t/a [2]. The biomass demand of the cement factory Ohorongo of the German company Schwenk Cement is approximately 80,000 – 85,000 t/a [25]. It aims to generate 75 % of its energy requirement from local biomass resources of neighboring farmers. The rest of 25 % is realized with fossil coal. Besides the mentioned applications for the industrial use of invader bush there is an additional biomass demand in form of firewood for urban households. Regarding to lumpy firewood a biomass demand of approximately 272,000 t/a can be assumed, based on estimated average biomass demand of approximately 1.7 tons per year and household and approximately 160,000 households in total [4].

Concerning the tremendous amount of land covered with invader bush and the resulting amount of sustainable biomass, the current purposes using this resource do not affect the actually available capacities for other applications and therefore do not limit the availability of invader bush biomass [3].

Conclusion:

Namibia has vast amounts of biomass resources that can be used economically for different applications. Although there are already a number of biomass based applica-

tions realized, the national biomass resource is big enough for the implementation of further “biomass to energy projects” for industrial and power generation applications. As the invader bush constitutes an economic setback for farmers by decreasing the carrying capacity of farmland the latter should be interested in long term supply contracts thus ensuring security of supply.

Sustainable utilization provided, biomass derived from invader bush has the potential to play a central future role in the Namibian economy. Invader bush could be the basis for various biomass fuels incl. chips, briquettes, pellets and bio-coal. Biomass fuels could become a relevant energy source, e.g. in decentralized biomass power plants serving as base load power plants. The utilization of own fuel resources would also allow to minimize the utilization of fossil coal or heavy fuel oil and thus the dependency on fuel imports. Biomass based fuels also provide for additional export potential to countries that will be facing a supply-demand gap in the near future. Despite such export opportunities, the utilization of Namibian biomass for own power generation purposes should be of priority.

5 Basic Investigations for an Energy Concept Development

5.1 Harvesting Options

The results of the analysis of the current power supply and biomass situation in Namibia show a big potential for the use of biomass to generate energy. Biomass is available in vast amounts and can be used for different applications. Otherwise, Namibia's power market has to face great challenges in future. In order to get independence on electricity imports new power generation capacities have to be created in Namibia. In this context biomass has the potential to play an important role in the future energy supply of Namibia as well as in the export of products. In the following chapters basics are worked out for the subsequent energy concept development on the basis of Namibian biomass.

5.1 Harvesting Options

Efficient harvesting and collecting of invader bush are very important aspects to develop economic applications for invader bush utilization. Generally, different harvesting methods are thinkable and can be differentiated by the degree of mechanization. Figure 5.1 shows different harvesting options, which are already used in Namibia.



Fig. 5.9: Harvesting options of invader bush

The easiest way to harvest invader bush is using a manual method. It can be done with the aid of felling axes, chainsaws and brush cutters. The investment costs are very low and a highly selective harvesting of the invader bush with a low environmental impact is possible. Otherwise, the manual harvesting needs a very high personal input and the resulting productivity per person is small. Furthermore, the invader bush as a dominant species of the dry savannah is equipped with a lot of thorns. That makes the manual invader bush harvesting complicated. A further difficulty will probably be that the farmers might be reluctant to accept a large number of workers harvesting on their farms. So the manual harvesting is a harvesting method, which is especially suitable for small-scale bush felling, but not for large scale bush harvesting.

One mechanical harvesting approach is the harvesting with the aid of skid-steer loaders. The skid-steer loader is equipped with a rotary saw located at the front end of the vehicle. The mobility of the skid-steer loader is high and several bushes can be cut and compiled consecutively before making a bundle at the side of a harvesting road [19]. A selectivity regarding the harvested bushes is possible. Before chipping the compiled bushes are dried by air for a few days, so that the moisture content is reduced to values of approximately 8 - 10 %. The feeding of the chipper, which is connected to a truck for the chipped bushes, can be done manually or mechanically, whereas a mechanical feeding is preferred. Disadvantage of this approach is that the skid-steer loader needs many maneuvers resulting in more soil disturbance and densification. Soil disturbance improves the distribution of seeds from invader bush.

The harvesting with excavator is another harvesting approach. The excavator with a feller buncher attachment is able to grab, hold, cut and compile several bushes subsequently before making a bundle at the side of a harvesting road. Similar to the approach with skid-steer loader the compiled bushes are dried by air before chipping. The feeding of the chipper can be done again manually or mechanically. With the aid of the jib-arm the excavator is able to work in approximately 20 m harvesting roads at any time, so that less soil disturbance is caused in comparison to wheel operated machines. The excavator can drive forwards and backwards. Simultaneously a high selectivity regarding to the harvested bushes is possible.

A fourth harvesting approach is the harvesting with the vehicle type "Kangaroo" of the company AHWI Pinoth. This harvesting method is specially designed to cut and shred/chip the bushes in one action, because the vehicle is equipped with an additional chipper and collection bin with hopper for the chipped biomass. After filling the collection bin the content is transferred to a truck, whereas the emptying takes place by a tipping process of the collection bin. Subsequently, an additional air drying takes place

at special open-air storage fields. Advantage of this harvesting approach is the time-saving combination of harvesting and chipping. But this harvesting method is not able to work selectively and the attrition is comparatively high. Furthermore, the soil disturbance and densification is high.

Table 5.1 shows an evaluation of the different harvesting options in due consideration of different evaluation criteria, which are relevant for the right choice.

Tab. 5.3: Evaluation of the different harvesting options

	High Selectivity	High Productivity	High Mobility	Suitable For Large-Scale Harvesting	Harvesting-Chipping-Collecting-Combination	Low Investment Costs	Low Operation Costs (including Maintenance)	Low Personal Input	Low Environmental Impact (Soil Densification)
manual harvesting	+	-	+	-	-	+	+	-	+
mechanical harvesting with skid-steer loader	0	+	+	+	-	0	0	+	-
mechanical harvesting with excavator	+	+	+	+	-	0	0	+	+
mechanical harvesting with vehicle type "kangaroo"	-	+	-	+	+	-	-	+	-

Conclusion:

There are different harvesting methods applied in Namibia with each method having its advantages and disadvantages. Regarding the annual harvesting capacity every mechanical harvesting option is designed for approximately 10,000 tons per year and vehicle (according to user information). Hence, other evaluation parameters are decisive for the right choice of harvesting method. On the basis of the evaluation presented in table 5.1 it seems that the mechanical harvesting method with excavator has some advantages over alternative options. But the differences are not significant. Hence, every mechanical harvesting option is suitable for large-scale harvesting. Manual harvesting, however, seems to be suitable primarily for small-scale harvesting or complementary to mechanical harvesting.

5.2 Biomass based Products, Production Technologies and Marketing Opportunities

The distinction of different biomass based products and their production technologies is an important aspect for the energy concept development, because the resulting properties of the different biomass based products are decisive for the subsequent application and marketing opportunities. For the utilization of biomass from invader bush different techniques are available for converting the biomass in a suitable product concerning further applications with the targets to reduce storage, transport and handling costs on the one side and to improve the desired material properties like combustion behavior or calorific value on the other side. Possible biomass based products could be mainly differentiated between chips, briquettes/logs, pellets and bio-coal (torrefied biomass). The strongly varying characteristics of these products are making them appropriate for different applications. Hence, it is important to find the right biomass based product for the right application, whereas the application and marketing opportunities are focused on the region Namibia/South Africa and Europe.

5.2.1 Biomass Chips

Biomass chips are a medium-sized solid material with a typical particle size distribution of 0 -100 mm, whereas the main particle size is mostly in the range of 30 - 60 mm (figure 5.2).



Fig. 5.10: Biomass chips

They are made by coarse grinding (cutting or chipping) of the raw biomass. The aim of grinding is a higher bulk density compared to untreated biomass, so that more biomass can be transported using the same transport volume. The bulk density of biomass chips is usually in the range of 150 - 250 kg/m³. The production of biomass chips requires the lowest appliance expenditure (investment costs) of all regarded biomass based products. Figure 5.3 shows a simplified process flow sheet for the production of biomass chips.

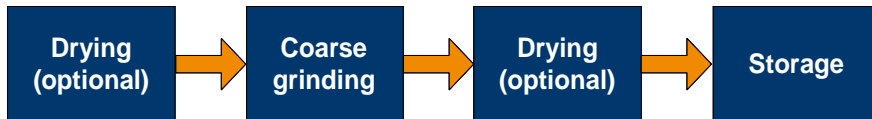


Fig. 5.11: Process flow sheet for the production of biomass chips

The shown process flow sheet contains an optional air drying step. The drying step leads to a lower moisture content and thus to lower transport costs due to lower weight of dried biomass. The optional drying step after harvesting of the biomass can be done before or after the grinding process. The necessity of a drying step depends on the further processing. Concerning the coarse grinding step cutters or chippers are normally used. Chippers are machines used for reducing biomass to smaller pieces (figure 5.4). They are often portable, being mounted on wheels on frames suitable for towing behind a truck or van. But there are also large, stationary installations, especially for industrial use.



Fig. 5.12: Chipper for the production of biomass chips

Chippers are typically equipped with a hopper, the chipper mechanism itself and a collection bin for the chips. The biomass is inserted into the hopper and started into the chipping mechanism. The chips exit through a chute and can be directed into a truck-mounted container or onto the ground. The chipper technology can be differentiated in disc chippers and drum chippers (figure 5.5). Disc chippers are normally used for round wood, while drum chippers are primarily used for woody residuals from saw mills and other (wood) industry. The resulting biomass chips are more uniform by disc chippers than by drum chippers. During the overall process there is no mass loss with the exception of the water content during the optional drying step.

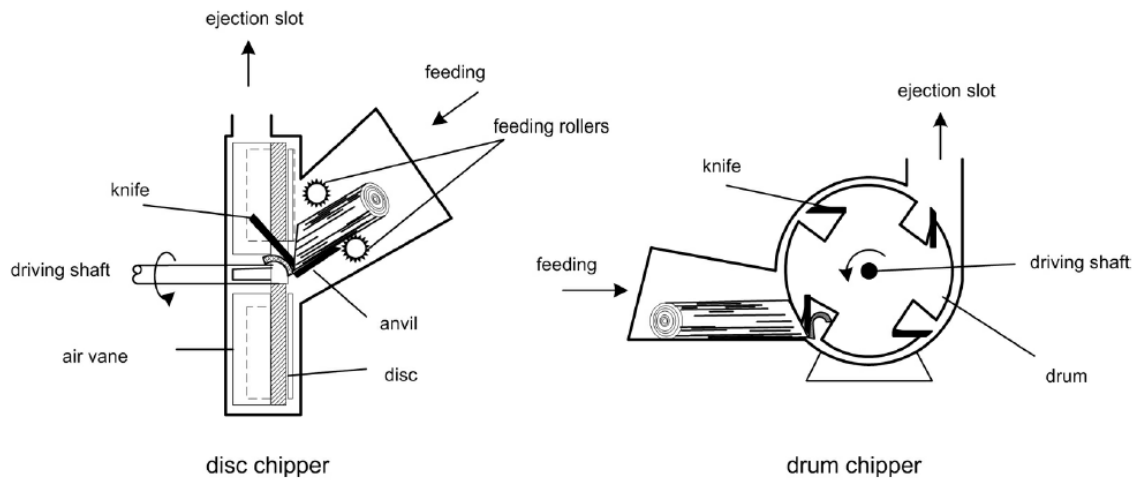


Fig. 5.13: Schematic illustration of disc and drum chippers [5]

The production of biomass chips is mostly used as pre-treatment step for further processing like the production of briquettes, pellets or bio-coal. But it can also represent the sole biomass treatment. For the combustion of biomass in biomass power plants for example, no further pre-treatments are technically necessary. Biomass power plants are usually able to combust biomass in form of dried or undried chips. Hence, biomass chips, especially wood chips, are a typical fuel for biomass power plants. Most of the European biomass power plants are based on biomass chips (wood chips), whereas undried chips are usually used. Further treatment steps are only then necessary, when long transport distances are given due to reduction of transport costs by increasing the bulk density and/or the energy density.

In Europe the marketing opportunities for biomass chips are generally high, because biomass chips are widely used fuels. The prices for wood chips are in the range of 30 - 50 €/t (400 - 650 N\$/t) depending on the chip quality. But nevertheless an export of invader bush from Namibia to Europe or South Africa will not be suitable due to high transportation costs. The energy density (approximately 2 - 3 GJ/m³) as well as the bulk density (approximately 150 - 250 kg/m³) of biomass chips is too small. Thus, the transportation costs for invader bush from Namibia to Europe would probably be higher than the sales prices in Europe. An economical marketing and competitive ability of Namibian invader bush chips in Europe or South Africa are not possible.

But biomass chips could have a great potential as biomass based fuel for the domestic sector in Namibia, especially when the utilization site of biomass chips is near to the bush growing area and production site. The specific production costs of biomass chips are low and the transportation costs are acceptable as long as the transportation distance can be kept short. So decentralized biomass combustion plants are a good ap-

plication for biomass chips, because biomass combustion plants (e.g. grate furnaces) are usually able to combust biomass chips. No further biomass treatments are technically necessary.

Conclusion:

Biomass chips are a fuel with great potential for a future biomass energy concept in Namibia. Biomass chips have low production costs and a wide field of applications. The application, however, is restricted to Namibia and excludes export. Low bulk and energy densities of biomass chips translate in high logistics costs that are prohibitive for long distance transport operations to South Africa and/or Europe.

5.2.2 Biomass Briquettes/Logs

Biomass briquettes/logs are made by fine grinding and subsequent compacting of dry, untreated biomass chips. Typical briquette/log dimensions are 20x6x6 cm with a weight of 0.8 -1.0 kg per briquette/log (figure 5.6).



Fig. 5.14: Biomass briquettes/logs

The aim of briquetting is a higher bulk and energy density compared to biomass chips, so that transport costs can be reduced and the combustion behavior can be improved (long intense burning). The bulk density of biomass briquettes/logs is usually in the range of 350 - 500 kg/m³ and the energy density in the range of 5.2 - 7.4 GJ/m³ [11]. Figure 5.7 shows a simplified process flow sheet for the production of biomass briquettes/logs.

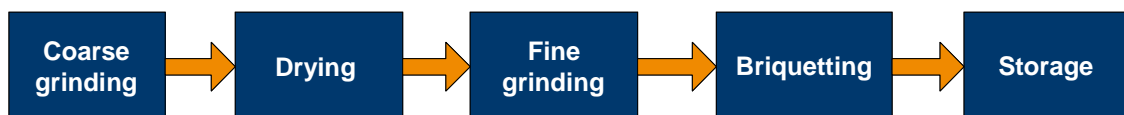


Fig. 5.15: Process flow sheet for the production of biomass briquettes/logs

The overall production process of biomass briquettes/logs contains several treatment steps, whereas the production of biomass chips (as described before) is part of the overall process. After coarse grinding (chipping) and drying an additional fine grinding takes place in a stationary grinding installation. The fine grinding, mostly done by a

hammer mill, is necessary for further particle size reduction and a homogenous particle size distribution. This leads to a better subsequent compacting, so that briquettes/logs with high energy density can be pressed. After passing a sieve (for a high quality guarantee) the biomass dust is fed into a silo for storing and further processing. The silo is normally equipped with a dosing screw that regulates the in-feed of the dust into the subsequent briquette/log press. The briquette/log press is usually an extruder press working with high pressure to force the material through a die which then forms the briquettes/logs (figure 5.8).

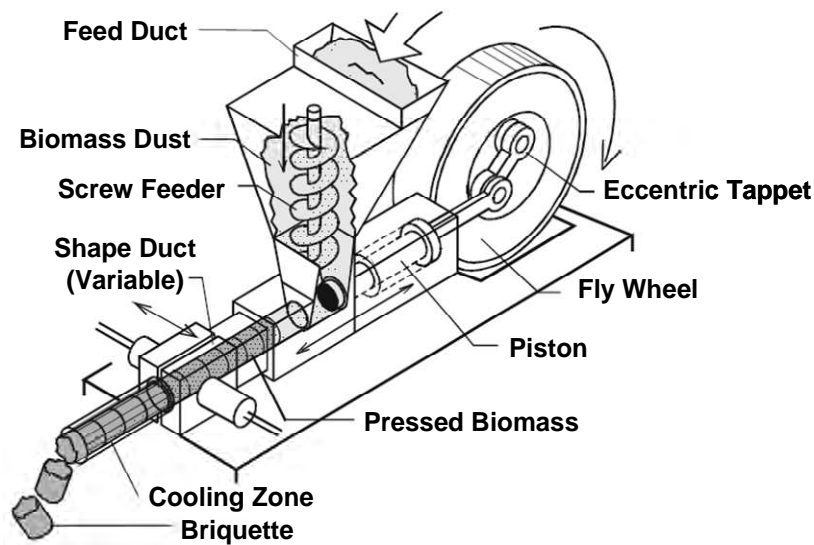


Fig. 5.16: Schematic illustration of an extruder press [16]

After leaving the briquette/log press the briquettes/logs pass a cooling line, because heat results from the press process due to the high pressure. For the press process no additional binder is necessary, because the cellulose fibres of woody biomass bind together. At the end of the overall process there is a saw that cuts the briquettes into the typical particle size. With the exception of the water content in the drying step there is no mass loss during the overall process.

The marketing opportunities for biomass briquettes/logs from Namibian invader bushes are available in Namibia/South Africa as well as in Europe. Supply and demand concerning biomass briquettes/logs is already existent. But the marketing amount seems to be limited in each region due to the limited applications. Briquettes/logs are a biomass based fuel which is primarily used in households (primarily for heating but also for barbecue) or in small-scale industrial applications. Hence, the demand for briquettes/logs as biomass based fuel is admittedly given but quantitatively limited. Only the production of relatively small quantities of biomass briquettes/logs (e.g. < 50,000 t/a) seems to be realizable with the focus on the domestic use. Typical market prices

for briquettes/logs are shown in table 5.2, whereas typical pallet prices (960 kg per pallet) as well as typical bag prices (10 kg per bag) of merchants and super markets are listed.

Tab. 5.4: Typical price ranges for biomass briquettes/logs in Namibia, South Africa and Europe

	Price per pallet (960 kg) in N\$	Price per bag (10 kg) in N\$
Namibia	1,000 - 1,500	20.00 - 30.00
South Africa	1,500 - 2,600	30.00 - 50.00
Germany	2,000 - 3,000	35.00 - 60.00

Besides several European countries have national standards, quality certificates for briquettes/logs, e.g. Germany. As an example, the chemical and physical properties of briquettes in accordance with the German standard "DINplus" and the European standard "ENplus" are shown in table 5.3. Additionally the chemical and physical properties of the Namibian invader bush are listed for comparison.

Tab. 5.5: Chemical and physical properties of Namibian invader bush in comparison to German and European standards of biomass briquettes/logs

Parameter	Unit	DIN EN 14961-3		Invader Bush	
		"DINplus" Briquetts	"ENplus" Briquetts		
Physical Parameter	Diameter	mm	variable	variable	n.a.
	Length	mm	variable	variable	n.a.
	Moisture Content	%	≤ 12	≤ 15	4.3 - 10.2
	Ash Content	%	≤ 0.7	≤ 1.5	1.7 - 6.6
	Net Calorific Value	MJ/kg	≥15.5	≥15.3	15.9 - 18.2
	Particle Density	g/cm ³	≥1.0	≥1.0	n.a.
Additives	wt%	< 2 % Biomass Only		n.a.	
Elementary Composition	S	%	≤ 0.03	≤ 0.03	0.05 - 0.07
	N	%	≤ 0.3	≤ 0.5	0.51 - 0.65
	Cl	%	≤ 0.02	≤ 0.02	0.04 - 0.11
Trace elements	As	mg/kg	≤ 1.0	≤ 1.0	< 2.13
	Cd	mg/kg	≤ 0.5	≤ 0.5	< 0.43
	Cr	mg/kg	≤ 10.0	≤ 10.0	< 1.81
	Cu	mg/kg	≤ 10.0	≤ 10.0	< 3.73
	Pb	mg/kg	≤ 10.0	≤ 10.0	< 5.33
	Hg	mg/kg	≤ 0.1	≤ 0.1	< 0.27
	Zn	mg/kg	≤ 100	≤ 100	< 10.7

It can be seen that the Namibian invader bush cannot observe each parameter in accordance with the standards "DINplus" and "ENplus". A few parameters (red marked) of Namibian invader bush (e.g. ash content, chlorine, sulfur) are higher than the limiting

values of both certificates. Concerning the trace elements only the boundaries of the used analysis method are listed. Hence, the real arsenic (As) and mercury (Hg) content should be lower than the values (orange marked) listed in table 5.3. But the shown noncompliance to the “DINplus” and “ENplus” certificates should not be a problem for the marketing opportunities of biomass briquettes in Europe, because such a certificate is admittedly helpful but not absolutely required for the marketing of biomass briquettes/logs in Europe. The standards act as solid quality proofs for the end-users so that the end-user can be sure that the biomass briquettes/logs contain no pollutants which could possibly endanger the oven (e.g. corrosion, slagging) and/or the human health. Furthermore, it is possible that a certification with “DINplus” and/or “ENplus” can improve the marketable amount and the selling price for the biomass briquettes/logs. But this impact does not seem to be of great relevance.

Conclusion:

Biomass briquettes/logs can also play a role in an energy concept for the utilization of Namibian invader bush. However, due to limited application options in small-scale private households only, the overall production potential is limited. Market opportunities exist in Namibia, in South Africa and other neighboring SADC countries as well as in overseas.

5.2.3 Biomass Pellets

Similar to biomass briquettes/logs biomass pellets are also made by fine grinding and subsequent compacting of dry, untreated biomass chips. But the particle sizes of pellets are much lower and the bulk density is normally much higher than of briquettes/logs. Typical sizes of biomass pellets are small cylinders with an average diameter of approximately 6 to 10 mm (figure 5.9). The bulk density is usually in the range of 550 - 750 kg/m³ and the energy density in the range of 7.5 - 11 GJ/m³.



Fig. 5.17: Biomass pellets

The aim of the pelletization process is the production of a homogenous product with higher energy and bulk density compared to the raw material, chips or briquettes/logs.

In comparison with biomass chips or biomass briquettes/logs biomass pellets have a better flow ability, so that the handling is much easier. Furthermore, the uniform characteristics make them suitable for large-scale combustion plants like coal-fired power plants and industrial furnaces. Figure 5.10 shows a simplified process flow sheet for the production of biomass pellets.

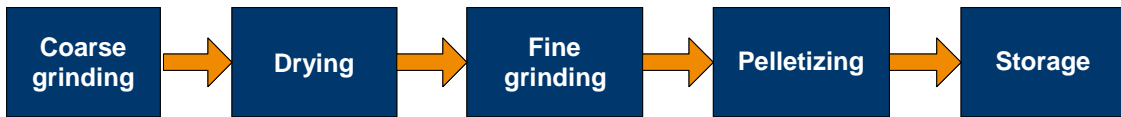


Fig. 5.18: Process flow sheet for the production of biomass pellets

The shown process flow sheet is very similar to the process flow sheet for the production of biomass briquettes/logs. The only difference between these both overall processes is the press process. As pellet press a flat die (shown in figure 5.11) or ring die press are normally used working with high pressure to force the material through the dies which then form the pellets. By the optional addition of steam, the particles are covered with a thin liquid layer in order to improve the adhesion.



Fig. 5.19: Biomass pelletizing system [24]

But before entering the pellet press the moisture content of the biomass should not be higher than approximately 12 %. The optimal moisture content for press process is between 8 and 12 %. If the material is too wet, the moisture contained in the pressings cannot be escape and enlarges the product volume, making it mechanically weak. The productivity of pellet presses ranges between some 100 kg to about 10 tons per hour. During the densification process the temperature of the pellets increases. Therefore, careful cooling of the pellets leaving the press is necessary to guarantee high durabil-

ity. With the exception of the water content in the drying step there is no mass loss during the overall process.

Biomass pellets are currently the most important and most used biomass based fuel worldwide. Table 5.4 gives an overview of the worldwide installed production capacities for biomass pellets differentiated to continent and countries.

Tab. 5.6: Overview of the installed biomass pellet production capacities worldwide (data based on [6] and 2011)

Europe			Spain	25 plants	651,600 [t/a]
Austria	26 plants	1,187,000 [t/a]	Sweden	34 plants	2,355,000 [t/a]
Belarus	4 plants	71,400 [t/a]	Switzerland	10 plants	260,000 [t/a]
Belgium	9 plants	532,000 [t/a]	Ukraine	13 plants	430,400 [t/a]
Bosnia-Herzegovina	6 plants	164,000 [t/a]	United Kingdom	11 plants	610,000 [t/a]
Bulgaria	6 plants	119,350 [t/a]	Total	435 plants	20,235,750 [t/a]
Croatia	6 plants	166,000 [t/a]	Africa		
Czech Republic	8 plants	184,000 [t/a]	South Africa	4 plants	240,000 [t/a]
Denmark	8 plants	492,500 [t/a]	Total	2 plants	240,000 [t/a]
Estonia	6 plants	417,000 [t/a]	Asia		
Finland	15 plants	645,000 [t/a]	China	16 plants	752,000 [t/a]
France	27 plants	1,049,000 [t/a]	India	3 plants	200,000 [t/a]
Germany	41 plants	2,825,000 [t/a]	Indonesia	1 plant	100,000 [t/a]
Greece	2 plants	30,000 [t/a]	Japan	4 plants	95,000 [t/a]
Hungary	4 plants	87,000 [t/a]	South Korea	8 plants	108,200 [t/a]
Ireland	2 plants	72,500 [t/a]	Total	32 plants	1,255,200 [t/a]
Italy	19 plants	725,000 [t/a]	Australia and Oceania		
Latvia	13 plants	757,000 [t/a]	Australia	2 plants	256,000 [t/a]
Lithuania	4 plants	115,000 [t/a]	New Zealand	3 plants	110,000 [t/a]
Netherlands	3 plants	195,000 [t/a]	Total	5 plants	366,000 [t/a]
Norway	7 plants	592,000 [t/a]	North America		
Poland	19 plants	971,000 [t/a]	Canada	34 plants	2,958,000 [t/a]
Portugal	14 plants	875,000 [t/a]	USA	84 plants	5,481,000 [t/a]
Romania	3 plants	200,000 [t/a]	Total	118 plants	8,439,000 [t/a]
Russia	68 plants	3,093,000 [t/a]	South America		
Serbia	4 plants	112,000 [t/a]	Brazil	1 plant	40,000 [t/a]
Slovakia	14 plants	153,000 [t/a]	Chile	3 plants	100,000 [t/a]
Slovenia	4 plants	99,000 [t/a]	Total	4 plants	140,000 [t/a]
			Total Worldwide	596 plants	30,675,950 [t/a]

The total worldwide production capacity of biomass pellets (mostly based on wood) is assumed at approximately 30.6 million tons per year. Especially in Europe and North America there are already great existing production capacities, whereas the share of Europe with approximately 20.2 million tons per year is approximately 65 % of the production capacity worldwide. The real production amount of pellets in Europe is valued at about 10 million tons per year and counting.

In table 5.5 an overview of the biggest worldwide installed biomass pellet production plants is shown. Additionally, the biggest installed biomass pellet production plants of Germany and South Africa are shown. Currently in South Africa there are only four biomass pellet production plants installed.

Tab. 5.7: Major biomass pellet production plants in the world, in Germany and in South Africa (data based on [6] and 2011)**Worldwide**

Capacity	Company	Location	Country
900,000	OJSC Vyborgskaya Cellulose	Leningrad Region	Russia
750,000	Georgia Biomass LLC (RWE)	Waycross/GA	USA
500,000	Green Circle Bio Energy Inc. (JCE Group AB)	Cottondale/FL	USA
450,000	Biowood Norway AS	Averøy	Norway
400,000	Pinnacle Pellet Inc.	Burns Lake/BC	Canada
250,000	Plantation Energy Australia Pty Ltd / GF Energy	Albany	Australia
220,000	Pinnacle Pellet Inc.	Strathnaver/BC	Canada
210,000	Pacific BioEnergy Corp (PBEC)	Prince George/BC	Canada
...

Germany

Capacity	Company	Location	Country
256,000	German Pellets GmbH	Herbrechtingen/BW	Germany
256,000	German Pellets GmbH	Wismar/MV	Germany
180,000	German Pellets GmbH	Leipzig-Wiederitzsch/SN	Germany
150,000	German Pellets GmbH	Torgau/SN	Germany
150,000	Heggenstaller Vertriebs GmbH	Unterbernbach/BY	Germany
140,000	Binderholz Deutschland GmbH	Kösching/BY	Germany
128,000	German Pellets GmbH	Ettenheim/BW	Germany
...

South Africa

Capacity	Company	Location	Country
100,000	EC Biomass	Coega, Port Elizabeth	South Africa
80,000	GF Energy (Zebra Pellets)	Sabie	South Africa
60,000	GF Energy (Biotech Fuels)	Howick	South Africa
n.a.	n.a.	Richards Bay	South Africa

As for biomass briquettes/logs national standards and quality certificates are applicable to biomass pellets in Europe. The chemical and physical properties for biomass pellets in accordance with the different German and European standards are shown in table 5.6. Additionally the chemical and physical properties of the Namibian invader bush are listed for comparison.

As for biomass briquettes/logs, the biomass pellets do not meet all parameters. A few parameters (red marked) of Namibian invader bush (e.g. ash content, chlorine, sulfur) are once more higher than the allowed values of the different certificates. However, as the quality certificates are optional, any non-compliance is no “killing factor” for the marketing in Europe. Different from the certification of biomass briquettes/logs the certification of biomass pellets impact on the marketing opportunities. Typical market prices for biomass pellets in accordance with German and/or European standards (“DINplus” and “ENplus” certificates) are in the range of 230 - 250 €/t (3,000 - 3,250 N\$/t) and for non-certificated biomass pellets, the so called industrial pellets, in the range of 130 -140 €/t (1,650 – 1,850 N\$/t).

Tab. 5.8: Chemical and physical properties of Namibian invader bush in comparison to German and European standards of biomass pellets

Parameter	Unit	DIN EN 14961-2				Invader Bush
		"DINplus" Pellets	"ENplus A1" Pellets	"ENplus A2" Pellets	Class B Pellets	
Diameter	mm	6 - 8	6 - 8	6 - 8	6 - 8	n.a.
Length	mm	3.15 - 40	3.15 - 40	3.15 - 40	3.15 - 40	n.a.
Moisture Content	%	≤ 10	≤ 10	≤ 10	≤ 10	4.3 - 10.2
Ash Content	%	≤ 0.7	≤ 0.7	≤ 1.5	≤ 3.0	1,7 - 6,6
Bulk Density	kg/m ³	≥ 600	≥ 600	≥ 600	≥ 600	n.a.
Net Calorific Value	MJ/kg	16.5 - 19.0	16.5 - 19.0	16.3 - 19.0	16.0 - 19.0	15.9 - 18.2
Ash Melting Behavior	°C	1,200	1,200	1,100	n.a.	n.a.
Fines < 3,15mm		≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	n.a.
Additives	wt%	< 2 % Biomass Only				n.a.
Elementary Composition	S	≤ 0.3	≤ 0.3	≤ 0.5	≤ 1.0	0.05 - 0.07
	N	≤ 0.03	≤ 0.03	≤ 0.03	≤ 0.04	0.51 - 0.65
	Cl	≤ 0.02	≤ 0.02	≤ 0.02	≤ 0.03	0.04 - 0.11
Trace Elements	As	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	< 2.13
	Cd	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.5	< 0.43
	Cr	≤ 10.0	≤ 10.0	≤ 10.0	≤ 10.0	< 1.81
	Cu	≤ 10.0	≤ 10.0	≤ 10.0	≤ 10.0	< 3.73
	Pb	≤ 10.0	≤ 10.0	≤ 10.0	≤ 10.0	< 5.33
	Hg	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.1	< 0.27
	Zn	≤ 100	≤ 100	≤ 100	≤ 100	< 10.7

As shown in figure 5.12, both prices are relatively stable during the last years.

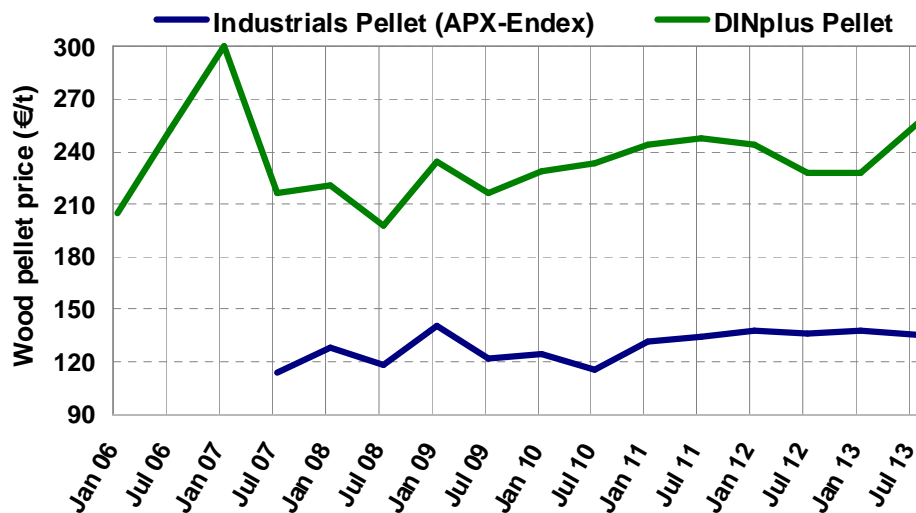


Fig. 5.20: Price development of certificated and non-certificated biomass pellets in Europe

The standards for biomass pellets are an important aspect for the possible application field. Most of the European pellet plants are plants with small capacities lower than 100,000 t/a. These pellet plants produce primarily biomass pellets with high quality standards, the so called "DINplus" or "ENplus" pellets for household or small scale ap-

plications like small furnaces. Supply and demand of high quality (certified) biomass pellets is currently fairly balanced with limited additional market scope. The quality noncompliance will effectively exclude a Namibian supplier from that high quality market segment.

The pellet plants with high production capacities higher than 100,000 t/a however produce primarily industrial pellets without certifications. The main consumers for the industrial pellets without certifications are coal-fired power plants and other big industrial furnaces. In opposite to the “DINplus” and “ENplus” pellets, the European market for industrial pellets is increasing annually. The reason for the high biomass pellet demand in Europe is the national promotion system for renewable energies in several European countries. In countries like the United Kingdom, Belgium, Denmark, Sweden or the Netherlands the co-firing of biomass in coal-fired power plants is promoted by the national law (e.g. feed-in tariff). In these countries the trend is towards the substitution of fossil coal by biomass pellets as much as possible so that the biomass pellet demand will increase continuously. The figure 5.13 illustrates the current and future biomass pellet demand in selected European countries.

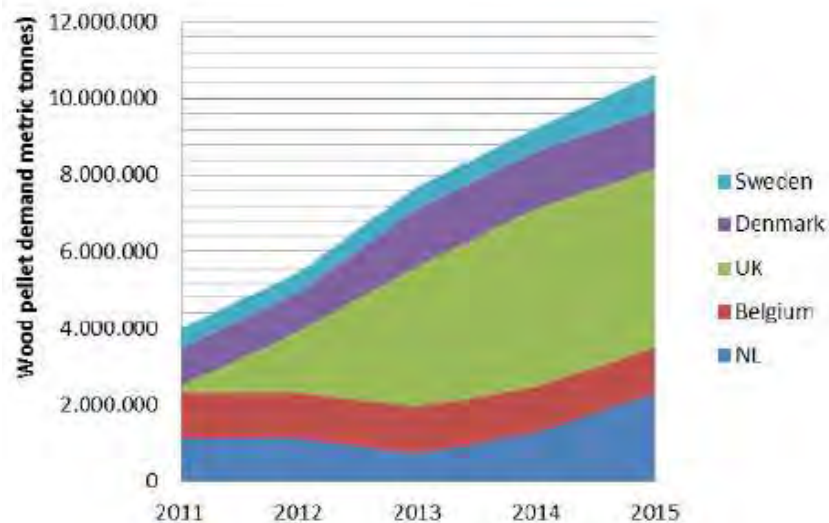


Fig. 5.21: Expected biomass pellet demand in Europe from 2011 to 2015 [26]

These impressive figures even exclude singular developments of a few power plant operators like Drax. The Drax Power Ltd., a British electrical power generation company, intends since a short time ago to convert two of its four 1,000 MW coal-fired power plants at Drax power station from fossil coal to biomass pellets (100 % substitution). Only this conversion means a future annual demand of more than 7 million tons of biomass pellets. This gap between European demand and European supply of biomass pellets must be closed by pellet imports.

In Namibia and South Africa there is currently no real biomass pellet market established. The local pellet plants in South Africa have even problems in the marketing of biomass pellets due to the missing pellet market within South Africa and the small production capacities and resulting high specific transportation costs for an export to Europe or other continents. A first pellet plant is already closed. Due to the exceedingly small demands for biomass pellets, the real market prices for biomass pellets are unspecified in South Africa, but probably in a range of approximately 2,000 - 2,500 N\$/t.

Eskom announced a large-scale biomass co-firing initiative with the aim to replace about 10 % of its yearly coal consumption which would translate in an absolute demand of > 20 million tons per year.

Conclusion:

Regarding an energy concept development on the basis of Namibian invader bush biomass pellets have great potential for export to Europe. The total demand will increase, particularly for coal-fired power plants in countries with established promotion system for the co-firing of biomass. A total supply - demand gap need to be closed by international imports. The requirements for competitiveness on the global market need to be explored by further in-depth research. Two factors are of critical importance being the material quality with regard to high ash content of local bush material, as well as the logistic costs due to the absence of any specialized infrastructure for big volume bulk biomass export operations both on rail and port side. In Namibia or South Africa, a biomass pellet market is not yet established. This however could change rapidly with biomass utilization in power plants and/or industrial furnaces. Due to high bulk and energy densities and low transportation costs biomass pellets have the future potential to supply industrial biomass markets in Namibia, South Africa and overseas.

5.2.4 Bio-coal Pellets/Torrefied Biomass Pellets

Bio-coal (torrefied biomass) is the product from the torrefaction, a thermo-chemical process. Torrefaction can be described as a mild form of pyrolysis in an oxygen free atmosphere with ambient pressure and typical temperatures between 250 and 320 °C. The residence time of the biomass ranges from 20 to 40 minutes and depends on the biomass and the particle size distribution. The aim of the torrefaction process (together with a subsequent pelletization) is an increase of the mass- and volume-weighted energy density so that transport costs can be significantly reduced. Simultaneously a product (torrefied biomass) with coal-like properties is formed, a so called bio-coal or green coal. Typical sizes of bio-coal pellets are small cylinders with an average diame-

ter of approximately 6 to 10 mm (figure 5.14), similar to usual biomass pellets. The bulk density is usually in the range of 750 - 850 kg/m³ and the energy density in the range of 15 - 20 GJ/m³.



Fig. 5.22: Bio-coal pellets (torrefied biomass pellets)

The overall process of torrefaction consists of several treatment stages such as coarse grinding and drying, which are also known from alternative production processes described before. Figure 5.15 shows a schematic process flow sheet of the overall torrefaction process, which can be operated continuously.

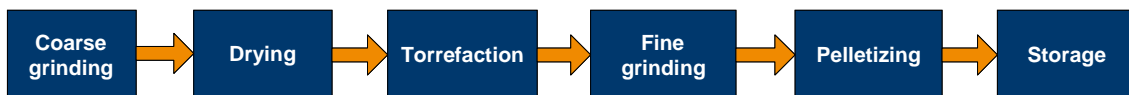


Fig. 5.23: Process flow sheet of the overall torrefaction process

The first steps are normally a coarse grinding to get a homogenous particle size distribution and a pre-drying to reduce the water content to lower than 10 %. A thermal pre-drying step is endothermic so that an external energy supply is necessary. This energy is usually the heat of hot gases from the combustion of volatile components of the biomass from the subsequent torrefaction step.

After the pre-drying the torrefaction, i.e. the pyrolytic decomposition of biomass, takes place in a special torrefaction reactor. Figure 5.16 shows a schematic overview of possible reactor types, which can be used for the torrefaction. During the torrefaction organic compounds of the biomass are thermally decomposed, whereas water and oxygenated compounds, mainly carbon monoxide (CO), carbon dioxide (CO₂) as well as organic acids, are extracted as volatiles from the biomass. The extracted volatiles, also known as torrefaction gases, are combusted in a special combustion chamber. The resulting heat is reused as energy source for the pre-drying and torrefaction step. Besides the extraction of volatiles the fibrous structure of the lignocellulosic biomass, especially from woody biomass, is destroyed. The detailed process conditions of the torrefaction regarding to temperature and residence time depends on the biomass. Both the temperature and residence time have to be chosen high enough for destroying the fibrous structure of the biomass. But the chosen temperature and residence time must

not to be too high due to the avoidance of unwanted mass and heat losses in form of additional volatiles. Typical process parameters for the torrefaction are temperatures of 250 - 300 °C, residence times of 20 - 40 minutes and almost atmospheric conditions. The remaining proportion of solids after torrefaction is known as bio-coal or greencoal. Similar to the pre-drying step the torrefaction step is also endothermic so that an external energy supply is necessary.

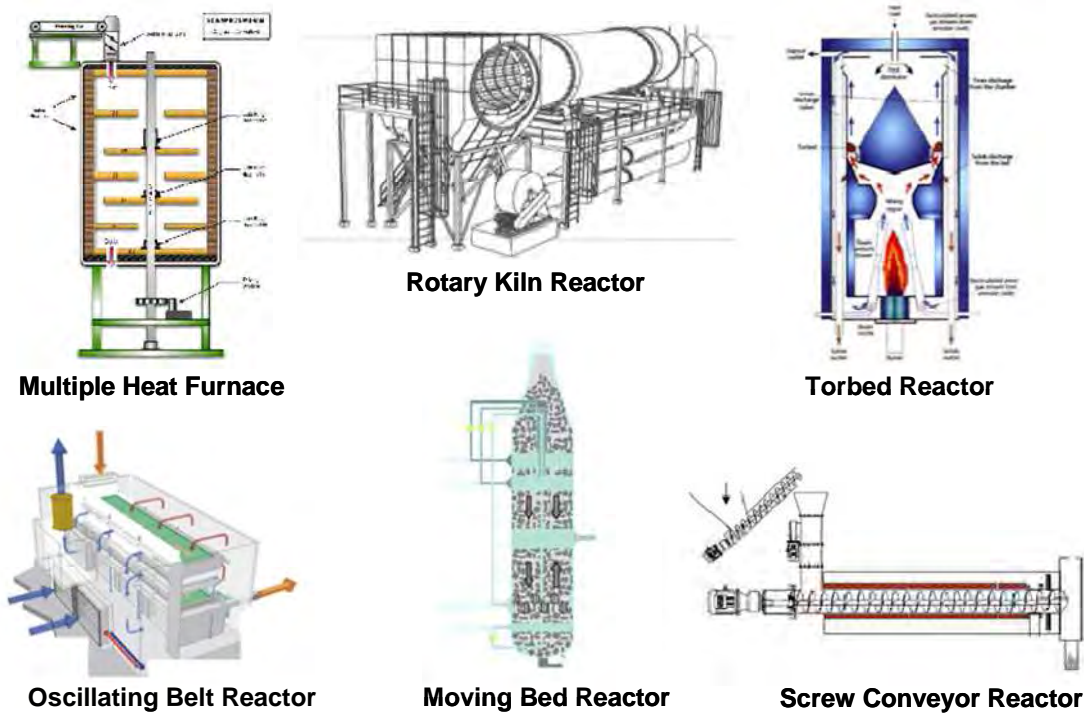


Fig. 5.24: Possible torrefaction reactor types

The process heat for the torrefaction and the previous drying can be provided through a direct or indirect heat supply. In the case of direct heat supply hot gases flow through the loose bulk of biomass and transfer heat by direct contact to the particles. Depending on the composition of the hot gases it can be additionally differentiated between the direct heat transfer by hot flue gases from the combustion of torrefaction gases in the combustion chamber and the direct heat transfer of hot torrefaction gases. To ensure a good and uniform through-flow through the reactor, the feed of the loose bulk of biomass is at the reactor head, whereas the torrefied biomass is discharged at the end of the reactor. In terms of the indirect heat supply the heat transfer takes place by the reactor wall. Figure 5.17 shows an overview of the various heat exchange concepts for the torrefaction process.

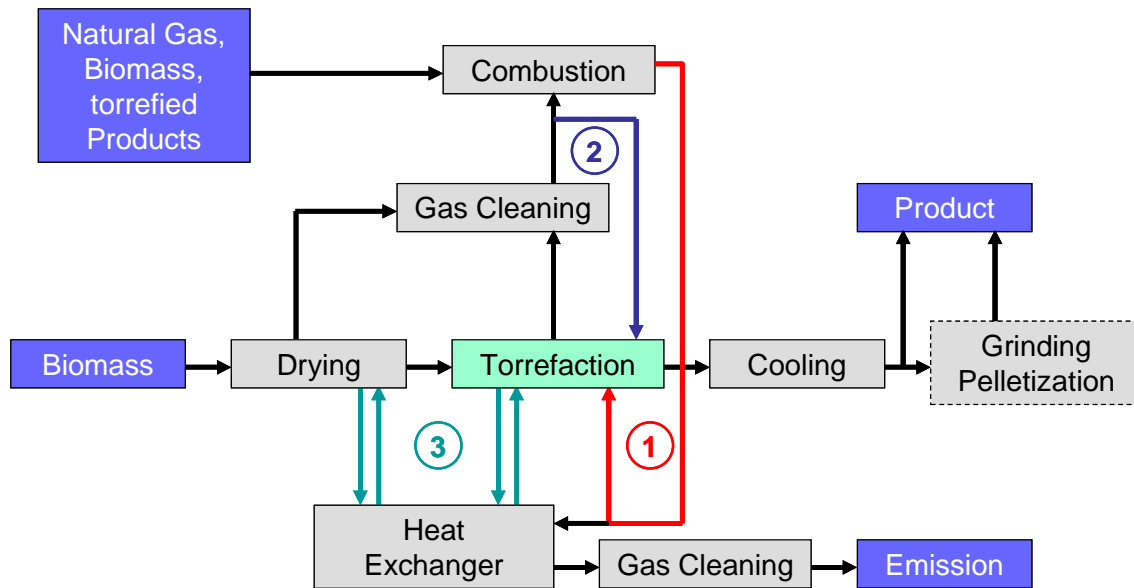


Fig. 5.25: Possible heat exchange concepts for the torrefaction process

Up to a water content of approximately 30 - 35 % in the raw biomass the overall process of all heat transfer concepts run self-sufficient, so that no external heat supply is required. The amount of heat resulting from the combustion of torrefaction gases is high enough to supply both steps, the thermal pre-drying step as well as the torrefaction step. Auxiliary fuel in form of natural gas or fuel oil is only needed for the start-up procedure. The mass loss of biomass is typically in the range of 30 - 50 % and the energy loss in the range of 10 - 20 %. But both values depend on the reaction conditions of the torrefaction step.

After the torrefaction step the torrefied biomass has to be cooled down quickly to temperatures of $< 70^{\circ}\text{C}$ in an inert atmosphere, in order to avoid possible reactions of hot torrefied biomass with oxygen. The cooling is usually indirectly with the aid of water. After the torrefaction and cooling step a fine grinding and pelletising or briquetting step take place in order to increase the bulk and energy density of the torrefied biomass/bio-coal. Due to the destruction of the fibrous biomass structure during the torrefaction step the technical and energy effort for the fine grinding of the total torrefaction process is much lower than the effort for the fine grinding of the total pelletization process (chapter 5.2.3). For fine grinding a pin mill can be used.

The torrefaction technology is a relatively new technology which is currently in the development phase. Only a few pilot plants are in operation till now. Figure 5.18 gives an overview of different torrefaction technology supplier in Europe differentiated to the reactor type and heat exchange concept.

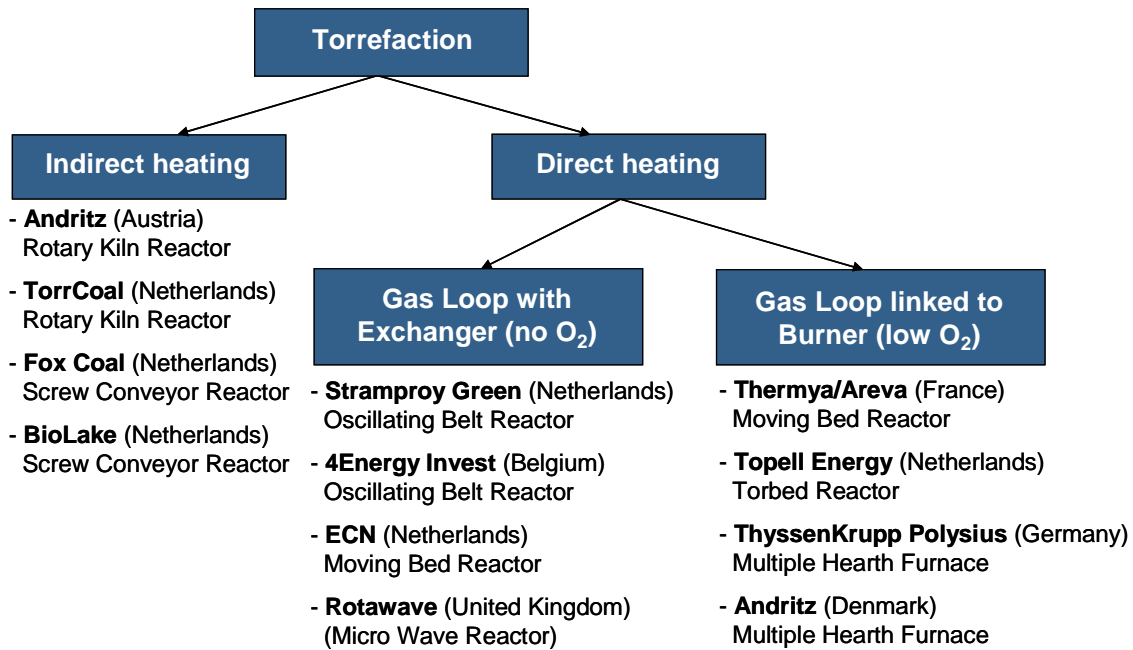


Fig. 5.26: Torrefaction technology supplier in Europe differentiated in reactor types and heat exchange concept

Bio-coal pellets can have a wide spectrum of applications. But at the moment there is no real bio-coal market established neither in Europe nor in South Africa or Namibia due to the missing amounts of available bio-coal pellets. Hence, the marketing opportunities for bio-coal pellets are currently not available, because the market is just developing. But the potential of bio-coal pellets should be very high, much higher than for biomass pellets, because the material properties of bio-coal pellets concerning bulk and energy density, grindability or storability are very close to fossil coal. Therefore, fossil coal can be better substituted by bio-coal than by usual biomass pellets. This applies especially for coal dust firing power plants, less for grate firing power plants. The expenditures concerning required retrofit measures at coal dust firing power plants, which are the most chosen power plant technology in Europe, are much lower for the use of bio-coal pellets than for the use of biomass pellets. This aspect makes the bio-coal so interesting, especially for Europe. Therefore, the bench market for bio-coal pellets in Europe should be the usual industrial pellets so that a possible market price could be in the range of 150 - 180 €/t (1,950 - 2,350 N\$/t) due to the higher heating value of bio-coal pellets compared to usual biomass pellets (energy equivalent conversion). European quality standards are currently not realized.

In South Africa, Eskom is planning to increase its biomass co-firing in coal based power plants to 10 %. Eskom is specifically interested in refined pellets, as the fuel is more coal-like in its characteristics when compared with untreated biomass. Eskom further sees the economic potential of the entire value chain supporting a future torrefaction

process. Interesting also that Eskom is explicitly sensitive on the potential impact on the long-term food-fuel dynamic in South Africa. The utility has started engaging with potential technology providers to settle on the most appropriate technology for South Africa's needs. The model proposed is that Eskom provides the security of demand needed for the creation of large-scale biomass production and processing to justify the logistics and materials handling investment that will be required. Besides South Africa's biomass potential will not suffice to meet the future demand for black pellets. This aspect opens opportunities for other countries which have sustainable torrefied biomass pellets supply. Given such resources, Namibia would find itself in a very competitive situation.

In Namibia, NamPower is planning to co-fire the rehabilitated van Eck power stations with biomass as from 2014/2015. NamPower is determined to utilize bio-coal due its material similarity to fossil coal and the high energy density. The total demand for one out of 4 units will be in the range of 220,000 - 260,000 tons of black pellets per year (depending on the annual operation hours). Also, smaller industrial boilers in the food or mining industry might be interested in black pellet combustion. Black pellets might be an alternative to other forms of biomass for locations being distant to the resource/supply area and requiring large distance transportation.

Currently, there are only two small-scale/pilot non-commercialized torrefaction plants in South Africa and one in Namibia (Greencoal). Their capacities are insignificant to satisfy or attract market for alternative energy or mitigation of carbon print. But a first indication for a possible market price for bio-coal should already be given. Current market prices of bio-coal in South Africa (and Namibia) can be estimated to be in the range of 150 - 180 €/t (1,950 - 2,300 N\$/t), comparable to European market prices.

Conclusion:

Regarding an energy concept development on the basis of Namibian invader bush, bio-coal pellets (torrefied biomass pellets) have great potential. However, there is no current bio-coal market yet established, neither in Namibia and South Africa nor in Europe. The chances are high, however, that such markets will develop in future. The market potential of bio-coal is high due to the coal-like material properties and the high demand for alternative biomass based fuels for big power generation plants like coal-fired power stations. As there is currently no major consumer for bio-coal on the market, a regular (white) pellet production plant should be established, and converted into a bio-coal plant (by retrofitting a torrefaction step into a usual pellet production process) as soon as a bio-coal market is established.

5.2.5 Comparison of different Biomass based Products

The different properties of the biomass products described above are summarized in the following table 5.7 to allow a comparison between the different biomass based products and fossil coal.

Tab. 5.9: Property comparison of different biomass based fuels with fossil coal

Characteristics	Units	Biomass Chips, undried	Biomass Briquettes/Logs	Biomass Pellets	Torrefied Biomass Pellets	Fossil Coal
Calorific Value	[MJ/kg]	9 – 13	16 – 18	16 – 18	20 – 25	24 – 29
Moisture	[wt.-%]	30 – 45	8 – 12	8 – 12	1 – 5	7 – 18
Volatile Matter	[wt.-%]	70 – 75	70 – 75	70 – 75	55 – 65	21 – 36.5
Ash	[wt.-%]	0 – 2	0 – 2	0 – 2	0 – 2	6 – 30
Bulk Density	[kg/m ³]	150 – 250	350 – 500	550 – 750	750 – 850	800 – 850
Energy Density	[GJ/m ³]	2 – 3	5.2 – 7.4	7.5 – 11	15 – 20	22 – 24
Hydrophobic (Interaction with Water)	[-]	Yes	Yes	Yes	No	No
Grindability in Standard Coal mill	[-]	No	No	No	Yes	Yes

These varying product properties lead to different priority depending primarily on combustion and logistics requirements. Bio-coal (torrefied biomass) is particularly suited for co-firing in coal-fired power stations due to its coal-like properties concerning calorific value, energy and bulk density, grindability and water resistance (hydrophobic property). Biomass pellets can be used as a fuel for co-firing systems too, but requiring additional installations in the supply chain and at plant site due to hydrophilic property and non-grindability in standard coal mills.

Furthermore, the energy and bulk density variations of the products impact on transportation costs. Hence, white pellets and specifically black pellets with their high bulk and energy densities qualify for long distances transportation between harvesting and plant site and further to the consumer/market. For the same reason, biomass chips are suitable for local consumption only.

Table 5.8 shows a price comparison of the different considered biomass products differentiated to the regions Namibia, South Africa and Europe. The table contains information in both N\$/t as well as in N\$/GJ. The indication in N\$/t allows a quick weight-related comparison with current market prices, the value in N\$/GJ an energy equivalent price comparison of the different biomass based fuels among each other due to different calorific values.

Tab. 5.10: Price comparison of different biomass based fuels differenced to the regions Namibia, South Africa and Europe

		Namibia	South Africa	Europa
Chips*	[N\$/t]	-	-	400 - 650
	[N\$/GJ]	-	-	31 - 50
Briquetts**	[N\$/t]	1,000 - 1,500	1,500 - 2,600	2,000 - 3,000
	[N\$/GJ]	56 - 83	83 - 144	111 - 167
White Pellets**	DinPlus [N\$/t]	-	-	3,000 - 3,250
	DinPlus [N\$/GJ]	-	-	167 - 181
	Industrial [N\$/t]	-	2,000 - 2,500	1,650 - 1,850
	Industrial [N\$/GJ]	-	111 - 139	89 - 103
Black Pellets***	[N\$/t]	-	-	1,950 - 2,350
	[N\$/GJ]	-	-	89 - 103

* calorific Value: 12 - 13 MJ/kg

** calorific value: 17 - 18 MJ/kg

*** calorific value: 22 - 25 MJ/kg

Conclusion:

Regarding an energy concept development on the basis of Namibian invader bush each considered biomass based fuel has advantages as well as disadvantages. The real potential depends on the technical application and resulting material properties and the transport distance. These aspects are critical for the selection of the optimum biomass fuel. Hence, a general-purpose recommendation cannot be made without consideration of above context conditions.

5.3 Logistics and Infrastructure

5.3.1 Point of Departure

5.3.1.1 Biomass and Supply Chain

Supply chain is a critical component impacting on the commercial viability of any biomass utilization in Namibia, and beyond. As a rule of thumb it can be assumed that supply chain costs account for < 30 % for local destination, depending on distance between supply and demand area, and for > 50 % for international destinations. That alone suggests that local consumption model is the preferable option, at least to kick start a large scale of biomass utilization program in Namibia. Figure 5.19 presents an example for the costs for biomass logistics and different destinations.

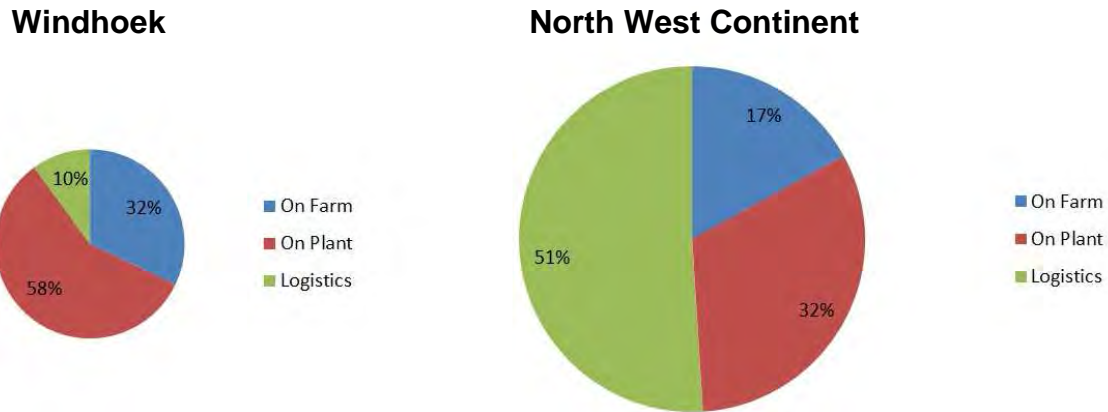


Fig. 5.27: Relative costs for biomass logistics and different destinations

5.3.1.2 Namibia Transport Infrastructure and Capacities

Figure 5.20 shows a Namibian map with the national road network differentiated according to the surface type of the roads. The total length of the road network in Namibia is about 45,387 km, but the main part of it is based on gravel roads or earth tracks. Just a small part of about 6,000 km consists of bitumen. These bitumen roads create a north-south link and a west-east link, with Windhoek as the capital lying central to this network. They further connect with neighboring countries like Angola, Zambia, Zimbabwe, Botswana and South Africa.

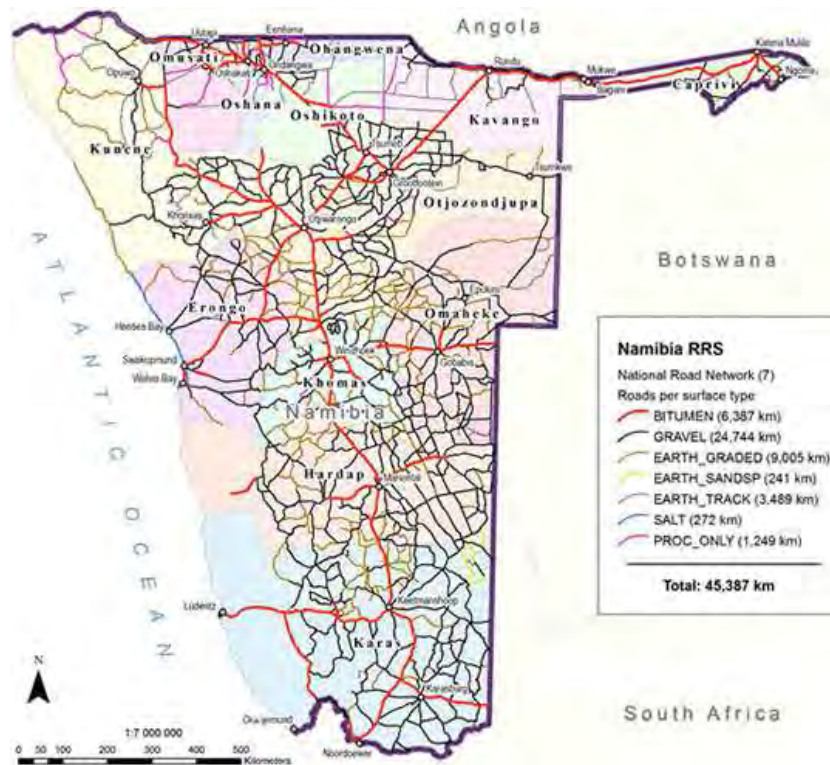


Fig. 5.28: Road network in Namibia differentiated to the surface type

Figure 5.21 shows the Namibia railway network. The rail network has a total length of 2,626 km only. It essentially provides a north-south link with railheads in the east and the north. The rail network is further connected to the port of Walvis Bay. The only regional connectivity is via the south to South Africa.



Fig. 5.29: Railway network in Namibia

The Namibia international seaports include the port of Walvis Bay and the port of Lüderitz. The port of Walvis Bay is the main Namibian commercial port which increasingly plays an international role as the western gateway to the South African Development Community (SADC). The port caters for containerized as well as break bulk and bulk cargo. It currently embarks upon a port expansion program aiming at creating a new container terminal and a bulk terminal to the north of the current port. Parallel or possibly depending on the Namport project realization, a private investment Gecko Vision Industrial Park plans for a privately operated bulk port north of Swakopmund. Scheduled implementation date for that project is 2016.

5.3.1.3 Implications of Transport Infrastructure provision on Biomass Bulk Transport

The Namibian transport infrastructure network bears a number of direct implications for biomass (bulk) transport, amongst them the following ones:

First, the road and rail network provides linear access to harvesting areas, favoring stretches along network lines and at modal nodes. It disfavors remote areas that are de-linked from the infrastructure network. That determines geographical patterns of priority harvesting and de-bushing areas. Secondly, Namibia is sparsely populated with few small urban population centers and economic hubs. The settlement patterns result in averaged large travel and transportation distances between point of origin and destinations. For example the distance between the central bush encroached areas and the port is minimum 350 km. Thirdly, and following from above, there are only few and defined trade and resulting transport patterns established, e.g. into the capital of Windhoek or northbound to the central north of Namibia. Biomass transport that complements such existing transport operations benefit from utilizing existing operational capacities and trade flows. In contrast, transport that is de-linked from current trade flows is burdened by equipment mobilization costs as well as possible return rates that effectively double the transport costs (for further details see below).

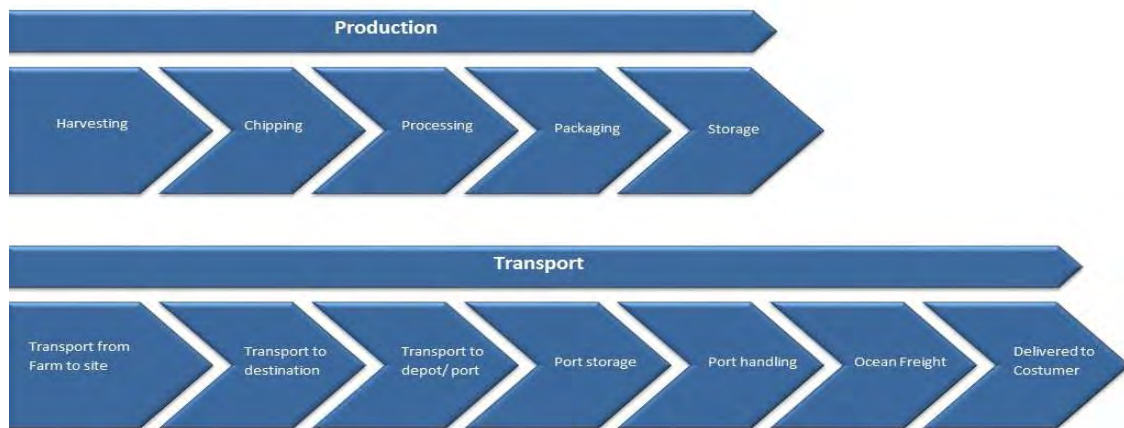
5.3.1.4 Assumption/Model

The logistics requirements depend on the business model pursued as regards production volumes, supply and demand areas and market requirements, i.e. product qualities. This study provides general logistics parameter for various modes of transport and destinations. Concrete costings relates to a biomass production model of 100,000 ton of biomass for industrial use or for generating energy. The supply area is Okahandja, 80 km north of Windhoek. This location takes account of an operational biomass harvesting and processing operation, and is well positioned with regard to resource supply and to demand areas. The model is small enough to support a pilot investment, and big enough to support industrial and/or energy-generating applications (see below).

5.3.2 Biomass Value Chain and Supply Chain

5.3.2.1 General

The biomass value and supply chain comprised the components of figure 5.22

Biomass Value Chain**Fig. 5.30: Biomass value and supply chain**

The supply chain must be differentiated between

- local level, i.e. logistics between harvesting farm area and processing site
- regional level, i.e. logistics between processing site and destination of industrial and/or power plant site
- international level, i.e. logistics between processing plant and international destination port

5.3.2.2 Local Level from Farm to Processing Plant

Following harvesting, drying of material and chipping, the biomass chips need to be transported from farm to plant. As described under chapter 5, there are different options for local transport ranging from small scale tractor/trailer combinations to large scale horse/trailer combinations. The volume and weight specifications of biomass chips ($150 - 250 \text{ kg/m}^3$) alone suggest a big volume transport option as the most economical solution. The study model scenario operates with a horse and a 108 m^2 trailer with a walking floor. The latter is specially built for ease of offloading of chips. It allows maximum capacity utilization of up to 27 tons which is close to the maximum payload of Namibian trucking operations.

Important is the distance between farm and processing site, or the (maximum) harvesting radius from the processing site. Current de-bushing operations operate with different harvesting radius varying between 25 km (OBI) and 75 km (EFF). The NamPower study calculates for three power plant locations (Otjiwarongo 5 MW, Otjikoto 20 MW and Ohorongo 20 MW) with similar range of transport distances of 35, 55 and 65 km respectively [13]. Contrasting these scenarios the STEAG/Transworld Cargo study cal-

culates for 5 MW power stations with distance from farm to plant of between 13 and 22 km.

Supply chain costs further include storage, handling and packing costs. These can be estimated to amount to a total of 60 N\$/t for handling and material costs. A rough approximation of farm bound transport costs result from a combined rate for gravel and tarred road utilization and is estimated to be around 20 N\$ per running kilometer. Obviously, for a harvesting area/radius a return rate must be applied.

5.3.2.3 Regional Level from Plant to Site

The regional transport covers the logistics from plant to demand site including storage and handling (e.g. loading). Here the scenario for plant to inland destination is considered for the Namibian capital Windhoek, the coastal business hub Walvis Bay, the northern population centre Oshakati and the regional hub of Johannesburg as example sites. Given the situation in Namibia and the scope of the pilot project, the most economical option is the transport in big bags (650 kg per bag for white pellets and 800 kg per bag for black pellets) as break bulk on rail or road depending on availability.

Rail transport is available along the main rail lines within Namibia for selected locations covering the medium sized municipalities of central and northern Namibia. The rail rates depend primarily on commodity, volume and origin/destination. The rail rate is 140 N\$/t for Okahandja to Walvis Bay, or approximately 0.4 N\$ per ton and km. That corresponds more or less with the trucking rate per running km, as per below. However, the t/km rail rate varies between destinations depending on location and trade flows. For example Okahandja to Windhoek costs approximately 1 N\$ per ton and km and is thus 2.5 times higher than from Okahandja to Walvis Bay.

On the road side, the existing flow of trade and availability of return loads impacts substantially on transport rates. In general a trucking rate of 13 N\$ per running km for a 33 ton truck or a N\$ per ton and km rate of 0.4 can be applied. In the absence of return loads, however, a full return rate must be applied. In contrast to this, the utilization of empty return loads on the route to South Africa (e.g. Johannesburg) will subsidize the transport rate to an amount of 7 N\$ per running km or a N\$ per ton and km rate of 0.2. Table 5.9 shows the rail and road rates for bulk transport from Okahandja to selected destinations.

Tab. 5.11: Rail and road rates for bulk transport from Okahandja to selected destinations

Destination	Distance [km]	Rail [N\$/t]	Road [N\$/t]
Walvis Bay	353	141	138
Windhoek	70	77	28
Tsumeb	530	213	208
Oshakati	810	388	319
Keetmanshoop	580	230	228
Johannesburg	1500	n.a.	303

In conclusion, the transport rates in the Namibian context are not a function of distance only. It can vary considerably depending on location and corresponding trade flows and infrastructure or service availability at supply/demand site. The scope of rates varies by a factor of 5, which underlines the importance of supply chain costs and corresponding locational factors.

5.3.2.4 International Level from Plant to International Port Destinations

The international transport covers the logistics from plant site to international port destinations including inland transport, port handling and ocean freight. Given the project scope, the preferable biomass handling is in break bulk giving access to existing transport equipment and rail and port infrastructure. The ocean freight is per part charter vessels with 5,000 to 7,000 tons parcel shipment. Such part charter vessels are available in Walvis Bay on the Europe-Southern Africa route, e.g. through MACS Shipping with a bi-weekly sailings out of Walvis Bay. Table 5.10 shows an overview of international transport costs from the supply area Okahandja.

Tab. 5.12: International transport costs based on the supply area Okahandja

Transportation Costs	[N\$/t]
Inland Rail Transport	141
Inland Road	138
Port Charges in Walvis Bay	22
Subtotal FOB Walvis Bay (app)	160
Ocean Freight	630
Total	790

The international costs vary tremendously with the volumes in question. A large scale export program of several hundred thousand tons per year would attract new and specialized services and considerably lower freight rates. It can be estimated that the ocean freight rate for a dedicated bulk transport to be at least 50 % less than the rates

offered above. Such volumes however also require investments in transport infrastructure and capacities both on the rail and the port side.

5.4 Levelled Costs of Electricity

The levelled costs of electricity are also an important aspect for a biomass concept development in Namibia, as biomass based power generation must be competitive against other technologies and energy sources. Figure 5.23 gives an overview of the expected levelled costs of electricity of different energy sources based on European standards/experiences and tailored to the context conditions of Namibia. Conventional as well as renewable energy sources are shown. Additional costs for CO₂-certificates for the combustion of fossil coal are not considered.

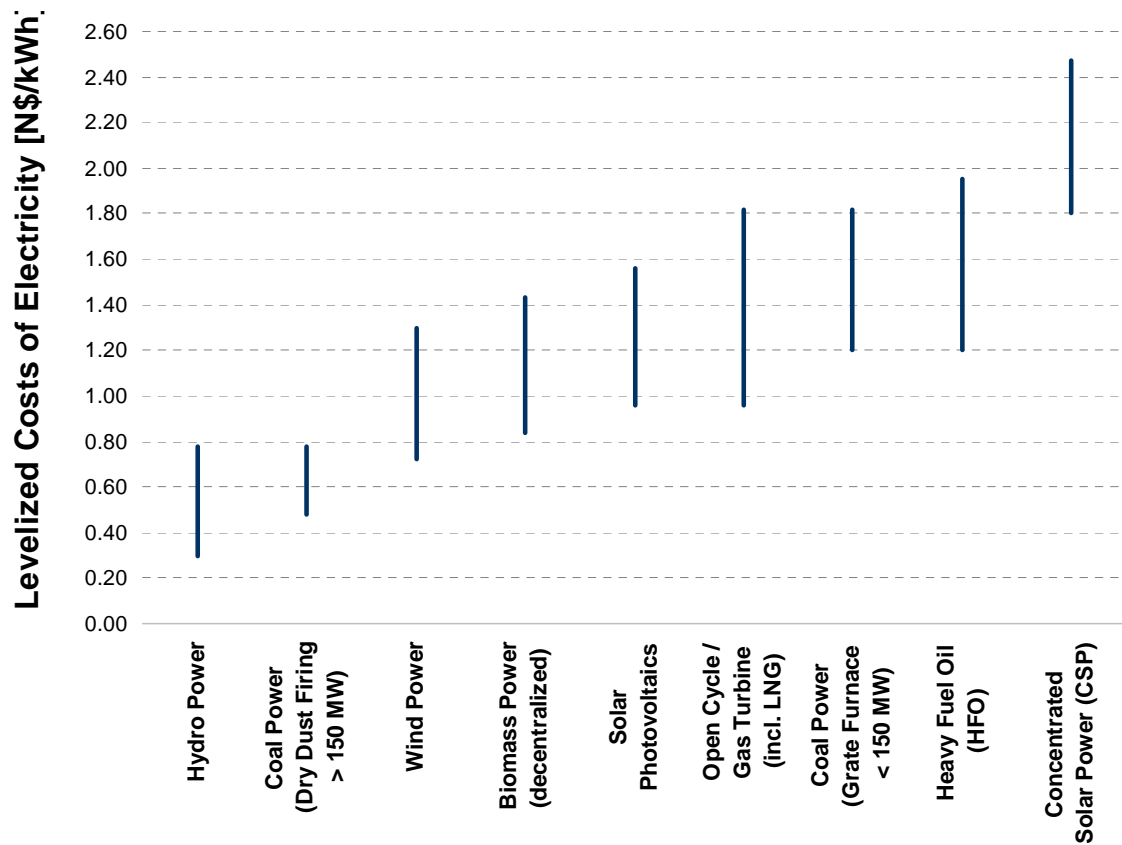


Fig. 5.31: Assumed levelled costs of electricity for Namibia

The figure illustrates that the costs for biomass power generation is at about 0.8 - 1.4 N\$/kWh and thus amongst the most competitive technologies. This figure is considerably lower than previous studies suggest but compares well against international benchmarks. The NamPower prefeasibility study for biomass power plant in Namibia

provides a power generation cost of a minimum of 1.7 N\$/kWh [13]. Unfortunately, the public version of the document does not allow to fully evaluating the underlying cost calculation. Our interpretation is that the biomass supply costs, the plant procurement costs as well as the operation and maintenance costs are in line with our estimates. The differences in bottom line generation costs remain unclear. At the other end of the scale is heavy fuel oil technology supported by the fact that the heavy fuel oil-fired power stations Paratus and Anixas are currently operated only as peak load power stations. The costing of heavy fuel oil also presents an opportunity for biomass to replace heavy fuel oil in industry applications.

Conclusion:

With the low and very competitive energy generation costs of biomass power plants, this technology provides a future complementary alternative to conventional power generation in Namibia. The biomass power plants are able to operate as base load plants and enhance the power supply situation in, and independence, of Namibia.

6 Concept Development for Future Utilization of Namibian Biomass

The following recommendations provide relevant options for the future biomass utilization. These options are guided, amongst others, by baseline data as presented in previous chapters of this report, and by current supply and demand parameters of the Namibian biomass sector and available technical expertise. This allows in principle for implementation in a short term perspective. Thus, these options should qualify as pilot developments/investments with the potential to subsequent roll out. Priority options in such a context are the following:

- Decentralized small scale biomass power station
- Decentralized small scale hybrid power station on the basis of biomass and solar heat
- Production of biomass based fuels (chips, white pellets, black pellets/bio-coal pellets) for national and/or foreign markets

The locational recommendation for an initial investment and/or pilot plant is for Okahandja in the Otjozondjupa region. Okahandja provides for a medium sized demand profile of a small municipality with an industrial cluster including food industries such as Meatco and the SAB Miller brewery, for sufficient availability of biomass resources being part of the heavily bush encroached area, as well as for an operational harvesting and processing facility with a sizeable scope of 10,000 t/a. In addition, it allows for direct access to national transport infrastructure for both rail and road which ensures good connectivity to local markets and, via Walvis Bay a/o Windhoek, to regional and international markets in South Africa and overseas. It thus allows for a combination of local and regional/international utilization options, e.g. by combining local strategies (e.g. wood chip production for decentralized biomass/hybrid plants) with regional/international strategies (e.g. pellet/bio-coal production for coal-fired power plant supplies). Finally, the power generation for local consumption is the strategic priority followed by biomass production for export markets.

6.1 Construction of Decentralized Biomass Power Stations

The use of Namibian biomass in decentralized biomass power stations is a very promising approach. The invader bush as fuel is cheap and has very good fuel properties.

Biomass power stations are able to combust invader bush in form of wood chips. And, the proposed biomass power stations with 5 MW capacities have the advantage of limited fuel supply requirements which allows for the proximity of harvesting/supply areas and the biomass power stations. So necessary pre-treatment as well as transportation costs for wood chips can be held at minimal levels.

Decentralized power stations are particularly suited for geographically integrated systems within the bush encroached area and close to towns with high power demand. Such locations have the further advantage of being independent on the national grid with only short distances to be bridged and low transmission related energy losses.

6.1.1 Plant Description

A decentralized biomass power station usually consists of different sectors: fuel storage, combustor, flue gas cleaning system and steam turbine. The fuel storage as first sector is designed on the biomass, the Namibian invader bush. The supply of the required biomass quantity proceeds by road transportation. Hence, the already chipped and pre-dried invader bush comes via truck from different pooling stations of the biomass area around the biomass power station. The unloading of the supplied biomass chips takes place at the storage area of the plant site. The biomass storage consists of several roofed or unroofed storage boxes, bunkers with push floors and an additional open fuel storage for longer storage times (reserve for biomass supply bottlenecks and long weekends). A wheel loader fills the storage boxes. For the case that oversized bulky wood material will be delivered (particle size > 300 mm), an additional mobile shredder will be needed for shredding of the wood, because excess lengths can lead to failures by blocking the transport systems. From the storage boxes the wheel loader feeds two bunkers with biomass. Each bunker is equipped with a push floor. The both push floors feed automatically a shared transport system, so that the biomass chips can be provided to the feed hopper of the subsequent furnace. The storage capacity of the two bunkers is rated at approximately 300 t that corresponds to approximately 750 m³ and one day of full load biomass combustion. The total biomass fuel storage is adequately sized, so that 100 % load operation of the biomass combustor is ensured for long durations without any supply of biomass, e.g. long weekends or other supply bottlenecks. Due to the climatic conditions in Namibia, the biomass storage could be performed open-air. Possible biological degradation is not an important issue concerning storage system and strategy.

For the combustion of biomass there are various combustion technologies available like grate furnaces or fluidized bed boilers. Figure 6.1 shows a typical process flow-sheet of a decentralized biomass power station with moving grate.

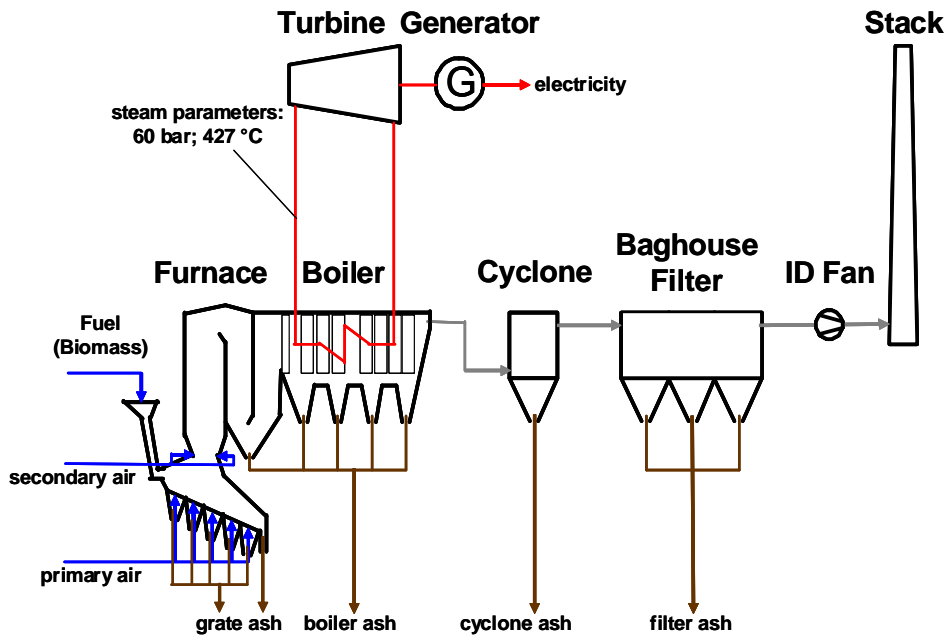


Fig. 6.32: Typical process flow-sheet of a biomass power station on the base of a moving grate

The different combustion technologies have specific advantages and disadvantages, depending on fuel properties. But for coarse materials like biomass chips the grate furnace system is preferred and mostly chosen due to a higher flexibility regarding to inhomogeneous particle size distribution and lower investment costs in comparison to fluidized-bed boilers. For regions like southern Africa moving-grate-stokers are the prevailing grate furnace type, which transports the material in axial direction through the combustion chamber. Primary air is fed from below through the moving-grate cooling the grate and offering the required oxygen for combustion. The feed of primary air can be staged along the grate so that the combustion conditions can be improved. Secondary air is fed above the moving-grate and is required for the total burnout of the hot flue gases.

After the secondary combustion the hot flue gas reaches the boiler where the flue gas is cooled down. At the same time process steam is generated via economizer, evaporator and super heater. The nominal steam conditions at the outlet of the boiler are set to 60 bar and 427 °C. Higher steam parameters would raise the risk of corrosion due to the chlorine and alkaline metal content of the biomass. Regarding to the flue gas cleaning system only a dust separation is necessary to fulfill emission restrictions. The

dust separation can consist of a cyclone in combination with a bag house filter or an electric filter. Figure 6.2 shows a typical site plan, which has to be adapted to the local conditions of each biomass power station.

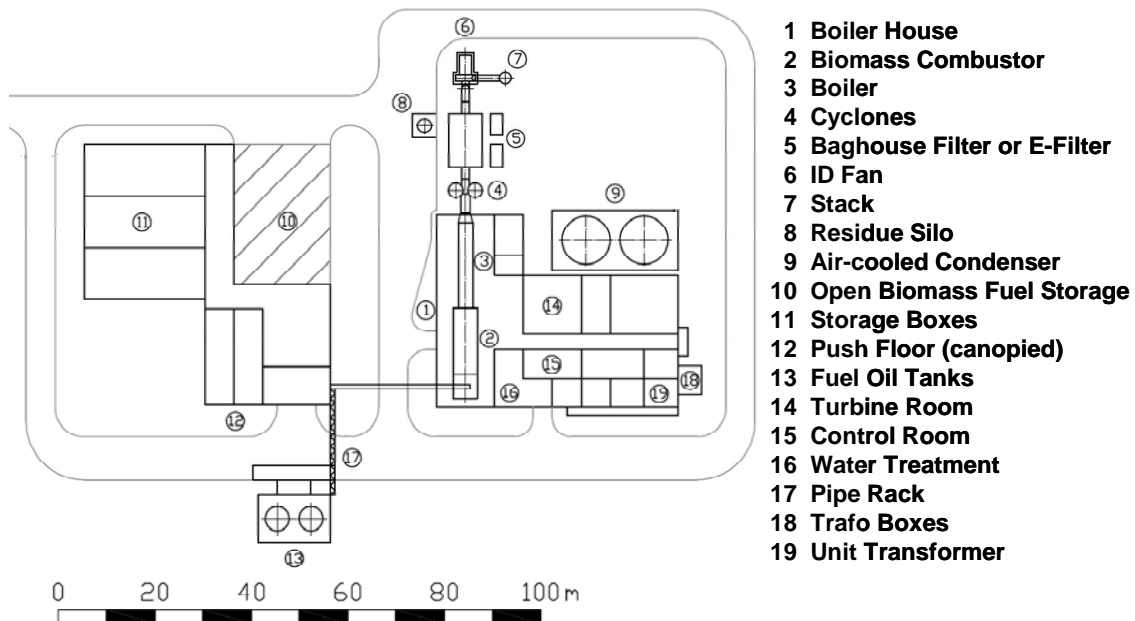


Fig. 6.33: Typical site plan of a biomass power station

Due to inspections, repairs, planned-outages and forced-outages, 7,500 full load hours of the incineration plant per year have been considered. Depending on the heating value of the biomass (16 - 18 MJ/kg) and the typical boiler efficiency of a grate furnace system of 86 % the capacity of the biomass combustor is rated at approximately 30,000 t/a so that approximately 45,000 t/a undried invader bushes (12 - 13 MJ/kg) have to be harvested. The flue gas flow is rated at approximately 25,000 - 35,000 Nm³/h. The design of the furnace and the steam boiler is based on European standards and finally has to be adapted to African technology.

6.1.2 Resource Supply Situation

Okahandja and others of the identified sites have an energy demand of approximately 5 MW, resulting from an averaged electricity consumption of 1,800 kWh per inhabitant and year. Table 6.1 gives an overview of other parameters for the concept design of decentralized biomass power stations.

Tab. 6.13: Parameter for the concept design of decentralized biomass power stations

Energy Demand Parameters		
Namibian Population	[P]	2,560,000
Namibian Power Demand	[GWh/a]	4.5
Specific Power Demand	[kWh/(a P)]	1,800
Plant Parameters		
Power Output	[MW]	5
Operation Hours	[h/a]	7,500
Electrical Efficiency	[%]	25
Biomass and Harvest Parameters		
Water Content before Air Drying	[%]	40
Calorific Value (Undried Biomass)	[MJ/kg]	12,5
Water Content after Air Drying	[%]	10
Calorific Value (Dried Biomass)	[MJ/kg]	18
Harvesting Cycle	[a]	10
Harvest Rate per Hectare	[%]	50

Table 6.2 presents the required harvesting area supporting a 5 MW biomass power plants, based on further variables such as differing local bush densities, varying resource costs and an availability factor that takes account of geographically or otherwise not available biomass resources (e.g. lack of farmers consent).

Tab. 6.14: Harvesting area and radius for biomass supply in support of 5 MW biomass power plants (Okahandja as pilot plant)

Location		Okahandja	Otjiwarongo	Grootfontein	Tsumeb	Otavi	Gobabis
Power Output	[MW]	5	5	5	5	5	5
Population	[-]	22,500	28,000	16,200	19,200	5,200	19,000
Theoretical Power Demand	[MW]	5.4	6.7	3.9	4.6	1.3	4.6
Biomass Demand (undried)	[t/a]	45,000	45,000	45,000	45,000	45,000	45,000
Bush Density	[t/ha]	10 - 15	15 - 20	15 - 20	15 - 20	15 - 20	10 - 15
Average Bush Density	[t/ha]	12.5	17.5	17.5	17.5	17.5	12.5
Harvesting Amount	[%]	50	50	50	50	50	50
Availability	[%]	50 - 100	50 - 100	50 - 100	50 - 100	50 - 100	50 - 100
Harvest Area	[ha/a]	7,000 - 14,000	5,000 - 10,000	5,000 - 10,000	5,000 - 10,000	5,000 - 10,000	7,000 - 14,000
Average Harvest Area	[ha/a]	10,500	7,500	7,500	7,500	7,500	10,500
Total Harvest Area for 10-Year-Harvest-Cycle	[ha]	105,000	75,000	75,000	75,000	75,000	105,000
Harvest Radius	[km]	15.4 - 21.4	12.8 - 18.1	12.8 - 18.1	12.8 - 18.1	12.8 - 18.1	15.4 - 21.4

however considers geographical aspects like hills or streets as well as the willingness of farmers to relinquish the biomass to such a biomass project.

Tab. 6.15: Scenario profitability analysis for 5 MW decentralized biomass power stations

Parameter	Unit	Range	No.	Scenario 1	No.	Scenario 2	No.	Scenario 3	No.	Scenario 4
Harvesting Amount	[t/a]	-	-	30,000	-	30,000	-	30,000	-	30,000
Biomass Price	[N\$/t]	0 - 50	-	0	-	0	-	50	-	50
Availability Factor	[%]	50 - 100%	-	100%	-	50%	-	100%	-	50%
Excavator	[N\$]	1,500,000	4	6,000,000	4	6,000,000	4	6,000,000	4	6,000,000
Mobile Chipper	[N\$]	2,000,000	4	8,000,000	4	8,000,000	4	8,000,000	4	8,000,000
Tractor (with Gripper Arm)	[N\$]	1,000,000	4	4,000,000	4	4,000,000	4	4,000,000	4	4,000,000
Trailer	[N\$]	500,000	4	2,000,000	6	3,000,000	4	2,000,000	6	3,000,000
Truck	[N\$]	1,000,000	4	4,000,000	6	6,000,000	4	4,000,000	6	6,000,000
Investment Costs	[N\$]	-		24,000,000		27,000,000		24,000,000		27,000,000
Service Lifetime	[a]	10	-	10	-	10	-	10	-	10
Maintenance Costs	[N\$]	2 % of Inv. / a	-	480,000	-	540,000	-	480,000	-	540,000
Personnel Costs	[N\$/a]	-	41	1,175,000	45	1,275,000	41	1,175,000	45	1,275,000
Fuel Costs	[N\$/a]	-	-	3,254,400	-	3,384,000	-	3,254,400	-	3,384,000
Biomass Supply Costs	[N\$/t]	-	-	275.0	-	298.0	-	325.0	-	348.0
Biomass Plant	[N\$]	240,000,000	1	240,000,000	1	240,000,000	1	240,000,000	1	240,000,000
Skip Loader	[N\$]	1,000,000	2	2,000,000	2	2,000,000	2	2,000,000	2	2,000,000
Maintenance Costs	[N\$/a]	3 % of Inv. / a	-	7,260,000	-	7,260,000	-	7,260,000	-	7,260,000
Personnel Costs	[N\$/a]	-	30	1,300,000	30	1,300,000	30	1,300,000	30	1,300,000
LCOE	[N\$/kWh]	-	-	1.027	-	1.046	-	1.067	-	1.086

All scenarios allow for energy generation costs of less than 1.1 N\$/kWh, in the range between 1.02 and 1.09 N\$/kWh. The result confirms the presentation of leveled costs of electricity under chapter 5.4 and the competitiveness of biomass based power generation. With these results, decentralized biomass power stations can play a central role in Namibia's future energy generation system.

6.2 Construction of Decentralized Hybrid Power Stations on the Basis of Biomass and Solar Heat

An alternative to the decentralized biomass power stations are hybrid power stations. A hybrid power station is a combined solar biomass plant, which consists of a biomass combustion plant and a solar thermal plant. Both single plants are combined via a joint water-steam-cycle to one plant with one turbine for the generation of electricity. The advantage of this hybrid power station concept is improved controllability concerning the power supply/demand in comparison to a biomass power station. The power generation of a hybrid power station can be better adjusted to the fluctuating power demand between day- and night-time. The biomass combustion plant acts as base load power plant for the generation of the base power demand, whereas the solar thermal plant however acts as peak load power plant for the generation of the peak power demand during day-time. The independency from the power grid and possible power imports would be extra high, if both parts are tailored to the specific conditions of the selected locations.

The environmental conditions in Namibia for a combined solar biomass plant concept are very supportive. In addition to the availability of biomass, as described in the previous chapter, Namibia enjoys high irradiation conditions during the entire year

STEAG is operating both biomass as well as solar power plants as individual and independent units. STEAG currently designs an integrated hybrid plant in India. A Namibia based pilot hybrid plant could thus benefit from existing R&D experiences, and position Namibia as an international technology innovation hub in hybrid power generation.

6.2.1 Plant Description

The combined solar biomass power station concept consists of a biomass combustion plant and a solar thermal plant which are linked together via a joint water-steam-cycle. The design of the biomass combustion plant including the biomass supply and storage system corresponds to the decentralized biomass power station and is described in chapter 6.1.1.

Especially parabolic trough collectors and linear Fresnel collectors are suitable to build up a solar thermal plant for a solar topping system. These two types of collectors allow an easy extension of the solar field later on. While parabolic trough collectors are usu-

ally operated with a heat transfer fluid like thermal oil, the generation of saturated steam is state-of-the-art for linear Fresnel collectors.

Using linear Fresnel collectors the solar field can be used to preheat and vaporize feed water in order to inject it directly into the boiler drum. Typical steam delivery conditions at the solar field outlet are saturated steam of 55 bar and approximately 270°C. At 800 W/m² corrected DNI (Direct Normal Irradiation) a typical linear Fresnel system can generate roughly 0.5 t/h saturated steam per 1000 m² land area. Figure 6.4 shows a typical site plan, which has to be adapted to the local conditions of each hybrid power station.

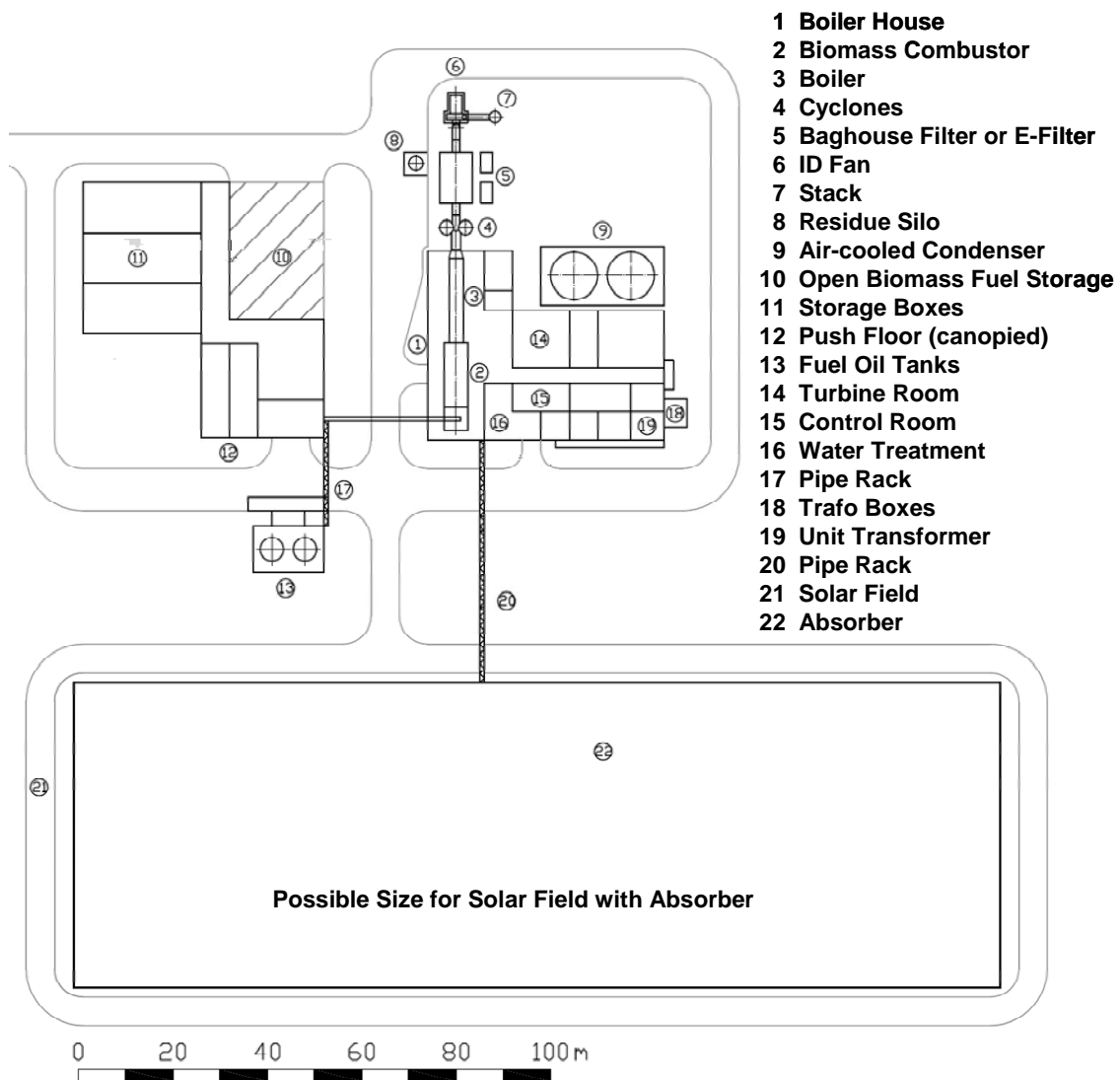


Fig. 6.35: Typical site plan of a hybrid power station with a combined solar biomass plant

A detailed solar field layout and design has to be based on the solar topping concept, general local conditions and type of solar thermal technology. If the concept is to gen-

erate approximately 20 % of the saturated steam in the biomass boiler based on solar energy at very high solar irradiation, a land area of approximately 10,000 m² will be necessary for the installation of a solar field.

The design parameters of the solar field are not worked out in this study. Based on the general conditions, the ambient conditions at site and the concept for the solar topping system the design parameters vary. For example the concept of the solar topping system will influence the design of solar part substantially. If saturated steam is generated directly, it can be injected in the boiler drum. If there is a feed water heating system, solar heat could also be utilized in this part of the power plant, which will result in another design of the solar part. Other important input parameters for the design concept are the solar irradiation conditions at site and the solar share in the plant. It has to be determined at which solar conditions which amount of steam has to be delivered. The design will be different whether a high solar contribution over the year or a high solar contribution at peak times should be realized.

6.2.2 Resource Supply Situation

The biomass part of the hybrid plant would not substantially differ from the sole biomass power plants. Thus the principal biomass parameters regarding resource requirements, harvesting demand etc. remain as described under the previous chapter 6.1.2.

6.2.3 Economic Analysis

A substantive economic analysis for a hybrid concept would require some further research. However, the leveled costs of electricity of chapter 5.4 give a first indication of the electricity costs of a hybrid plant. It is fair to assume that the resulting leveled costs of electricity are definitively higher for a hybrid power station than for a stand-alone biomass power station, but considerably lower than for a stand-alone solar thermal plant. With the aid of the solar thermal plant the fuel costs of the biomass combustion plant can be reduced admittedly, but simultaneously the resulting investment costs in combination with the required area should be significantly higher. Therefore, a stand-alone biomass power plant should always have cost-effective advantages in comparison to a stand-alone solar thermal plant as well as a hybrid power plant.

6.3 Production of Biomass based Fuels for the National and Foreign Markets

The production of biomass based fuels for national and foreign markets would include torrefied biomass (bio coal/black pellets), biomass pellets (white pellets) and biomass chips. The preference primarily depends on the used combustion technology with resulting fuel requirements, and the involved logistics. The potential priority markets would include

- Windhoek with the rehabilitated van Eck Power Station as well as industries such as Meatco and Namibian Breweries as consumers
- Erongo region (e.g. Swakopmund) with the mining sector including Gecko Vision Industrial Park (gecko power plant under consideration)
- biomass supply for Europe destined to ARA ports (Amsterdam, Rotterdam, Antwerp as harbor)

All geographic segments have potentially big volume demand for biomass:

Windhoek, the capital of Namibia, hosts a number of energy-intensive companies from the wider food industry sector. These companies use fossil fuels, especially costly chestnut coal, which could be substituted by biomass based fuels. NamPower is committed to co-combust biomass in the rehabilitated van Eck Power Station, with a preference on bio-coal. However, it might be worthwhile to alternatively consider the use of biomass chips thus allowing van Eck to become a base load power station as opposed to a peak load station only. That however would require further investigation and possibly test runs with individual units.

In the Erongo region (Swakopmund/Walvis Bay), the expanding mining sector as well as the fishing industry has a potential future demand for biomass. The first includes the Gecko Vision Industrial Park which pursues the plan for a local power plant. The fishing industry uses lumpy chestnut coal or heavy fuel and, given the energy generation costs, could benefit from a biomass substitute.

Europe and specifically countries with a biomass supportive legislation such as United Kingdom, Belgium, Sweden, Denmark, Poland and the Netherlands have an increasing demand for biomass based fuels for co-combustion and substitution of fossil coal in coal-fired power plants. It is generally accepted that these demands can not be met by European production but must be imported.

A similar situation applies to South Africa provided that Eskom in future commits to the complementary use of biomass. Again, the potential future demand can not be met by South African resources and needs to be imported primarily from the Southern Africa region.

The production of biomass based fuels is proposed to complement decentralized biomass power stations in order to capitalize on synergies. The latter would include the utilization of biomass infrastructure and logistics, the availability of biomass supply capacities including manpower and know how as well as the material combination/separation for differing combustion purposes (e.g. separation of components with high ash content concerning higher product quality and combustion in decentralized biomass power station).

A total production capacity of 300,000 t/a should be considered that is possibly shared by three supply areas. This volume is based on the biomass demand of van Eck (one of the four 30 MW grate furnaces could be completely fired with biomass or bio-coal). This could be complemented by bulk exports to South Africa or Europe. The processing plant for white or black pellets depends on the consumer/market demand and opportunity. The process could start with a pilot plant of approximately 50,000 - 100,000 t/a production capacity being located in Okahandja. This initial investment could be successively scaled up with volume related process and cost optimization effects.

6.3.1 Plant Description for White/Black Pellets

The design of the three biomass based fuel production plants corresponds to the simplified plant descriptions in chapter 5.2. Each site is designed for a capacity of 100,000 t/a. The process flow sheet for the production of usual pellets (white pellets) is shown in figure 6.5. By implementing a torrefaction step between raw material storage and hammer mill the pellet plant can be upgraded for the production of bio-coal pellets (black pellets). For the production of biomass chips however only a collecting site is required due to the air drying and chipping process at the biomass sites on the farms. In comparison to other biomass supply regions no additional thermal drying is required which reduces both investment and production costs substantially. On-farm air drying alone produces material with a moisture content of approximately 10 %, which is the optimal moisture content for the feed of the torrefaction and pelletizing step.

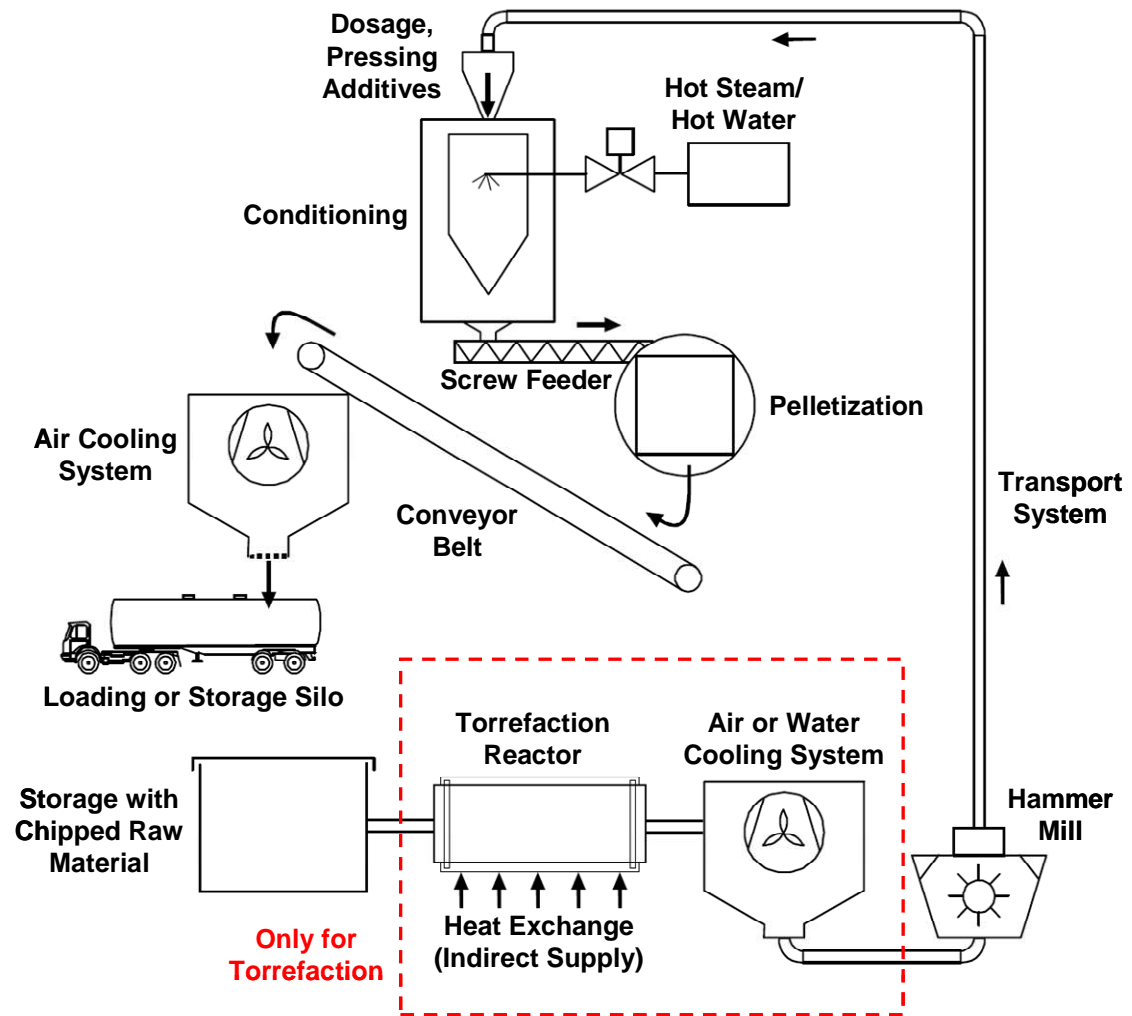


Fig. 6.36: Process flow sheet for the production of white pellets with an optional integrated torrefaction process step for the production of black pellets (red marked)

Due to inspections, repairs, planned-outages and forced-outages, 7,500 full load hours of the biomass based fuel production plant per year have been considered. Depending on the heating value of the dried raw biomass (16 - 18 MJ/kg) the capacity of each production plant is rated at approximately 100,000 t/a so that approximately 145,000 t/a undried invader bushes (12 - 13 MJ/kg) have to be harvested. The resulting heating values of white pellets are at about 18 MJ/kg. Due to the additional mass and energy loss during the torrefaction process approximately 210,000 t/a undried invader bush have to be harvested, whereas the heating value of black pellets is around 22 - 25 MJ/kg. The design of the biomass based fuel production plants is based on European standards and is adapted to Namibian context (e.g. weather conditions).

6.3.2 Resource Supply Situation

The concept approach for the production of biomass based fuels for the national and foreign power industry has been developed for three selected plant sites with sufficient biomass supply (for 5 MW biomass plant and an additional 100,000 ton production capacity) as well as access to transport infrastructure. Table 6.4 gives an overview of additional parameters for the concept design of biomass based fuel production plants.

Tab. 6.16: Parameters for the concept design of decentralized biomass power stations

Energy Demand Parameters		
Namibian Population	[P]	2,560,000
Namibian Power Demand	[GWh/a]	4.5
Specific Power Demand	[kWh/(a P)]	1,800
Plant Parameters		
Power Output	[MW]	5
Operation Hours	[h/a]	7,500
Electrical Efficiency	[%]	25
Biomass and Harvest Parameters		
Water Content before Air Drying	[%]	40
Calorific Value (Undried Biomass)	[MJ/kg]	12,5
Water Content after Air Drying	[%]	10
Calorific Value (Dried Biomass)	[MJ/kg]	18
Harvesting Cycle	[a]	10
Harvest Rate per Hectare	[%]	50

Furthermore, various invader bush densities were assumed for each location depending on the average invader bush density given in the figure 4.1. These assumptions result in a required harvesting area and radius. The calculated harvesting area and radius for biomass supply of the three proposed biomass chips or white pellet production plants are shown in table 6.5, for the black pellet production plants in table 6.6. The harvesting area and radius for the production of black pellets are slightly higher than for the production of chips or white pellets due to the mass and heat loss during the torrefaction process and the corresponding biomass demand.

Tab. 6.17: Calculated harvest area and harvest radius for biomass supply of the biomass power stations and the integrated biomass chips or white pellet production plants at selected sites (Okahandja as pilot plant)

Location		Okahandja	Otjiwarongo	Gobabis
Power Output	[MW]	5	5	5
Pellet Output	[t/a]	100,000	100,000	100,000
Biomass Demand (undried)	[t/a]	145,000	145,000	145,000
Bush Density	[t/ha]	10 - 15	15 - 20	10 - 15
Average Bush Density	[t/ha]	12.5	17.5	12.5
Harvesting Amount	[%]	50	50	50
Availability	[%]	50 - 100	50 - 100	50 - 100
Harvest Area	[ha/a]	23,000 - 46,000	17,000 - 34,000	23,000 - 46,000
Average Harvest Area	[ha/a]	35,000	25,500	35,000
Total Harvest Area for 10-Year-Harvest-Cycle	[ha]	350,000	255,000	350,000
Harvest Radius	[km]	27.2 - 38.4	23.0 - 32.5	27.2 - 38.4

Tab. 6.18: Calculated harvest area and harvest radius for biomass supply of the biomass power stations and the integrated black pellet production plants at selected sites (Okahandja as pilot plant)

Location		Okahandja	Otjiwarongo	Gobabis
Power Output	[MW]	5	5	5
Torrefied Pellet Output	[t/a]	100,000	100,000	100,000
Biomass Demand (undried)	[t/a]	210,000	210,000	210,000
Bush Density	[t/ha]	10 - 15	15 - 20	10 - 15
Average Bush Density	[t/ha]	12.5	17.5	12.5
Harvesting Amount	[%]	50	50	50
Availability	[%]	50 - 100	50 - 100	50 - 100
Harvest Area	[ha/a]	34,000 - 68,000	24,000 - 48,000	34,000 - 68,000
Average Harvest Area	[ha/a]	51,000	36,000	51,000
Total Harvest Area for 10-Year-Harvest-Cycle	[ha]	510,000	360,000	510,000
Harvest Radius	[km]	32.7 - 46.3	27.6 - 39.1	32.7 - 46.3

Tab. 6.19: Rough assumption concerning the biomass supply costs for the three destinations Windhoek, Erongo and Europe according to different biomass based fuels

Parameter	Unit	Chips	White Pellets	Bio-Coal Pellets	
Harvesting	Harvesting Amount	[t/a]	145,000	145,000	210,000
	Biomass Price	[N\$/t]	0 - 50	0 - 50	0 - 50
	Availability Factor	[%]	50 - 100	50 - 100	50 - 100
	Service Lifetime	[a]	10	10	10
	Harvesting Costs	[N\$/t]	287 - 375	287 - 375	287 - 375
Process	Investment Costs per Plant	[N\$]	-	96,000,000	300,000,000
	Pellet Production Costs	[N\$/t]	-	572 - 660	905 - 1,030
Windhoek	Transport Costs (< 250 km)	[N\$/t]	100 - 325	32 - 85	28 - 58
	Supply Costs per Tonne	[N\$/t]	356 - 444	640 - 724	973 - 1,098
	Supply Costs per Energy	[N\$/GJ]	19.7 - 24.6	35.5 - 40.5	44.2 - 49.9
Erongo Region	Transport Costs (< 600 km)	[N\$/t]	380 - 730	100 - 230	80 - 150
	Supply Costs per Tonne	[N\$/t]	757 - 845	710 - 794	1,023 - 1,148
	Supply Costs per Energy	[N\$/GJ]	42.0 - 46.9	39.4 - 44.1	46.5 - 52.2
Europe	Transport Costs (ARA)	[N\$/t]	1,300	630	580
	Supply Costs per Tonne	[N\$/t]	2,057 - 2,145	1,340 - 1,424	1,583 - 1,708
	Supply Costs per Energy	[N\$/GJ]	114 - 119	74.4 - 79.1	71.2 - 77.6

Figure 6.8 illustrates graphically the biomass supply costs for the three biomass based fuels chips, white pellets and black pellets differentiated to the considered end-user locations Windhoek, Erongo and Europe. Different results can be seen for the three regions, whereas a great dependency on the transport distance is shown. The transport distance primarily defines the biomass based fuel with the lowest specific supply costs per GJ. For the region Windhoek, chips are the most competitive biomass based fuel and provide definite cost advantages as compared to white or black pellets. White pellets however are the cheapest fuel for the Erongo region, whereas black pellets have the lowest supply costs for Europe due to high bulk and energy densities which lead to significant lower transportation costs compared to the other fuels chips

and white pellets. A possible biomass supply for South Africa (not shown) will be slightly higher than for the Erongo region.

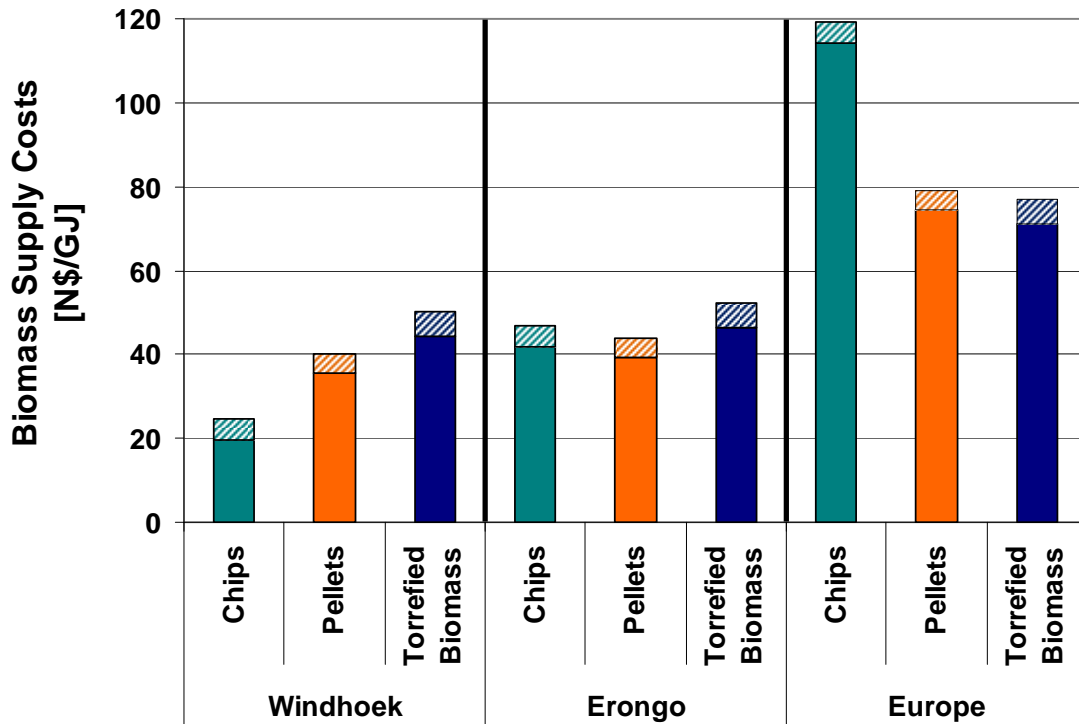


Fig. 6.39: Biomass supply costs for different biomass based fuels and different end-user locations (Windhoek, Erongo and Europe)

Table 6.8 shows a comparison of the roughly calculated supply costs for the three biomass based fuels at ARA (Amsterdam, Rotterdam, Antwerp) with current market prices in Europe.

Tab. 6.20: Comparison of biomass supply costs of the biomass based fuels chips, white and black pellets with current market prices at ARA in Europe

	Chips*	White Pellets**	Black Pellets***
Current Market Prices (ARA) [N\$/t]	400 - 650	1,650 - 1,850	1,950 - 2,350
[N\$/GJ]	31 - 50	89 - 103	89 - 103
Biomass Supply Costs (ARA) [N\$/t]	2,057 - 2,145	1,340 - 1,424	1,583 - 1,708
[N\$/GJ]	114 - 119	74.4 - 79.1	71.2 - 77.6

* calorific Value: 12 - 13 MJ/kg
 ** calorific value: 17 - 18 MJ/kg
 *** calorific value: 22 - 25 MJ/kg

The table indicates that the production and marketing of white or black pellets in Europe should probably be able to compete economically (green marked). The difference between the current market prices at ARA and the roughly calculated biomass supply

costs is positive. The production of chips for the European market however is not financially attractive due to high biomass supply costs (red marked).

Above considerations support the following conclusions concerning the optimum choice, which depends, as shown above, not only on the combustion technology and its material requirements, but also on the transport distance. A general recommendation would be to:

- Primarily consider the supply of chips for decentralized biomass or hybrid power plants as well as industrial applications in Windhoek
- Primarily consider the supply of white pellets for power plant or other industrial applications in the Erongo region
- Primarily consider the supply of bio-coal (black pellets) for overseas export purposes (e.g. coal-fired power plants in Europe). The figures presented, however, indicate that the international export of biomass is economically viable especially as big volume scenario, whereas small volumes like 50,000 - 100,000 t/a reduce the economic viability. A large volume scenario would utilize large scale shipment parcels with resulting cost advantages, but would also require an upgrade of rail and port infrastructure.

The optimal fuel supply for van Eck Power Station in the form of chips or of bio-coal pellets is recommended to be further investigated. The technical feasibility of co-combustion of wood chips need to be explored with regard to optimum capacity utilization. Chips could be an alternative to bio-coal as price competitive fuel and/or as a possible interim solution until that point in time when sufficient and reliable bio-coal supply is secured. In support of the NamPower rehabilitation schedule, chips could provide a fuel solution that can be made available on a short- to mid term perspective. Clearly, the realization of a torrefaction plant and process will still take a minimum of 3 - 4 years.

As far as the current biomass market situation is concerned, the demand is rather for white pellets than for black pellets as no black pellet market is established. That suggests to start with the production of white pellets and convert the plant to a black pellet option later as soon as the local and international market demand is confirmed. Such a conversion is possible by adding a torrefaction step between raw material storage and fine grinding step (see figure 6.5). However, a torrefaction pilot plant in Namibia is an interesting option with three potential future market opportunities:

- NamPower, van Eck power station: the future role of the rehabilitated van Eck power station (as base load or peak load power plant) and the optimum biomass fuel supply need to be clarified,
- South Africa: Eskom's midterm biomass policy and perspectives need to be substantiated,
- Europe and other oversea markets: the international mid- to long term demand and potential suppliers need to be reliably established.

Further research and the substantiation of these market segments are required. Any potential investor or developer of torrefaction plants will require a confirmed market demand. In a positive perspective, the development of a torrefaction plant, possibly together with the realization of a biomass/solar hybrid power plant, would position Namibia as an international energy innovation hub.

7 List of Figures

Fig. 3.1: Percentage distribution of local electricity generation (based on [8])..	8
Fig. 3.2: Workload of Namibia's power plants during the last decade 2001-2011 (based on 7500 operating hours per year)	8
Fig. 3.3: Power demand energy production and import [18].....	9
Fig. 3.4: Percentage distribution of Namibia's energy supply in 2012 (based on [18])	9
Fig. 3.5: Forecast of power consumption and supply in Namibia including peak demand (based on [8], [14], [28])	10
Fig. 4.6: Invader bush distribution in Namibia [27].....	13
Fig. 4.7: Namibian rangeland with and without bush encroachment	14
Fig. 4.8: Examination of the current utilization of invader bush	14
Fig. 5.9: Harvesting options of invader bush	17
Fig. 5.10: Biomass chips	20
Fig. 5.11: Process flow sheet for the production of biomass chips	21
Fig. 5.12: Chipper for the production of biomass chips	21
Fig. 5.13: Schematic illustration of disc and drum chippers [5].....	22
Fig. 5.14: Biomass briquettes/logs	23
Fig. 5.15: Process flow sheet for the production of biomass briquettes/logs	23

Fig. 5.16: Schematic illustration of an extruder press [16].....	24
Fig. 5.17: Biomass pellets	26
Fig. 5.18: Process flow sheet for the production of biomass pellets.....	27
Fig. 5.19: Biomass pelletizing system [24]	27
Fig. 5.20: Price development of certificated and non-certificated biomass pellets in Europe.....	30
Fig. 5.21: Expected biomass pellet demand in Europe from 2011 to 2015 [26]	31
Fig. 5.22: Bio-coal pellets (torrefied biomass pellets)	33
Fig. 5.23: Process flow sheet of the overall torrefaction process.....	33
Fig. 5.24: Possible torrefaction reactor types	34
Fig. 5.25: Possible heat exchange concepts for the torrefaction process.....	35
Fig. 5.26: Torrefaction technology supplier in Europe differentiated in reactor types and heat exchange concept.....	36
Fig. 5.27: Relative costs for biomass logistics and different destinations	40
Fig. 5.28: Road network in Namibia differentiated to the surface type	40
Fig. 5.29: Railway network in Namibia	41
Fig. 5.30: Biomass value and supply chain	43
Fig. 5.31: Assumed leveled costs of electricity for Namibia.....	46
Fig. 6.32: Typical process flow-sheet of a biomass power station on the base of a moving grate	50

Fig. 6.33: Typical site plan of a biomass power station	51
Fig. 6.34: Selected sites for biomass power plants and supporting harvesting area (Okahandja as pilot plant)	53
Fig. 6.35: Typical site plan of a hybrid power station with a combined solar biomass plant.....	56
Fig. 6.36: Process flow sheet for the production of white pellets with an optional integrated torrefaction process step for the production of black pellets (red marked)	60
Fig. 6.37: Namibian map with sites for biomass chips or white pellet production linked with decentralized biomass power stations including the necessary harvest area (Okahandja as pilot plant).....	63
Fig. 6.38: Namibian map with sites for black pellet production linked with decentralized biomass power stations including the necessary harvest area (Okahandja as pilot plant)	64
Fig. 6.39: Biomass supply costs for different biomass based fuels and different end-user locations (Windhoek, Erongo and Europe).....	66

8 List of Tables

Tab. 3.1: Main national power plants for current energy supply in Namibia	7
Tab. 3.2: Overview of discussed or planned energy projects in Namibia (based on [1], [12], [14], [15], [18], [22], [23])	11
Tab. 5.3: Evaluation of the different harvesting options.....	19
Tab. 5.4: Typical price ranges for biomass briquettes/logs in Namibia, South Africa and Europe.....	25
Tab. 5.5: Chemical and physical properties of Namibian invader bush in comparison to German and European standards of biomass briquettes/logs	25
Tab. 5.6: Overview of the installed biomass pellet production capacities worldwide (data based on [6] and 2011).....	28
Tab. 5.7: Major biomass pellet production plants in the world, in Germany and in South Africa (data based on [6] and 2011).....	29
Tab. 5.8: Chemical and physical properties of Namibian invader bush in comparison to German and European standards of biomass pellets.....	30
Tab. 5.9: Property comparison of different biomass based fuels with fossil coal.....	38
Tab. 5.10: Price comparison of different biomass based fuels differenced to the regions Namibia, South Africa and Europe	39
Tab. 5.11: Rail and road rates for bulk transport from Okahandja to selected destinations	45
Tab. 5.12: International transport costs based on the supply area Okahandja.	45

Tab. 6.13: Parameter for the concept design of decentralized biomass power stations.....	52
Tab. 6.14: Harvesting area and radius for biomass supply in support of 5 MW biomass power plants (Okahandja as pilot plant).....	52
Tab. 6.15: Scenario profitability analysis for 5 MW decentralized biomass power stations.....	54
Tab. 6.16: Parameters for the concept design of decentralized biomass power stations.....	61
Tab. 6.17: Calculated harvest area and harvest radius for biomass supply of the biomass power stations and the integrated biomass chips or white pellet production plants at selected sites (Okahandja as pilot plant).....	62
Tab. 6.18: Calculated harvest area and harvest radius for biomass supply of the biomass power stations and the integrated black pellet production plants at selected sites (Okahandja as pilot plant).....	62
Tab. 6.19: Rough assumption concerning the biomass supply costs for the three destinations Windhoek, Erongo and Europe according to different biomass based fuels.....	65
Tab. 6.20: Comparison of biomass supply costs of the biomass based fuels chips, white and black pellets with current market prices at ARA in Europe	66

9 List of Acronyms

ARA	Amsterdam, Rotterdam, Antwerp
CBEND	Combating Bush Encroachment for Namibia's Development
CCF	Cheetah Conservation Fund
CSP	Concentrated Solar Power
DNI	Direct Normal Irradiation
EDM	Electricidade de Moçambique
EFF	Energy for Future
ESCOM	Electricity Supply Commission
FOB	Free on Board
HFO	Heavy Fuel Oil
LCOE	Leveled Costs of Electricity
LNG	Liquid Natural Gas
OBI	Omuriro Biomass Investment
R&D	Research and Development
SADC	Southern African Development Community
SAPP	South Africa Power Pool
SWAWEK	South West Africa Water and Electricity Corporation
ZESA	Zimbabwe Electricity Supply Authority
ZESCO	Zambia Electricity Supply Corporation Limited

10 Reference List

- [1] Erasmus, D.; et. al.:
„Environmental and Socio-Economic Impact Assessment for a coal-fired Power Station in the Erongo Region of Namibia”
Aurecon, 2012
- [2] Schulz; R.:
„Bush to Electricity - Guidelines for Independent Power Producers”
CBEND, 2011
- [3] von Oertzen, D.:
„Biochar in Namibia: Opportunities to Convert Bush Encroachment into Carbon Offsets”
Study, 2009
- [4] Moses, A.; Nelumbu, D.; Pallet, J.:
„Biomass Workshop on Wheels - Renewable Energy and Energy Efficiency Capacity-building Project”
2007
- [5] van Loo, S.; Koppejan, J.:
„The Handbook of Biomass Combustion & Co-firing”
Earthscan, UK/USA, 2008
- [6] N.N.:
„The World of Pellets”
SBSAB/Bioenergy International Magazine, Stockholm, 2013
- [7] de Klerk, J.N.:
„Bush Encroachment in Namibia”
Study, 2004
- [8] von Oertzen, D.:
„Namibia’s Energy Future – A Case for Renewables in the Electricity Sector”
Study, Konrad Adenauer Stiftung, 2012
- [9] Diekmann, U.; Muduva, T.:
„Namibia’s Black Gold – Charcoal Production, Practices and Implications”
Study, Legal Assistance Centre, 2010
- [10] Mlunga, L.:
„Material Flow Analysis of Wood Fuel in Small Urban Areas”
2012
- [11] N.N.:
„Biomass Fuel Procurement Guide”
Carbon Trust, 2012
- [12] Schulz, R.; et. al.:
„Energy Policy Scenarios for Namibia”
Ministry of Mines and Energy; GOV of Namibia, 2007

- [13] N.N.:
„Pre-Feasibility Study for a Biomass Power Plant in Namibia Fuelled by Encroacher Bush”
NamPower, 2013
- [14] Shilamba, P.:
„Electricity Supply Update”
Presentation to a Chamber of Mines, NamPower, 2013
- [15] Chalakova, I.
„Angola Namibia 600 MW HPP Baynes”
SeeNews Renewables, 2013
- [16] Kaltschmitt, M.; Hartmann, H.; Hofbauer, H.:
„Energie aus Biomasse – Grundlagen, Techniken und Verfahren”
Springer-Verlag, Berlin Heidelberg, 2009
- [17] von Oertzen, D.:
„Green Energy in Namibia”
VO Consulting, 2009
- [18] von Oertzen, D.:
„Namibia’s Biofuel Potentials”
VO Consulting, 2009
- [19] Leinonen, A.:
„Wood Chip Production Technology and Costs for Fuel in Namibia”
Study, VTT, 2007
- [20] Feller, S.; et. al.:
„Development of the Bushblok Industry in Namibia”
Worcester Polytechnic Institute, 2006
- [21] Baldiga, J.; et. al.:
„Bush Harvesting Sustainability through Accommodation and Aftercare Recommendations”
Worcester Polytechnic Institute, 2008
- [22] Leuscher, E.:
„Strom aus Altöl”
Allgemeine Zeitung, 2013
- [23] N.N.:
„Vision Industrial Park and Related Gecko Projects”
Gecko, 2013
- [24] N.N.:
„Kahl Pelletpressen für Futtermittel, Trockengrün, Trockenschnitzel, Stroh und weitere nachwachsende Rohstoffe”
Amandus Kahl, 2013
- [25] N.N.:
„Energy for Future: Bush-to-Fuel Project”
ColinChristian & Associates CC, 2010

- [26] N.N.:
„Global Wood Pellet Industry Market and Trade Study”
IEA Bioenergy, 2011
- [27] N.N.:
„National Integrated Resource Plan”
World Bank Group & Electricity Control Board of Namibia, 2012
- [28] N.N.:
„Update on progress of NamPower projects and initiatives aimed at addressing the power supply situation in Namibia”
NamPower, 2012
- [29] N.N.:
„Facts about Namibia Ecologs”
<http://woodco.biz/index.php/products>