Feasibility study to use waste as fuel for cement factories

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Output 1:

Report on the technical feasibility study for RDF production and its use as fuel in cement factories

Introduction

Municipal Solid Waste Management (MSWM) represents an important challenge for cities as it does not only contribute significantly to climate change, but also has important socioeconomic and environmental impacts. Worldwide, 12% of total global methane emissions are generated by landfills (Hoornweg and Bhada-Tata, 2012). Another considerable source of methane emission is waste incineration. Together, the two sources generate around 40 MMTCO2e/year (UNEP, 2010).

Waste generation rates are normally correlated to per capita energy consumption, GDP and final private consumption, and although developed countries are striving to decouple waste generation from economic growth, reduction in waste generation still remains a challenge, particularly where populations are increasing. As developing countries progress towards achieving higher living standards, overall waste generation and generation per capita is set to increase accordingly with increasing production and consumption patterns (UNEP, 2010). While waste generation is expected to increase, developing countries also struggle with the lack of proper infrastructure for handling the increasing amounts of municipal solid waste (MSW). Open burning of waste is still common practice in many developing countries. Even though developing countries are experiencing a shift from open dumping or burning of waste to waste disposal in controlled landfills, and higher rates of waste collection services to the urban population, municipalities often lack financial resources for MSWM, due to under budgeting by central governments and inefficient strategies to recover the costs of waste services (waste taxation and collection of fees).

The lack of resources and proper infrastructure results in low quality waste management services, being characterized by low collection rates, and a continuing high incidence of non-controlled waste disposal practices (e.g. open waste dumping and open incineration). These unsustainable MSWM practices lead to a number of issues, not only related to climate change. Environmental and human health damage, biodiversity loss, air and water pollution, and soil erosion can be added in the list of negative effects of inappropriate MSWM practices. The health effects impacts the quality of life for both urban and rural population, spreading vector-borne diseases and affecting the health of local communities. In addition, the waste sector in developing countries is in the absence of a well-established formal sector, usually serviced by informal waste pickers struggling with social issues such as poverty, discrimination, child labour, social rejection, lack of education, etc.

Being faced by these challenges related to MSWM, and with expectations of increasing urbanization, an expected increase in waste generated, developing countries are looking to solutions to improve their MSWM and utilize the untapped resources in the waste streams. Simultaneously, expected higher fuel prices are pressing the cement industry to look for alternative fuels for clinker production. Since cement manufacturing requires extremely high temperatures, it consumes more energy than other industrial processes, which is why the cement industry is also responsible for a large part of GHG emissions. The large energy requirements and fossil fuel usage also lead to high costs in the production process. Therefore, reducing the use of fossil fuels in an economically efficient way represents a challenge for the sector.

Experiences from European countries with well-developed waste collection systems and high disposal costs show that the use of MSW to produce refuse-derive fuel (RDF) in the cement production can save companies large amounts of money, and provide and alternative controlled disposal of waste. However, the potential use of RDF in developing countries still remains largely untapped (Lechtenberg, 2008). This report investigates the potential for synergies between the current efforts in MSWM management and the cement industry in Mozambique, looking at the potential for RDF production from MSW in Maputo to be used in clinker production by CdM.

The situation of the MSW sector in Mozambique shares many of the characteristics described above. Despite having experienced high average growth rates of 8%/y between 2001 and 2011, the country is still in dire need of development, with approximately 60% of its 23.9 million strong population living on less than US$ 1.25 per day (Tas, Belon, 2014). According to the latest National Communication to the UNFCCC, the rate of solid waste generation per capita in the urban areas is about 1 kg/head/day, resulting in 1,574,280 tons of solid waste generated in 1994, and a total emissions of 74,190 tons CH_4, or 1.56 $MtCO_2e$ (MICOA, 2003). Waste generation is expected to increase rapidly, due to a general population growth in the country and an increasing rate of urbanization. It is estimated that Mozambique now generates approximately 2.5 million tons of municipal solid waste per year, (Tas, Belon, 2014). Growing waste quantities and the lack of economic resources places Mozambican municipalities in a difficult position, not allowing them to improve waste management infrastructure and services to meet the increasing needs of waste management. Nowadays, the final destination of solid waste in Mozambique is mostly open bins and uncontrolled dumpsites with no or very little waste treatment, leading to GHG emissions and significant health threats to the urban population.

Given the many challenges Mozambique is facing in handling its municipal solid waste, and expected increase in waste generation and urbanization, the country is now looking for technological solutions to address this issue. One of the potential opportunities is the creation of synergies with industries that could utilize waste or fractions of waste as a resource in their processes. The use waste as refuse-derived fuel (RDF) in the cement production has been proven to be successful under certain pre-conditions, and has been already implemented in other countries, mostly high and medium income countries.

The Mozambican cement sector has showed a rapid growth in the last years. According to Global Cement, the cement production capacity in Mozambique is expected to increase from 2.66 million tons / year today to 5.5 million tons / year in the coming years. Building on the potential synergy between the municipal solid waste the cement industry the Mozambican government created the Working Group - Waste in 2014 aiming at identify climate finance opportunities for the treatment of Municipal waste, as well as discussing different MSWM approaches and technologies. The use of MSW and fuel in cement plants has been discussed as part of these strategies. The working group is led by MITADER (Ministry of Earth, Environment and Rural Development) with the participation of ANAMM – the Association of the Mozambican Municipalities, but also FUNAB, Carbon Africa and AMOR. Last year, the Working Group decided to include the waste to energy concept as a part of the national NAMA for the waste sector, which is currently being developed by the Government.

In summary, the interest of both the private sector and the public sector to use municipal waste as fuel for cement factories has been proven. Moreover, the company 3R is developing Waste Transfer and Recycling Centres with the aim to treat municipal waste for recycling. Currently, the Nord Development Fund is financing the designing of a NAMA for waste recycling and transfer centres, including the construction of a Waste Transfer and Recycling Centre in the Municipality of Beira. This approach is expected to be expanded to 4 additional cities till 2018. In addition to recycling, it is expected that these facilities will treat the residual waste materials for its transformation into RDF.

Having this background, this project aims to determine the technical and financial feasibility of the production and use of municipal solid waste in cement factories in Mozambique. However, knowing that the only cement plant able to use RDF as fuel in its operation is Cimentos Mocambique (CdM), this study only analyses the potential use of RDF for the Matola plant, which is also conveniently located near the municipality of Maputo and Matola, where the highest generation, concentration and collection of municipal solid waste is located.

This report will deliver a technical desk study with focus on the potential production of Refuse Derived Fuel (RDF) from MSW from unsorted waste in Maputo and Matola, the quality specifications, as well as the RDF production flow. Furthermore, this report will describe the technical requirement that needs to be fullfilled by CdM, in order to be ready for using RDF as fuel for its processes.

1 Municipal Solid waste in Maputo and Matola

1.1 Current waste generation and waste management

More than 20% of urban waste in Mozambique is being generated in the Greater Maputo-Matola Metropolitan Area. Maputo city is the largest city in Mozambique, with and area of 316 km2. Maputo has approx. 1,194,121 inhabitants (2012), with a 1.45% population growth rate[1]. The "Cidade de Cimento" (urban area of Maputo and Matola) and the sub-urban areas concentrate the largest amount of population. Both areas had 925,523 inhabitants in 2007 (Maputo MSW plan, 2008). With a waste generation rate of 1.15 Kg/day-person in Cidade de Cimento and 0.49 in the sub-urban areas (Maputo´s MSW plan, 2008), the total MSW amount generated in 2007 was around 64,690 tonnes. In Cidade de Cimento, 65% of the MSW is collected either by the municipality or private service providers (GIZ, 2012), while in the sub-urban areas only 25% of the waste is collected (MSW plan Maputo, 2008). The rest remains on non-authorized sites, such as streets, open dumps, water bodies, etc. There is one controlled landfill serving the whole Maputo city, including the Cidade de Cimento, the Hulene Landfill, which was opened in the mid 1960s and should have been closed in 2012. The site is located about 10 km from the city center and near the airport. It has an area of about 17 hectares and, currently, between 280 and 350 tons a day are deposited in the dump (estimates of the Municipality are as high as 850 tons per day)[2]. This landfill does not have any kind of technical monitoring or revision. Normally, waste pickers work collecting recyclables on the street and in the landfill, being exposed to health and physical risks related to handling of waste.

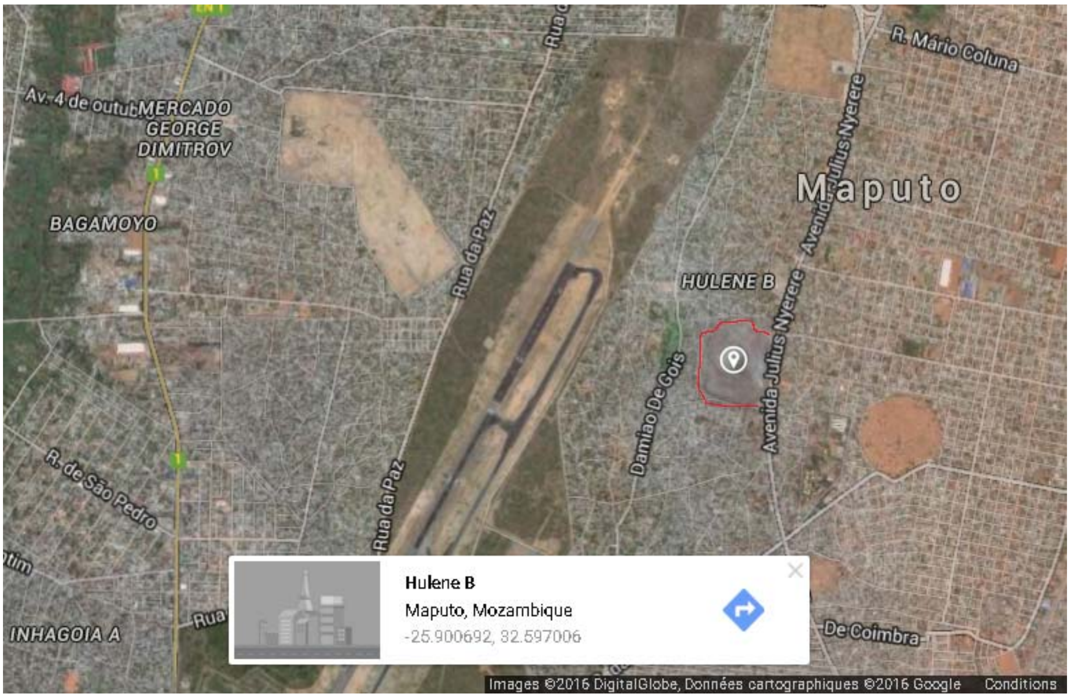

Figure 1: Hulene dumpsite and GPS coordinates

Matola uses a separate landfill of Matlhampsene, covering an area of 20ha, of which only 4ha are utilized at this stage.

[1] Instituto Nacional de Estatistica, Anuário Estatístico Cidade de Maputo 2008-2012

[2] AMOR A Comprehensive Review of the Municipal Solid Waste Sector in Mozambique (2014)

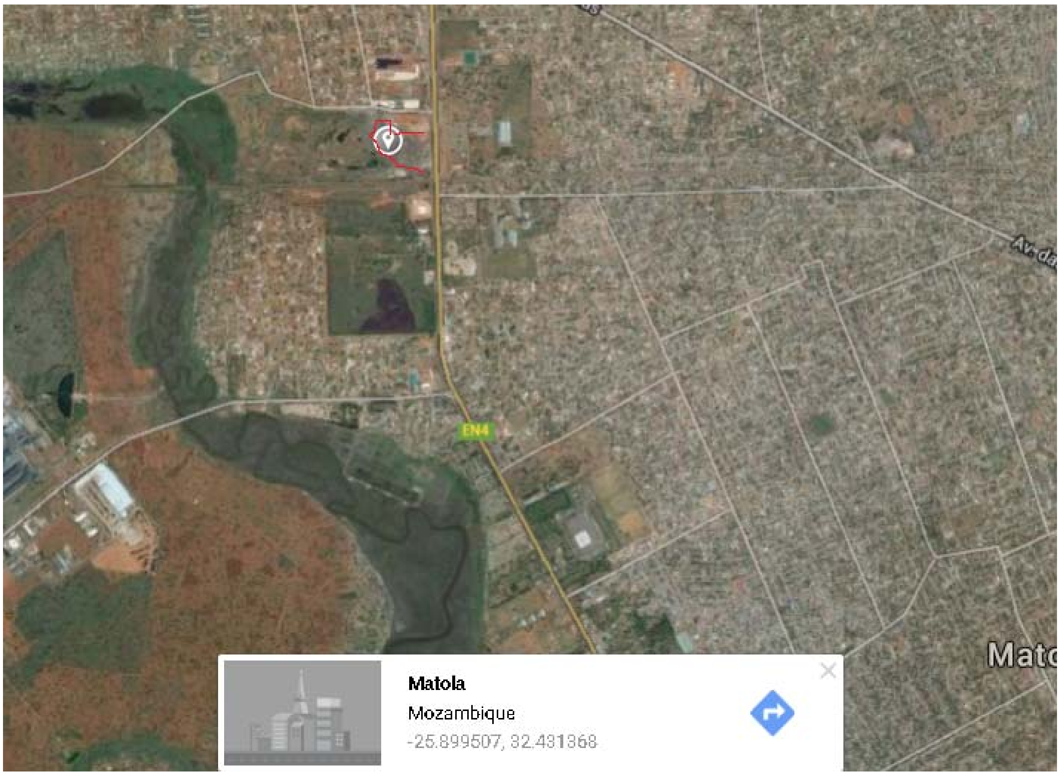

Figure 2: Matlhampsene dumpsite and GPS coordinates

There is no recycling plant in operation in Maputo, but several formal small-scale recycling activities are taking place. It is estimated that 450t to 500t of waste/month are recycled in Mozambique, 85% of it in Maputo/Matola, corresponding to approximately 4,080 t/year, or 1,3% of the waste produced. The recycled material is mostly intended for export to South Africa, while some strong plastic waste (HDPE, PP) is converted to pellets for the national market. Some national glass bottles are collected and then sold to the national brewery for re-use.

The informal waste pickers usually collect recyclable material, both at established waste collection points distributed throughout the city, and at the Hulene landfill. Most of the waste pickers are single males and work under unsafe and unsanitary conditions. The waste pickers mostly gather hard plastic material, iron, glass, aluminum, paper and cardboard, and sell them at local markets in the city, providing an average income of 97,3 Mt/day (1,3 USD/day) (Mertanen et.al, 2013). The Mozambican Association for Recycling (AMOR) estimates that only 1% of the urban waste produced in Mozambique, especially in Maputo and Beira, is recycled by the formal sector with designated companies in charge of the operations (Tas, Belon, 2014).

The waste collection system in Maputo is commissioned by the municipality but privately operated. In most of the residential areas of Maputo and neighboring Matola, household waste is unsorted and collected through a system of secondary collection points, meaning that residents drop off their waste in strategically positioned containers close to their homes. The waste is collected at a daily frequency, and mainly transported by trucks to the disposal site. There are, however, variations in how the system works. In higher income areas, the residents receive door-to-door service as the waste is collected at the doorstep. In the outskirts of the city, where the roads are not accessible for trucks, the municipalities have set up a system of micro-enterprises which collects the waste door-to-door, and bring it to collection points.

The residents pay a fee for the service that is charged through the electricity bill. The current rates cover the cost of running the system up to 90%; the municipality makes up for the shortfall.

The waste collection company ECOLIFE covers the city center, along a 14 km route in downtown, Alto Maé, Malhangalene, Polana and in part of the Coop and Sommerschield neighborhoods. Their operation is run with nine waste trucks and more than 1,000 1,1k liter waste containers and 5 m3 waste bins placed on the ground, of which the company also is responsible for cleaning. The service covers approximately 130, 000 inhabitants, with an estimated daily collection of 130 tons of waste and its transportation to the Hulene municipal waste site. The company Enviroserv covers the sub-urban areas of Maputo. Both companies operate with suitable collection trucks, and most also have a compressor system to improve the efficiency of collection. Waste from institutions, commercial buildings and industries are collected through separate bilateral contracts between the waste producer and mostly private waste collection entities.

The waste collection service is almost absent in rural areas around Maputo, including Catembe and Inhaca. Due to the fact that the waste collection services in Cidade de Cimento and the sub-urban area are more established than in the rest of the urban districts, the project will consider treating the waste flows generated in serviced areas, which are intended for disposal at the landfill.

1.2 Expected development on Municipal Solid Waste Management in Maputo and Matola

A new landfill is currently being prepared in the area of Matlemele in the Matola municipality, which will replace the landfill of Hulene in Maputo. The new landfill will service both municipalities, and is designed to cover an area of 100 hectares with a capacity to receive 1,400 tons of waste per day, and. It is envisioned that the landfill will also feature a recycling center where the waste will be separated into paper, plastic, glass bottles and organic waste, aiming at a recycling rate of 200 tonnes of waste a day.

The authorities have not designated a final location for an eventual recycling and RDF plant as further consultation and negotiations with stakeholders in the public and private waste sector should be carried out. For the purpose of this study, the site destined for the Project will be located in Matlamele, Matola, where the future landfill is being planned. Providing an area available for the project (under concession) is a possibility but this should be established and formalized in further discussions with the Municipalities involved.

The future Matlemele's landfill will have and of 100 ha. However, at the moment, only 60 ha are still available, due to illegal occupation of approximately 40 ha. Currently, it is planned that the landfill will require approximately 20 ha; meaning that another 40 ha would be available for waste treatment operations. The new landfill of Matlemele is located in the Northern part of the new circular road of Maputo, approximately 6 km to the west from the cross of the Zimpeto Stadium (intersection of EN1 with circular road).

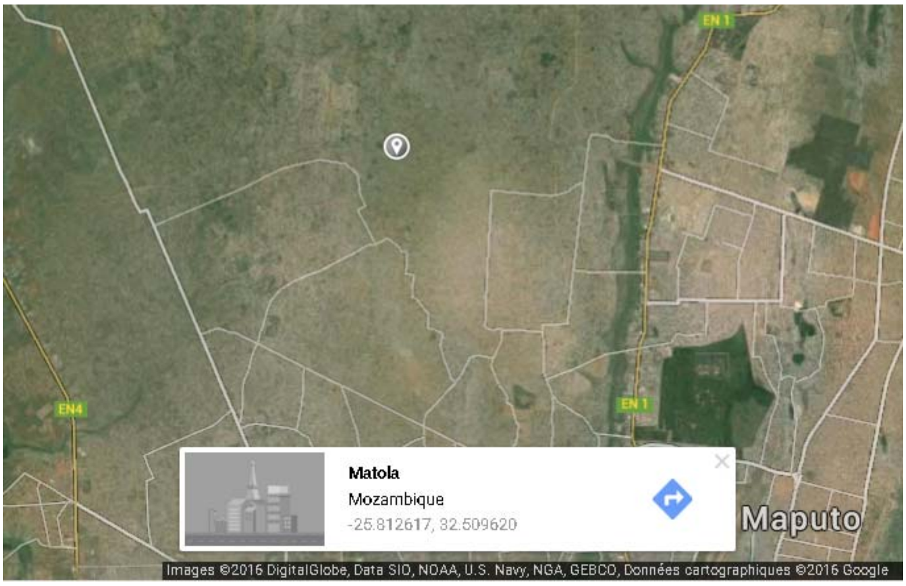

Figure 3 Location of the future Matlhemele's landfill (AMOR, 2016)

The transport distance from Maputo city centre (from the Municipal Town Hall) to the future landfill is approximately 25 km and the distance of Matola City (from, the Municipal Auditorium) to the future landfill is approximately 21 Km. The transport distance between the landfill and Cement of Mozambique (expected main buyer of RDF) is 20.4 km. Currently the Municipality of Maputo transports the MSW 9.2 Km to the Hulene landfill (AMOR, 2016).

1.3 Waste availability for the Project

To plan for the most appropriate management and use of MSW it is necessary to forecast future MSW generation and composition. However, waste composition and generation forecasting is usually difficult to do in developing countries due to lack of sufficient reliable historical data of MSW characteristics (Intharathirata et. al., 2015). This is also the case for waste generation and composition data for Maputo and Matola.

This RDF project was initiated through a partnership among several actors. According to several meetings among stakeholders of the public sector, the Municipality of Maputo would provide the access to the waste and implement a "postura municipal" to enhance waste separation (to screen the most interesting material for RDF already at source). The possibility of providing transport of the waste to the RDF facility, in coordination with the private operator of the RDF Facility (not established yet) has also been discussed.

To be able to analyze the waste's applicability for RDF production it is necessary to analyze its composition, Table 1 presents the MSW composition of Maputo disposed at the dumpsite of Hulene (AMOR, 2016)

Type of waste	Maputo (Cement City)
Paper	3.80%
Cardboard	5.60%
Rag, tyres	1.5%

Metal	2.80%
Glass	7.50%
Soft plastics	5.20%
Strong plastics	3.20%
One use paper	3.80%
Organic	63.70%
Fine fraction	0.00%
Others	2.80%
Total	99.90%

Data collected from a one week survey of waste collected at source

Table 1: Waste composition: Maputo (AMOR, 2016)

The waste composition can be expected to gradually change in the future, as consumption patterns are expected to change in line with economic growth and development. Changing consumption patterns caused by economic growth and urbanization also lead to changes in the waste composition, with an expected in increase the paper, paper packaging, plastics, multi material packing items and general 'consumer products'. For this study, the current waste composition has been used.

To be able to make projections on the potential future RDF generation, it is necessary to make predictions over the future expected waste generation. Future waste generation depends mainly on expected population and economic growth, allowing for increased consumption, leading to increasing waste streams. Based on the projections for population growth of the National Statistical Institute of Mozambique and literature sources (GIZ, 2012; MSW plan for Maputo, 2008), Table 2 shows the projections for MSW generation in Maputo (Cement city) from 2017 up to the year 2040. The amount of total waste collected can be expected to increase more than the estimations in this report, as collection service coverage is expected to be expanded. Although, a conservative approach has been used here.

YEAR	POPULATION MAPUTO (Cidade de Cimento)	AMOUNT TOTAL GENERATED MSW year (tonnes)	AMOUNT TOTAL COLLECTED MSW year (tonnes)
2017	151,459	63,575	41,324
2018	151,946	63,779	41,457
2019	152,453	63,992	41,595
2020	152,971	64,210	41,736
2021	153,492	64,428	41,878
2022	154,009	64,645	42,019
2023	154,525	64,862	42,160
2024	155,042	65,079	42,301
2025	155,556	65,294	42,441
2026	156,061	65,506	42,579
2027	156,553	65,713	42,714

2028	157,035	65,915	42,845
2029	157,506	66,113	42,973
2030	157,963	66,305	43,098
2031	158,400	66,489	43,218
2032	158,812	66,661	43,330
2033	159,195	66,822	43,434
2034	159,550	66,971	43,531
2035	159,874	67,107	43,620
2036	160,166	67,230	43,699
2037	160,427	67,339	43,770
2038	160,655	67,435	43,833
2039	160,851	67,517	43,886

Table 2 MSW generation of Maputo up to 2040

2 Refused Derived Fuel (RDF)- requirements for utilization in cement production

2.1 Definition

Basically, the term of "Refused Derived Fuel" (RDF) is used to define any material that can be co - combusted and used as a secondary fuel in incineration and/or industry plants. There is no legal definition for RDF and its interpretation depends frequently on the countries´ standards and requirements for its use. For instance the name assigned to secondary fuels may reflect the desire of the users to have the material treated in a specific way under existing legislation.

Industrial solid waste is typically more homogeneous in its physical and chemical characteristics. In de context of co-combustion, those materials are named as secondary fuel, substitute fuel and substitute liquid fuel (SLF). Examples of these fuels include waste tyres, waste oils, spent solvents, bone meal, animal fats, sewage sludge and industrial sludge (e.g. paint sludge and paper sludge). These terms can also refer to non-hazardous packaging or other residues from industrial/trade sources (e.g. plastic, paper and textiles), biomass (e.g. waste wood and sawdust), demolition waste or shredded combustible residues from scrap cars.

Regarding Municipal Solid Waste (MSW), there are different denominations according to the predominant waste fraction. Materials such as paper, plastic, packaging and other materials (separately collected but too contaminated to be recycled) can be used as secondary fuel, being named as Packaging Derived Fuels (PDF), Paper and Plastic Fraction (PPF), etc. However, typically the term "RDF" is used to indicate a secondary fuel derived from mixed waste fractions, different coarser grain sizes and variable physicochemical characteristics. The term of "Solid Recovered Fuel" (SRF) is used to define any secondary fuel that fulfils the standard CEN/TC 343, having a more homogenous structure, with standardized and predictable characteristics (Glorious, 2014).

There are different criteria for classifying RDFs. The table 5 shows different types and qualities of RDF for different uses in the industry, according to net calorific value and particle size:

Parameter for Classifica-tion	SRF-Specifications							
	Unit	Coalfired Power Station	Calciner	Grate Firing	Fluidized Bed	HOT DISC Cement Kiln (HDF)	Primary Burner Cement Kiln (PBF)	Blast Furnace (Steel Plant)
				Utility boilers				
Net Calorific Value	MJ kgOS-1	11 - 15	11 - 18	11 - 16	11 - 16	14 - 16	20 - 25	> 25
Particle Size	mm	< 50	< 50 - 80	< 300	< 20 - 100	< 120	< 10 - 30	< 10
Oversize	%	0	< 1	< 3	< 2	*	< 1	0
Impurities (extraneous material)	w%DM	< 1	0	< 3	< 1 - 2	*	< 1	0
Chlorine	w%DM	< 1.5	< 0.8	< 1.0 - 0.8	< 1.0 - 0.8	0.8 - 0.6	< 1.0 - 0.8	< 2
Ash	w%DM	< 35	*	*	< 20	20 - 30	< 10	< 10

*: no distinct limitation, depending on feeding system or ash discharge

Table 3 Classification of different RDF qualities used for co-incineration in different industrial sectors[3]

In order to simplify the terminology along this study, the term of "RDF" will be adopted to indicate a secondary fuel produced from mixed MSW, following standardized processes, complying international quality standards for its use in cement plants.

2.2 Typical characteristics of RDF

As known, the composition of the RDF from MSW depends strongly on the type of waste and its characteristics (e.g. Households, municipal like industrial waste, etc), to the collection system (mixed MSW, source separated) and treatment applied (mechanical, biological or a combination of both). The characteristics defining the quality of an RDF are mainly the calorific value, water content, ash content, sulphur, and chlorine content.

The Table 4 presents average compositions (quality) of RDF from different sources across Europe (CEN, 2001)[4].

[3] Use of Solid Recovered Fuels in the Cement Industry Roland Pomberger and Renato Sarc, 2014
[4] European Commission – directorate general environment refuse derived fuel, current practice and Perspectives (b4-3040/2000/306517/mar/e3) final report, July 2003

Parameter	Mixed MSW [a)]		Source-separated MSW [b)]	Source-separated ind. and com. waste [c)]	Monostreams of ind. and com. waste [d)]		Demolition and commercial waste [e)]		Range	EURITS limits
	median	80%-ile	mean	mean	Median	80%-ile	median	80%-ile		
Net Calorific Value (MJ/kg)	13.3	16.1	22.3	20.1	22.9	25.3	20.6	25.1	13-22	15
Moisture content (%)	24.7	22.0	33.6	16.6	11.5	17.2	13.4	18.8	11-34	
Ash content (%)	16.0	17.7	10.2	6.7	9.6	11.6	13.8	20.6	7-18	5
Chlorine total (%)	0.6	0.8	0.4	0.3	0.4	0.7	0.7	1.1	0.3-0.7	0.5
Fluorine total (%)	0.01	0.02	nd	nd	0.01	0.04	0.01	0.04	0.01	0.1
Sulphur total (%)	0.2	0.3	0.2	0.1	0.1	0.1	0.1	0.4	0.1-0.2	0.4
Cadmium (mg/kg dm)	0.6	1.6	1.2	Nd	0.8	3.2	2.2	4.9	0.6-2.2	10
Mercury (mg/kg dm)	0.4	0.5	0.3	0.1	0.2	0.4	0.2	0.3	0.1-0.4	2
Thallium (mg/kg dm)	<0.8	<0.8	Nd	Nd	0.5	1.5	0.4	0.5	0.4-0.5	2
Arsenic (mg/kg dm)	3.0	4.9	8.8	Nd	1.5	1.7	1.0	2.0	1.0-8.8	10
Cobalt (mg/kg dm)	3.7	5.8	nd	Nd	2.0	3.8	2.9	4.7	2-4	200
Nickel (mg/kg dm)	21.5	33.3	20	Nd	6.2	16.0	13.1	26.3	6-21	200
Selenium (mg/kg dm)	<2	<2	nd	nd	1.0	2.5	0.4	1.7	0.4-1	10
Tellurium (mg/kg dm)	<1	<1	nd	nd	1.0	5.0	0.4	1.0	0.4-1	10
Antimony (mg/kg dm)	10.1	20.3	nd	nd	9.4	33.9	10.8	42.4	9-10	10
Beryllium (mg/kg dm)	0.2	0.3	nd	Nd	0.2	0.3	0.2	0.3	0.2	1
Lead (mg/kg dm)	121	189	52.4	nd	25.0	64.4	89.0	160.0	25-121	200
Chromium (mg/kg dm)	70.0	103	140	Nd	20.0	43.9	48.0	82.9	20-140	200
Copper (mg/kg dm)	59.5	88	80	Nd	48.0	118	97.5	560.0	48-98	200
Manganese (mg/kg dm)	nd	Nd	210	Nd	28.0	47.0	61.0	94.0	28-210	200

Table 4 Average composition of RDF across Europe (CEN, 2001)

It can be seen from the values presented in Table 4 that source separated and more homogenous waste have higher calorific values than mixed waste. The moisture content of RDF is more favourable for non-MSW (i.e. demolition waste, commercial and industrial waste) than for MSW (25-34%). The ash content of RDF from commercial and industrial waste streams appears to be lower (7-10%) than for the other waste streams (10-16%), but higher than the EURITS (European Association of Waste Thermal Treatment Companies for Specialised Waste) requirement. However, this norm has been reported by the cement industry as being too stringent[5].

Regarding MSW, its composition (distribution of waste fractions) has an enormous influence on the physicochemical features, such as heat value, moisture, etc. As it can be seen from the previous table, the higher moisture content in waste, the less calorific value has the resulting RDF. In Europe, producing RDF from MSW does not represent a big challenge, due to the appropriate waste composition (low organic fraction, high inorganic dry fraction). This is not the case of MSW generated in developing countries, where MSW is characterized by higher amounts of organic waste and low contents of dry fraction. In addition to this, waste pickers perform recycling activities, sorting out fractions with high calorific content such as plastic, paper and cardboard, so the dry fraction in the MSW becomes even lower. Hoornweg and Bhada-Tata (2012) compiled information about waste composition by cities and countries worldwide, including data for 105 countries. Below, table 7 presents waste composition averages by region. The table shows indeed the notable difference between the waste composition in developed countries and developing countries, where the MSW has high content of organic matter and low content of dry fraction.

[5] European Commission – directorate general environment refuse derived fuel, current practice and Perspectives (b4-3040/2000/306517/mar/e3) final report, July 2003

Region	Waste materials					
	Organic %	Paper %	Plastic %	Glass %	Metal %	Other %
Sub-Saharan Africa	57	9	13	4	4	13
East Asia and the Pacific	62	10	13	3	2	10
Eastern and Central Asia	47	14	8	7	5	19
Latin America and the Caribbean	54	16	12	4	2	12
Middle East and North Africa	61	14	9	3	3	10
OECD	27	32	11	7	6	17
South Asia	50	4	7	1	1	37

Table 5 Waste composition by region (Hoornweg and Bhada-Tata , 2012)

2.3 Quality of RDF/SRF according international standards

Basically there are two criteria defining the viability of using waste as input for RDF: its homogeneity regarding physicochemical characteristics and long term waste availability. As mentioned before, the calorific value, particle shape and size, chlorine, moisture, heavy metals, and ashes contents are influenced by the waste characteristics and the treatments to RDF.

Developed by CEN/TC343, the EN15359 - 2011 (Solid Recovered Fuels – specifications and classes) is the most crucial. EN15359 provides a system for specification and classification of SRF. It also provides for a set of compliance rules that points out how SRF can be characterized in a reliable way. The EC 15359 identifies three properties for describing and/or classifying SRF (RDF that fulfils the standards):

- Net calorific value (increasing market value of the fuel)
- Chlorine, unwanted as it contributes to corrosion. High chlorine content will lower the market value.
- Mercury (Hg), of all relevant heavy metals, Hg is selected as an indicator of the environmental quality of a SRF. Because of its high volatility, Hg is the heavy metal most likely to be emitted.

Although the classification system focuses on Hg, all heavy metals according to the Waste Incineration Directive (WID) are obligatory parameters for specification according to EN 15359. Per property mentioned, five classes have been established (see table 8).

Classification characteristic	Statistical measure	Unit	Classes 1	2	3	4	5
Net calorific value (NCV)	Mean	MJ/kg (ar)	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3

Classification characteristic	Statistical measure	Unit	Classes 1	2	3	4	5
Chlorine (Cl)	Mean	% (d)	≤ 0.2	≤ 0.6	≤ 1.0	≤ 1.5	≤ 3

Classification characteristic	Statistical measure	Unit	Classes 1	2	3	4	5
Mercury (Hg)	Median 80th percentile	mg/MJ (ar) mg/MJ (ar)	≤ 0.02 ≤ 0.04	≤ 0.03 ≤ 0.06	≤ 0.08 ≤ 0.16	≤ 0.15 ≤ 0.30	≤ 0.50 ≤ 1.00

Table 6 Classification system for RDF according to the EN 15359:2011 (Glorious, 2014[6])

Besides the EN 15359, there are different initiatives for specifying minimum quality requirements for waste derived fuels. Standards for RDF have been developed in in Finland, Italy, and Netherlands (Table 9), while in Germany the certification label RAL is used (RAL-GZ 724). Sweden and UK have developed standards for secondary fuels specifically for the cement industry (table 10). Other countries such as the Flemish Region of Belgium adopted the standards issued by European Federation for Waste Treatment Plants - EURITS for production and use of waste fuel in clinker production (table 11).

		Italy	Finland[1)]			
Characteristic	Unit		DL	Quality Class I	II	III
Water content	%	<25				
Calorific Value	KJ/kg	15,000				
Ash content	%	20				
Chlorine content	% (m/m)[2)]	0.9	0.01	<0.15	<0.50	<1.50
Sulphur Content	% (m/m)[2)]	0.6	0.01	<0.20	<0.30	<0.50
Nitrogen Content	% (m/m)[2)]	-	0.01	<1.00	<1.50	<2.50
Potassium and sodium content [3)]	% (m/m)[2)]	-	0.01	<0.20	<0.40	<0.50
Aluminium Content	% (m/m)[2)]	-	0.01	[4)]	[5)]	[6)]
Mercury Content	Mg kg^{-1}	-	0.1	<0.1	<0.2	<0.5
Cadmium Content	Mg kg^{-1}	-	0.1	<1.0	<4.0	<5.0
Lead	Mg kg^{-1}	200				
Copper	Mg kg^{-1}	300				
Manganese	Mg kg^{-1}	400				
Chromium	Mg kg^{-1}	100				
Zinc	Mg kg^{-1}	500				
Nickel	Mg kg^{-1}	40				
Arsenic	Mg kg^{-1}	9				
Cadmium+mercury	Mg kg^{-1}	7				

[6] Production and use of Solid Recovered Fuels – developments and prospects, Glorious Thomas, REMONDIS GmbH, Cologne/Germany, 2014

Table 7 Quality standards for RDF in Italy and Finland (EU Commission, 2003)

Parameter	Criteria	
	"Specialbränsle A"	**"Lattbränsle"**
Calorific value	23.9 – 31.4 MJ/kg	25.1 – 31.4 MJ/kg
Flash point	< 21°C	< 21°C
Specific density at 15°C	0.9 – 1.1 kg/dm^3	0.80 – 0.95 kg/dm^3
Viscosity	Pumpable	1 – 5 cst at 50°C
Ash content	5 – 10 %	0.6 – 0.8 %
Water	< 30 %	< 10 %
Cl	< 1 %	< 1 %
S	N/A	< 0.5 %
Cr	< 300 ppm	< 30 ppm
V	N/A	< 50 ppm
Z	N/A	< 300 ppm
Zn	< 2000 ppm	N/A
Cd	< 10 ppm	< 5 ppm
Pb	< 350 ppm	< 100 ppm
Ni	N/A	< 10 ppm
Hg	N/A	< 5 ppm
PCB	N/A	< 5 ppm

Table 8 Specification for RDF used in cement plants in Sweden (EU Commission, 2003)

Parameter	Unit	Value
Calorific value	MJ/kg	15
Cl	%	0.5
S	%	0.4
Br/I	%	0.01
N	%	0.7
F	%	0.1
Be	Mg/kg	1
Hg/Ti	Mg/kg	2
As, Se (Te), Cd, Sb	Mg/kg	10
Mo	Mg/kg	20
V, Cr, Co, Ni, Cu, Pb, Mn, Sn	Mg/kg	200
Zn	Mg/kg	500
Ash content (excl Ca, Al, Fe, Si)	%	5

Table 9 EURITS criteria for co-processing of waste in cement kilns (EU Commission, 2003)

2.4 Emission limits values for cement plants using RDF

In Europe, the emissions limits for cement plants using RDF are determined by each country, within the framework of the European Directive for Hazardous Waste Incineration (1994). Based on this, some countries such as Belgium, Spain and United Kingdom apply the "mixing rule" specified in the Hazardous Waste Incineration Directive; meaning that for an energy substitution from hazardous waste lower than 40%, the emission limits are proportional to the volume of exhaust gas resulting from the incineration of waste. However, some countries do not allow the mixing rule for cement plans (e.g. Austria, France, and Netherlands) not even at a lower substitution rate. In Germany, above 25% of energy substitution, the limit values applying to co-incineration plants are more stringent than limits laid down in 1994 Incineration Directive.

The table 12, shows the emission limit values for cement kilns using waste as RDF, specified by the Directive for Hazardous Waste Incineration (1994).

Pollutant	C
Total dust	30
HCl	10
HF	1
NO_x for existing plants	800
NO_x for new plants	500 (1)
Cd + Tl	0,05
Hg	0,05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	0,5
Dioxins and furans	0,1

Pollutant	C
SO_2	50
TOC	10

Table 10 Total emission limit values[7] (all values in mg/m^3; for Dioxins and furans ng/m^3)

2.5 RDF requirements for utilization in Cimentos de Moçambique

Cimentos de Moçambique (CdM) intends to gradually scale up the use of RDF at the Matola factory with a target use of 33,375 tons in 2026.

Year	RDF consumption (tons)	RDF consumption (tons/day)
2018	9,512	30
2021	25,031	80
2026	33,375	107

Table 11: RDF requirements at Matola I

[7] Incineration directive EU DIRECTIVE 2000/76/EC of the European parliament and of the council of 4 December 2000 on the incineration of waste

Mozambique does not have specific standards and guidelines regarding the use of RDF in the cement industry. International RDF specifications are given by the standard ASTM E856-83 (2006) which classifies the RDF on the following categories:

Code	Description
RDF-1	Waste used in as discarded form
RDF-2	Waste processed to coarse particle size with or without ferrous metal separation such as 95% by weight passes through 150 mm mesh screen (**Coarse RDF)**
RDF-3	Waste processed to separate glass, metal and inorganic materials, and shredded such that 95% by weight passes through 50 mm mesh screen (**Fluff RDF**)
RDF-4	Combustible waste processed into powder form, such that 95% by weight passes through 10 mm mesh screen (**Powder RDF)**
RDF-5	Combustible wastes densified (compressed) into the form of pellets, slugs, cubettes or briquettes (**Densified RDF)**
RDF-6	Combustible wastes processed into liquid fuels (**Slurry RDF)**
RDF-7	Combustible wastes processed into gaseous fuels (**Syngas RDF)**

Figure 4: Example of fine RDF for Main Burner[8]

For cement co-processing, RDF-2 and RDF-3 are normally used, coarse and fluff RDF respectively. The RDF should have high calorific value and low concentration of toxic chemical especially for metals and chlorine. Chlorine is a limiting factor for RDF quality not only for ecological reasons but for technical reasons since it will affect the kiln operation and the final quality of the cement. Other important parameters are water, ash and sulphur content. The values of these elements will vary according to the sources (i.e. households, offices, construction, etc.), according to the collection system (mixed MSW, source separated) and treatment applied (screening, sorting, grinding, drying).

[8] Source: http://www.wtert.eu/default.asp?Menue=13&ShowDok=49

RDF source	Calorific value (MJ/kg)	Ash residue (% w)	Chlorine content (% w)	Sulphur content (%w)	Water content (% w)
Household waste [1)]	12-16	15-20	0.5-1		10-35
Household [2)]	13-16	5 –10	0.3 –1	01 –0.2	25 -35
Commercial waste[2)]	16-20	5-7	<0.1-0.2	<0.1	10-20
RDF from industrial waste[1)]	18-21	10-15	0.2-1		3-10
Demolition waste[2)]	14-15	1-5	<0.1	<0.1	15-25

Ref:
1) RDC and Kema 1999
2) Data reported for Finland

Table 12: Quality of RDF from household and industrial sources in Europe[9]

In the cement industry, consistency in quality of the secondary fuel is a crucial factor for industrial process and product quality. Strict internal control procedures for analyzing secondary fuel composition will be required to ensure compliance with industry specifications.

Based on information received from CdM, the RDF will need to meet the following requirements to be able to be utilized in the current cement production:

Parameter		Unit	Amount	
	Calorific value	KJ/kg	≥	18,828 (4500 cal/kg)
	Ash content	%		---
	Water content	%	≤	10-20
	Sulphur (S)	%	≤	1.2
<<	Chlorine (Cl^-)	%	≤	0.3
	Fluoride (F^-)	%	≤	0.3
	P_2O_5	%	≤	2.0
	Maximum particle size	mm	≤	10.0
	Granulometria-passante P-50 mm	%		100.0
	Flash point	^oC	≥	80.0
General				
	Barium (Ba)	ppm	≤	3.000
(1)	Copper (Cu)	ppm	≤	5.000
(1)	Manganese (Mn)	pmm	≤	10.000
(3)	Cyanides (CN^-)	pmm	≤	100
(2)	Zinc (Zn)	pmm	≤	3.000
(2)	Berilium (Be)	ppm	≤	100

[9] European Commission - Directorate General Environment (2003) *Refuse Derived Fuel, Current Practice and Perspectives.*

<<	$SiO_2+Al_2O_3+Fe_2O_3+CaO+MgO+SO_3+Na_2O+K_2O+F^-$	%		---
	Radioactive waste	---		Absent
	Medical waste	---		Absent
	Hospital waste	---		Absent
	PVC	---		Absent
<<	PCBs (Polychlorinated Biphenyl)	ppm	≤	50
	Pesticides	---		Absent
	Explosives	---		Absent
	Benzene	ppm	≤	5.000
	SVOC (Semi-volatile Organic Compounds)	ppm	≤	2.000
	PAH (Polycyclic Aromatic Hydrocarbons)	ppm	≤	1.500

Table 13: RDF requirements by Cimentos de Moçambique

In the cement industry, consistency in quality of the secondary fuel is a crucial factor for industrial process and product quality. It is therefore necessary to identify if the unsorted MSW of Maputo and Matola will adhere to several of the parameters described by the requirements from CdM. Strict tests and internal control procedures for analysing secondary fuel composition will be required to ensure compliance with industry specifications. Although, the main parameter to assess the feasibility of utilization of MSW for RDF is the calorific value of the waste used as RDF. The requirement set by CdM is a minimum of 18,828 KJ/kg. It is therefore necessary to investigate if and how the collected MSW can achieve this minimum requirement.

2.6 Calorific value calculation of untreated MSW from Maputo and Matola

A new report elaborated by the NGO AMOR (2016) presents updated data (2015) regarding the composition of the waste received at the Landfill Hulene. Based on this, the following table presents a theoretical estimation of the calorific value of the MSW.

				Calorific values		Weighted calorific value	
				Hawf	**Hinf**	**Hinf**	
Waste composition	%	Moisture % (W)	Combustible (C%)	KJ/kg	**KJ/kg**	**KJ/kg**	**Kcal/kg**
Soft and hard plastic	8.40%	29%	63%	33,000	20,147	1,692	404.4799
Thin/thick organic	63.70 %	66%	21%	17,000	1,905	1,214	290.0755
paper, Cardboard, one use paper	13.20 %	47%	47%	16,000	6,435	849	203.0115
Ferrous/non-ferrous metal	2.80%			0	0	0	0
Glass	7.50%			0	0	0	0
Rags/Leather/rubber	1.50%	11%	63%	23,000	14,267	214	51.1486
Others	2.80%			0	0	0	0
Fine fraction <10mm	0.00%	32%	22%	15,000	2,578	0	0
TOTAL	100%					**3,969**	**949**

Table 14 Estimation of the calorific value, based on the waste composition reported by AMOR (2016)

The calculations were done based on the following formula[10]:

$$H_{inf} = H_{awf} * C - 2445 * W \text{ in kJ/kg}$$

Where: Hinf: lower calorific value and Hawf: ash and water free calorific value.

As illustrated by Table 14, the current composition of MSW in Maputo and Matola would give a Calorific value of 3,969 KJ/kg. This would be way below the minimum requirements set by international standards and CdM, to be used directly as RDF. For the MSW to be used as RDF it would have to be technologically processed to increase the RDF's calorific value. This can be done either by separating the fractions with high calorific value and only use those as RDF, or by removing moisture from waste fractions with high moisture content. The different alternatives are described in the following sections.

3 Potential technological processes for RDF production in the Mozambican context

3.1 Mechanical processing

The RDF from MSW is frequently produced by mechanically separating the waste fractions with high calorific value (plastics, paper and cardboard) from the fractions with low calorific value (organic matter with high water content, inert materials)[11][12][13][14].

The main process steps for mechanical waste treatment for RDF are first separation at source (ideally), followed by sorting or mechanical separation, size reduction (shredding, chipping and milling), separation and screening, blending, drying and pelletizing. MSW is first treated in a pre-shredder followed by magnetic separator to separate metals. It is then sent to a ballistic separator to separate the low calorific value wastes (mainly separated by grain size). The rest of the waste material is screened to remove remaining recyclable fractions, the inert fractions (e.g. glass) and the fine wet putrescible fractions (e.g. food) prior to pulverization of the material. The waste is sent to fine (final) crushers for reduction to an appropriate size used in cement factories[15.]

This process is mainly appropriate for MSW with low organic matter content and where waste separation happens at source. This is not the case for MSW produced in Maputo and Matola.

[10] WORLD BANK TECHNICAL GUIDANCE REPORT, Municipal Solid Waste Incineration, 1999 http://www.worldbank.org/urban/solid_wm/erm/CWG%20folder/Waste%20Incineration.pdf

[11] European Commission – directorate general environment refuse derived fuel, current practice and Perspectives (b4-3040/2000/306517/mar/e3) final report, July 2003

[12] Use of Solid Recovered Fuels in the Cement Industry Roland Pomberger and Renato Sarc, 2014

[13] Mechanical-Biological Waste Treatment and Utilization of Solid Recovered Fuels – State of the Art, Wolfgang Müller and Anke Bockreis, 2015

[14] Markets for Solid Waste Management in Arabic Countries Ayman Elnaas, Abdallah Nassour and Michael Nelles, Waste Management, ISBN: 978-3-944310-22-0, 2015

[15] Environmental and economic advantages associated with the use of RDF in cement kilns, Mustafa Kara, Resources, Conservation and Recycling 68 (2012) 21– 28

Although, the plan to establish a recycling center at the new landfill could provide an opportunity to produce RDF with high calorific values from waste fractions recovered on site. The plastic fraction could meet the needed calorific requirements set by CdM. Although, the use of plastic as RDF would have to compete with the market for recycled plastic.

To enable RDF production from MSW not sorted at source would require a production line consisting of several "stations" arranged in series aimed at separating unwanted components and conditioning the combustible matter in order to obtain an RDF of predetermined characteristics (Caputo and Pelagagge, 2002). The process and amount of stations needed to achieve the desired RDF qualities can become quite complex and costly. The technical solutions that could be included in a production line are illustrated in Table 15.

Line equipment cost data					
Equipment	Capacity (t/h)	Power (kW)	Cost (kEUR)	Amortization (EUR/h)	Operating cost (EUR/h)
Densifier	6	5	206.58	4.73	3.62
Air classifier	5	12	41.31	0.95	0.87
Dryer	6	140	309.87	7.09	10.12
Belt conveyor		6	15.49	0.35	0.43
Hammer mill	2	200	129.11	2.96	14.46
	4	250	144.6	3.31	18.08
	6	300	154.93	3.55	21.69
Pelletizer	4	50	206.58	4.73	3.62
Eddy current separator	5	2.2	7.23	0.83	0.27
	10	2.2	11.87	0.96	0.45
	15	2.2	14.97	1.14	0.48
Magnetic separator	5	3.75	36.15	0.17	0.16
	10	6.25	41.83	0.27	0.16
	15	6.6	49.57	0.34	0.16
Hand sorting				0	23.65
Shredder	6	25	56.81	1.3	1.81
	10	50	108.45	2.48	3.62
	15	50	129.11	2.96	3.62
	25	55	154.93	3.55	3.98
Trommel screen	15	20	103.29	2.36	1.45
	25	30	154.93	3.55	2.17

Table 15: Line equipment cost data (Caputo and Pelagagge, 2002)

According to literature, if unsorted MSW is utilized, even the more complex process including 10 stations with a total production cost of 21.18 EUR/ton RDF, would only achieve a maximum of 3590 kcal/kg, still below the 4500 kcal/kg required by CdM, as illustrated in Table 16. This is assuming a waste composition with a higher content of fractions with higher calorific values (14% plastic) and lower organic content (51%) with low calorific values.

Performance of fluff RDF production lines at varying input waste mix							
Line #	Line configuration	MSW input (%)	Efficiency (%)	Moisture (%)	Ash (%)	LHV (kcal/kg RDF)	Production cost (EUR/t RDF)
1	PT–HS–MS–S–T–M–T	100	18.3	8.76	6	3478	16.56
2	T–HS–MS–S–T–M–T	100	24.9	9.05	6.67	3388	15.07
3	T–HS–MS–S–T–MS–M–T	100	24.3	9	6.28	3403	15.64
4	T–HS–MS–S–T–MS–M–T–MS	100	23.8	9	6.22	3406	16.18
5	T–HS–MS–S–T–ECS–M–T	100	24.1	9.1	5.3	3434	15.93
6	T–HS–ECS–S–T–ECS–M–T	100	24	9.1	5.28	3438	16.19
7	T–HS–MS–S–T–S–T–M–T	100	20.9	6.9	6.42	3546	20.15
8	T–HS–MS–S–T–MS–S–T–M–T	100	20.5	6.9	6.06	3559	20.78
9	T–HS–MS–S–T–ECS–S–T–M–T	100	20.3	6.9	5.23	3590	21.18
10	S–T–MS–M–T	100	30.7	10.7	8.5	3152	9.48
11	S–T–MS–S–T–M–T	100	24.7	7.4	7.7	3409	12.45
12	S–T–MS–S–T–MS–M–T	100	24.1	7.4	7.3	3424	12.97
13	S–T–ECS–S–T–MS–M–T	100	23.7	7.4	5.5	3488	13.37
14	S–T–ECS–S–T–ECS–M–T	100	23.6	7.4	5.3	3494	13.59

ECS=eddy current separator, HS=hand sorting, LHV=low heating value, M=mill, MS=magnetic separator, MSW=municipal solid waste, PT=preliminary trommel screen, S=shredder, T=trommel screen

Table 16: Performance of RDF production lines at 100% input waste mix (Caputo and Pelagagge, 2002)

This indicates that RDF production from MSW in Maputo and Matola would not be technologically feasible with mechanical processing without initiating separation at source. In the following, other potential processes are investigated.

3.2 Biological processes

The term MBT is used to define waste treatment involving mechanical and biological processes, which will separate mixed MSW in different fractions. For producing RDF from MSW with a higher organic fraction, the Mechanical Biological Treatment (MBT) is the most applied technology. Due to the fact that the MSW generated in Maputo has very high organic matter content, this section focuses on MBT technologies and their suitability to produce RDF from mixed waste with high organic fraction generated in both cities. Depending on the waste quantities and composition, the mechanical treatment will involves similar steps to the ones previously mentioned: mechanical separation, size reduction (shredding, chipping and milling), separation and screening, blending, drying and pelletizing. For the fine waste fraction (mainly organic fraction with some non-recyclable dry fraction) separated after the mechanical treatment, the MBT offers three different options:

1. Mechanical-biological treatment with anaerobic digestion (MBT)
2. Mechanical-physical aerobic stabilisation (MPS) (similar to composting)
3. Mechanical-biological stabilisation (MBS) or biological drying,

In mechanical biological treatment processes, metals and inerts are separated out and organic fractions (containing some non-recyclable dry waste) are screened out for further stabilisation using composting processes, either with or without a digestion phase (1 and 2). It also produces a residual fraction which has a high-calorific value as it is composed mainly of dry residues of paper, plastics and textiles (non-recyclable dry fraction).

RDF can also be produced through a dry stabilisation process (biological drying), in which residual waste (minus inerts and metals) are effectively dried (and stabilised) through a composting like process, leaving the residual mass with higher calorific value and suitable for combustion. The high calorific output of this process developed in Germany has the trade name of "Trockenstabilat".

3.2.1 MBT with anaerobic digestion

Anaerobic digestion (AD) is a biochemical process which takes place in the absence of oxygen and results mainly in the formation of a carbon dioxide and biogas. Anaerobic Digestion is very often referred to as a separate MBT approach. This technological approach usually requires a separation at source, allowing mostly the organic waste to be treated to optimize the biogas production. This process is ideal in case of generating renewable energy (e.g. electricity) for being distributed and sold through the national electricity grid. Then AD as a part of a MBT would represent an optimal option for waste treatment with energy recovery in a country with favourable regulatory framework and technical conditions in place. Regarding the RDF production, after the biodigestion, the organic fraction is dried through composting; leaving a dry stabilized high mineralised organic material. This material also contains some non-recyclable dry waste, which is finally separated and used as RDF. Although, compost produced by unsorted waste can result in a contaminated product not suitable to be used as biofertilizer. Figure 5 shows the process flow of an MBT with AD.

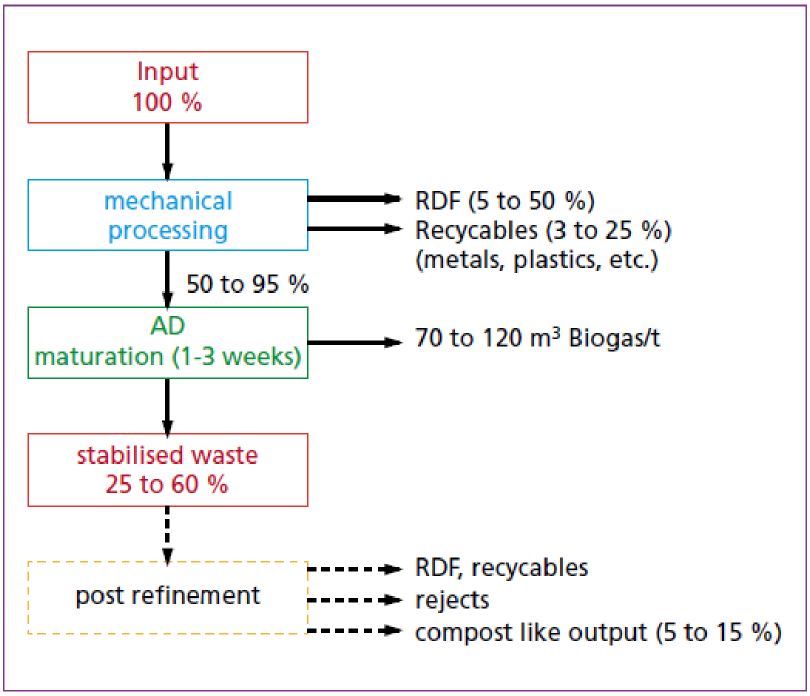

Figure 5 MBT with anaerobic digestion (Müller and Bockreis, 2015)[16]

[16] Wolfgang Müller and Anke Bockreis, Mechanical-Biological Waste Treatment and Utilization of Solid Recovered Fuels – State of the Art, 2015

Due to the main goal of this study, which is the RDF production for cement plants, the AD option does not represent a technology that would optimize the RDF production. The lack of separation of waste fraction at source also complicates the utilization of the remaining compost and does not contribute to the optimization of biogas production, why this technology option will not be considered further.

3.2.2 Aerobic stabilisation

The key target of this option is mainly to treat MSW treatment for further disposal, without economic dependency on other markets such us energy or RDF. Here, the organic fraction is stabilised reducing the amount of biodegradable municipal waste going to landfill.

Typically, the biological treatment is combined with mechanical processing steps to separate RDF products from the waste prior or/and after the biological treatment. When the RDF fraction is separated first, the material left after the separation of the RDF is enriched with easily degradable components like kitchen waste and dirty paper, like tissues, which are not suitable for recycling. This material is then treated through an aerobic process (composting). This process uses some of the energy and material in the organic matter, generating carbon dioxide and heat.

After the biological hydrolysis, the waste is stabilized and ready for landfilling. Further possible treatment would be a post-refinement stage, where more RDF can be separated from the stabilised compost-like material. Adding this stage depends mostly on the economic feasibility more than on technical issues. Figure 6 presents an example of this process, with waste streams.

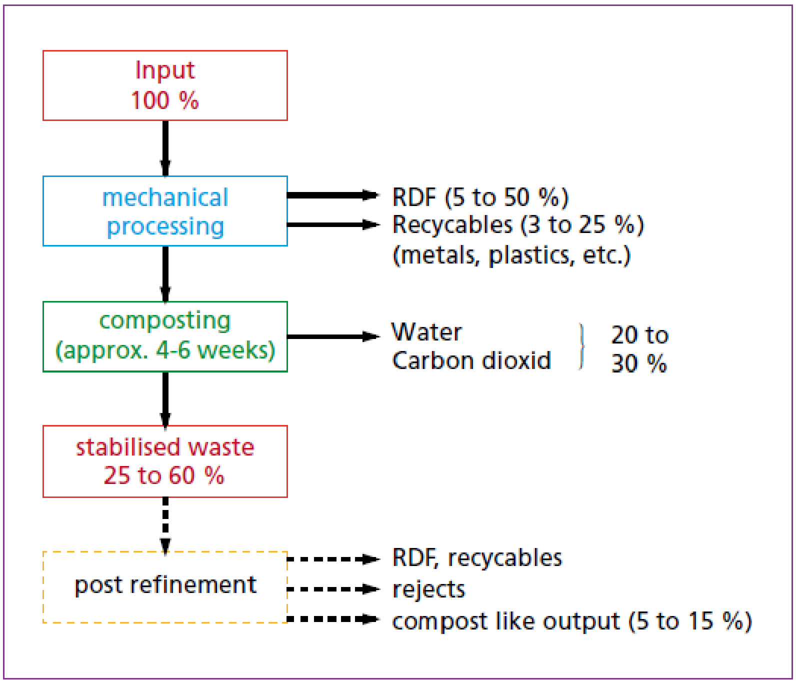

Figure 6 MBT with stabilisation (Müller and Bockreis, 2015) [17]

[17] Wolfgang Müller and Anke Bockreis, Mechanical-Biological Waste Treatment and Utilization of Solid Recovered Fuels – State of the Art, 2015

Due to the main goal of this study, which is the RDF production for cement plants, the composting option does not represent a technology that would optimize the RDF production and it will not be considered further. Although, given the assumption that the new landfill will include a recycling center, composting of organic material could be considered for electricity generation.

3.2.3 Biological drying

This approach seeks to make use of the energy content of the waste to produce a (high quality) RDF, which can be burnt in industrial plants like cement kilns for a lower price than in a combustion facility or mass burn incineration.

This technology was first developed by technology providers in Germany (called "trockenstabilisierung"). However, other composting technologies can also be used for biological drying by modifying the process control parameters. This "compost-like" process aims at removing the water content from the organic waste fraction, through producing heat; enabling an easier mechanical treatment after it. Müller and Bockreis (2015) explain a typical MBT process with biological drying as follows:

The waste is shredded and placed in enclosed bio-drying boxes, where air is forced through the waste creating optimum conditions for microbiological activity, which will produce the heat for removing moisture from the waste (drying). The biological drying process is stopped at 15% to 20% water content, however, further drying can be performed by passing pre-heated air (produced with heat exchangers). With the drying of the waste the calorific value of the material is increased.

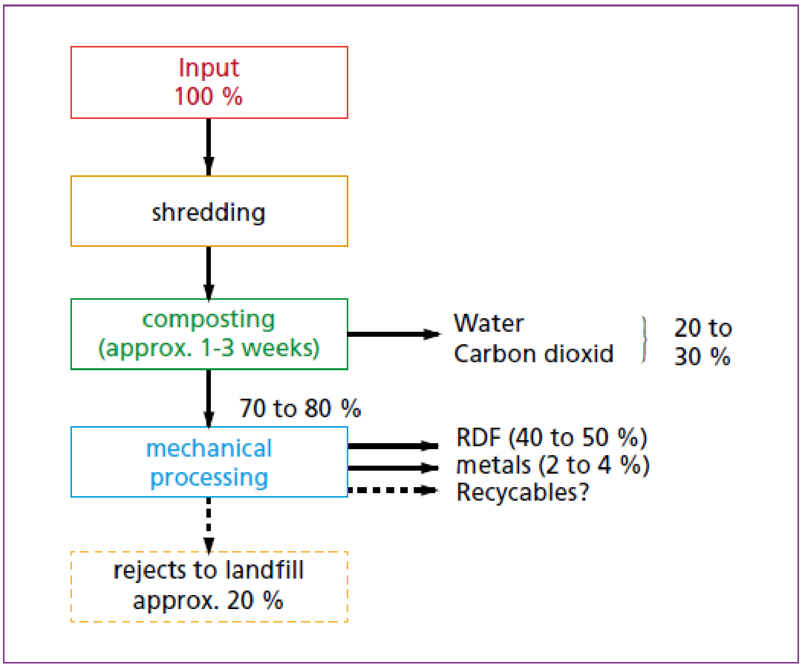

Figure 7 MBT with biological drying (Müller and Bockreis, 2015)[18]

[18] Wolfgang Müller and Anke Bockreis, Mechanical-Biological Waste Treatment and Utilization of Solid Recovered Fuels – State of the Art, 2015

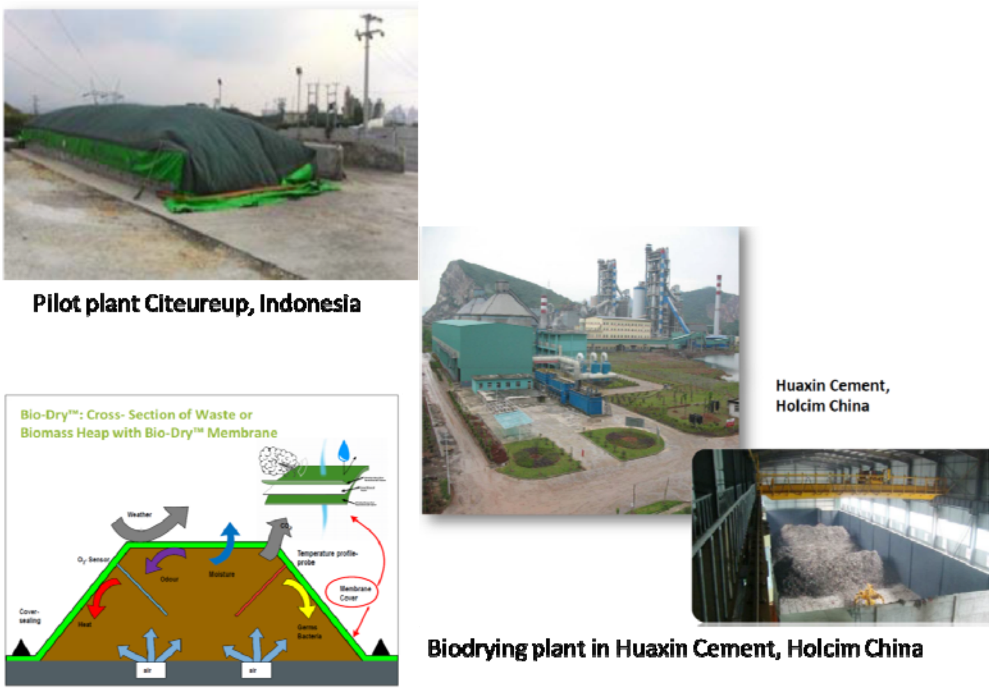

Figure 8 Biological drying process [19]

Biological drying - Processing parameters

An experience of biological drying applied to treat MSW in developing countries is the case of the pilot project run in Beja, Tunisia, which was supported by the KfW in 2014 and 2015. As explained before, the recyclable materials are taken out of the waste for recycling, before starting the waste treatment in the plant.

Then, the organic waste fraction is dried through a compost-like process (in composting windrows, covered by semi-permeable membranes) and monitored by an automatic temperature control system. The system optimizes the biological activities using forced aeration and weekly waste turning, maintaining the temperature between 40 ˚C and 70 ˚C. The drying process takes around 3 weeks. After this, the waste can be screened efficiently into a coarse fraction with a high calorific

[19] Larsen Ib, RDF as an alternative fuel for the cement industry in an South East Asian context, Stakeholder workshop "mitigation efforts in the cement and steel industry" Malaysia, 2015

value which can be used as a basis for the production of substitute fuel (RDF) (Elnaas et al. 2015). For the case of the pilot project in Beja, the mass of input waste will be reduced by approx. 60 %. Below, the Figure 9 presents the process flow of the pilot plant in Beja, Tunisia.

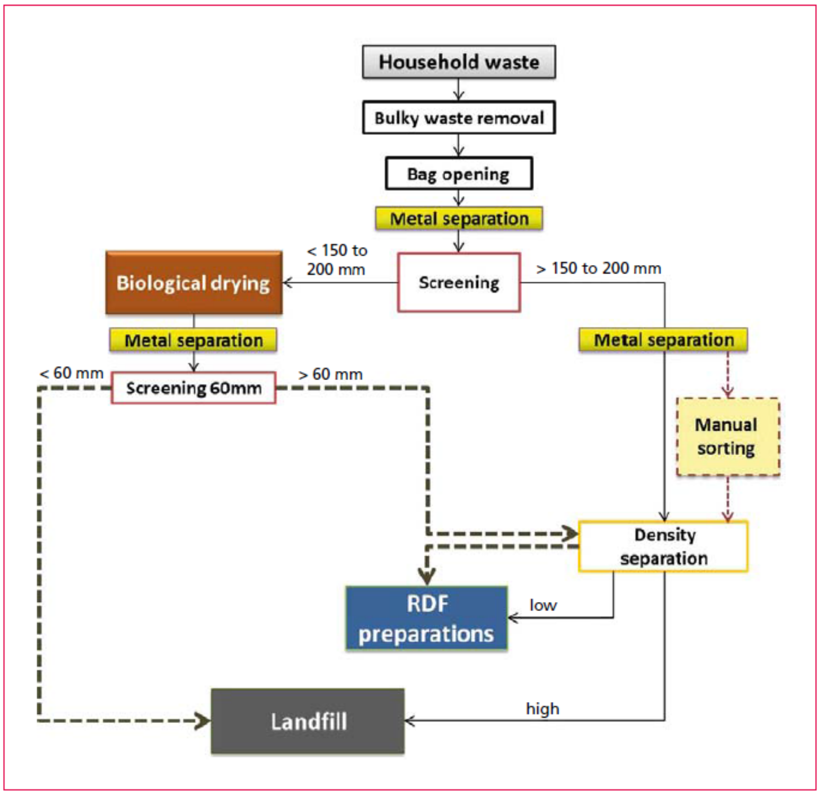

Figure 9 Production process biological drying, RDF production and recyclable material recovery[20]

The waste input used for this pilot plant had 62.8% organics, with a total calorific value between 15.56 and 16.79 MJ/kg (average: 16.2 MJ/Kg). The RDF resulting from this process (> 80 mm) contained textile (21.2 %), plastics films (19.7 %), nappies (10.5 %) and cardboard (6.4 %). Others combustible materials included paper (15.4 %), other plastics (4.5 %) and organics (14.5 %). Impurities in the RDF contained non-combustible materials namely, metals (5.5 %) and glass and inerts (2%). The moisture content was very variable, ranging from 25 % to 50 %. The calorific value was between 18.87 and 20.61 MJ/kg. Regarding the ash content, it appears to be at the high range, between 20 % to 31 %. Chlorine is also a limiting factor for RDF quality, not only for ecological reason but also for technical reasons (0.94 as average).

It is important to highlight that the mass flows, efficiency of mass conversion, parameters and quality of the final RDF will strongly depend on the composition of the fresh MSW, input of the MBT plant. The values mentioned above just indicate a reference of what the conversion rates could be. The final process parameters, efficiencies and mass conversion rates will be presented in the following chapter, corresponding to a more detailed technology description, according to a representative technology provider.

[20] Markets for Solid Waste Management in Arabic Countries Ayman Elnaas, Abdallah Nassour and Michael Nelles http://www.vivis.de/phocadownload/2015_wm/2015_WM_85-98_Nassour.pdf

After presenting these three technological approaches for producing RDF from MSW with high organic contents, the "biological drying" option is considered the most appropriate for achieving the goal of this project, which is the RDF production for cement plants.

4 Feasibility of using biological drying for RDF production

This chapter aims at analyzing more in-depth if biological drying could be used as technology to achieve an RDF which would meet the predefined requirements by CdM specific technical features and processing parameters of the chosen technology for the project.

Several technology providers for RDF production technologies were contacted, aiming at obtaining some technical reference parameters regarding the mass flows, conversion efficiencies, possible capital and operational costs, etc. for RDF plants, suitable for the Mozambican context. As a result, some general technical information was received, which has been used here, for describing the state-of-the-art technology, often applied for processing MSW from developing countries and yields to be expected.

As a result of the pre-screening of technology providers, 5 contacted companies showed interest in the project, providing general technical information. The following enterprises were contacted:

For RDF technology:

- HERHOF (Germany) http://www.herhof.com/
- CONVAERO (Germany) http://www.convaero.com/
- ENTSORGA (Italy) http://www.entsorga.it/
- TAIMWESER (Spain) http://www.taimweser.com/
- COMPOST SYSTEMS (Austria) http://www.compost-systems.com/

ENTSORGA, CONVAERO and TEIMWESER provided enough technical information, making possible to compare them. Based on the reference offers and general data from these companies, the company ENTSORGA was selected as an ideal example of a flexible and adaptable option to the Mozambican context, with experience of RDF plants in the African Region (e.g. Egypt).

It is necessary to point out that the information provided by the technology providers are just referential. In order to make possible for the technology providers to design more detailed offers, it is necessary to perform more accurate data collections, reflecting the real current situation of the MSWM system in both cities. This may be carried out in a further study for this project.

For this stage of the study, it was assumed that the project will be sized with a capacity suitable to treat mixed MSW received from Maputo (cement city) in the 3th year of the project (2019). By the third year of the project it is expected the plant to treat around 41,595 tonnes mixed MSW/year. The project considers 1 working shift per day (8 hours-net), 5 working days per week, and 260 days operation per year, which means that the plant will be sized to process around 161 tonnes mixed MSW/day. The technology option presented in this study will allow the RDF plant to expand in a flexible manner, as MSW generation increases. The reference offer of Entsorga does not include: transport, taxes and civil works.

The standard processing flow offered by technology providers is similar. Table 17 presents the expected conversion rates MSW/RDF and calorific values of the evaluated technology providers.

	Conversion rate MSW to RDF							
	Entsorga	**TeinWesser**	**Herhof**	**Compost Systems**	**Convaero**	**Literature 1** [21]	**Literat. 2** [22]	**Literat. 3 (15-20%)**[23]
RDF/MSW	31% (for medium quality RDF)	64%	53%	15-25%	40%	24%	45%	17.5%
Heat values ranges (KJ/Kg)	15,574	15,000-20,000	15,000-18,000	no data	18,000	16,240	no data	16,736
Heat value (KJ/Kg)	15,574	17,500	16,500	no data	18,000	16,240	no data	16,736
Heat value (Kcal/Kg)	3,722	4,183	3,944	no data	4,302	3,881	no data	4,000

Table 17: Expected conversion rates MSW/RDF and calorific values

One of the technology providers contacted for this study (ENTSORGA), reported a conservative %RDF yield (conversion rate MSW - RDF), and expected to be reached under consideration of the waste composition of Maputo. Further, this value is closer to the yields reported by the literature for RDF experiences in developing countries. The achieved calorific value by the technology providers are generally not able to meet the requirements of 18,828 KJ7Kg (4500 kcal/kg) required by CdM. In addition, Entsorga calculated a possible calorific value of the MSW in Maputo (Cement City):

[21] Markets for Solid Waste Management in Arabic Countries Ayman Elnaas, Abdallah Nassour and Michael Nelles (2014)
[22] Mechanical-Biological Waste Treatment and Utilization of Solid Recovered Fuels – State of the Art Wolfgang Müller and Anke Bockreis (2015)
[23] http://www.bioenergyconsult.com/?s=calorific+value (accessed 29.07.2016)

	composition	moisture %	LHV kcal/kg (dw)	LHV kcal/kg	LHV kcal/kg
Paper/ cardboard	12.4%	35%	3'249	1'902	236
Textiles	2.3%	21%	4'363	3'321	76
Wood	0.0%	30%	4'520	2'984	-
Plastic/ rubber	9.9%	22%	7'261	5'532	548
Inerts	3.3%	9%	-	- 54	- 2
Ferrous	1.8%	9%	-	- 54	- 1
Aluminium	0.0%	9%	-	- 54	-
Organic	68.4%	76%	6'977	1'218	833
Fines< 2 cm	0.0%	45%	1'827	735	-
Others	1.9%	20%	587	350	7
Total		60%			1'697
				kJ/Kg	7'094

Table 18: Estimated calorific value of MSW generated in Maputo (Entsorga)

For the calculation of the possible final quality of the RDF, calorific value of the input waste and the output RDF, and the mass balance, the technology provider used a waste composition based on local and international literature sources regarding the MSW situation in Maputo (AMOR-Carbon Africa, 2014; GIZ, 2012). However, it should be taken into account that these results are just referential and they just can be used to give an idea of the possible outputs of the process. As illustrated by Table 18, ENTSORGA estimates a calorific value of 7,094 KJ/Kg for the MSW generated in Maputo and Matola before treatment. Their estimation is relatively high, compared to theoretical calorific value calculated MSW received at the Landfill Hulene using updated data (2015) of 3,969 Kj/Kg, as represented in Table 14. Based on this information, the potential for even lower calorific yields should be considered.

Table 19, presents the projected waste amounts (from Maputo) to be processed for RDF production, and the expected yield in tonnes if treated by the conservative estimates observed by Entsorga.

Year	Total amount of waste for RDF (Tonnes/year)	RDF yield in tonnes (31% efficiency)
2017	41,324	12,810
2018	41,457	12,852
2019	41,595	12,894
2020	41,736	12,938
2021	41,878	12,982
2022	42,019	13,026
2023	42,160	13,070
2024	42,301	13,113
2025	42,441	13,157
2026	42,579	13,200
2027	42,714	13,241
2028	42,845	13,282
2029	42,973	13,322
2030	43,098	13,360
2031	43,218	13,397

2032	43,330	13,432
2033	43,434	13,465
2034	43,531	13,495
2035	43,620	13,522
2036	43,699	13,547
2037	43,770	13,569
2038	43,833	13,588
2039	43,886	13,605
2040	43,931	13,619

Table 19 Expected waste input for the RDF plant

All current available information points towards the fact that the MSW produced in Maputo and Matola will not be able to be utilized for RDF without going through a pre-sorting process. Although, if the requirements for RDF set out by CdM would go down to requirements more aligned with European standards, reaching a medium quality RDF with a heating value of 15,574 KJ/Kg, the utilization of RDF from MSW could be considered.

The following chapters present a theoretical estimation of GHG emission reduction potential from the utilization of MSW as RDF, if utilized in the future, and eventual needed adaptations for the cement plant in Mozambique to allow for the utilization of RDF.

5 Calculation of the Greenhouse gas (GHGs) reduction potential

This section describes the rationale used for estimating Greenhouse Gas mitigation potential of the present project, as well as the results of these estimations.

The GHG reduction potential was calculated considering only the potential reductions from replacing current unsustainable waste management practices with the technical solution proposed by this project (RDF production). In addition to this, the calculation included the GHG avoided from partially replacing the consumption of fossil fuels for the heat generation in the cement plant CdM with the RDF generated by this project.

The GHG emissions generated at the RDF processing plant were neither calculated nor considered here. The reason for this decision was the high uncertainty of the scenarios defining the RDF process. For instance, conditions such as final quality (composition) of the RDF, final processing technology, adaptation need for the Cement plant to burn the RDF of the project are unknown. These and another parameters influence on the possible GHG emissions generated in both processes. The calculation of possible GHG emissions would require a number of assumptions that would increase the uncertainty and possible deviation of the final results. Therefore, the decision regarding GHG reduction potential was to calculate the avoidance of GHG emissions on existing IPCC methodologies and defaults for "more standardized" processes (avoiding landfilling, replacing fossil fuels in stationaries burning processes, such as cement plants).

The GHG emissions generated by the RDF production may be calculated in a further stage of this project, after a detailed data collection regarding MSW in both cities, the final definition of the RDF technology, and piloting testing determining the emissions of burning this specific RDF in the cement plant "CdM".

Regarding the GHG emissions reduction from transport, this study considers that the RDF plant would not avoid emissions from transport, compared with the baseline scenario. Here, the municipality will close the current landfill Hulene and open a new one Matlamele, Matola. The study considers that the RDF plant would be located at the same site. Then, the transport distances and the emissions generated by this activity would be the same, independently of the project. Therefore, this aspect is not considered in the project as potential GHG reductions.

The methodological approach of Volume 5, Chapter 3 of the *2006 IPCC Guidelines for Greenhouse Gas Inventories* was used for calculating the emissions of avoiding landfilling practices. The calculations of the emissions were done based on the standard IPCC spreadsheet model *IPCC Spreadsheet for Estimating Methane Emissions from Solid Waste Disposal Sites (IPCC Waste Model)*.

5.1 Scope of the GHG Inventory

The calculations were done for the MSW generated in Maputo (Cement City). Regarding possible alternatives for waste treatment and disposal, the IPCC 2006 Guidelines distinguish between the following sources of emissions in the waste sector:

- Emissions from solid waste disposal;
- Emissions from biological treatment of waste;
- Emissions from the incineration and open burning of waste;
- Emissions from wastewater treatment and discharge;
- Other emissions.

Based on the study of AMOR and Carbon Africa (2014), two main disposal practices were identified for Mozambique: Open waste dumping and open burning. However, no literature could be found regarding the percentage of MSW being disposed of in open dumps or being burned. Therefore, it was decided to consider the emissions mitigation only from avoided MSW disposal, being this decision supported by the chapter 2, waste generation, composition and management data, Volume 5 of the IPCC Guidelines (2006), which indicates a default value for MSW treatment in African countries of 69%, being the rest attributed to unspecified practices. In addition to MSW disposal, this study also calculates the GHG emissions avoided through the replacement of fossil fuels by RDF from waste, in cement plants.

Regarding the type of emissions from MSW disposal, the current calculations are limited to methane (CH_4) emissions related to the decomposition of solid waste disposed at dumpsites and/or landfills. The inventory is limited to municipal solid waste, generated by the urban population Maputo (Cement city).

The following list shows the different data sources and methodologies used for the calculation of GHG from the waste sector:

- 2006 IPCC Guidelines for GHG inventories: Approach for data collection and assessment of GHG emissions:Volume 5, Chapter 2
- 2006 IPCC Guidelines for GHG inventories: Calculation of GHG emissions - solid waste disposal: Volume 5, Chapter 3 and the Spreadsheet model IPCC for estimating methane emissions from SWD sites (IPCC model)

- For data regarding climate conditions in Maputo:
- Climate Mozambique World Bank http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Africa&ThisCCode=MOZ
- Population in Maputo : Mozambican Census (2007), projections (National Institute for Statistics, Mozambique), the MSW plant of Maputo (2008)

The data of the whole country (Mozambique) was considered for determining average yearly temperature and rainfall. The Mean Annual Temperature in Mozambique was estimated at 24.06 °C and the Mean Annual Precipitation is 973 mm per year (period 1990 - 2012).Then, according to the IPCC guidelines (2006), the climate conditions describe above would be classified as dry-tropical.

5.2 Selection of Tier

The IPCC 2006 Guidelines indicates three tiers to estimate the CH_4 emissions from solid waste disposal sites:

- **Tier 1:** The estimations of the Tier 1 methods are based on the IPCC FOD method using mainly default activity data and default parameters.
- **Tier 2:** Tier 2 methods use the IPCC FOD method and some default parameters, but require good quality country-specific activity data on current and historical waste disposal at solid waste disposal sites.
- **Tier 3:** Tier 3 methods are based on the use of good quality country-specific activity data (see Tier 2) and the use of either the FOD method with (1) nationally developed key parameters, or (2) measurement derived country-specific parameters.

According to the IPPC Guidelines 2006 (Volume 3, Chapter 2), it is good practice that countries use data on country-specific MSW generation, composition and management practices as the basis for their emission estimation. Then, the guideline indicates that country-specific data can be obtained from:

- Waste statistics;
- Waste surveys (municipal or other relevant administration, waste management companies, waste association organizations, other); and
- Research projects.

For the case of Maputo, the TIER selected for the calculations was TIER 2. Specific information regarding population was taken from the Mozambican Institute of Statistics and the MSW plan of Maputo. The waste composition and waste generation rate was provided by diverse literature review (GIZ, the Municipality of Maputo, and information provided by the NGO AMOR (report 2016)).

5.3 Urban Population projections

The table below presents the projections of population in Maputo, from 2017 to 2040:

	Population Maputo, cement city
2017	151,459
2018	151,946
2019	152,453
2020	152,971
2021	153,492
2022	154,009
2023	154,525
2024	155,042
2025	155,556
2026	156,061
2027	156,553
2028	157,035
2029	157,506
2030	157,963
2031	158,400
2032	158,812
2033	159,195
2034	159,550
2035	159,874
2036	160,166
2037	160,427
2038	160,655
2039	160,851
2040	161,016

Table 20 Projected population Maputo (Cement City)

5.4 Waste generation projections

The following table shows the projections of the waste generated in Maputo (Cement City)

	Waste generated Maputo (cement city) (Tonnes/year)
2017	63,575
2018	63,779
2019	63,992
2020	64,210
2021	64,428
2022	64,645
2023	64,862
2024	65,079

2025	65,294
2026	65,506
2027	65,713
2028	65,915
2029	66,113
2030	66,305
2031	66,489
2032	66,661
2033	66,822
2034	66,971
2035	67,107
2036	67,230
2037	67,339
2038	67,435
2039	67,517
2040	67,586

Table 21 Projections total waste generation

5.5 Waste composition

Table 19 presents the waste composition for Maputo, cement city. The composition corresponds to the waste received at the dumpsite Helene.

Type of waste	Maputo (Cement Cities)
Paper	3.80%
Cardboard	5.60%
Rag, tyres	1.5%
Metal	2.80%
Glass	7.50%
Soft plastics	5.20%
Strong plastics	3.20%
One use paper	3.80%
Organic	63.70%
Fine fraction	0.00%
Others	2.80%
Total	99.90%

Table 22 Waste composition Maputo (AMOR, 2016)

5.6 Fraction of waste disposed at SWDS

For this project, it is assumed that the recycling and RDF plant will treat 100% of the waste collected (65% for Maputo cement city) (GIZ, 2012). Therefore, the calculations of GHG reductions for avoided landfilling will be calculated based on the amount of collected waste.

Year	Maputo: Waste collected (Tonnes/year)
2017	41,324
2018	41,457
2019	41,595
2020	41,736
2021	41,878
2022	42,019
2023	42,160
2024	42,301
2025	42,441
2026	42,579
2027	42,714
2028	42,845
2029	42,973
2030	43,098
2031	43,218
2032	43,330
2033	43,434
2034	43,531
2035	43,620
2036	43,699
2037	43,770
2038	43,833
2039	43,886
2040	43,931

Table 23 MSW amounts to be treated by the project

5.7 FOD default parameters for Maputo

The table below presents the default FOD parameters chosen for the calculation of GHG emissions from the disposal of solid waste (dry-tropical climate):

DOC (Degradable organic carbon)	
(weight fraction, wet basis)	**Default**
Food waste	0.15
Garden	0.2

Paper	0.4
Wood and straw	0.43
Textiles	0.24
Disposable nappies	0.24
DOCf (fraction of DOC dissimilated)	0.5
Methane generation rate constant (k)	
(years^{-1})	**Default**
Food waste	0.085
Garden	0.065
Paper	0.045
Wood and straw	0.025
Textiles	0.045
Disposable nappies	0.065
Delay time (months)	6
Fraction of methane (F) in developed gas	0.5
Conversion factor, C to CH_4	1.33
Oxidation factor (OX)	0

Since no specific description was found regarding the disposal techniques in the dumpsite of Helene, the default value for "Uncategorized SWDS" is applied (0.6).

5.8 Results GHG reduction potential from avoided landfilling

For converting CH4 to CO2eq, the following global warming potential (GWP) factors were used (recommendation in the IPCC guidelines 2006): 1 Ton CH4 = 23 Tonnes CO2

	From avoided landfilling	
	CH_4 avoided	CO_2 avoided
year	Tonnes/year	Tonnes/year
2017	0	0
2018	82	1,882
2019	158	3,636
2020	229	5,273
2021	296	6,802
2022	358	8,230
2023	416	9,565
2024	470	10,813
2025	521	11,982
2026	569	13,078
2027	613	14,104
2028	655	15,067
2029	694	15,971

2030	731	16,820
2031	766	17,617
2032	799	18,367
2033	829	19,072
2034	858	19,736
2035	885	20,361
2036	911	20,948
2037	935	21,502
2038	957	22,022
2039	979	22,513
2040	999	22,974

5.9 Results GHG reduction potential through replacing fossil fuels at the cement plant (with RDF)

The calculations of GHG emissions avoidance was done based on the default values for the emission factor of Natural gas and oil, burned in cement industries: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 2 STATIONARY COMBUSTION, Volume 2: energy.

TABLE 2.8
KILNS, OVENS, AND DRYERS SOURCE EMISSION FACTORS

Industry	Source	Emission factors[1] (kg/TJ energy input	
		CH_4	N_2O
Cement, Lime	Kilns - Natural Gas	1.1	NA
Cement, Lime	Kilns - Oil	1.0	NA
Cement, Lime	Kilns - Coal	1.0	NA
Coking, Steel	Coke Oven	1.0	NA
Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer - Natural Gas	1.1	NA
Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer – Oil	1.0	NA
Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer – Coal	1.0	NA

[1] Source: Radian, 1990. Values were originally based on gross calorific value; they were converted to net calorific value by assuming that net calorific values were 5 per cent lower than gross calorific values for coal and oil, and 10 per cent lower for natural gas. These percentage adjustments are the OECD/IEA assumptions on how to convert from gross to net calorific values.

NA, data not available.

The emission avoidance was calculated based on the amount of RDF produced by the project, the calorific values of Natural Gas: 37.76 MJ/kg, oil (liquid: 45.46 MJ/kg, solid: 19.49 KJ/kg) and a possible calorific value for the RDF (value provided by Entsorga) of 14.48 MJ/kg. As mentioned before, the emission factor considered for calculation the emissions was taken from the IPCC guidelines (1.1 kg CH4/TJ for natural gas and 1 Kg CH4/Kg for oil). The cement plant reported following fuel consumption:

Fuel	**Fuel input (ton/year)**	**Calorific Value (MJ/kg)**	**Total Calorific value (MJ) per year**
Rubber	0.98	16.75	16,415
Crude oil (solid)	519.67	19.49	10,128,368
Paper waste	32.22	7.54	242,939
Crude oil (liquid)	98.41	45.46	4,473,719
Gas	33,232.73	37.76	1,254,867,885
Total heat			1,269,729,326

Table 24 Fuel consumption Cimentos Mozambique (Carbon Africa, 2016)

Even though the cement plant was consulted about its future fuel consumption, the information was not delivered. Therefore, it was considered the same fuel consumption in all years.

CdM has reported its targets regarding its future RDF consumption. The following table shows these targets:

Year	**RDF consumption (tons)**	**RDF consumption (tons/day)**
2018	9,512	30
2021	25,031	80
2026	33,375	107

Table 25 RDF future requirement at Cimentos de Mozambique (Carbon Africa Report, 2016)

Based on this data and the expected RDF production of the project, it is assumed that 100% of the RDF target consumption of CdM will be covered by the project during the first years. For the purpose of this study, it will be considered that the RDF production will increase according to the amounts of MSW available in Maputo (Cidade de Cimento). A decision of increasing the scope of the project (increasing the waste amounts to be treated, e.g by including another areas in Maputo or other cities), in order to satisfy the 100% of the Cement plant´s demand would be decided in a further stage.

The table 21 shows the results of the estimations (assuming that 100% of the RDF produced is used at the cement plant).

Year	Energy consumption from gas and oil (MJ/year)	Emissions (Tonnes CH4/year)	Emissions (tonnesCO2year)	RDF to be used (Tonnes/year)	Total Heat from RDF (MJ/year)	Avoided emissions (Tonnes CH4/year)	Avoided emissions (Tonnes CO2-eq/year)	% avoided emissions
2017	1,269,469,972	1.4	32	12,810	185,519,484	0.2041	4.69	15%
2018	1,269,469,972	1.4	32	12,852	186,115,860	0.2047	4.71	15%
2019	1,269,469,972	1.4	32	12,894	186,737,540	0.2054	4.72	15%
2020	1,269,469,972	1.4	32	12,938	187,371,916	0.2061	4.74	15%
2021	1,269,469,972	1.4	32	12,982	188,009,432	0.2068	4.76	15%
2022	1,269,469,972	1.4	32	13,026	188,642,562	0.2075	4.77	15%
2023	1,269,469,972	1.4	32	13,070	189,274,551	0.2082	4.79	15%
2024	1,269,469,972	1.4	32	13,113	189,908,414	0.2089	4.80	15%
2025	1,269,469,972	1.4	32	13,157	190,537,316	0.2096	4.82	15%
2026	1,269,469,972	1.4	32	13,200	191,155,826	0.2103	4.84	15%
2027	1,269,469,972	1.4	32	13,241	191,759,256	0.2109	4.85	15%
2028	1,269,469,972	1.4	32	13,282	192,348,883	0.2116	4.87	15%
2029	1,269,469,972	1.4	32	13,322	192,925,742	0.2122	4.88	15%
2030	1,269,469,972	1.4	32	13,360	193,486,033	0.2128	4.90	15%
2031	1,269,469,972	1.4	32	13,397	194,021,671	0.2134	4.91	15%
2032	1,269,469,972	1.4	32	13,432	194,525,713	0.2140	4.92	15%
2033	1,269,469,972	1.4	32	13,465	194,995,619	0.2145	4.93	15%
2034	1,269,469,972	1.4	32	13,495	195,429,510	0.2150	4.94	15%
2035	1,269,469,972	1.4	32	13,522	195,826,257	0.2154	4.95	15%
2036	1,269,469,972	1.4	32	13,547	196,184,695	0.2158	4.96	15%
2037	1,269,469,972	1.4	32	13,569	196,503,988	0.2162	4.97	15%
2038	1,269,469,972	1.4	32	13,588	196,783,729	0.2165	4.98	16%
2039	1,269,469,972	1.4	32	13,605	197,023,917	0.2167	4.98	16%
2040	1,269,469,972	1.4	32	13,619	197,225,177	0.2169	4.99	16%

Table 26 Possible GHG emission avoidance from replacing fossil fuels with RDF in Cimentos de Mozambique

5.10 Total avoidance of GHG emissions

The table below shows the expected emissions avoided through the use of RDF from unsorted MSW. As mentioned before, this is not including the emissions generated by the RDF plant nor its combustion at the cement plant. As can be seen by the total emissions that could be avoided, the use of RDF would not achieve a large climate change mitigation impact.

Year	From Landfilling	From replacement of fossil fuels	Total avoided GHG emissions
	CO2 eq tonnes/year	CO2 eq tonnes/year	CO2 eq tonnes/year
2017	0	4.69	5
2018	1,882	4.71	1,887
2019	3,636	4.72	3,641
2020	5,273	4.74	5,278
2021	6,802	4.76	6,807
2022	8,230	4.77	8,235

2023	9,565	4.79	9,569
2024	10,813	4.80	10,818
2025	11,982	4.82	11,987
2026	13,078	4.84	13,082
2027	14,104	4.85	14,109
2028	15,067	4.87	15,072
2029	15,971	4.88	15,976
2030	16,820	4.90	16,825
2031	17,617	4.91	17,622
2032	18,367	4.92	18,372
2033	19,072	4.93	19,077
2034	19,736	4.94	19,741
2035	20,361	4.95	20,365
2036	20,948	4.96	20,953
2037	21,502	4.97	21,507
2038	22,022	4.98	22,027
2039	22,513	4.98	22,518
2040	22,974	4.99	22,979

Table 27 Total expected avoided emissions from the project

6 Possible technical adaptation needs for the cement plant in Mozambique

6.1 Required processes and practices for using RDF in cement plants: experiences in other countries

The present study compiles technical information from different sources (guidelines, case studies, etc.) of using RDF as an alternative fuel and raw material in the cement industry. It is known that developed countries such the EU countries have gained strong knowledge and experience in cement co-processing, developing as well guidelines, standards, and legal frameworks for regulating the use of RDF. Reflecting in these good practices, cement plants and cities in developing countries are showing progressing interest in using waste as a secondary fuel, due to the potential environmental and economic benefits of this practice.

This is the case of Holcim Ltd and CIMPOR, being the last one present in several African Countries, such as Mozambique. Both Cement companies have already experience with using RDF in their cement kilns in different countries, having satisfactory results. For instance, CIMPOR - Brazil co-processes used tyres, footwear industry waste, and other substitutes for natural raw materials such as those from the aluminium industry[24]. Another example is Holcim Ltd Indonesia, which has been co-processing the non-recyclable MSW fraction since 2008[25].

Regarding co-processing MSW in cement kilns, Holcim Ltd has showed an extensive experience and practical knowledge in this topic, developed with the support of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. In 2003, Holcim Ltd and the GIZ started a PPP

[24] http://www.cimpor.pt/output_efile.aspx?id_file=15804
[25] http://www.holcim.com/sustainable/sustainable-development/case-studies/our-case-studies-by-topic/casestudies/pt-holcim-indonesia-co-processing-municipal-waste.html

cooperation of six years, aiming improving the waste management in selected developing countries and increasing resource efficiency through responsible use of waste as fuel and raw materials in the cement industry. Further, this cooperation aimed at developing technical knowledge and building local capacities for processing waste to RDF. The PPP's first milestone achievement was the development of internationally recognized guidelines on co-processing waste materials in cement production and the model application of co-processing in four pilot countries (Chile, Mexico, Morocco, Philippines). After its validation, the guideline has been implemented in more than 20 countries, combined with the provision of training and advisory services to interested parties from the public and private sector. The guidelines and training material are available not only for Holcim Ltd, but also for other cement plants interested in incorporating co-processing of waste into their cement production[26].

Below in this chapter, this report will present some general technical recommendations and required process adjustments for co-processing of treated MSW (RDF) in cement kilns. The recommendations are extracted from the guidelines of Holcim and GIZ, as well as further sources (Cement Heidelberg in Germany, Cement Sustainable Initiative (CSI-WBCSD).

6.1.1 Technical suitability of the cement kiln for co-processing RDF from MSW

a) Choosing appropriate Feeding points

There are different specific characteristics of the kiln production process, leading to the elimination of different pollutants because of the high temperatures and long retention time. Typically, cement kilns are successful in eliminating dioxins and furans, volatile organic compounds (VOC) and lower heavy metals emissions compared with other thermal waste treatment technologies (such as incineration). Kilns operate at high temperatures, where the process requires: 2,000°C or higher in the flame of the main burner, 1,450°C in the material to make clinker, and 1,000 to 1,200°C in the calcination zone. The typical residence time of combustion gases in the kiln is more than five seconds at a temperature higher than 1,000°C. By contrast, gas residence time in a typical incinerator is two seconds. Residence time for solid materials varies from 20 minutes to an hour depending on the cement process (CSI- WBCSD, 2014).

All the processing conditions and factors mentioned above should be considered when identifying the feeding points for RDF into the cement kiln process. After the identification of the characteristics and quality of the RDF to be used in the cement kiln, the second logical step is to identify the feeding points according to the RDF characteristics and the process parameters. Given the differences in temperature between different parts of the process (precalciner and main burner), it is important that RDF is introduced at the correct points in the process, to ensure complete combustion or incorporation, avoiding unwanted emissions. For example, RDF with volatile organic components (VOC) may be introduced in the cement kiln at the main burner, in mid-kiln, in the riser duct, or at the precalciner (high temperatures). However, they should not be introduced with other raw materials, except where tests (trial burning tests) demonstrate that this will have no effect on gas emissions. Figure 15 shows the possible feeding points for a standard cement kiln.

[26] http://www.coprocem.com/trainingkit/pages/home.html

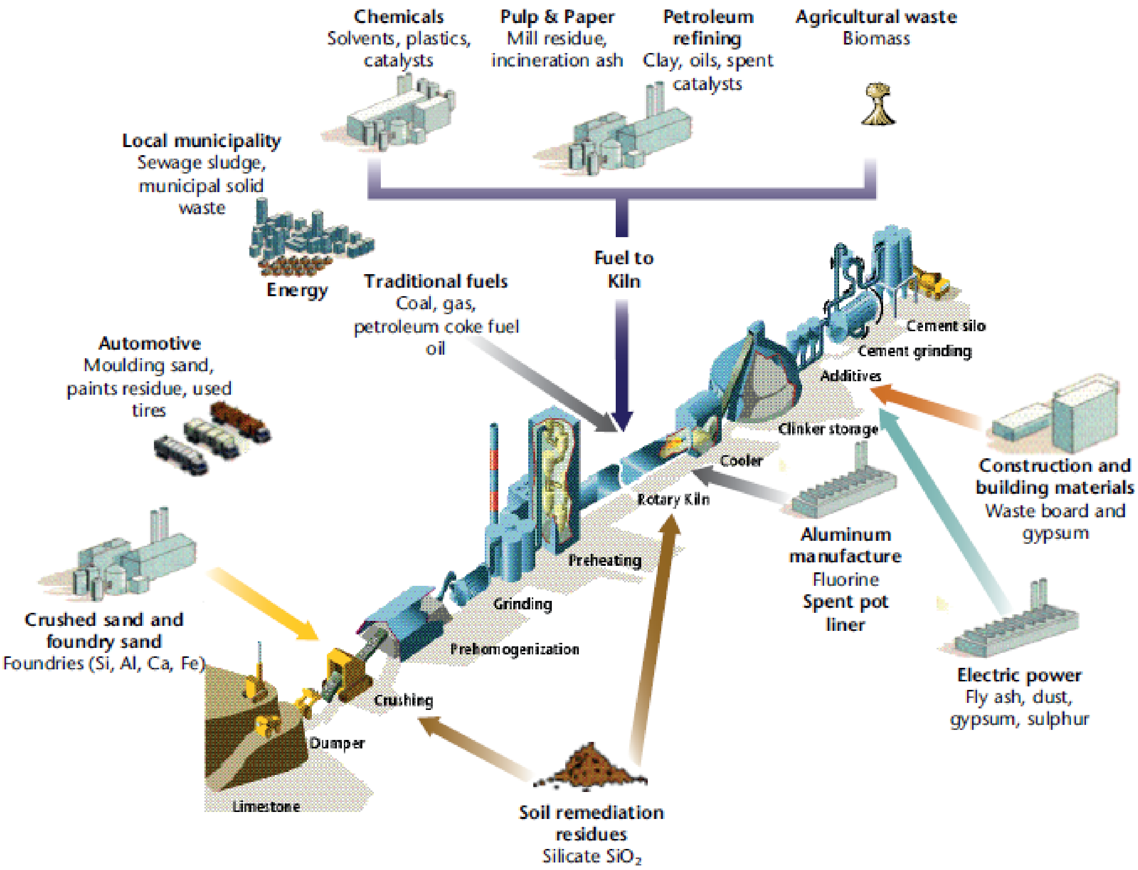

Figure 10 Examples of feeding points for RDF in the cement kiln (CSI - WBCSD, 2014)

Appropriate feeding points will be selected according to the physical, chemical, and (if relevant) toxicological characteristics of the RDF used. As mentioned before, feeding points should be high-temperature combustion zones of the cement kiln. Fine RDF with high calorific value is used in the main burner while coarse RDF with moderate calorific value is fed into the precalciner burner. However, RDF containing toxic should be fed to the main burner to ensure complete combustion due to the high temperature and the long retention time.

Considering the principles mentioned above, the most common ones are (Holcim - GIZ, 2006):

- Via the main burner at the rotary kiln outlet end via a feed chute at the transition chamber at the rotary kiln inlet end (for lump fuel)
- Via secondary burners to the riser duct
- Via precalciner burners to the precalciner
- Via a feed chute to the precalciner (for lump fuel)
- Via a mid-kiln valve in the case of long wet and dry kilns (for lump fuel).

The way of feeding the RDF into the cement kilns is the same way of used for standards fuels and raw materials. However, for RDF containing VOC should not be fed via the normal raw meal supply.

b) Possible changes/upgrading of cement kilns

The need of a cement kiln to be technologically upgraded /modified depends on the current technology of the kiln, the type and characteristics of the RDF, also on the substitution rate aimed by the cement kiln. Pomberger and Sarc (2014) suggest in their analysis of the use of solid recovered fuels in cement plants the following possibilities regarding technical adaptation of cement kilns for co-processing:

c) Use of pre-combustion chambers

The Pre-combustion chambers (for example HOTDISC or PREPOL) allow the use of inhomogeneous RDF with higher grain sizes and lower heating values (typically produced from mixed waste with high organic content). This kind of pre-combustion chambers has a high tolerance to hard impurities, making it optimal for cement kilns in developing countries.

The following Figure 16 describes the technological development and the use of HOTDISC system in the cement industry. This technology was used for the first time for co-processing of alternative fuels by Holcim cement plant Rohožnik (Slovakia). This plant co-processes middle calorific SRF with larger particle size (d95 > 80 mm). HOTDISC technology offers the possibility of using less recycled waste; therefore the material specific characteristics required for the co-processing (in particular calorific value and grain size) can be met with a few processing steps.

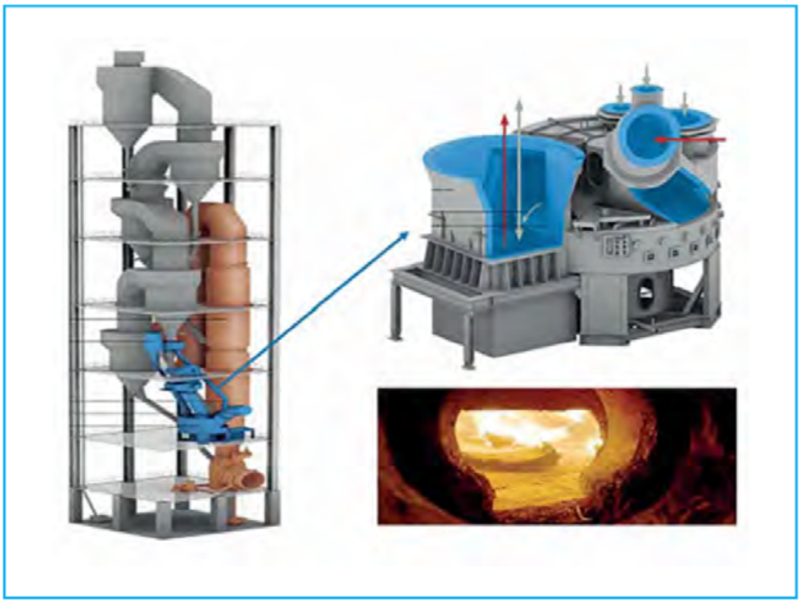

Figure 11 Location and detail of pre-combustion chamber, system HOTDISC (Pomberger and Sarc, 2014)

Therefore, the demands on the quality of fuel in the secondary combustion is lower than in the primary firing, which requires higher heating value (i.e. Hu > 18 MJ/kgOS) and smaller grain size (i.e. d95 < 30 mm). The pre-combustion chamber HOTDISC is installed in the region of the cyclone heat exchanger of the rotary kiln. Then, the RDF is loaded via a damper system and the combustion takes place on a refractory lined rotary plate which is passed by a stream of the furnace exhaust gases. Combustion exhaust gas preheats the raw meal and supports calcining process (Pomberger and Sarc, 2014).

a) Drying of waste

Normally, the demand for high calorific quality - assured RDF is high. Thus, drying of low calorific wastes (e.g. rejects from paper industry, materials from the mechanical biological waste treatment plants, etc. with a calorific value smaller than 11 MJ/kgOS) becomes significance. The drying increases the heating value and allows the use of RDF in the cement rotary kiln (refinement). Waste that is presently used as a medium-calorific SRF, could even reach the qualities of high-calorific substitute fuels (heating value > 18 MJ/kgOS) after drying (= increasing of the heating value). However, this assumption still requires further research and practical trials.

The first aspect to be stablished is the homogeneity of waste. Then, there are several approaches to dry the waste. On one hand, waste heat from the cement kiln can be used for the drying of medium and high-calorific substitute fuels from industry (e.g. cement and paper industry). On the other hand, there is the possibility for drying of waste mechanical - biological stabilization (biological drying), followed by a mechanical – physical stabilization. The biologically stabilized fraction currently used for covering landfills can be used in cement kilns.

b) Fine materials

There are different kiln technologies working with different material handling systems. This means that not every cement kiln can handle every type of RDF. Depending on the handling system, a specific grain size and homogeneity will be needed for kiln. In the example of scrap tyres, not all kilns will be technically able to burn entire scrap tyres. Some of them may be limited to use chipped tyres. Experiences have showed that for some kilns, adding whole tyres into the kiln slows down in the belts moving into the kiln, resulting in insufficient oxygen for tire combustion (US EPA, 2008)

In other cases, the material handling systems of the kilns are not able to process different types of RDF at the same time. This means that cement kilns with this issue should have this as a critical condition for choosing their final RDF option. Materials handling systems can be designed to accommodate multiple types of materials, however there is an increased capital cost involved in such flexible design.

The adjustment of the physical characteristics of the RDF to the Kiln can be done in the RDF production plant, but could also be carried out immediately prior to the furnace by the individual cement plant itself. The cement plant can adjust and optimizes the grain size itself, integrating additional isolated process steps such as cutting-shredding.

c) Chlorine reduction in material

The chlorine content is a known issue in the cement industry. The higher the substitution rate is, the better must be the quality of the RDF (less chlorine content). A solution for this could be the previous separation of the chlorine-rich fractions present in the RDF. Some RDF production plants have such processing steps, increasing the quality of the RDF making it constant as well.

d) Oxygen feeding into the furnace

With declining calorific values on the main burner, the addition of oxygen to the combustion air can improve the burnout and increase the flame temperatures. Through this measure, the substitution rate can be improved at the main burner.

6.1.2 Recommended operational practices for using RDF in cement kilns

a) Selection of fuels and raw materials

As mentioned before, the quality of the RDF is a critical aspect to consider. The composition and further characteristics of the RDF influence on the efficiency of the burning process, the quality of the kiln, and the emissions. Therefore, the following variables should be considered when selecting the RDF to be used in the cement kiln (CSI - WBCSD, 2014)

Factor influencing the kiln operation:

- Contents of alkali, sulfur and chloride: Excessive inputs of these compounds may lead to build-up and blockages in the kiln system. Where these cannot be captured in the cement clinker or kiln dust (CKD), a bypass may be required to remove excess compounds from preheater/ precalciner kiln systems. High alkali content may also limit the recycling of kiln dust (CKD) in the kiln itself.
- Calorific value: optimal for the kiln process
- Water content: moisture content may affect productivity, efficiency and also increase energy consumption.
- Ash content: the chemical composition of the ash needs to be monitored to ensure that the final composition of the raw mix meets the necessary requirements for clinker production.
- RDF ´state (liquid, solid), preparation needed according to the physical characteristic of the RDF(shredded, milled) and the material handling system of the cement kiln

Factor influencing the emissions of the kiln:

- Organic content: If the RDF is fed through unsuitable points or during unstable operating conditions the organic component may generate CO (in case of incomplete combustion), total organic carbon (TOC) and dioxin/furan emissions. If the burning happens in inappropriate technical conditions, the feeding of the alternative fuels must immediately stop until the process again becomes stable.

- Chloride content: Chlorides may combine with alkalis to form fine, difficult to control particulate matter. In some cases, chlorides combines with ammonia present in the limestone feed, producing a visible detached plume of fine particulate with high ammonium chloride content.
- Metals content: The non-volatile behaviour of most heavy metals allows most of them to pass straight through the kiln system and be incorporated into the clinker. Volatile heavy metals will partly be recycled internally by evaporation and condensation until equilibrium is reached, with a very small portion being emitted in the exhaust gas. In the cases of thallium and mercury, they are highly volatile, followed by cadmium, lead, selenium and their compounds. Dust control devices can only capture the particle-bound fraction of heavy metals and their compounds; therefore, emissions of the gaseous species must be controlled. In general, it is recommended to reduce to the extent possible the mercury content in the RDF.
- Kiln gas bypass exhaust gas (alkali bypass) can be released from either a separate exhaust stack or from the main kiln stack in systems equipped with an appropriate bypass. The same air pollutants are found in both the main and kiln gas bypass stacks. Where an alkali bypass system is installed, appropriate control of the exhaust to atmosphere also needs to be provided on the bypass exhaust, similar to that required for the main exhaust stack.
- High sulfur content in the RDF may result in the release of sulfur dioxide (SO_2)

Regarding the limits for heavy metal content, the CSI - WBCSD recommends the following criteria:

Hg + Cd + Tl < 100 ppm

Cu< 1,000 ppm for long and Lepol kilns,

Cu< 3,000 ppm for pre-calciner kilns

As + Ni + Co + Se + Te + Cr + Pb + Sb + Sn + V < 10,000 ppm

Cr < 150 ppm / fraction material (loss free basis) in raw mix.

b) Before using RDF in kiln: Baseline testing and RDF - trial testing

Emissions from kilns should be kept low in order to comply with the country´s environmental regulations. Processing conditions (temperature, time of incineration, air, etc.) interact with the chemical components of waste materials causing the emissions. Additionally, some emissions (such as volatile components) are not homogenous in the raw materials, causing as well variable emissions day by day. For this reason, cement kilns are equipped with different control and monitoring systems to keep the emission under the limit.

Co-processing RDF increase the uncertainty regarding the emission flows and their variation over time. Therefore it is recommended to run a "baseline testing" followed by a "trial testing". In the baseline testing, current emissions and fluctuations from using standard fuels are measured and standardized for the cement kiln. The "trial testing" tries forecast and measure emissions changes and fluctuations from using RDF in the cement kiln. This is mostly based on expert know-how, testing and chemical analysis, or real emission measurements in the kiln. According to the country´s regulation, some authorities may require the kiln to perform this "burning trials" before authorizing the use of RDF. However, from a technical point of view, it is recommended anyway to run such tests, in order to prevent possible high emissions when co-processing RDF.

For carrying out a baseline and the trial testing, the following principles/rules should be considered:

The baseline test takes place over four to six days without the RDF in question, during which:

- Dust, SO2, NOx(sum of NO and NO2), CO, and VOC are measured continuously
- HCl, HF, NH3, benzene, PCDDs/PCDFs
- Hg, Tl, Cd and other heavy metals.

The trial burn test is identical to the baseline test but includes the AFR. The same emissions should be measured.

c) Collection and transport of RDF

In principle, the collection and transport of the RDF to the cement kiln should be performed under consideration of the country´s waste regulation for these cases, including an appropriate labelling for the RDF. Only fully qualified and licensed transporters who are conversant with and conform to the applicable legal requirements should be used in order to avoid accidents and, in particular, incidents due to the incompatibility of poorly labelled or poorly characterized waste or by-products being mixed or stored together.

d) Acceptance of RDF in the cement kiln

The RDF should be characterized regarding its mineral composition, level of organic material and heavy metal composition, controlling that these characteristics meets the Kiln's pre-determined acceptance criteria. It is recommended that the RDF´s quality is specified and stablished between the RDF producer and the Kiln by a written contract, being the quality verified every time during the RDF´ s reception. The acceptance criteria should be reviewed (and updated) on a regular basis. The monitoring and updating of the quality criteria for RDF should be registered through appropriate reception protocols. The cement kiln should also define procedures in case of non-compliance of the quality criteria.

In addition to the RDF labelling, technical sheets for RDF and other documentation provided by the RDF producer, the Cement kiln should perform laboratory tests to verify the information on the documentation. This could be done in a lab in the cement kiln or through extern service.

e) Kiln operation

Good practices for the operation of a kiln using RDF comprise the measurement and monitoring of all relevant process parameters, including their recording and evaluation. This should cover free lime in the clinker, excess oxygen, carbon monoxide levels, and total hydrocarbon (THC) emissions in the stack gas (CSI - WBCSD, 2014). as mentioned in previous chapters, the selection of an appropriate feeding point together with an appropriate RDF quality and emission control systems ensure an optimal operation of the kiln.

RDFs containing highly chlorinated organic compounds should be introduced at the main burner to ensure complete combustion through high combustion temperature and long retention time. If the cement kiln wants to use a different feeding point, this should be done after burning test, proving high destruction and removal efficiency rates. RDF with volatile organic components (over 5,000 mg/kg) should not be introduced with other raw materials in the process unless tests have shown that undesired emissions at the stack do not occur.

f) Emissions control and monitoring

Cement kilns generate emissions that are subject to legal regulation. Emission should be measured, monitored and reported according to the legal requirements, but also to document and improve the environmental performance of the cement kiln. Controlling and monitoring of emissions would also serve as an input for communication with the local community and other stakeholders.

The monitoring and reporting of emissions should be carried out according to permit specifications and regulatory requirements, or, where these do not exist, these procedures should be developed by the cement kiln, following international guidelines and/o standards. The CSI guidelines mention the use of measurement equipment for monitoring parameters such as oxygen, carbon monoxide (CO), particulate, SO2, NOx, dust and THC emissions, as well as conducting periodic measurement tests for heavy metals and dioxins/furans. For more information about the CSI: www.wbcsdcement.org/emissions.

6.2 Technical assessment determining the requirements and suitable technical options for upgrading Mozambican cement factories

6.2.1 Current state of the art - cement kiln in matola - Cimentos Mozambique

The cement sector in Mozambique has an estimated production capacity of 2.72 million ton per year. Seven cement production facilities are currently operational in the country. Only Matola I, owned by Cimentos de Mocambique (CdM), is a fully integrated facility with clinker production. Two more integrated facilities are under development, one in Nacala (InterCement) and one in Inhaminga (China-Mozambique Cement & Mining). **Error! Reference source not found.** provides an overview of active and planned cement production facilities in Mozambique.

Company	Location	Type	Status	Capacity (Mt/y)
Cimentos de Moçambique	Matola I	Integrated	Active	0.70 (Dry)

(InterCement)				
InterCement	Nacala	Integrated	Now only Grinding	0.10
China-Mozambique Cement & Mining	Inhaminga	Integrated	Planned	1.0 (Dry)
Cimentos de Moçambique (InterCement)	Matola II	Grinding	Active (Rented)	0.22
Cimentos de Nacala SA (InterCement)	Nacala	Grinding	Active	0.35
Cimento Nacional (Cimento Brennand)	Maputo	Grinding	Active	0.55
Cimentos de Beira	Beira	Grinding	Active	0.80
Consolidated General Minerals	Beira	Grinding	Under Construction	0.80
Austral Cimentos	Dondo	Grinding	Commissioning	0.55
PCC Mozambique	Tete	Grinding	Under Construction	0.50

Table 28 Active and planned cement production facilities in Mozambique[27]

The main cement producer in Mozambique is Cimentos de Moçambique SARL, member of InterCement. The InterCement group is a Brazilian multinational, controlled by Camargo Corrêa SA. InterCement is a leader in the cement markets in Portugal, Argentina , Mozambique and Cape Verde, and also operates in the Brazilian market , Paraguay, South Africa and Egypt .

About 75% of InterCement's units that produce clinker (integrated facilities) have co-processing activities integrated into their process. In 2013, Intercement co-processed 587,000 metric tons of waste worldwide. With this, InterCement did not consume 235,000 metric tons of fossil fuels, thus reaching a 12% level of thermal substitution, in addition to saving 130 metric tons of mineral waste.28

On 20 October 2014, the Matola I cement factory in Maputo obtained an environmental license for co-processing industrial waste for the partial substitution of raw material and fuel.

Matola I cement factory

The Matola I cement factory is located in Língamo district in the industrial area of Matola Municipality of Matola, covering an area of 130,000 m2, of which 2,016m2 is the area occupied by the factory premises and the remaining 127,984 m2 as expansion area (see **Error! Reference source not found.**).

[27] Adopted from http://www.globalcement.com/magazine/articles/894-the-cement-industries-of-southern-africa
[28] Intercement (2013) Annual Report

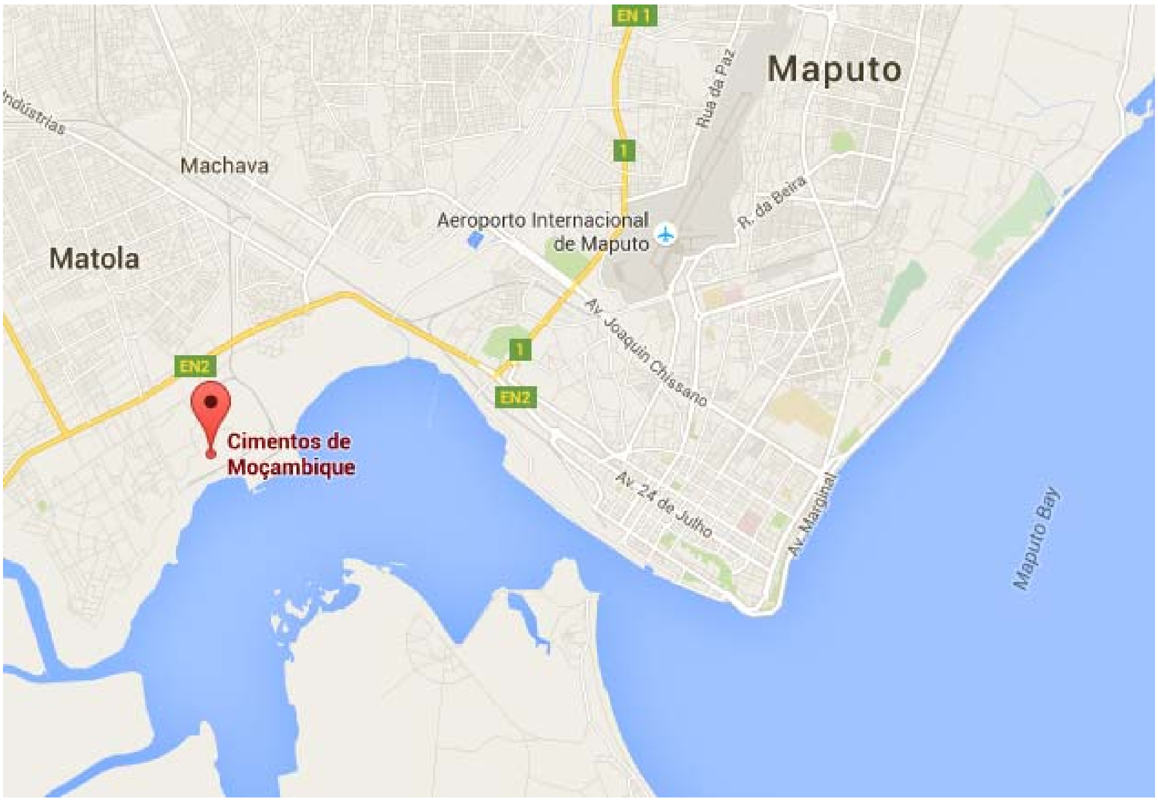

Figure 12 Location of the Matola I cement factory

The manufacturing activities of CdM in Matola began in 1920 with a line of wet production, passing in 1974 to a dry production process. Since then the plant has undergone several renovations and expansions of production lines. Currently, the plant has a capacity to produce 540,000 tons of clinker per year.

CdM has been certified by SABS on 17 July 2013 under permit number 8990/14243 for their cements to be considered as Portland limestone cement (cimento Portland de calcário) of the following types and strengths corresponding to the standard SANS 50197-1/SABS EN 197-1:

- CEM II A-L 42.5 N
- CEM II B-L 32.5 N

Production in 2015 included:

- Crushed limestone: 769,263 tons
- CEM II/A-L 42.5N: 305,648 tons
- CEM II/B-L 32.5N: 353,580 tons
- Clinker: 321,528 tons

Technical description

The cement facility in Matola uses the dry process. The kiln system consists of a tower of heat exchange cyclones in which the dry feed is preheated by the rotary kiln's hot exit gases. The dry material enters at the top of the upper cyclone and moves downwards through the cascade into the rotary kiln. When the meal enters the rotary kiln, calcination is already about 30% completed because the kiln feed is already heated to a temperature of approx. 850 °C by using the exhaust gases. The cement facility in Matola does not have a pre-calciner, which is normally a source of additional heat/fuel demand.

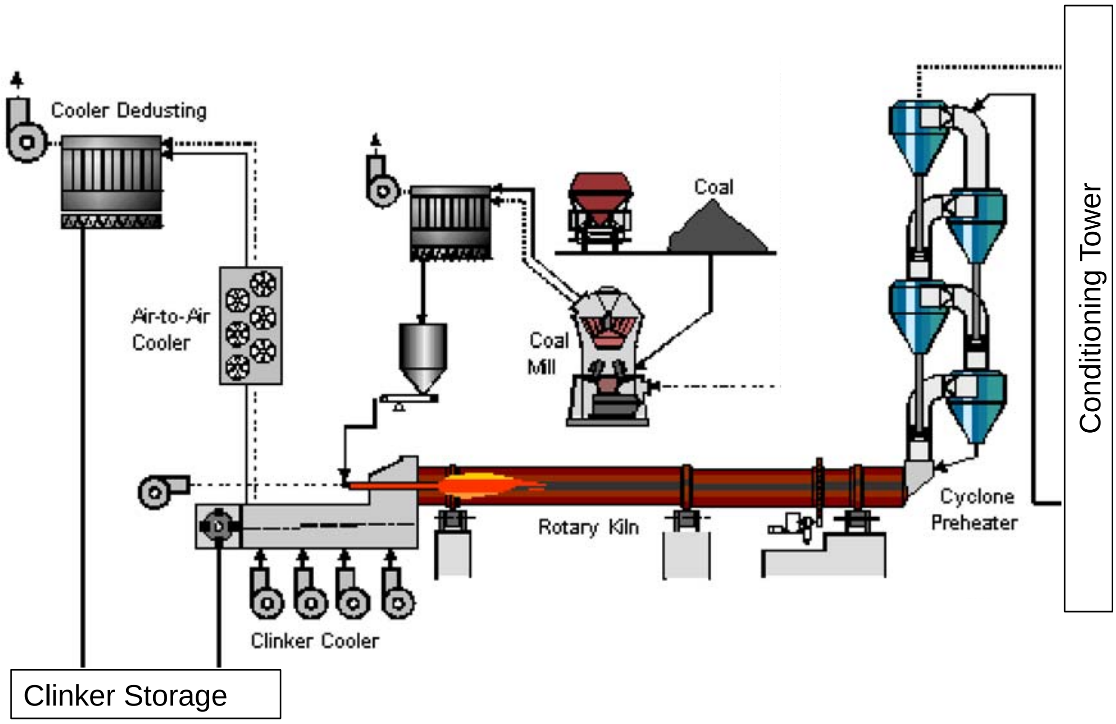

Figure 13 Schematic overview of the clinker production process at Matola I factory[29]

The rotary kiln is 72 meters long and has a diameter of 4.8 meter. Process temperatures in the sintering zone of the rotary kiln are kept at between 1400 and 1500°C, and the flame temperature at about 2000°C.

The rotary kiln uses a multi-channel burner, which is designed for the use of different fuel types, including waste.

[29] Adopted from European Commission (2013) *Best Available Technique Documents for the Production of Cement, Lime and Magnesium Oxide.* Industrial Emissions Directive 2010/75/EU (Integrated Pollution, Prevention and Control)

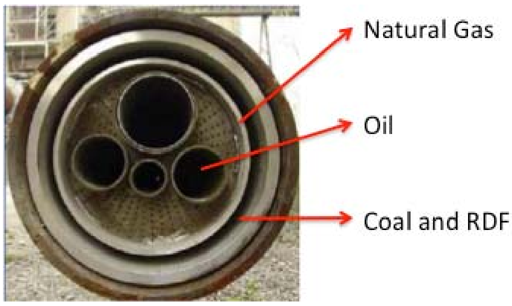

Figure 14 Multi-channel burner

After leaving the rotary kiln, the clinker is cooled with air and then stored. The clinker cooler is an integral part of the kiln system and has a decisive influence on performance and economy of the cement factory. The cooler has two tasks: to recover as much heat as possible from the hot (1450°C) clinker so as to return it to the process; and to reduce the clinker temperature to a level suitable for the equipment downstream.

Capacity	2,000 tons/day	Length	72 m
Diameter	4.8 meter	Engine power	300 kW
Slope	3.5%	Revolutions	1.3 rpm

Figure 15 Rotary kiln at Matola I cement facility

Processing flows and processing parameters

In 2015, CdM's cement plant in Matola produced 321,528 ton of clinker. The cement types produced include:

- CEM II A/L 42.5R;
- CEM II A/L 32.5N;
- CEM II B/L 32.5N

All cement products are produced in conformity with Standard SAN50197-1/SABS EN 197-1 of the South Africa Bureau of Standards (SABS).

The **specific heat consumption**[30] is estimated at 3,948 to 4,264 MJ per ton of clinker produced (Data for 2015). Primary fuels are natural gas and crude oil. Previously, CdM also used coal. Since 2014, small amounts of RDF are being used, mostly in the form of paper waste (see Table 29). The RDF currently enters the process via the last cyclone in the pre-heater. In 2015, CdM also received 291.41 tons of carbon dust from an aluminum smelter facility just outside Maputo. The carbon dust is being mixed with the raw materials entering the clinker production process. Table 29 provides an overview of the fuel consumption data for 2015. Table 30 provides an overview of average fuel consumption for CdM per year and related costs. As can be seen by the Table 30, CdM charges for co-processing of the currently received RDF, which would indicate that there is low financial incentive to co-process RDF at this stage, as long as quantities are not substantial. The financial feasibility of the use of MSW as RDF is analysed more in depth in a separate document[31] "Output

	Fuel input (ton/year)	**Calorific value (kCal/kg)**	**Calorific Value (MJ/kg)**	**Total Calorific value ('000 kCal/year)**	**Total Calorific value (MJ/year)**
Rubber	0.98	4,000.00	16.75	3,920	16,412
Crude oil (solid)	519.67	4,656.15	19.49	2,419,661	10,130,638
Paper waste	32.22	1,800.00	7.54	57,996	242,817
Crude oil (liquid)	98.41	10,857.86	45.46	1,068,522	4,473,687
Gas	33,232.73	9,017.83	37.76	299,687,110	1,254,729,990
				303,237,209	1,269,593,546

Table 29 CdM fuel consumption data for 2015

Item	**Consumption**	**Costs for purchasing energy/fuels in Meticais**
Electricity	42,527,724 kWh/year	46,064,800 MZN/year
Natural gas	33.233 t/year	253,659,610 MZN/year
Shredded paper and biomedical waste	50 t/year	No costs, CdM charges for co-processing
heat source/fuel: Liquid waste	300 m3/year	No costs, CdM charges for co-processing
Carbon dust	2,700 t/year	No costs, CdM charges for co-processing

[30] Specific Heat Consumption is the amount of energy that is required to produce one unit of output. Modern cement plants have an energy consumption of 3,000-3,300 MJ per ton of clinker, whereas the wet process with long kilns consumes up to 6,000 MJ per ton.

[31] "Feasibility study to use waste as fuel for cement factories, Reference number: 2015-036/MOZ-01 Output 2: Economic study of producing RDF from MSW and its use as fuel for cement factories"

Table 30 Fuel consumption Cimentos Mozambique (AMOR, 2016)

Description of possible feeding points

As shown in Figure 16, different feeding ports can be used to charge fuels into the kiln. The potential feeding ports in a cement production plant are:

(1) Via the main burner at the rotary kiln outlet end;

(2) Via secondary burners to the riser duct at the kiln inlet;

(3) Via precalciner burners to the precalciner;

(4) Via a feed chute to the precalciner (for lump fuel).

CdM has carried out its own internal assessment based on which it was concluded that feeding the RDF via the main burner (1) is the only viable option. This is partly based on the fact that the kiln system does not have a pre-calciner and partly because the current way of feeding the RDF through the cyclone system has found to be impractical.

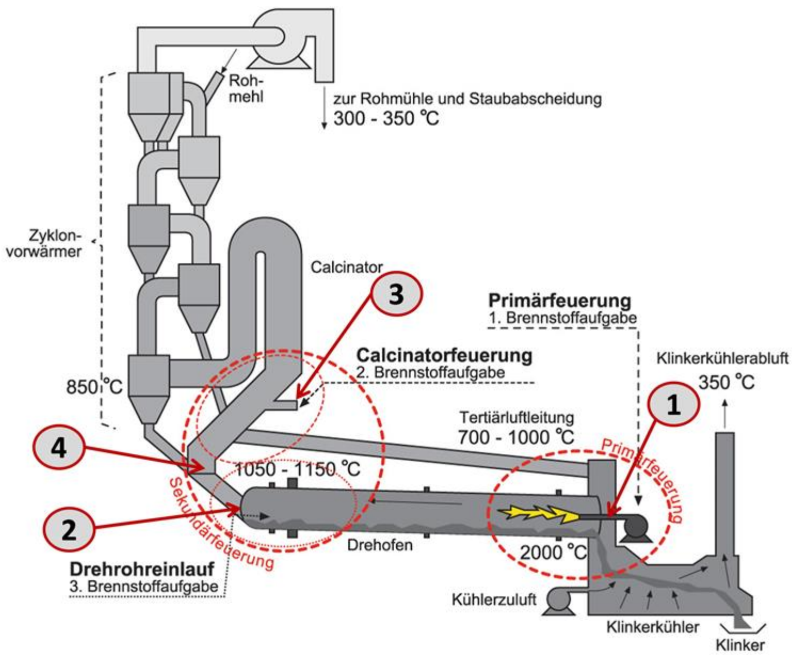

Figure 16 Potential feeding ports for RDF into the cement kiln

6.2.2 Cimentos Mocambique: TECHNICAL NEEDS/UPGRADING - Adjustments to existing facility

The main goal of the project is to establish an RDF handling system to feed RDF of 10 mm size (see also Table 13[32] to the main burner of the kiln with a capacity of up to 5 tons per hour, 24 hours per

[32] Size of RDF could be slightly bigger up to 35mm (see for instance http://www.wtert.eu/default.asp?Menue=13&ShowDok=49)

day. No special firing technology has to be installed because the kiln already uses a multi-channel burner which can feed RDF into the kiln. The RDF handling system will include:

- Storage hall with 1,000 m^2 and covered, concrete walls up to 7 m height and metallic roof;
- Disc screen for screening of received material;
- The system has to be upgradable to include an online shredder in the future if needed;
- Feeding hopper with a capacity of 10 m^3, steel plate manufactured, with the top edge at the same level as the storage hall floor, equipment with a grid (to define the mesh dimension);
- Drag chain conveyor to intermediate hopper at the dosing equipment level (volume of 15 m^3);
- Drag chain conveyor to the dosing equipment (capacity of 10 tons per hour);
- Dosing equipment (e.g. Schenck Multiflex with hopper capacity of 5 m^3);
- Rotary valve feeder (e.g. Schenck IDMS star feeder)
- Blower for rotary valve feeder (capacity to be defined);
- Piping from the feeder to the main burner;
- Accesses and platforms to equipment drives;
- All field electrical and automation equipment needed such as auxiliary panels, local control box or VCS (visual cut-off switch) for each LV consumer above 1.5 kW;
- Firefighting system – Connection to the existing network and two hydrants on the storage hall;
- Civil works;
- Steel structure;

The total price for the RDF handling system to be installed at the cement facility is estimated in the order of EUR 2.5 million.[33] This does not include the buildings and equipment that may be required to produce the RDF.

[33] Estimate obtained from Cimentos de Moçambique)

7 Conclusions

This report concluded that it is technically feasible to produce a medium - quality RDF from the MSW generated in Maputo (Cidade de Cimento), although, given the current waste composition and MSW infrastructure not creating separated waste streams at source, the final RDF will not be able to meet the requirements to be used by CdM. The new landfill currently being prepared in the area of Matola, can provide future possibilities for the utilization of separated waste streams from its proposed recycling center. Especially the plastic fraction might become suitable, given the calorific value requirements set by CdM. Although, current uncertainties regarding the future of the recycling centre and expected amounts of the recycled plastic fraction doesn't make it possible to establish the appropriateness of future utilization of the plastic fraction for RDF.

Mechanical processing of MSW will not be able to reach the established requirements set by CdM, although, if waste separation at source is introduced in the future, this technology option could provide a viable solution for the production of RDF with high calorific content.

If the calorific requirements for RDF from CdM were to change to accept medium quality RDF with a calorific value of 15,574 KJ/Kg, the process of Mechanical-biological stabilisation (MBS) or biological drying could be used to produce RDF from unsorted MSW. Although, it is important to note that this study was based on general literature sources and local data not updated to the current state. There is therefore a high uncertainty which could only be minimized through data collection on the field, such as current waste amounts received at the landfill, waste composition (based on a characterization study), real calorific value of the MSW and determination of the RDF calorific value from MSW (determined by laboratory test and piloting tests).

If CdM was to accept medium quality RDF with a calorific value of 15,574 KJ/Kg, and given that they would utilize the RDF produced by biological drying. The use of RDF could mitigate a relatively low amount of GHG emissions. The emission reductions from fossil fuel replacement could range from 4.69 tCO_2e/year by the start of the use of RDF, to 4.99 tCO_2e/year by 2040. Emissions avoided from landfilling would give ha higher GHG mitigation result, achieving 22,974 tCO_2e/year by 2040. The total avoided emissions would therefore be in the rage of only 5 tCO_2e/year the first year, and achieve 22,979 tCO_2e/year by 2040. It can be expected that the amount of collected MSW would increase over time as collection service coverage expands, which could lead to a higher RDF production and increased emission reductions over time. Therefore, the MSW in the future could potentially provide more than the estimated 13,619 tRDF/year. Although, the amount of RDF that would be able to receive would only reach 33,375 t/day in 2026 according to the current information.

CdM is currently charging fees for co-processing of the small amounts of RDF it uses, mainly paper, liquid fuel waste and carbon dust. This indicates that there is little financial incentive to co-process RDF as long as quantities remain low, and the fuel doesn't meet the specific requirements set out by CdM.

It is recommended that RDF production from MSW is not pursued at the current state of development of the MSW management in Maputo and Matola. When the new landfill in Matola is established, together with a recycling center, the different recycled waste streams could be subjected to laboratory and pilot testing to determine the real energy and material potential of the different recycled waste streams. This would allow identifying if some of the separated waste could be used as RDF.

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