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BIOMASS ENERGY FOR CEMENT PRODUCTION: OPPORTUNITIES IN ETHIOPIA



UNEP
RISØ ENERGY, CLIMATE
CENTRE AND SUSTAINABLE
DEVELOPMENT

CDM Capacity Development
in Eastern and Southern Africa

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FOREWORD

Biomass and biomass residues, if sourced in an environmentally and socially sustainable fashion, represent a vast – and largely untapped – renewable energy source for the countries of sub-Saharan Africa. This guide, jointly developed by UNDP and UNEP Risoe Centre, seeks to outline the potential, taking the Ethiopian cement sector as a specific example of how biomass energy might be deployed in practice. Many of the issues covered, such as the need for biomass pre-treatment and densification, the problems of biomass availability in space and time, and the importance of appropriate on-site storage and handling facilities, are equally applicable to other countries of the region and, indeed, other manufacturing sectors.

It is hoped that the guide will assist policy makers, industrial operators and the technical community to engage with the opportunities and challenges presented by the use of biomass energy, particularly in the context of the financing opportunities provided by the Clean Development Mechanism.

The guide is based on three studies conducted by acknowledged Ethiopian experts: Yisehak Seboka, Ethiopian Ministry of Mines & Energy; Mulugeta Adamu Getahun, energy consultant; and Yared Haile-Meskel, industrial consultant. The views expressed by the authors are those of the authors alone.

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CHAPTER ONE

SOURCING & TREATMENT OF BIOMASS FOR ENERGY APPLICATIONS IN THE CEMENT INDUSTRY

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1. BACKGROUND

Agricultural and agro-industrial residues constitute 15% of the total energy consumed in Ethiopia. Residues are mostly used in the domestic sector for cooking and baking, using very low efficiency devices. Residue supply is seasonal and residue use as fuel is also seasonal.

In different parts of the country, various types of crops are cultivated and, as a result, a considerable volume of crop residues is also produced. Generally, for use as fuel, crops with a higher residue-to-seed ratio provide the largest volume of potential biomass. However, it is often not desirable, socially and environmentally acceptable or, indeed, economically viable to divert all types of biomass residue for fuel.

Agricultural residues have different uses. Residues from wheat and maize, for example, may be left on the ground or burned in the field to recycle soil nutrients; some parts are used as animal feed, as building materials and as cooking fuel. The fraction that is available for fuel, either for direct use or further processing, is therefore limited and varies from crop to crop.

In the small (subsistence) scale farming context, residues are generally better used for ecological, agricultural or construction purposes than for fuel. However, in large commercial farms and in agro-industries a large proportion of the residue available cannot be used on-site due to limited demand in the immediate vicinity. As a consequence, residue tends to be disposed of wastefully.

Crop and agro-industrial residues have low bulk and energy density, and for these reasons cannot be transported far from production sites without some form of processing. Residues from large commercial farms and agro-industries can be converted to relatively high-quality and high-energy density fuels for use in the domestic, commercial and industrial sectors through a number of physical, biological and thermo-chemical conversion processes.

Cement factories can potentially use alternative fuels, including biomass and biomass residues, to heat their kilns. The substitution of fossil fuel by biomass and biomass residues qualifies, in principle, for CDM carbon crediting. Biomass can substitute for approximately 20% of process heat requirements without the need for major capital investment.

Throughout this Guide, reference will be made to Muger Cement plant as an indicative example of the opportunities and challenges Ethiopian cement operators can expect to encounter should they decide to utilize biomass energy in their operations. Muger Cement plant is a large, state-owned cement factory located 105 km west of Addis Ababa. Currently, the plant produces 900,000 tonnes of cement per year - Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) – and plans are being implemented to expand its capacity to 2.3 million tonnes/year.

The production process of cement clinker is energy-intensive and requires a large amount of fuel. Table 1 shows the increase in fuel consumption experienced by Mugher Cement plant over time.

*Table 1. Furnace Oil Consumption by Mugher Cement Plant, 1999-2000
(Taddele, 2008)*

Year	Fuel Consumed (litres)	Fuel (Birr)
1999	57,614,478	88,645.635
2000	57,673,490	97,095.467
2001	58,303,321	123,116.129
2002	59,080,215	129,527.180
2003	61,080,215	134,291.435

2. OBJECTIVES

- To replace 20% of Heavy Fuel Oil (HFO) or other fossil fuel with agro-industrial wastes such as coffee husks, cotton stalks, saw dust, castor husks or chat stem. This will significantly reduce the fossil fuel usage required to produce cement.
- To introduce alternative fuels into the cement-making process without compromising the clinker quality or quantity.
- To reduce the amount of imported fossil fuel used for cement production.
- To achieve greenhouse gas emission reductions through partial substitution of fossil fuels with alternative fuels in cement manufacture.

3. SOURCES OF BIOMASS/BIOMASS RESIDUES TO BE USED AS AN ENERGY SOURCE IN THE ETHIOPIAN CEMENT INDUSTRY

3.1. COFFEE HUSK

Coffee is a major commodity export-earner for Ethiopia, accounting for 61% (by value) of the country's annual commodity exports. It is estimated that the total area covered by coffee is approximately 400,000 hectares, with a total production of 200,000 tonnes of clean coffee per year (Gemechu, 2009).

3.1.1 COFFEE PROCESSING

There are essentially two ways of processing coffee beans from the freshly picked red cherries of the coffee plant: wet and dry processing. Each process produces a different quality of "green coffee" and residues with very different characteristics.

3.1.2 SUN-DRIED (UNWASHED) COFFEE RESIDUES

In the dry process, the red cherries, which initially contain approximately 65% moisture content, are sun-dried until they reach approximately 10-12% moisture content. After the cherries are dry, they are put through a dry mechanical pulping (or decorticating) process in which the green coffee bean is separated from the outer residue material (skin and husk) of the cherry. The dry process removes the upper hard cover (the husk) and the inner skin (parchment) in the milling process. This residue material is generally blown out of the rear of the processing plant, where it accumulates during the processing season and eventually composts due to ingress of moisture. Heat generated during the composting of this waste occasionally spontaneously ignites the dry layers of recently added materials, commonly resulting in slowly smouldering heaps next to the processing plants.

A mass of 100 kg of red cherries picked at 65% moisture content will result in approximately 40 kg of sun-dried coffee cherries delivered to the processing plant. Of this mass, about 17 kg will become sun-dried coffee beans while the remaining 23 kg will end up as residue at the processing plant.

3.1.3 WASHED COFFEE RESIDUES

In the wet (washed coffee processing) process the fresh cherries are milled using wet pulping machines to remove the outer skin and some of the mucilage. The processed cherry is then left to ferment in tanks for a specified period of time and the removal of the remaining mucilage is effected while the parchment is left intact.

As a result of the washed processing method, two distinct types of residue are generated. The first is the wet coffee pulp, which consists of the epicarp that is removed at the washing plants in the coffee growing regions. For 100 kg of ripe cherries delivered to a washing plant, 60% by mass ends up as washed coffee pulp with the remaining 40% consisting of the green bean and endocarp (parchment). Of this 60% washed coffee pulp, only 20 kg remains after sun-drying of the bean and parchment. This is then shipped to the washed coffee processing facility in Addis Ababa where the parchment is removed. The result is 16 kg of washed coffee beans ready for export and 4 kg of parchment as residues.

The average residue production per tonne of wet red cherry is about 600 kg or, based on green coffee bean production, the residue potential would be 1.4 times the mass of green beans produced (ESMAP, 1986).

3.1.4 RESIDUE AVAILABILITY

Most of the coffee production areas and processing plants in Ethiopia are found in the southern and eastern parts of the country, notably in the Southern Nations, Nationalities and People's Region (SNNPR) and in Oromia, which each host more than 500 coffee processing plants.

In the case of dry processing of coffee, all residues are effectively available at the processing plant; in wet processing, about 14% of the residue (the parchment) is available at about 10 central processing stations (Addis Ababa). Currently, 84% of the coffee arriving at the central auction stations in Addis Ababa and Dire Dawa are dry-processed. Wet processing results in a better quality of coffee products, however, and its share of the market is growing.

3.1.5 POTENTIAL OF COFFEE RESIDUES: COFFEE PULPING AND HULLING PLANTS

These are concentrated in the major towns of the coffee growing areas of the country. In the Dilla area, for example, there are more than a hundred such establishments. Residue pulp is mostly dumped in streams, although a small amount of it is sold as fuel or for 'tea' making in rural areas.

With increasing participation of the private sector both in production and export, the production of coffee and coffee arrivals at coffee processing stations has increased over recent years. The total volume of coffee supply to the official market is estimated to be about 160,000 tonnes per year. However, it is estimated that a considerable amount of coffee is also traded illegally and total coffee production could be as high as 250,000 tonnes per year. Considering the lower production figure, the corresponding annual coffee residue production would be at least 200,000 tonnes.

Currently, the wet pulp is discharged into local streams and rivers where it tends to clog, forming a putrescent mass and producing a highly acidic effluent which pollutes the water, destroying aquatic life and generating an offensive odour. Recovery of this pulp for industrial fuel use would require collecting the residues as they are discharged from the pulping machine and processing them to greatly reduce the moisture content.

Husks represent over 90% of the coffee residues produced. However, the extremely low bulk density (approximately 50-80 kg/m³) of the husks produced precludes their economic transport to cement factories 300-500 km distant. Densifying or pelleting this material to a density of 500-600 kg/m³ would greatly reduce transport, handling and storage costs and facilitate its use as industrial fuel.

The regional distribution of coffee residues is indicated in Table 2 below.

Table 2. Regional Distribution of Coffee Residues (Kebede, 2001)

Process	Location	Green Coffee (tonnes/yr)	Coffee Residue (tonnes/yr)	No. of Processing Plants
Dry Process	Regional total	130,350	184,024	
	SNNPR	35,060	49,496	113
	Oromiya	94,145	132,911	273
	Gambela	1,033	1,458	2
	Others	112	158	
Wet Process	Regional total	25,019	30,275	
	SNNPR	16,533	20,006	309
	Oromiya	6,959	8,421	189
	Gambela	1,519	1,838	6
	Others	8	10	
Grand Total		155,369	214,299	

3.1.6 BRIQUETTE PRODUCTION POTENTIAL

Coffee residues have very low bulk density, 50-80 kg/m³, and are difficult to handle and transport. Coffee residue is generally not used as a significant fuel source in the regions where coffee is produced and, presently, has very little financial value. Residues, however, could be effectively used for the production of fuel briquettes as substitutes to fuelwood, coal and fuel oil in cement factories.

3.2. POTENTIAL OF COTTON RESIDUES

State farm plantations, mostly concentrated in the Awash River Basin, dominate cotton production in Ethiopia. Some private cotton cultivators are also active in these areas and others. At present, the residues are not utilised but are burnt in the field to control pathogen and insect infestation of the following crops and are then ploughed under.

The bulk density of cotton stalk residues collected in the field is approximately 140 kg/m³. The cotton-producing state farms in Awash are approximately 300 km from Addis Ababa. Economic transport and use of the cotton stalk residues would require that the material be densified. Cotton stalk and other residues from the farms can be densified directly, or charred and then densified, to make domestic and commercial fuel. Proven technologies are available.

Based on studies conducted by the Ethiopian Rural Energy Development & Promotion Centre (EREDPC, 2000), the total volume of residues from cotton plantations (state farms) is estimated to be 89,000 tonnes per year. The national distribution of the residues is indicated in Table 3.

Table 3. National Annual Cotton Stalk Production and Areas Planted for 1997/98 from State Farms

Region	Location	Area Cultivated (ha)	Residues (tonnes)
AFAR	Middle Awash Cotton Plantation	4,782	18,170
	• Melka Warer	3,242	12,318
	• Melka Sedi	1,440	5,472
	• Middle Awash Banana & Cotton Plantation	100	380
	Tendaho Cotton Plantation	7,350	27,930
	• Dufti	4,000	15,200
	• Ditbara	3,350	12,730
Tigray	Hummera (and others in Tigray)	11,260	42,822
	Total	23,392	88,922

Table 4. Regional Distribution of Cotton Plantation at the State Farms (MoARD, 2009)

Region	Area Under Production (ha)	Residues (tonnes)
Afar	14,132	53,702
Tigray	11,435	43,453
SNNPR	3,800	14,440
Oromiya	2,888	10,975
Gambella	1,000	3,800
Total	33,255	126,370

According to Hiwot (2007), the potential total area agro-ecologically conducive for cotton production in Ethiopia is estimated to be 2,575,810 ha. However, in spite of high-potential areas existing in the country, actual current production does not exceed 125,000 ha.

Cotton production in Ethiopia (from 2003-2006) is indicated in Table 5. As this table shows, the production of cotton is increasing annually, implying that cotton residues are also increasing – which can be promising for the production of an industrial biomass energy resource.

Table 5: Cotton Production and Residues in Ethiopia from Smallholder, Private and Public Farms (Hiwot, 2007)

Year	Area Under Cotton (ha)	Total Production (Tonnes)	Cotton Residues (Tonnes)*
2003	110,000	136,000	374,680
2004	125,000	137,000	377,435
2005	120,000	144,000	396,720
2006	122,000	145,300	400,301.5
Total	477,000	662,300	1,549,136.5

*Residue to product ratio is 2.755 at 12% moisture content (Bhattacharry *et al*, 1990)

3.3. SAW DUST POTENTIAL OF ETHIOPIA

The total number of saw mills in Ethiopia is approximately 39, with a total of 5-10 factories involved in the production of plywood. A total of 200-300 joinery and furniture factories also operate in different parts of the country.

Most of the saw mills are located in the southern and south-western parts of the country. The total number of sawmills and their log-intake capacities is relatively low (at about 3,500 solid cubic metre/year, single shift); moreover, due to the low availability of wood-logs, most mills operate below their nominal capacity.

Sawmill residue is estimated to total about 25,000 tonnes per year. Residues generated in sawmills located in remote areas of the country have insignificant economic value and are usually dumped or piled up and allowed to rot. Although no recent surveys have been conducted at national level, EREDPC conducted one in some of the saw mills in the Oromia region in 2000. According to this survey, the average annual log (wood) processed in these mills varies from as little as 1,000 m³ to a high of 3,500 m³/year. The total residue potential from the four saw mills included in Table 6 below is about 4,600 tonnes/year.

At Tiro Botor Betcho and Ethio Plywood Enterprise (Jimma), the off-cuts and slabs are used for firing the boilers, while saw dust is disposed of into the river or piled up in fields; at the Ethio Plywood Enterprise in Jimma, the saw dust is freely given to workers.

Some of the sawmills located in remote areas (away from large towns) might nonetheless be of interest as these mills have already piled up a considerable amount of residue for lack of alternative uses.

Table 6. Sawmill Residues from Selected Saw Mills in Oromia Region, 1990/2000 (Kebede, 2001)

Location	Logs – Input (m ³)	Estimated Residue (tonnes)
Tiro Botor Betcho (Jimma Zone)	1,000	500
Ethio Plywood Enterprise (Arusi)	1,182	591
Sigmo wood Enterprise	3,500	1,750
Ethio Plywood Enterprise (Jimma Zone)	3,500	1,750
Total	9,182	4,591

Chat is among the most important cash crops grown and consumed in Ethiopia, particularly in the eastern and southern parts of the country. Chat is also one of the major crops exported to neighboring countries, earning significant amounts of foreign currency for the country. Total land under chat in 2004/05 was over 120,000 hectares, up by 8% on preceding years (CSA, 2005). Cultivation of chat trees and consumption of chat has recently expanded to the northern part of the country where, until recently, it was little known or used.

A study conducted to assess Harrar coffee production (Woldu *et al*, 2002), found that in the past three decades chat has become one of the major crops grown in a separate field, or integrated with coffee trees, by farmers in the “two [eastern and western] zones of Harrarge as well as some pocket areas of the neighbouring Somali and Harar regional states.”

In 2000/01, chat farms in the two zones of Harrarge, Dire Dawa Administrative Council and part of the regional state of Somali was 154,400 hectares. Over 74% of these chat farms are located in the two zones of Harrarge, where the reported total chat production volume for 2000/01 was 157,700 tonnes.

Table 7. Estimated Gross Chat Residue Generation in Addis Ababa (Kebede and Seboka, 2006)

	2004	2005	2006
Addis Ababa			
Chat inflow (tonnes/year)	10,134	12,181	9,440
Chat residue generated (tonnes/year)	7,094	8,526	6,608
Air-dry chat residue (tonnes/year)	3,547	4,263	3,304
Gross charcoal production potential (tonnes/year)	887	1,066	826

3.5. RESIDUES FROM THE BIOFUEL SECTOR

3.5.1 JATROPHA

The Jatropha plant is widely distributed in Ethiopia, existing in many low-lying areas of the country (North Shewa, Wello, Benishangul-Gumuz, Gambela, Welayita, Bale and others). Large volumes of residue are expected to be available from the biofuel processing industry over the coming years. The husk (outer cover) of the Jatropha seed has high fibre content and may be used as fuel – in briquette form – in the same way as coffee husks.

The Ethiopian Government is promoting Jatropha as an alternative fuel source to help reduce the country’s dependence on costly imported fossil fuel. Increasing the bio-diesel blend will require processing of more Jatropha seeds, resulting in a corresponding increase in the volume of waste that can be tapped for biomass briquetting. Promoting production and use of briquettes in this way will help people realise profit from Jatropha waste.

In medium- and large-scale processing plants, the depulping of Jatropha fruit may be done at processing sites to ensure the quality of kernels. In large processing plants depulping will be by mechanical means. Residue pulp will be substantial and can be another source of income for the processing plants.

The Jatropha fruit is 40% pulp, 30% kernel and 30% oil. About 0.4 tonnes of pulp will be available from 1 tonne of seed processed. A small (3 tonnes per day), processing

plant will produce 1.2 tonnes of pulp per day while a large (130 tonnes per day) processing plant will generate 50 tonnes of residue per day. If used properly, this represents a significant energy source. But it can also pose serious disposal and environmental problems if it is not.

3.5.2 CASTOR

The castor bean is native to Ethiopia. The castor plant grows in diverse climates but favours warm, dry climates (600-700mm of rain; 1,600-2,600 masl altitude). It requires moist, deep and well-drained soils for optimal yields. It can tolerate saline or alkaline soils and is also drought resistant. Since yield depends on soil moisture, there may be a requirement for irrigation in arid zones.

There is a large castor plantation planned in the adjacent area to the Mughher cement factory (near Woliso town). A significant source of castor husks is also available in Southern Region around Wolayita Zone, from an enterprise called Global Energy.

3.6. INVASIVE SPECIES THAT HAVE NO FUNCTIONAL VALUE

3.6.1 PROSOPIS JULIFLORA

Prosopis is a wild tree / shrub that grows across hundreds of hectares of the Afar and Somali regions. It was introduced to Ethiopia some three decades ago for the purpose of soil conservation. However, with time it has developed into a real nuisance as a weed, fast growing and coming to dominate cultivated lands along the middle and lower Awash valley of Afar region.

Pastoralists cut and remove the upper stem and branches of the plant, leaving the root and the main stem undisturbed and causing the tree to regenerate at a faster rate. They use the prosopis wood as fuelwood and for fence and house construction.

The Afars have continuously appealed for the eradication of this noxious plant, complaining of the injuries they suffer from the thorns of the plant. Because it has formed thick forest, prosopis also serves as shelter for warthogs and hyenas that have been blamed for attacking gardens and people. The economic and social benefits of using prosopis wood or branches as a fuel energy for industry are quite evident.

3.7. BAMBOO

Bamboo is native to Ethiopia, which has possibly the largest bamboo growing area in Africa. Bamboo is a rapidly renewable natural resource and can represent a sustainable source for industrial fuel. Increased use of bamboo would significantly reduce pressure on local timber resources and contribute to afforestation and soil conservation efforts. Greater use of bamboo would act to offset current deforestation of other tree species; this in turn would lead to the conservation of

trees and the rebuilding of the natural resource wealth of the country and the environment.

Bamboo in Ethiopia has the potential of improving the livelihoods of countless families. Although bamboo is wood, it differs in one important respect in that it can be harvested annually, despite being a perennial plant. Such annual harvests (or even monthly harvests), if undertaken sustainably, do not affect the health of the plant or its future growth and productivity. This on-demand harvest potential provides the material for use when needed, and the income when needed – not just annually but even monthly.

Table 8. Major Bamboo Areas in Ethiopia

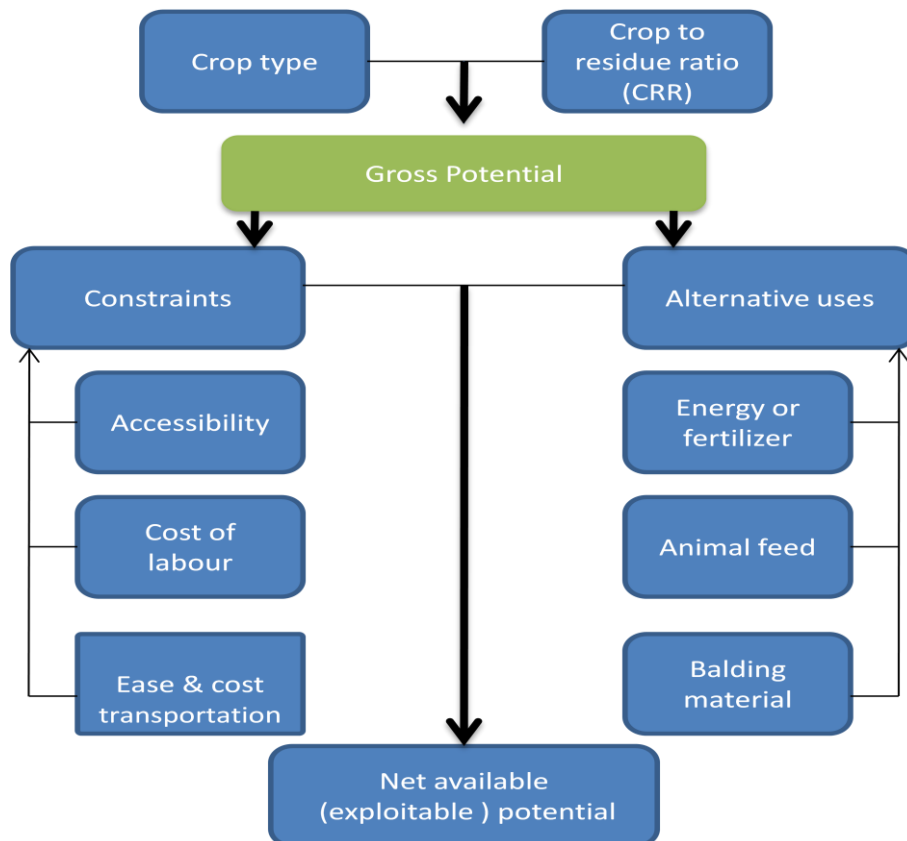
Region	Specific Area	Covered Area (ha)
Amhara	Injibara	-
	Hinde	8,670
Benishangul Gumuz	Asosa	77,947
	Bambesi	64,245
	Begi	21,509
	Demi	27,612
	Dibate	14,200
	Guba	7,757
	Kamashi	33,723
	Pawe	53,830
Oromiya	Agaro	-
	Gera	-
	Bale mountains	56,851
	Shenen, Jibat mountain	1,774
	Gimbi	29,125
	Guten	6,044
	Gera bamboo forest	1,052
	Gera-Lola	34,493
SNNPR	Agere Selam- Bore	-
	Chencha	-
	Indibir-Jembero	-
	Jima-Ameya	-
	Mizan Teferi- Kulish	-
	Wushwush- Bonga	-
	Bonga-Ameya	7,997
	Masha	18,652
	Shashemene	4,183

3.7.1 ESTIMATION OF NET RESIDUE AVAILABILITY

Residues may have one or multiple uses, including use as fertilizer, as animal fodder, as building material and as cooking fuel. The availability of certain types of agricultural or process residue also depends on its accessibility and ease of collection and transportation.

For example, while the bulk of cotton stalks produced in large farms are burned on-site as a means of disposal, other agricultural residues, such as coffee husks and sawmill residues produced in urban areas, are used as household fuels.

Figure 1. Factors Determining Gross Potential & Net Residue Availability
(Kebede, Seboka & Yilma, 2002)



*Table 9. Summary of Potential Bio-Residues in Ethiopia (tonnes)
(State Enterprise Development Supervisory Authority, 2009)*

Location	1	2	3	4	5
	Coffee residue	Cotton stalk	Prosopis juliflora (ha)	Bamboo tree waste (ha)	Saw dust
Tigray	-	42,822			1.9m
Afar	-	46,100	700,000		
Amhara	-				7.4m
Oromiya	141,322				10.6m
Somali	-				
Benshangul	-				
SNNPRs	69,503				4m
Gambela	3,298				0.12m
Harari					0.02m
Addis Ababa					
Dire Dawa					0.04m
Others	168				
Total	214,299	88,922	700,000	1,000,000	24.1m

1 includes: coffee husk, parchment and pulp.

Total cotton residues are undoubtedly an underestimate in light of ever-increasing cotton production.

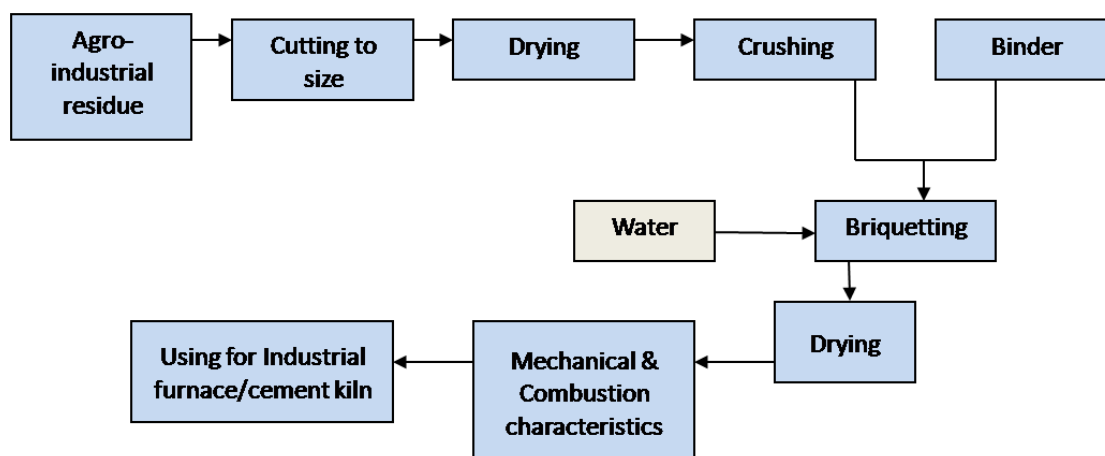
4 TECHNOLOGIES FOR BRIQUETTING OF BIOMASS AND BIOMASS RESIDUES

The system and equipment needed for the use of biomass energy in cement production includes alternative fuel storage, waste transportation and collection systems, and fuel feeding and burning systems. As agro-industrial wastes have lower heating values than heavy fuel oil, adjustment to a cement factory's airflow and furnace design may also be required.

To transform the low-density biomass into a useful energy substitute for cement production, it would have to be densified under high pressure and temperature to form wood-like logs known as briquettes.

The following process flow diagram, Figure 2, presents the activities that would need to be undertaken in the production of briquettes from agricultural and process residues.

Figure 2. Schematic Flow Diagram for Simple Briquetting Process (Kebede, Seboka & Yilma,2002)



Aside from the problems of transportation, storage, and handling, the direct burning of loose biomass in conventional grates is associated with very low thermal efficiency and widespread air pollution. In addition, a large percentage of unburnt carbonaceous ash has to be disposed of. Briquetting of the biomass residues could mitigate these pollution problems while at the same time making use of an important industrial energy resource.

4.1 MAJOR EQUIPMENT REQUIRED

- i. Biomass chopper
- ii. Briquetting Plant Equipment
- iii. Hammer mill
- iii. Piston briquettor
- iv. Screw press briquettor
- v. Bagging station
- vi. Other

Table 10. Estimated Prices for Briquetting Plants: Construction and Equipment Costs

Construction	US\$
Site preparation	5,000
Buildings	100,000
Total	105,000
Type of machine	
Biomass chopper	3,500
Hammer mill crusher	3,400
Briquetting Machine	
Piston Briquettor	100,000
Screw press	70,000
Collection /storage equipment	10,000
Conveyors	30,000

Silos	40,000
Electrical	30,000
Bagging station	10,000
Workshop equipment	35,000
Spares	50,000
Transport and Delivery	45,000
Engineering and Installation	70,000
Sub-total	496,900
Other/Miscellaneous	30,095
Total	631,995

Source: <http://www.satglobal.com/briqplant.htm>; personal communications

5 SPATIAL PROXIMITY OF BIOMASS TO CEMENT FACTORIES

Cement factories will need to utilise surplus agricultural residues that are readily available and in close proximity to them. Regarding Mughher cement factory, such residues would include castor husks from around the factory area, coffee husks (around Awassa – 300km distance), cotton stalk and prosopis (around Melka Sedi – 350km distance).

6 THERMAL ENERGY CHARACTERISTICS

Table 11. Properties of common biomass residues (Da Silva, Kutty & Kucel, 2006)

Residue	LHV (MJ/kg)	Ash content (%)	Volatile matter (%)	Moisture content (%)
Coffee husk	16.4	11.4	69.4	11.4
Saw dust	18.8	58.4	80.1	1.6
Cotton stalk	17.4	3.3	75.8	12.0
Cotton stalk briquette	19.1	3.2	N.A	5.9

7 TEMPORAL AVAILABILITY OF BIOMASS

Agricultural residues such as cotton stalk, coffee husk and others are seasonal (not available all year round). Collection and storage of residues during the months of availability will be necessary; alternatively, different residues could be sourced at different times of the year.

Table 12. Seasonal Availability of Selected Biomass Residues

Biomass Type	Season (months) of Availability
Coffee husk <ul style="list-style-type: none"> • Washed coffee pulp • Sun-dried coffee 	September to January December to July
Cotton stalk	November to February

8 COST OF THE BIOMASS

Table 13. Average Cost of Biomass and Biomass Briquettes

Biomass Type	Cost of Biomass (\$/tonne)	Total Cost of Biomass Briquette (\$/tonne)
Cotton stalk	10	114
Coffee husk	20	106
Chat stalk	20	80-90
Jatropha/castor husk	15	95
Prosopis juliflora	30	90-110
Bamboo	40	100-130

Sources: <http://www.hedon.info/BP12>; Kebede, Seboka & Yilma, 2002.

Table 14. Distance and Delivered Costs of Briquette to End-Use Site (Mugher) (UNDP/World Bank, ESMAP, 1986)

Production Site	Distance (km)	Delivered Cost of Briquettes (US\$/tonne)
Coffee Husk (Dilla)	Mugher (430)	88.97
Cotton stalk (Awash)	Mugher (370)	126.75
		Average 108

9 THE FRAGMENTATION OF SUPPLY

In Ethiopia, biomass residues are distributed over a large area in small quantities: farms are scattered. But for some wastes, such as coffee husks, a few large-scale suppliers (coffee processing plants) are available.

10 THE CURRENT USES OF THESE BIOMASS RESIDUES

Crop and agro-industrial residues have low bulk and energy density and, for these reasons, cannot be transported far from production sites. Where residue supply exceeds local demand, residues are usually disposed of wastefully and harmfully (typically burnt in the field or at agro-industrial sites, or dumped into streams).

Crop residues such as teff, wheat and barley are important sources of animal feed and are additionally used for soil nutrient recycling.

11 PRE-TRANSPORT PROCESSING

Prior to densification, agricultural residues have to undergo a number of stages including collection, storage, cleaning, drying, size reduction and feeding. Depending on the residue, each of the above stages will require a certain expenditure on equipment, materials and labour.

11.1. COLLECTION

Depending on the agricultural residue, collection can be a major component of the densification process. For example, materials such as cotton stalks tend to be widely dispersed in the fields and must be collected and transported to a central location. Alternatively, materials such as coffee husks are produced at central locations and do not present a major collection effort.

11.2. STORAGE

The type of storage required will depend on the residue and the environmental conditions it is subjected to. Usually, the residue will be stored in an open-air heap, a shed, a bin or within retaining walls or fences. If the collected residue is dry and open-air storage would result in the accumulation of moisture, then closed or sheltered storage is necessary. Conversely, wet residue can be reduced in moisture content through carefully managed open storage.

11.3. CLEANING

Cleaning is necessary if the residue contains foreign materials (such as stones, soil or metal) that could damage the processing and densifying equipment. Cleaning can usually be achieved with pneumatic, mechanical and / or magnetic screens.

11.4. DRYING

In general, most extrusion-type densification equipment requires that the feedstock be in the range of 10-20% moisture content on a wet basis (% mcwb). If the moisture content of the feedstock is too high (above 20% mcwb) the excess water becomes a superheated liquid because of the high pressure required for densification and the

resultant frictional heat build-up. The water will flash to steam as it exits the densifier and the pressure is lowered, usually exploding the briquette or pellet.

Stored at moisture contents above 20% for extended periods, any biomass will begin to decompose, reducing its calorific value and posing a risk of spontaneous combustion. Because of this, drying of the residue prior to densification is required if the material as received is above 20% mcwb. The method of drying will depend on several factors, including environmental conditions, the initial moisture content of material, the level of throughput, the size of material, the type of densifying equipment, etc.

11.5. SIZE REDUCTION

Most densification equipment requires that the maximum particle size of the incoming feedstock be no more than 25% of the diameter of the resulting briquette or pellet. For example, a piston extruder producing briquettes 50 mm in diameter has a maximum particle size constraint of 12 mm. Feedstock size reduction is usually achieved with a hammer mill. With the exception of saw dust and other materials of similar size, all other materials should be crushed to 6-8 mm size with 10-20% fines to achieve optimum briquetting results. While many types of crushing and grinding equipment are available on the market, for biomass materials hammer mills are considered the most suitable. These are available in various sizes, from a few kg/hr to 10-15 tonnes per hour.

11.6. DENSIFICATION, BRIQUETTING/PELLETING

There are essentially four main types of extrusion densification process:

- Piston press briquetters
- Screw press briquetters
- Roll briquetters;
- Pellet mills

There follows a brief description of each of these processes.

11.6.1 PISTON PRESS BRIQUETTING

In this process, a reciprocating piston forces the feed material into a die, where pressure and friction heat the feedstock to 150-300°C before it is extruded through a die 25-100 mm in diameter. In most cases, the die is water-cooled to reduce wear. The briquettes then enter a cooling line which, by friction, provides a back pressure on the material exiting the dies so that the cooling takes place with gradually diminishing pressure. A sudden pressure drop can cause the high temperature water to flash to steam, exploding the briquettes. The back pressure can often be adjusted to allow optimum production for fuels with varying moisture contents. As they exit the cooling line, briquettes may be cut or broken off at any desired length.

Capacity ranges from 150kg-1.5 tonnes per hour. Piston press briquetting is characterised by high capital costs (US\$500,000) and moderate operating costs (\$130,000)

11.6.2 SCREW PRESS BRIQUETTING

- Low production capacity (750-1,000kg) per hour
- High labour cost (\$7.2/tonne) and high capital cost per tonne of output (\$15).
- High amount of friction heating by the screw, resulting in higher die temperatures and increased wear on the screw and die head.

11.6.3 ROLL BRIQUETTING

- Feedstock is pre-compressed with a screw feeder and compacted between two rollers with opposing cavities to form pillow-shaped briquettes 25-50 mm in size.
- This method requires little energy input since there is little friction heating of the material.
- Maintenance requirements are lower.
- Rolled briquettes are generally less durable than extruded products unless a binder is used.

11.6.4 PELLET MILL

In a pellet mill, a hard steel die, cylindrical or disc-shaped, is perforated with a dense array of holes 5-15 mm in diameter, and a press roller forces the biomass through the holes. As the pellets are extruded from the holes they may be cut off at a specified length, usually less than 30 mm.

The unique characteristics of the pellet – its small size, smooth rounded edges, high bulk density and durability – make it most suitable for bulk storage and handling.

Pellets have a lower tendency to bridge in hoppers and are easily handled by screw conveyers which often have difficulty with larger briquettes or cubes. In addition, pellets are the only densified form that can be handled pneumatically.

One negative consequence of the small size is that the feedstock particle size must be smaller as well, which can increase the cost of pre-processing. Another significant aspect of pelletising is the high production capability of pellet mills, from 2-10 tonnes per hour. High output can result in lower labour costs and lower capital costs per tonne of output. (Joint UNDP/World Bank, ESMAP 1986).

*Table 15. Estimated Range of Densification Costs for Extrusion Processes
(UNDP/World Bank ESMAP, 1986)*

Equipment type	Capacity (tonnes/hr)	Equipment Cost (US\$ 000)	Energy Consumption (kWh/tonne)	Maintenance Cost (US\$/tonne)	Labour requirements (Man-hour/tonne)
Piston Press briquettor	0.15-1.50	40-100	30-80	2-3	3-0.5
Screw Press briquettor	0.1-1.0	20-70	60-120	3-5	3-0.5
Roll briquettor	1.0-10.0	75-300	12-25	0.5-1.0	1.0-0.2
Pellet mill	4-6	130-300	20-35	1-2	0.5-0.2

12 LOGISTICAL COSTS AND REQUIREMENTS OF TRANSPORTING BIOMASS TO ETHIOPIAN CEMENT FACTORIES

Table 16. Potential Industrial Briquette Demand of Muger Cement Plant at 20% of Heavy Fuel Oil Replacement by Biomass

Fuel oil consumption (litre/year)	60,000,000 (100% HFO)
Cost of modification (US\$)	600,000-1,000,000
Fuel oil displaced (litre/year)	12,000,000 (20% replacement by biomass)
Fuel oil savings (US\$/year)	6,000,000
Briquette demand (tonnes/year)	50,000
Cost of briquettes (US\$/year)	5,400,000

1litre fuel oil cost = \$0.5; 1-tonne briquette cost = \$108

12.1 SPECIAL STORAGE OR TRANSPORT REQUIREMENTS OF THE BIOMASS

The raw material that is collected should be stored near to the briquetting site. All agricultural residues feeds are relatively light, with bulk densities ranging from 0.05-0.08 g/cc (50-180 kg/m³). Because of their bulky nature, such residues are usually stored in the open; when the location lies in a heavy-rainfall region, the residues should be stored in ground-level bins that can be covered by heavy waterproof sheets or, alternatively, a side-open shed could be provided.

Depending upon the reliability of supply, feed material for a 15 day-3 month period should be stored at the plant site. It should be stored in such a manner that the heaps are naturally aerated and heavy wind effects are minimized. Approximately 3-4 m² of open space is needed to store one tonne of material.

13 PRICE ELASTICITY OF DEMAND FOR PARTICULAR SOURCES OF BIOMASS / BIOMASS RESIDUE

If demand for a biomass residue increases (e.g. from the cement sector), the price of the residue will tend to increase. Establishing plantations of fast-growing trees around the cement factory to provide a guaranteed, stable source of biomass supply can help to address this problem.

14 GENERAL BARRIERS TO USING BIOMASS RESIDUES IN THE CEMENT INDUSTRY

14.1 INFORMATION / EDUCATION

Fostering the use of biomass or biomass residues in Ethiopian cement factories will require a focused informational and educational programme aimed at potential users. Emphasis will need to be placed on convincing both managerial and technical personnel of the economic advantage of converting to the use of biomass briquettes. Measures should be identified for overcoming or dealing with some of the disadvantage of briquettes, such as the relatively high ash content, the greater generation of particulates, the necessity to isolate briquettes from direct contact with water, etc.

14.2 LOCAL TECHNICAL ASSISTANCE

Currently, no organised means to provide technical assistance to cement factories willing to convert to biomass briquettes exists. Technical assistance, both for conversion and during the initial periods of briquette use, will ensure efficient and proper use of the product.

14.3 CAPITAL FOR CONVERSION

Cement factories that require modification of equipment and / or additional facilities in order to use biomass briquettes will require upfront capital. If the availability of capital to the cement sector is limited it would act to constrain potential conversion.

14.4 RELIABILITY OF SUPPLY

Cement plants that make a capital investment to convert to biomass briquettes will be concerned about the reliability of the biomass supply. Also, the uniformity of briquette quality, given process needs, may be a concern for cement plants with no previous experience with this kind of fuel.

Biomass availability is subject to seasonal fluctuations due to the vagaries of nature. Hence, although sufficient quantity of surplus biomass is estimated, in the long run

continuous supply of sufficient quantities of biomass fuels is not assured and risk mitigation measures must be put in place.

This problem of supply is compounded by the sheer volume of biomass that would be required: biomass energy conversion efficiency is very low compared with fossil fuel energy conversion efficiencies. Further, the storage of biomass materials presents additional problems. The characteristics of biomass fuels can change quickly within short time-periods. Most importantly, the calorific value decreases due to the loss of volatiles and deterioration of the biomass, which affects the performance of the kiln. Hence, biomass materials cannot be stored for long periods.

15 BENEFITS

15.1 LOCAL BENEFITS

Use of biomass by Ethiopian cement factories would provide financial benefits to farmers / pastoralists.

15.2 NATIONAL BENEFITS

Use of nationally-sourced biomass would help to retain foreign exchange that would otherwise have been spent on imported fossil fuels.

15.3 GLOBAL BENEFITS

Global benefits from the implementation of biomass usage instead of heavy fuel oil would be the reduction of greenhouse gas (GHG) emissions. Provided the biomass or biomass residues are sourced sustainably, biomass is considered to be a zero-emission fuel.

CHAPTER TWO

BIOMASS ENERGY FOR THE CEMENT INDUSTRY IN ETHIOPIA

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1. ABSTRACT

Cement production is an energy-intensive process. Conventional fuels used in the cement industry, such as coal, petcoke and furnace oil, are notoriously polluting to the environment in terms of greenhouse gas emissions. With suitably designed feeding and combustion systems, biomass fuels can be used in cement factories in considerable proportions, thereby replacing polluting fossil fuels with carbon-neutral biomass fuels. Switching to biomass fuels is attractive for the cement industry from both environmental and financial perspectives. In some cement factories in Ethiopia, with minor plant modification, it is possible to replace 15-20% of the fossil fuels currently used. In the longer term, with more rigorous plant redesign and modification, a greater proportion of biomass fuel use is possible in some cement factories. New, upcoming cement factories have ample opportunity to incorporate into their design the provision for utilization of biomass fuels in considerable proportions.

2. INTRODUCTION

Conventional fuels used in cement factories, such as coal, petcoke and furnace oil, can be partially replaced by biomass fuels. The financial and environmental benefits of fuel switching are attractive for most cement factories. Switching to biomass fuels of 15-20% in the short term, and a greater percentage in the longer term, is a feasible option for some cement factories in Ethiopia. Switching to biomass fuels will have financial benefits arising from the reduced cost of fuels. The factories can also benefit from added revenue from the Clean Development Mechanism (CDM), as biomass fuels can reduce CO₂ emissions from cement plants substantially. At the national level, there are benefits such as foreign exchange savings and job creation.

In this chapter, the key issues that must be considered by any cement factory wishing to partially switch to biomass fuels and biomass-based waste fuels are discussed. The attempt here is only to indicate some critical issues that must be given due attention when fuel-switching is anticipated by a cement factory.

In order to be able to explain the issues clearly, the case of Mughher cement factory is considered in a number of instances as an example. Some of the critical issues discussed with reference to Mughher cement factory are, however, generic and can also be applied to other factories.

3. CEMENT PRODUCTION PROCESS AND ENERGY USE

3.1 CEMENT PRODUCTION

The production process of cement starts with raw material supply, which involves such activities as blasting of rocks, transporting the raw material from quarries by dump trucks, crushing the rock on-site and transporting it to the cement plant by

conveyer belts. The raw material transported to the plant is stored and homogenized at the plant storage facilities. Raw meal is obtained by grinding the homogenized raw material. The raw meal is pre-heated in cyclone heaters, calcined and sent to the kilns.

The kilns used in cement production are of two types. These are: the small-scale vertical type of kilns that are predominantly used in developing countries; and the large-size horizontal rotary type of kilns widely used in industrialized countries. Large-scale rotary kilns are more energy-efficient (Taylor *et al*, 2006).

In the kiln, a flame of 2,000°C heats the raw material to about 1,500°C. After air cooling, clinker is obtained. Clinker is the principal ingredient in cement production and is a mixture of approximately 80% limestone and 20% clay (Lafarge, 2008). The clinker formation process has four stages (Karstensen, 2006):

- **Stage 1: Drying and pre-heating**, which releases free and chemically-bound water, takes place in a temperature range of 20-900°C.
- **Stage 2: Calcination**, which is the stage of CO₂ release in the initial reactions associated with formation of clinker minerals and the intermediate phase. This stage occurs in a temperature range of 600-900°C.
- **Stage 3: Sintering or clinkerisation**, which is essentially the stage of formation of calcium silicates and the liquid phase. This stage takes place in a temperature range of 1,250–1,450°C.
- **Stage 4: Kiln internal cooling**, in which crystallisation of calcium aluminates and calcium ferrite occurs in the temperature range of 1,350-1,200°C.

3.2 CEMENT TYPES

Cement is produced by fine grinding the clinker with gypsum. Portland cement, for instance, is produced by grinding 95% clinker with 5% gypsum. Various other additives can be introduced to obtain blended cement. The most commonly used additives are fly ash and blast furnace slag. Fly ash is produced as a result of burning coal in coal power plants. Fly ash contains vitreous silica, alumina, iron oxide and lime. It has hydrophilic properties and can substitute for clinker. Slag is obtained from iron smelting blast furnaces. Slag has hydraulic properties similar to clinker and is a suitable additive for cement. Blended cement that has high proportion of slag reduces the setting speed of concrete. Fly ash-blended cement, on the other hand, improves mechanical resistance (Lafarge, 2008).

Table 1: Composition Of Different Cement Types (Taylor et al, 2006)

Cement type	Cement types			
	Portland cement (%)	Portland fly ash cement (%)	Blast furnace cement (%)	Activated slag cement (%)
Clinker	95	75	30	
Fly ash		25	-	45
Blast furnace slag			65	-
Synthetic slag				45
Water glass				10
Gypsum	5		5	-

Different types of cement are produced, depending upon the contents of the cement additive materials. The most common types of cement obtained by various additives are exhibited in Table 1.

3.3 ENERGY USE IN CEMENT PRODUCTION

Cement production is an energy-intensive process. Pyroprocessing – the process of clinker production in the pre-heaters / pre-calciners, kilns and coolers – is a particularly energy-intensive system. Energy consumption of the pyroprocessing system is, however, dependent upon the technology of the production process. There are fundamentally five basic technologies of cement production: namely, the wet process, the dry process, the semi-wet/semi-dry process, the dry process with pre-heaters, and the dry process with pre-heaters and pre-calciners.

A considerable amount of energy is wasted at various stages of the pyroprocessing system. Depending upon the type of clinker production process, 7-38% of the energy consumption in the pyroprocessing system is wasted in the evaporation of moisture. Some of 13-27% of the energy is carried away with exit gas, and 5-12% of the energy is wasted by the kiln shell. The typical energy losses in pyroprocessing systems are indicated in Table 2.

*Table 2: Thermal Energy Balances of Clinker Production In Process Kilns
(Choate, 2003)*

Energy Use Area	Wet Kiln		Dry Kiln		Pre-heater Kiln	
	MJ/tonne	%	MJ/tonne	%	MJ/tonne	%
Theoretical Requirement	1,783.0	30.5	1,825.2	36.6	1,761.9	50
Exit Gas Losses	752.3	12.9	1,382.1	27.7	496.9	14
Evaporation of Moisture	2,236.7	38.3	300.7	6.0	235.3	7
Dust in Exit Gas	11.3	0.2	13.0	0.3	1.3	0
Clinker Discharge	56.7	1.0	61.2	1.2	65.8	2
Clinker Stack	189.9	3.3	590.8	11.8	614.0	18
Kiln Shell	677.3	11.6	606.7	12.1	175.1	5
Calcination of Waste Dust	40.7	0.7	18.5	0.4	6.2	0
Unaccounted Losses	88.9	1.5	192.0	3.8	173.0	5
TOTAL	5,840.8	100	4,994.6	100	3,612.5	100

Specific energy consumption for various production processes is depicted in Table 3. It is evident from this table that wet processes are more energy-intensive and wasteful than dry processes. The dry process with rotary kiln and pre-heaters and pre-calciners is the most energy-efficient pyroprocessing system.

Table 3: Specific Thermal Energy Consumption of Different Clinker Production Processes (Tokheim, 2007)

Process type [MJ/t clinker]	Specific energy consumption
Wet process long kilns	5,000-6,000
Dry process long kilns	up to 5,000
Semi-dry/semi-wet processes (Lepol kilns)	3,300-4,500
Dry process kilns equipped with cyclone pre-heaters	3,100-4,200
Dry process rotary kilns equipped with multi-stage cyclone pre-heaters and pre-calciner kilns	3,000

A substantial capacity increase can be obtained with pre-calciner kilns with a second combustion device between the rotary kiln and the pre-heater section. In the pre-calciner, up to 60% of the total fuel of the kiln system can be burnt. At an exit temperature of about 880°C, the hot meal is calcined to a degree of around 90% when entering the rotary kiln. Kiln systems with 5 or 6 stage cyclone pre-heater and pre-calciners are considered

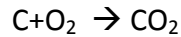
Standard technology for new plants today, as the extra cyclone stages improve thermal efficiency (Karstensen, 2006).

4. CO₂ GENERATED IN CEMENT PLANTS AND REDUCTION MEASURES

CO₂ emissions from cement plants originate from two sources. The first, and major, source of CO₂ emission is the de-carbonisation of the raw material at high temperature:



The second source of CO₂ emissions is the combustion of carbon fuels in the kiln according to the following simplified form of chemical reaction:



With regard to the first source of CO₂ emissions, those deriving from de-carbonisation of the calcinaceous raw material, such emissions can be reduced in two ways:

1. By reducing the proportion of clinker in the cement mix by blending the clinker with additives such as fly ash, gypsum or slag. The use of these materials will serve to reduce carbon emissions originating from the use of lime in proportion to the amount of lime that is displaced.
2. By using alternative raw materials for clinker production that do not contain carbonates. Examples include waste ash from fuel consumption in thermal power plants, blast furnace slag, anhydrite or fluorite.

With regard to the second source of CO₂ emissions, such emissions can be reduced in two ways:

4.1 FUEL-SWITCHING

Since it is only the combustion of carbon that generates CO₂, fuels with relatively high hydrogen content, such as natural gas, generate lower energy-specific emissions of CO₂. Fuels, such as coal and petcoke, with lower hydrogen content, have higher energy-specific CO₂ emissions. For example, coal has an energy-specific CO₂ emission factor of 96kg/GJ, whereas natural gas has a CO₂ emission factor of 56kg/GJ (Tokheim, 2007). Therefore, by switching from pure coal-firing to pure natural gas, a 40% reduction of CO₂ emissions can be achieved. The main impediment here, however, is that natural gas can rarely be used for pyroprocessing because it is an expensive fuel compared with other fossil fuels.

Some alternative biomass fuels have lower energy-specific CO₂ emissions than coal; others have higher emissions. Hence, absolute carbon content does not provide the rationale for switching from coal to biomass. Rather, the critical aspect of biomass in this regard is that it can, in certain circumstances, be regarded as a *net zero-emission* fuel-source, even if CO₂ is liberated during its combustion. If biomass, or biomass residues, is/are cultivated sustainably – that is, if the rate of biomass extraction is not higher than the rate of biomass re-planting or replenishment – then the biomass is considered to be ‘carbon-neutral’. The logic is that the biomass grown to replace the combusted biomass is considered to absorb CO₂ from the atmosphere while growing, thereby in effect ‘cancelling out’ the CO₂ emissions associated with the combustion of the cultivated biomass: the net effect on the atmospheric carbon balance is zero. Sustainably-cultivated biomass has, in effect, an emission factor of

zero. It is evident, then, that fuel switching, particularly to carbon-neutral biomass, can significantly reduce net CO₂ emissions.

CO₂ emissions from the combustion of some commonly-used and alternative fuels are shown in Table 4.

Table 4. CO₂ Emissions of Commonly-Used and Alternative Fuels In the Cement Industry (Tokheim, 2007)

Fuel	Lower Heating Value (GJ/t)	Gross CO ₂ emission factor (kg/GJ)	Gross CO ₂ emission factor (t _{co2} /t)	Fossil fraction	Net Co ₂ emission factor (Kg/GJ)	Net emission factor (t _{co2} /t)
Coal	29.3	96.0	2.8	100%	96.0	2.8
Petcoke	33.9	92.8	3.1	100%	92.8	3.1
Waste oil	34.0	74.0	2.5	100%	74.0	2.5
Plastic	37.7	75.0	2.8	100%	75.0	2.8
Solid hazardous waste	14.9	74.0	1.1	100%	74.0	1.1
Liquid hazardous waste	15.7	74.0	1.2	100%	74.0	1.2
Refuse-derived fuels	13.5	87.0	1.2	10%	8.7	0.1
CCA waste wood ¹	12.6	110.0	1.4	0%	0.0	0.0
Animal meal	16.8	88.0	1.5	0%	0.0	0.0
Wood	15.7	110.0	1.7	0%	0.0	0.0

4.2 ENERGY EFFICIENCY

Net CO₂ emissions are proportional to the energy consumption of the pyroprocessing system (expressed in GJ/tonne of cement) and to the net emission factor (expressed in kgCO₂/GJ). Improving the efficiency of the pyroprocessing system can reduce energy consumption and hence CO₂ emissions (tCO₂/t) considerably. Measures to improve energy efficiency in cement production can include (Choate, 2003):

- a) Lower kiln exit gas losses
 - Install devices to provide better conductive heat transfer from the gases to the materials (e.g. kiln chains).
 - Operate at optimal oxygen levels (control combustion air input) and optimize burner flame shape and temperature.
 - Improve or add pre-heater capacity.
- b) Reduce moisture absorption opportunities for raw meal and fuels (avoiding the need to evaporate adsorbed water).
- c) Reduce dust in flue gases by minimizing gas turbulence. (Dust carries energy away from the kiln where it is captured in dust collectors. The dust is recycled into the raw meal and fed into the kiln where it is re-heated.)

¹ Chromated Copper Arsenate treated wood

- d) Lower the clinker discharge temperature (retaining more heat within the pyroprocessing system).
- e) Lower the clinker cooler stack temperature:
 - Recycle excess cooler air.
 - Reclaim cooler air by using it for drying raw materials and fuels or pre-heating fuel or air.
- f) Lower kiln radiation losses by using the correct mix and more energy efficient refractory to control kiln temperature zones.
- g) Lower cold air leakage:
 - Close unnecessary openings.
 - Provide more energy-efficient seals.
 - Operate with as high a primary air temperature as possible.
- h) Optimize kiln operations to avoid process disruptions and downtime.
- i) Upgrade existing technology: the addition of pre-heater sections, pre-calcination sections or more efficient clinker coolers serves to maximize heat recovery.
- j) Adopt new technology: large-scale fluidized-bed kilns (200 tonnes/day of clinker) have been developed and have demonstrated significant energy savings. It is estimated that a full-scale fluidized-bed (3,000 tonnes/day) system will consume approximately 3,000 MJ/tonne of clinker – as efficient as the most advanced kiln utilizing a pre-heater and pre-calciner Fluidized-bed systems are estimated to have capital costs equivalent to 90% of the capital costs of a modern cement facility and operating costs equivalent to 75% of a modern cement facility's operating costs (Choate, 2003).
- k) Cogeneration: large industrial thermal energy demand offers opportunities for cogeneration of electricity and/or steam production, particularly if the cogeneration system is part of the initial plant design. Some cement manufacturing plants in the USA co-generate electricity on-site.

5. EXPERIENCES OF USING ALTERNATIVE FUELS IN CEMENT PLANTS

The conventional fuels used in the cement industry are coal, petcoke, heavy furnace oil and natural gas. Recently, there has been a trend to substitute conventional fuels with alternative fuels derived from industrial waste, urban waste and biomass.

Cement kilns are well-suited for waste combustion because of their high process temperature and because the clinker product and limestone feedstock act as gas-cleaning agents. Used tyres, wood, plastics, chemicals and other types of waste can be co-combusted in cement kilns in large quantities. Some cement factories in

Belgium, France, Germany, the Netherlands and Switzerland have reached substitution rates ranging from 35% to more than 70% of the total energy used. However, very high substitution rates can only be accomplished if a tailored pre-treatment and surveillance system is in place. Municipal solid waste, for example, needs to be pre-treated to obtain homogeneous calorific values and feed characteristics (Taylor *et al*, 2006).

Most waste-derived fuels have heating values lower than those of fossil fuels such as coal, oil and gas. Typically, waste-derived fuels contain relatively high levels of moisture and ash. The moisture increases the gas flow in the system, which means that extra thermal energy has to be added to achieve the correct operational temperatures in the system. Hence, a kiln system applying a high percentage of low-calorific fuels tends to have high specific thermal energy consumption – and, as a consequence, higher absolute CO₂ emissions.

This is a drawback of using high waste-fuel blends. However, from a greenhouse gas perspective, this drawback is more than outweighed by the advantage of reduced CO₂ emissions when the fuels used are CO₂-neutral (for example, sustainably-sourced biomass residues). Although the gross emissions may increase, the net emissions will decrease. The indirect effect of reduced waste disposal is another positive effect of utilizing waste fuels in the cement kiln system. This is true for all types of waste fuels, whether they are CO₂-neutral or not.

The emissions from cement kilns using alternative fuels are no different than those from traditional cement plants. Nor is the quality of the cement affected by the use of alternative fuels.

Some experiences of using alternative fuels in the cement industry are outlined below:

- In France, bone meal has been used as a substitute fuel since 1998. It is instantly destroyed when placed into the kiln's flame at 2,000°C, with no detrimental impact on the environment (Lafarge, 2008).
- In Norway, the Norcem plant in Brevik carried out an extensive modernization project in 2004-5, and, as a result of this, the plant uses about 100,000 tonnes of CO₂-neutral waste fuels every year, originating from different types of waste (Tokheim, 2007).
- In Uganda, the Hima cement plant has reduced fossil fuel consumption by 30% by using coffee bean husks as an alternative fuel. After harvesting and drying, the coffee grains are separated from their husks, which were formerly treated as waste. Instead, they are now transported to the cement plant, where they are burned in the furnaces, in a system developed especially for this purpose (Lafarge, 2008).

- In Malaysia, part of the coal used in the cement plants of Rawang and Kanthan has been replaced by biomass (palm kernel shells). This is said to have saved over 60,000 tonnes of CO₂ per year and uses by-products from the local production of palm oil which would otherwise be wasted. This initiative was approved as a Clean Development Mechanism (CDM) project in April 2007 (Lafarge, 2008).
- In Brazil, a waste management joint venture, Eco-Processa, supplies plants with substitute fuels. In some cement plants in Brazil, 42% of the fuel used comes from biomass or waste, which reduced emissions of 156,000 tonnes of CO₂ in 2007 (Lafarge, 2008).
- In the USA, at the Atlanta cement plant, scrap tyres are used as an alternative fuel. They are placed whole in the kiln at 2,000°C, which allows them to be completely destroyed and avoids dispersing black smoke. Furthermore, the material is homogeneous and has a high calorific value, which makes it a very effective fuel for cement plants. The cement industry in the United States burns 53 million used tyres each year (Taylor *et al*, 2006).
- In Japan, around 200 kilo-tonnes (kt) of used tyres, 450 kt of waste oil, 340 kt of wood chips and 300 kt of waste plastic were burnt in cement factories in 2005. This is equivalent to approximately 42 PJ of energy from alternative sources (Taylor *et al*, 2006).
- In the UK, the Caudon plant was the first cement plant in the country to use scrap tyres as an alternative to petcoke and coal. Over the last ten years, it has used approximately two million tyres a year, allowing an annual saving of 24,000 tonnes of fossil fuel (Lafarge, 2008).

6. TECHNICAL OPTIONS RELATING TO THE USE OF BIOMASS ENERGY IN THE CEMENT INDUSTRY

Among the alternative fuels available for fuel switching in cement plants, biomass is the only carbon-neutral fuel. The following technical options are available when using biomass in cement plants:

- a) Direct combustion of biomass in pre-heaters / pre-calciners and in the kiln by part-replacing the fossil fuel used in raising the temperature of the raw meal. This can happen in two ways:
 - By mixing crushed and pulverized biomass with coal or petcoke for use in the kiln.
 - By direct feeding of biomass in solid lump form (such as pellets and briquettes) into the rotary kiln and / or pre-heater/pre-calciner combustion chamber.

- b) Transforming biomass into producer gas (also known as ‘synthesis gas’ or ‘syngas’) and co-firing it in the kilns using a gas burner.

Each of the options has its own advantages and disadvantages, which will be discussed in detail in the following sections.

6.1 DIRECT COMBUSTION OF SOLID BIOMASS IN PRE-HEATERS, PRE-CALCINERS AND KILNS

The technical implications of using biomass in the pyroprocessing system of cement plants are challenging. Biomass fuels have to be cleaned, prepared, dried and homogenized to have uniform heating value. Biomass fuels prepared in pieces of up to 150 mm diameter or in pellet or in briquette form can be directly burned in combustion chambers arranged between pre-heaters / pre-calciners and the kiln. Modification of the kiln and the pre-heaters / pre-calciners, particularly the combustion chamber, is mostly necessary to be able to use biomass fuels in the pyroprocessing system. Fuel preparation and cleaning units have to be designed and integrated into the plant.

Biomass can be utilized in pulverized or in lump solid form. The fuel-feed system and plant modification have to be designed according to the form of solid biomass.

6.1.1 PULVERIZED BIOMASS FUELS

Biomass fuels in crushed, ground and pulverized forms can be used in cement plants. This is the case, for instance, if charcoal residue, sawdust, coffee husk and similar types of biomass fuels are considered.

After they are delivered to the plant, these types of biomass fuels should be stored in dry locations within the factory. Pulverized biomass should be cleaned, dried and transferred by mechanical or pneumatic conveyors to intermediate silos in the plant. Pulverized biomass can be suitably utilized mixed with coal or petcoke. Careful metering, proportioning and mixing have to be conducted in the fuel preparation section.

As the heating value of biomass fuels is approximately half that of coal and petcoke, the feed rate of biomass-coal or biomass-petcoke mixture has to be increased proportionally to compensate for the lower heating values of biomass fuels. For example, for a 10% biomass and 90% coal or petcoke blend, the feed rate has to increase by approximately 10%. The precise feed rate has to be calculated on the basis of the heating values of the mixture and that of the original fuel.

6.1.2 LUMP SOLID BIOMASS FUELS

Biomass fuels in solid form, such as wood chips, pellets, briquettes and the like, can be burned in combustion chambers arranged in pre-heaters / pre-calciners or can be

co-combusted in rotary kilns. These types of fuels are less suitable for vertical shaft kilns.

Generally, to use lump-solid biomass in the kilns (rotary or vertical shaft kilns) is problematic due to uncontrolled mixing of fuel ash in the clinker. In vertical shaft kilns, the most common fuel, petcoke, is ground into small granules and is mixed with raw meal and fed into the kilns.

Biomass fuels, particularly waste-derived fuels, require a lot of prior cleaning, drying and preparation (cutting to size, making pellets or briquettes) so that efficient combustion can be achieved without affecting the clinker production process.

The cleaning and fuel preparation has to take place in biomass storage houses, which should preferably be located outside of the plant premises, due to the large space requirement. Ready-to-use solid biomass can be transported to the plant by mechanical conveyors and should be chute-fed to the combustion chambers or kilns.

6.2 GASIFICATION OF BIOMASS AND WASTE

Gasification is a process of converting carbonaceous materials by partial oxidation into gaseous fuels (producer gas) of low heating value, containing carbon monoxide, hydrogen, methane and traces of higher hydrocarbons such as ethane (Cioni *et al*, 2002).

All biomass fuels can be converted into producer gas for use in cement plants. Gasification of urban solid waste creates particular convenience due to the difficulties of directly combusting such material. Producer gas can be co-fired with fuel oil (furnace oil) in the rotary kilns. New plants can incorporate into their design producer gas co-firing systems. However, existing plants have to be modified by adding a gasification reactor and a gas injection and firing system into the kiln. Although challenging, it is a technically feasible option. Producer gas can also be conveniently used in pre-calciners.

The most utilized gasification technology for industrial-scale applications is the fluidized bed gasifier. Fluidized bed technology offers the following benefits (Cioni *et al*, 2002):

- Relatively simple construction and operation
- Tolerance to different particle size, feedstock heating value and composition
- High carbon conversion and good quality of raw gas produced (low tar and particle content)
- Good temperature control and high reaction rate
- Feasibility of retrofitting in existing plants

Silica sand is usually used as the fluidizing material and air as the oxidizing agent; the typical operating temperature is 800-850°C and gasification occurs in isothermal conditions. The high thermal capacity due to the inert bed and the high mass

transfer rate due to the good mixing of the solid phase leads to carbon conversion approaching 100% within the bed.

The main disadvantage of the technology is the carry-over of fine particles produced from the elutriation² of ash and fuel, which enriches the gas with solids that must be removed. In a Circulating Fluidized Bed (CFB) gasifier, the fluidizing velocity is high enough to let the gas entrain some of the fine particles, both sand and fuel. The cyclone separates the raw gas from the solid particles, which are recycled back to the bed. Ashes are discharged from the bottom of the gasifier in solid form and, to reduce the content of fine particles in the bed, by bleed from the bottom part of the cyclone.

Worldwide, there are a number of examples of using producer gas for pyroprocessing systems in cement plants. One such example is in Germany, at Rüdersdorfer Zement GmbH cement plant (Greil *et al*, 2002). The plant underwent a major modification, with a new kiln with a capacity of 5,000 tonnes of clinker per day. The kiln was designed with high flexibility for utilizing secondary raw materials and alternative fuels for cement production without compromising the quality of the cement product and without adversely affecting the environment.

As the most feasible option for its specific technical requirements, the plant installed a fluidized bed gasification reactor between the raw mill and the kiln. This made it possible to convert a variety of residues, such as those containing carbon with high mineral proportions and fuels with high or low heating values, into producer gas. The gas is fed without any treatment to the calciners of the cement kiln where two-thirds of the total fuel demand of the kiln plant is supplied. As secondary fuel, shredded used wood and light recycling materials are principally used. Four different types of materials and feeding system are employed with the gasification reactor. These are:

- Materials that can be blown, by directly blowing them into the gasification reactor by means of pneumatic conveyors.
- Lump fuels that can be conveyed into the gasification reactor by means of mechanical conveyors.
- Mineral residues with upstream drying by means of mechanical conveyors to the seal pot.
- Residues that are difficult to handle or lumpy fuels by means of mechanical conveying into the sealed pot.

The burnt out ash is conveyed through an ash cooler into the raw mill, where it is accurately metered into the raw mill as a feed component. By using a fluidized bed in this plant, it is possible to completely convert waste into a resource material for cement production, in the form of both energy and as feed material (Greil *et al*, 2002).

² The separation of finer lighter particles from coarser heavier particles in a mixture by means of a usually slow upward stream of fluid so that the lighter particles are carried upward.

In Italy, one cement plant is using producer gas. The Grève-in-Chianti gasification plant has been operating since 1992 and is based on TPS (Thermal Processing System) technology. It consists of a bubbling fluidized bed combined with a second circulating fluidized bed used as a cracking reactor where catalyst is added. The specific configuration of this plant provides for a single circulating fluidized bed whose bottom part operates as a bubbling bed (Cioni *et al*, 2002).

The Grève-in-Chianti plant processes 200 tonnes of RDF (Refuse-Derived Fuel) per day. The plant is comprised of two CFB gasifiers, each of 15 MWth fuel capacity. The gasifiers operate at close to atmospheric pressure and approximately 850°C, employing air as the gasification / fluidizing agent. The gasifiers are able to handle relatively large-sized fuel particles: the maximum length of the RDF pellets delivered to the plant is 150 mm (Lundberg and Morris, 2008).

The plant represents a simple application of the gasification technology as the raw gas from the gasifiers is not required to be cleaned before it is fed to either the adjacent cement kiln or to a dedicated boiler.

7. OPTIONS FOR BIOMASS UTILIZATION IN CEMENT PLANTS IN ETHIOPIA

7.1 THE ETHIOPIAN CEMENT INDUSTRY

There are seven cement factories already operating in Ethiopia and around 39 new factories are at various stages of investment, planning and development. When the planned plants are completed there will be approximately 46 cement factories in total.

Only three of the operating cement factories, namely Mughher, Mosobo and National, have rotary kilns with five-stage pre-heaters. None of these factories currently has pre-calciners, although the new, third, line of Mughher cement factory is anticipated to have pre-calciners.

Mughher cement factory uses furnace oil while National and Mosobo use imported coal. The other cement factories, Abissinya, Dashen, Jemma and Koka, which use vertical shaft kilns without any pre-heaters, use petcoke.

Furnace oil, petcoke and coal are all notoriously polluting to the environment, particularly in terms of greenhouse gas emissions. Using biomass-based alternative fuels in these cement plants would have obvious benefits from the perspective of reducing greenhouse gas emissions.

Biomass-based alternative fuels, such as coffee husks, can be considered for use in Ethiopian cement plants. The logistics and costs of transporting these fuels to the plant sites can be minimised by using cement delivery trucks (which deliver cement to local markets) to transport coffee husks back to the plants on their return trips.

Such trucks typically make their return trip to cement plants empty, without any load.

Table 5: Technology and Fuel Use in Ethiopian Cement Plants

Cement plant	Capacity (tonnes/day of cement)	Technology	Fuel
Mugher cement	2,000	Rotary kiln with 5-stage cyclone pre-heaters	Furnace oil
Mosobo cement	2,000	Rotary kiln with 5-stage cyclone pre-heaters	Furnace oil, coal
National cement	300	Rotary kiln	Coal
Abissinya	300	Vertical shaft kiln	Petcoke
Jemma cement	150	Vertical shaft kiln	Petcoke
Dashen cement	300	Vertical shaft kiln	Petcoke
Koka cement	300	Vertical shaft kiln	Petcoke

Source: Information gathered by the author

Table 6: Planned Future Investment in Cement Plants in Ethiopia (Ethiopian Investment Agency)

Name of Investor	Region of Investment	Capital (x1,000) US\$ ³
Abkit Construction material factory PLC	Oromia	1,332.3
Acces Capital service share Company	Oromia	31,166.1
Amhaf Cement Industries PLC	Oromia	2,131.6
B.M Cement Technology PLC	Dire Dawa	133.2
Chamu Industrial PLC	Oromia	46,630.6
Chen Genfu	Dire Dawa	23,981.5
DARER RUIYA PLC	Dire Dawa	13,323.0
Derba Midroc Cement PLC	Oromia	322,819.6
Emaar-Pak Cement Factory PLC	Dire Dawa	6,661.6
Ethio Cement PLC	Oromia	71,838.9
Ethio Cement PLC	Oromia	124,056.5
Ethio Cement PLC	Oromia	124,056.5
Ethio-Korean Development	Dire Dawa	257,775.2
Falath Pertoluem/Ethiopian Branch/	Dire Dawa	124,710.6
Fa-Nur Cement PLC	Dire Dawa	261,264.5
Gulfmeera General Business Development PLC	Oromia	8,393.5
Gulfmeera General Business Development PLC	Oromia	8,393.5
Hilmat PLC	Oromia	7,549.6
Hua Yi Cement PLC	Oromia	7,993.9
Ismaile Kassa	Amhara	532.9
Jatish Manilal Patel	Multiregional	9,992.3
Lafarge Cement Ethiopia PLC	Oromia	452,982.7
Lafarge Cement Ethiopia PLC	Oromia	452,982.7
Makarus Filotheso Farag Wassef	Multiregional	6,661.6
Melake Mikiru	SNNPR	2,131.6
Mohaned Osman Mahamed Mhamoud	Multiregional	6,661.6
Mugher Cement Enterprise	Oromia	193,589.8

³ 1 USD = 11.13 Ethiopian Birr (March, 2009)

Murtadha A. Abduljalil	Multiregional	6,661.6
Myk Cement Industries PTE LTD (Ethiopian Branch)	Multiregional	93,261.1
P & F General Business PLC	Oromia	2,131.6
Peacock Oil PLC	Oromia	19,984.6
Rina International Investment (ETH) PLC	Oromia	175,981.1
Samuel Langan Deno	SNNPR	134.6
Sri Sai Flora PLC	Multiregional	7,546.1
Sunrise Industrial Activities Construction & Trading Service Ethiopia PLC	Oromia	1,106,558.6
Super Sunrise Industrial PLC	Oromia	1,263,164.3
T.N.T.M Industrial PLC	Oromia	599,536.1
Ture Dire Dawa Cement Factory S.C.	Dire Dawa	41,023.5
Universal Cement PLC	Multiregional	1,332.3

The cement plants that are under various stages of planning and investment are far greater in number than the ones that are operational. Around 39 investors intending to establish cement factories in Ethiopia have already received their investment licences. These plants have ample opportunity to incorporate into their design a provision for flexible fuel use so that they can use biomass-based fuels in greater proportion. In the longer term, new plants can plan to use biomass from dedicated energy forestry plantations that can be established as integral components of the cement plants. Though they are not using it for energy purposes, Hima cement plant in Uganda is planting trees in old quarries to reclaim the natural beauty of the land.

7.2 CANDIDATE CEMENT PLANTS FOR BIOMASS UTILIZATION

Some of the cement plants in Ethiopia face favourable circumstances for partially switching to biomass fuels. The plants that have the greatest opportunities for using biomass-based fuels – because of their proximity to the resources and because of their current utilization of fuels such as petcoke and coal – are indicated in Table 6 below.

Table 7: Proposed Alternative Biomass Fuels for Ethiopian Cement Plants

Cement Plant	Location	Type of kiln	Production Capacity (tonnes /day)	Fuels used currently	Proposed alternative biomass fuels
Abissinya	Chancho	Vertical Shaft	300	Petcoke	Coffee husk, urban waste
Dashen	Dejen	Vertical shaft	300	petcoke	Energy forestry
National	Dire Dawa	Rotary	300	Coal	Cotton stalk, energy forestry
Jemma	Muketuri	Vertical shaft	300	Petcoke	Coffee husk, urban waste
Mossobo	Mekelle	Rotary	2,000	coal	Cotton and sesame stalk, energy forestry
Mugher	Mugher	Rotary	2,000	Furnace oil	Coffee husk, urban waste and energy forestry
Koka Cement	Koka	Vertical shaft	300	Petcoke	Coffee husk, urban waste and energy forestry

7.3 TECHNICAL OPTIONS FOR BIOMASS UTILIZATION

As with cement plants elsewhere, Ethiopian cement factories wishing to use biomass –based fuels have two options for biomass utilisation: to use solid biomass by directly feeding it into pre-heaters / pre-calciners and the kilns, or to convert the biomass into producer gas and use the gas in a co-combustion system.

7.3.1 DIRECT COMBUSTION IN THE PRE-HEATERS AND PRE-CALCINERS

In principle, the preferred option for combusting solid biomass is in the pre-heaters / pre-calciners, where more than 60% of the energy input is used. For this, a specially-designed combustion chamber has to be arranged in between the pre-heater / pre-calciner and the kiln.

However, it must be noted that, at the moment, no plants in Ethiopia have pre-calciners. The third line of Mugher cement factory, which is currently under construction, is anticipated to incorporate pre-calciners in its pyroprocessing system. Solid biomass fuels can be utilized in the pre-calciners of this third line by incorporating into the design a suitable combustion chamber. The other option would be to modify the first two lines to include a pre-calciner unit. However, this option would require a major plant redesign and modification.

7.3.2 DIRECT COMBUSTION IN THE KILN

The other option of using biomass is to directly combust it in the rotary kilns. Vertical shaft kilns (VSK) are not suitable for using lump solid biomass. Solid biomass use in vertical shaft kilns is possible only by pulverizing it and mixing it with petcoke, the fuel mostly used in VSK.

Direct combustion of solid biomass fuels, particularly urban waste-derived fuels, in the rotary kilns is the preferred option from the perspective of safer disposal of the waste, as the high kiln temperature enables complete combustion and minimizes the risk to the environment from un-combusted fuel. High temperatures and longer retention times in the kilns offer greater energy-efficiency when combusting the fuel.

In the Ethiopian context, urban waste, particularly household waste, is by and large composed of biomass and contamination from release of chromium, lead, mercury and chlorine rarely occurs. Industrial waste can contain these metals, though not in substantial quantities.

The feeding of solid biomass fuels into rotary kilns can be performed by chute feeding into the raw meal inlet section of the kilns. Alternatively, solid biomass can be chute-fed into the burner end of the kiln. Feeding at the transition section, though not preferred, is also possible for these kinds of fuels. Depending upon the feeding point, care has to be taken to make a controlled feed of biomass so that the optimum operational temperature profile of the kiln is not disturbed. In addition,

controlling the feeding system fuel homogeneity with uniform heating value and moisture content is vital for maintaining the correct kiln temperature profile.

Little modification is required in the case of feeding biomass fuel at the ends of the kilns. However, the kilns have to be modified considerably if the feed point is to be in the transition section.

A major challenge, when considering direct combustion of biomass fuels in clinker kilns, is the amount and nature of fuel ash produced in the kilns. Some fuel ash can be added to the raw meal without any problems arising. However, the content of the fuel ash is crucial in determining the amount that can be added. For instance, a high content of minerals in fuel ash would substantially influence the quality of the resulting cement product (Greil, 2002). The final composition of Portland cement, for example, consists of 50% tricalcium silicate (Ca_3SiO_5 or $3\text{CaO}\cdot\text{SiO}_2$), 25% dicalcium silicate (Ca_2SiO_4 or $2\text{CaO}\cdot\text{SiO}_2$), 10% tricalcium aluminate ($\text{Ca}_3\text{Al}_2\text{O}_6$ or $3\text{CaO}\cdot\text{Al}_2\text{O}_3$), 10% tetracalcium aluminoferrite ($\text{Ca}_4\text{Al}_2\text{Fe}_2\text{O}_{10}$ or $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3$) and 5% gypsum ($\text{CaSO}_4\cdot 2\text{H}_2\text{O}$), (Choate, 2003). This composition has to be maintained in order to obtain a good-quality cement product. In using biomass fuel ash in raw meal, care has to be taken not to significantly affect the chemical composition of the final product.

7.3.3 USING PRODUCER GAS

The other option of using biomass in cement plants in Ethiopia is to generate producer gas from biomass fuels using circulating fluidized bed gasifiers. With this technology a variety of biomass fuels, such as urban waste-derived fuels, agricultural waste and residues (for example coffee husks and cotton stalks, forest residues and solid wood from energy forestry) can all be transformed into producer gas. The gas so produced can be used, often with minimum need for cleaning, in pre-heaters / pre-calciners and as a secondary fuel in the rotary kiln. The advantage of this system compared with the use of solid biomass is that it enables easy control of a number of parameters that can otherwise affect the pyroprocessing system.

The gasification reactor can be located outside the cement plant in the raw biomass fuel storage house, where fuel cleaning, preparation and storage is performed. Fuel conveyance to the plant and feeding can be performed through sealed gas pipes.

Producer gas can be combusted in a controlled manner in a combustion chamber arranged at the pre-heaters / pre-calciners or can be co-combusted in the clinker kiln.

The system of producer gas supply can be kept autonomous in case of system disturbance in the pyroprocessing unit. The plant designs or modification designs should allow operation with 100% of the original fuel when the need to close the producer gas supply system (for maintenance or other reasons) occurs.

7.4 THE NEED FOR PLANT REDESIGN AND EQUIPMENT ACQUISITION FOR BIOMASS UTILIZATION

Biomass-based alternative fuels tend to have lower heating values than the fossil fuels typically used.

Taking the case of Mughar cement factory as an example, and assuming the minimum specific energy consumption of the pyroprocessing system to be 4.2 MJ/kg of cement and the heating value of furnace oil to be 42 MJ/litre, daily fuel consumption of Mughar cement factory, with a production capacity of 2,000 tonnes per day, is estimated at 200,000 litres of heavy furnace oil. Replacing 20% of the furnace oil consumption would require about 120,000-160,000 kg (equivalent to 286m³-381m³ stacked⁴ wood) of biomass-based alternative fuel (assuming a heating value of 14 GJ/m³). This is a considerable amount of fuel to handle on a daily basis.

Due to the bulky nature of biomass fuels, properly designed fuel storage, cleaning and preparation units have to be designed and built outside the cement plant, as considerable space is required for biomass storage. The fuel preparation unit should consist of: storage halls, a cleaning-and-separation of foreign materials unit, drying and crushing / grinding facilities (for pulverized fuels), and a pelletizing and / or briquette-making facility.

The ready-to-use biomass fuel then has to be conveyed by mechanical conveyors (if in lump form) or pneumatic conveyors (if in pulverized form) into an intermediate silo in the plant, from where it can be directly fed to the combustion chambers of pre-heaters / pre-calciners or the kilns.

During storage and preparation, care has to be taken that deterioration of the biomass does not lead to methane emissions. Storage of wet and damp biomass fuels has to be avoided. If the plant does receive biomass fuel with high moisture content, it must be immediately dried with the flue gas from the plant. Failure to do this can result in emission of gases such as methane.

Cement plants opting to use biomass have to consider a number of options.

First, they must decide what type of biomass they will use. This decision is made largely on the basis of availability in the vicinity of the plant. For instance, Mughar, Abyssinia and Jemma cement factories can consider using coffee husks and urban waste-derived biomass fuels because of their proximity to the resource bases of these fuels. Mossobo and National cement can consider using cotton and sesame stalks for the same reason. In the longer term, all cement factories can consider utilizing biomass from dedicated energy forestry. Some cement plants can consider using existing wood plantations. In this regard, Dashen plant at Dejen, for instance, can consider immediately utilizing woody biomass from existing plantations near the

⁴ 1m³ stacked wood ~ 420kg

plant with a contingent plan to reforest the utilized forest land and develop new energy forestry with fast-growing trees for future use.

Second, once the decision on the type of biomass to be utilized is reached, a detailed study has to be conducted by the plant to consider the technology suitable for the particular type of biomass chosen. The options to be considered are:

- To use solid lump fuels such as woody biomass, briquettes or pellets in the kilns.
- To use biomass in pulverized form mixed with petcoke, particularly in the kilns (suitable for vertical shaft kilns) or mixed with coal for use in rotary kilns.
- To transform biomass into producer gas and use it in the pyroprocessing system.

For all of these options, plant redesign and equipment acquisition is necessary. This will be further elaborated in the following sections.

7.4.1 SOLID LUMP BIOMASS FUELS

In the case of using solid lump fuels in pre-heaters / pre-calciners, which is applicable in today's Ethiopian context only for the upcoming Mughar third line, the combustion chambers have to be arranged in between the pre-heaters / pre-calciners and the kilns have to be designed, so that biomass combustion can be performed without any problems such as fuel feeding and un-controlled ash mixing with clinker.

If biomass fuels are to be used in the kilns, the feed system (chute feed) and feeding rate monitoring system have to be designed for fuel feed at the inlet and firing ends of the rotary kiln and have to be installed. A major redesign and modification will be required if the fuel is to be fed into the transition section of the rotary kiln.

Using solid biomass fuels, particularly in the kilns, requires undertaking the following plant modification and construction:

- Depending upon the type of fuel, the moisture content of the fuel and the content of undesirable material, the fuel warehouse has to have fuel-cleaning and fuel-drying sections equipped with the necessary facilities. The design of this section is dependent on the particular situation of each plant and the nature of the biomass fuel.
- Particular consideration should be given to whether or not to receive wet or damp fuels. Fuels supplied to the cement plant can preferably be dried at the site of resource base. This will minimize the space requirement at the plant for drying fuels. If drying is absolutely necessary, the plant should consider designing the drying facility using the flue gas heat from the plant. When

using flue gas for drying, due consideration has to be given to environmental issues to prevent undesirable emission of particles and gases.

- The need and method of cleaning is dictated by the biomass being used. Manual cleaning and sorting can suffice for certain types of woody biomass. Magnetic separation of foreign metallic materials will be required in the case of urban waste-derived fuels. Cleaning of fuels is very important for two reasons: to prevent or minimize undesirable material that can alter the quality of clinker and result in corrosion of the kilns, and to avoid the release of environmentally-damaging substances such as chromium, lead, chlorine and mercury. Fuel cleaning is, therefore, an important task that should be designed carefully on the basis of the nature and content of the fuel.
- Fuel preparation is another important task that has to be undertaken with care. Fuel preparation consists of homogenizing the fuel to obtain uniform heating value and preparing it to the required size. Urban waste-derived fuels, agricultural waste and agricultural residues have to be pelletized and / or briquetted to increase their density and energy content per unit volume. If the fuels have to be transported over a long distance, pelletizing and / or briquette-making can be conducted at the resource site in order to reduce transportation cost and create convenience in handling and transportation. However, the pellets and briquettes can also be made at the cement plant. The economics, health and environmental issues will determine which option is best suited for a particular cement plant. If it is chosen to make pellets and/or briquettes at the plant, the pellet/briquette press has to be installed as an additional section of the fuel preparation and storage facility.
- The finished ready-to-use fuel has to be stored in a clean, dry place separate from the 'raw' (unprocessed) biomass. The ready-to-use fuel can be conveyed to the plant using mechanical conveyors and delivered to a buffer silo in the plant. From the buffer silo, the fuel can be chute-fed to the combustion chambers of the pre-heaters / pre-calciners or the kilns at a pre-determined rate.

The feed rate is determined by the energy requirement. For instance, a 20% fuel oil replacement at Mughar will require a daily feed rate of approximately 120,000-160,000kg of biomass. Adjustment and fine tuning of the rate can be done in initial test runs and in the course of repeated usage.

The equipment required for solid biomass utilization consists of:

- Fuel cleaning facility – including magnetic separation of metallic elements if required
- Fuel drying facility – drying bed and flue gas duct, flue gas Induced Draft Fan (IDF)
- Cutting, shredding and / or crushing and sizing equipment
- Pellet or briquette-making equipment (if required)

- Conveyor to the plant – bucket conveyors and / or belt conveyors
- Buffer silo
- Chute feed
- Combustion chamber at the pre-heaters / pre-calciners (if required)

7.4.2 PULVERIZED FUELS

All of the tasks and facilities indicated above for solid lump fuels also apply for pulverized fuels.

In addition, due to the particular nature of pulverized fuels, the conveyance system and fuel preparation system have to be designed in a different manner. After cleaning and drying, the biomass fuel crushing and / or grinding has to be done in a separate area.

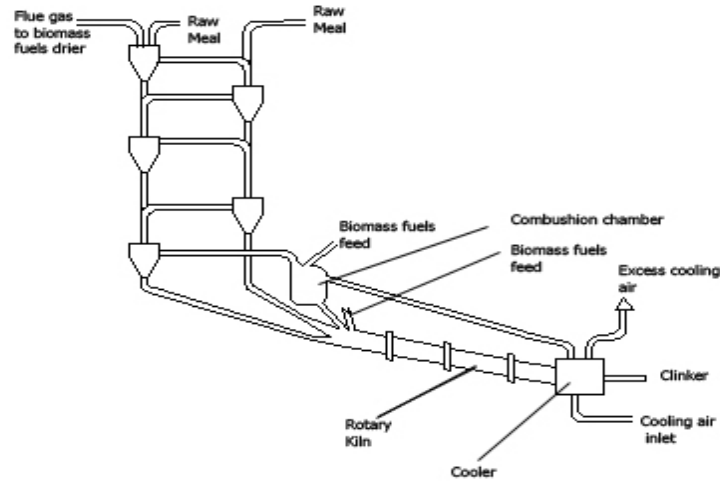
Pulverized fuels are preferably used in vertical shafts, mixed with petcoke in pre-determined proportions. Pulverised biomass can also be used in rotary kilns mixed with coal. The mixture fuel can then be pneumatically conveyed to an intermediate silo in the plant from where it can again be pneumatically conveyed to the kiln combustion point. Care has to be taken when blowing pulverized fuel mixture, particularly in rotary kilns, so that backfiring and explosions do not occur. In the case of using pulverised fuels in rotary kilns, the blowing air pressure has to be sufficiently higher than the pressure in the kilns.

The equipment required for utilization of pulverized biomass mixed with coal or petcoke consists of:

- Cleaning facility – magnetic separation of metallic materials if required (manual cleaning is possible for some biomass-types)
- Fuel-drying system using the flue gas from the plant
- Shredding, crushing and / or grinding mill
- Fuel metering and mixing facility
- Pneumatic conveyors – to the silo in the plant and from the silo to the kilns
- Intermediate silos
- High-pressure blowers
- Piping for fuel transport and flue gas ducts for drying

Based on the foregoing, a suggested biomass fuel feed and combustion system that could be constructed at Mughar cement plant is indicated in the figure below. The addition of a biomass combustion chamber at the pre-heaters / pre-calciner using the hot gas from the kiln and clinker cooler is one suggested modification for Mughar cement factory. The other alternative modification is the arrangement of biomass feed system at the inlet end of the kiln.

Figure 1: Proposed Biomass Fuel Feed and Combustion Points at Mughar Cement Factory



7.4.3 BIOMASS ENERGY IN THE FORM OF PRODUCER GAS

Transforming biomass into producer gas using a Circulating Fluidized Bed gasification reactor is the most convenient means of using biomass fuels in the cement industry.

The efficiency of utilization, from raw biomass to process heat, is lower than other alternatives because of the heat loss at the gasification reactor. However, converting biomass into producer gas has many advantages:

- A variety of biomass fuels, such as urban waste-derived fuels, agricultural residues, forest residues and forest waste, woody biomass from energy forestry etc., can all be utilized for producer gas generation with little requirement for drying, cleaning and fuels preparation.
- Relatively large sizes of up to 150 mm pieces of biomass fuel can be utilized without any need for significant size reduction.
- Fuel ash can be conveniently disposed without any disturbance to clinker production. If desired, measured quantities of fuel ash can be added to the raw meal.
- Flexibility: the cement plant can be designed to use a high proportion of producer gas in the fuel mix but can also retain the flexibility of using 100% fossil fuel if the need arises.

Bubbling fluidised bed gasification reactors can be used in combination with circulating fluidised bed gasification reactors. The first reactor enables full gasification of carbonaceous materials and the second reactor facilitates the cracking

of tar. The combined effect of these two reactors is that they act like one single circulating fluidised bed gasification reactor with bubbling bed. This type of gasification reactor enables the utilization of a variety of biomass fuels with different carbonaceous mineral contents, size and moisture contents.

The gas from the gasification reactor can be utilized without cleaning or with little cleaning at the pre-heaters / pre-calciners, in the case of the third line at Mughher, or as a secondary fuel in rotary kilns. The fuel ash can be cooled, the contents checked by laboratories and, if found suitable, can be added into the raw meal, thereby displacing a considerable amount of raw material for clinker production.

7.5 INVESTMENT

Little information is available on the magnitude of additional investment requirement. Knopf (1995) indicates that the additional investment costs for combustion of 22 kilo-tonnes of municipal solid waste (MSW) in a kiln with a capacity of 500 kt clinker per year is in the region of EURO 750,000 (EUR 35/t MSW) and the additional operational and maintenance costs are EUR 220,000 (EUR 10/t MSW) (De Feber and Gielen, 2000).

Using this information, the estimated investment cost for 20% biomass fuel switching at Mughher cement factory (which would amount to 48,000 tonnes of biomass fuel per year) would be about EUR 2.16 million. This estimated plant modification cost in Ethiopian Birr would be about Br 24 million⁵.

7.6 RUNNING COSTS

Running costs are related to the fuel preparation process and the fuel feed process. The running costs consist of:

- Biomass fuel cost at the source site
- Labour cost for fuel cleaning and preparation
- Utilities such as electricity and water
- Transportation

All of these cost components add to the raw material cost and give the total cost of biomass fuels. The average cost of solid biomass fuel delivered at the factory gate is estimated at Birr 1.25/kg (this is simply an estimate and each factory will face different costs). This cost is deliberately taken on the high side to account for any contingencies – for example, so that cement factories can set attractive prices for third-party biomass supply companies if cement producers choose to opt out of direct sourcing themselves. The current fuel wood cost in Addis Ababa is approximately Birr 0.5/kg.

⁵ 1 EUR ~ Birr 11 (May, 2009)

7.7 FINANCIAL BENEFITS OF FUEL SWITCHING

7.7.1 FUEL DISPLACEMENT

The benefits of using biomass fuels to displace fossil fuels used in the cement industries are financial and environmental. The financial benefits are the difference in unit cost of useful thermal energy of the fossil fuels and that of the substitute biomass fuels. To displace a litre of fuel oil, 3-4 kg of biomass fuel will be required. The biomass fuel requirement will be on the higher side, about 4 kg, if the producer gas route is used because of energy losses in the gasification reactor.

Taking the Mughher case as an example, 20% fuel oil replacement would represent 160,000 kg per day of biomass fuel. Assuming the average biomass fuel cost to be Birr 1.25 /kg, the total daily biomass fuels cost would, therefore, be approximately Birr 200,000.

The price of furnace oil fluctuates between 7.02 birr/litre to 5.47 birr/litre. For our calculation here, the higher furnace oil price is taken. The cost of 20% of the daily consumption of furnace oil at Mughher cement factory is approximately Birr 240,000.

The estimated net saving from fuel replacement is, therefore, Birr 40,000/day. This amounts to a total saving of about Birr 12 million (US\$1.1 million) per annum (300 working days) from fuel displacement alone.

The investment cost for plant modification for 20% biomass fuel switching would be approximately Birr 32 million. The investment cost could, therefore, be recovered in less than 30 months from savings in the fuels cost alone.

7.7.2 REVENUE FROM CDM

Cement factories opting for biomass fuel switching can reduce their CO₂ emissions considerably. This reduction in CO₂ emissions can enable them to apply for revenue from the CDM (Clean Development Mechanism).

Taking again Mughher Cement as an example, it can be noted that with 20% fuel switching, about 40,000 litres of furnace oil can be displaced. Assuming an average 300 working days per year, this quantity translates into about 12 million litres per year.

The CO₂ emission factor of heavy furnace oil is about 92kg/GJ and the average heating value of heavy furnace oil is 42 MJ/litre. The estimated CO₂ emission reduction would, therefore, be about 46,368 tonnes per year.

With this reduction, revenue from the CDM (at US\$14/tonne of CO₂) would be about US\$650,000 (approximately Birr 7.15 million) per year.

7.8 OUTSOURCING BIOMASS SUPPLIES

In the preceding section, the estimated cost of ready-to-use biomass fuel is taken to be Birr 1.25 per kg. This price is on the high side. Some sources indicate that the biomass fuel price may, in reality, be nearer Birr 0.5/kg.

Cement operators may not be interested in becoming involved too deeply in the task of fuel sourcing and preparation. The alternative for such plants is to out-source the supply of biomass to other companies.

Biomass fuel supply companies can enter into contracts to prepare and supply biomass fuels from known and agreed sources with pre-specified homogeneity, form and moisture content. The biomass supply companies can also enter into agreements to observe certain environmental norms in their production and processing.

By out-sourcing biomass fuel supply, cement factories will also be saved the space requirements for fuel drying and preparation. Another positive aspect of out-sourcing is that a number of companies may emerge and may compete to supply cement factories with biomass fuels from a variety of sources, including agricultural residues, forest waste, urban waste and energy forestry. As a first step, in the initial phases of planning for biomass fuels switching a cement factory can issue tenders for the supply of biomass fuels.

8. CONCLUSIONS

Fuel switching, from conventional fossil fuels to biomass, is a feasible and attractive option for Ethiopian cement plants. Biomass fuel switching of even 20% can be financially rewarding, with the financial benefits accruing from the reduced cost of fuel and the revenue from the CDM.

Biomass fuel switching in the cement industry, in addition to the financial revenues flowing to the cement factories, has nationwide benefits such as:

- Reduced foreign exchange requirements
- The creation of considerable job opportunities in biomass fuel development, preparation and transportation

Mugher Cement has a unique opportunity to switch to biomass fuels, especially in the third line where pre-calciners will be added. Similarly, most new cement factories have ample opportunity to incorporate into their design pre-calciners fitted with special combustion chambers for biomass fuel utilization.

9. RECOMMENDATIONS

The financial and other benefits of switching to biomass fuels in cement plants are evident from the discussion in the preceding section. Cement plants in Ethiopia have to consider the option of utilizing biomass fuels and thereby replacing some portion of the fossil fuels they are currently using.

Cement factories need to study what types of biomass fuels are available in their locality and what can effectively be utilized in the short term to replace 15-20% of the conventional fuels they are using. In the longer term, they need to study all options for switching to higher-percentage biomass fuel utilization. In these studies, they must consider plant modification requirements and the option of developing new dedicated energy plantations (possibly in old quarries or other disused land) so that they can supply themselves with a considerable portion of their biomass fuel requirement.

Mugher Cement factory especially, which faces the possibility of switching to biomass fuel in the first two production lines and particularly in the new third line, should pursue a biomass fuel-switch policy. Similarly, all upcoming cement factories should consider in their design a flexible fuel use so that they can exercise the option of using biomass in greater proportions.

CHAPTER THREE

ENVIRONMENTAL & ECONOMIC BENEFITS OF BIOMASS FUEL USE IN CEMENT CLINKER PRODUCTION

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1. INTRODUCTION

Biomass refers to biological materials derived from living or recently dead biological materials, encompassing materials from both plants and animals. It includes plant tissues such as wood, charcoal and yarns; farm wastes such as coffee husks, teffe and chat; animal wastes, such as animal fat, dung, meats and bones; and household or industrial biological degradable wastes. These materials are primarily composed of carbon-based organic matter, which releases energy when it reacts or combusts with oxygen. When cultivated or sourced in a sustainable manner (such that the total stock of the resource does not diminish in size), biomass can be regarded as a form of renewable energy. (Nicholls, Monerud and Dykstra, 2008).

Although fossil fuels are also made from the remains of dead animals and plants, fossil fuels are not considered renewable on any scale of time that matters to humans (Shafiee and Topal, 2009).

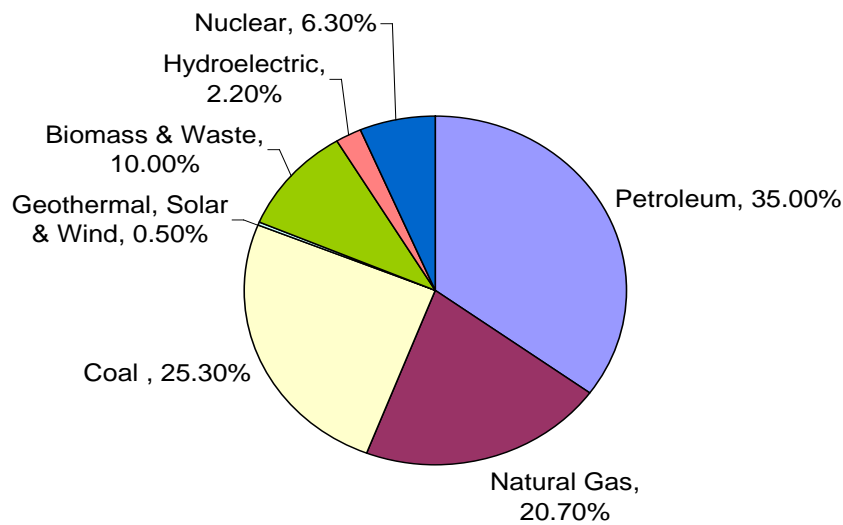
1.1. BIOMASS AS AN ENERGY SOURCE

Biomass is the oldest source of energy, in use since mankind first harnessed fire and used wood as a source of heat, light, and power. For centuries before the invention of the steam and internal combustion engines, most of the world's energy came from biomass. The advent of industrialisation created the need for a large quantity, and more concentrated source, of energy. This led to large-scale exploration and utilisation of fossil fuels (Winandy *et al*, 2008). Nonetheless, biomass still accounts for 10 percent of global energy use, which is approximately five times more than the energy generated from hydroelectric power (IEA, 2006). In the United States alone, about eleven gigawatts (GW) of electrical power are generated from bioenergy sources. This makes biomass the second-largest US renewable energy source next to hydropower (94 GW), and more significant than wind energy (5 GW) and geothermal (2.7 GW) (Nicholls *et al*, 2008).

In the Less Developed Countries (LDCs), biomass accounts for almost one-third of all energy consumption. In fact, in sub-Saharan countries biomass accounts for more than 80 percent of all energy needs, and is primarily used for cooking, lighting and heating (Palz and Kyramarios, 2000). Figure 1 shows world energy demand by source.

With the growing realisation of the impact of fossil fuels on global warming, coupled with volatile energy prices and an emerging energy security agenda, there is a renewed interest in using biomass as a carbon-neutral and cost-effective alternative. For example, Nicholls *et al* (2008) state that wood energy could potentially supply up to 10 percent of U.S energy demand. Currently it is below four percent and is expected to grow to five percent by 2020. As shown in Table 1, Wright (2006) put US biomass consumption at a lower level of 2.8 percent in 2005 and Brazil at 27.2 percent.

Figure 1: 2007 World Energy Demand by Source (IEA, 2006)



Biomass can be used as an energy source in a variety of ways: as a direct combustion feedstock in home stoves, thermal power plants, furnaces and boilers (possibly in combination with coal or other fossil fuels); or as a feedstock for pyrolysis, gasification, charcoal production, briquetting, transesterification or fermentation (the latter two for producing biodiesel and bio-ethanol (Kelly, 2009).

Table 1. Biomass Consumption by Country (Wright, 2006)

Country	Total (EJ ⁶)	Biomass (EJ)	Biomass %
Brazil	7.3	1.98	27.2
China	45.5	7.5	16.4
Canada	13.1	1.77	13.5
Sweden	2.2	0.34	15.9
Denmark	0.83	0.098	11.8
EU-25	70.5	2.75	3.9
U.S	103.4	2.92	2.8
UK	9.48	0.06	0.6

1.2. PURPOSE

The purpose of this chapter is to evaluate the opportunities, barriers and costs associated with utilising biomass for thermal combustion in cement factories. It seeks to address the following questions:

- Is it possible to use biomass / biomass residues in cement plants?
- How is cement produced and where can biomass be used?

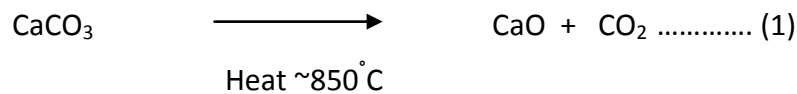
⁶ EJ – exajoule = 10¹⁸ joules

- What engineering modification or redesign of cement plants is required to burn solid biomass in cement kilns?
- What are the experiences of the global cement industry and available technologies?
- What preparation methods are needed to make biomass acceptable in an industrial application, such as size reduction and drying?
- What are the benefits?
 - Environment
 - Economical
 - Social
- What are the barriers for use of biomass in cement kilns?
 - Cost
 - Environmental, regulatory and legal issues
 - Technical, perception and skills
- What are the environmental and health and safety risks?
- Finally, recommendations are put forward, highlighting the potential benefits of using biomass in Ethiopia’s cement factories.

2. CEMENT CHEMISTRY AND IMPACT ON THE ENVIRONMENT

Cement production is a large user of fossil fuels and producer of greenhouse gases (GHGs) (Worrell *et al*, 2001). In cement production, there are three sources of greenhouse gases.

1. **The first source** comes from the inherent nature of cement production. Cements are made from limestone, which predominantly contains more than 90 percent calcium carbonate (CaCO₃). As shown in chemical equation 1, when heat is applied to CaCO₃ it dissociates into calcium oxide, which is the main ingredient for cement, and carbon dioxide, which is a greenhouse gas.



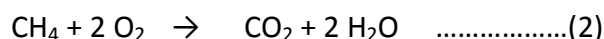
For every 100 grams of calcium carbonate heated in a kiln above 750°C, about 44 grams of carbon dioxide and 56 grams of calcium oxide are produced. In effect, for every 56 grams of calcium oxide that is used by the construction industry, about 44 grams of carbon dioxide are released into the atmosphere. According to the European Cement Association (2009a), approximately 525kg CO₂ per tonne of ‘clinker’ is produced. (Clinker is a solid intermediary cement product that is formed at high temperature through total or partial fusion of cement raw materials). In 2007 alone about 2.77 billion tonnes of cement were produced globally, which means up to 1.45 billion tonnes of CO₂ were released from de-carbonisation of CaCO₃ alone into the atmosphere.

*Table 2. 2007 World Cement Production by Region
(European Cement Association, 2009a)*

Cement Production	Percentage [%]
Asia	70.1
<i>China</i>	48.7%
<i>Japan</i>	2.4%
<i>India</i>	6.1%
<i>Other Asia</i>	12.9
USA	3.4
Other America	6.2
European Union 27	9.7
Africa	4.4
Oceania	0.4
CIS	2.4

2. **The second source** of greenhouse gases comes from the combustion of carbon-containing fossil fuels such as methane, furnace fuel, coal or alternative fuels such as biomass, re-ground tyres, and household and industrial wastes.

The mechanism by which carbon-containing fuel burns to give off carbon dioxide is given in equation 2 using the smallest hydrocarbon compound, methane (CH₄).



The European Cement Association (2009a) estimates that overall carbon dioxide production from combustion of fuel in the kiln is approximately 335 kg of CO₂ per tonne of cement.

3. **The third source** of carbon dioxide derives from the use of electricity produced by power stations that are burning fossil fuels. This accounts for approximately 50 kg of CO₂ per tonne of cement produced (European Cement Association, 2009a). Countries, such as Ethiopia, that generate a significant fraction of their electricity from hydroelectric power stations do not produce large quantities of carbon dioxide from the use of electrical motors. However, cement plants in these countries do, of course, produce carbon dioxide from the first two sources.

When all the carbon dioxide produced from the three sources is added together, the cement industry releases about 0.8 tonne of carbon dioxide into the atmosphere per tonne of cement produced. This makes cement production one of the largest sources of greenhouse gases, producing 5 percent of global emissions (Worrell *et al*, 2001). This is more than the emissions from the global steel industry. According to the Intergovernmental Panel on Climate Change (IPCC), the steel industry accounts for between 3 to 4 percent of total world greenhouse gas emissions (World Steel Association, 2007).

Carbon dioxide (CO₂) from decarbonisation of limestone can be reduced by diluting cement clinker with raw, thermally untreated rocks such as pumice⁷, gypsum⁸, pozzolan⁹ or ground furnace slag¹⁰. For example, pumice rock can be added up to 15 percent with some compromise on physical properties, strength or setting time of cement for less critical constructions (Hossain, 2003). Hence, carbon dioxide from decarbonisation of limestone can be reduced – but cannot be fully eliminated – as long as cement is made from CaCO₃. There is ongoing research into the development of ‘eco-cement’ made from magnesium oxide (MgO) which can absorb carbon dioxide and water to set and harden (Harrison, 2009). But the chemistry of cement *per se* (as opposed to the energy sources used to make the cement) is beyond the scope of this chapter and will not be considered further.

However, CO₂ from the burning of fossil fuels can be reduced and, even more importantly, can be made carbon-neutral with the utilisation of biomass as an energy source for pyroprocessing.

To understand how this can be achieved, it is important to understand how cement is produced and the types and amounts of energy needed to make cement.

2.1 CEMENT PRODUCTION PROCESS

Cement manufacturing starts with the quarrying of more than one raw material to provide a source of necessary metallic oxides, such as calcium oxide from limestone, iron and aluminium oxides from clay and silicon oxide from sand. Big rocks blasted from quarries are crushed into gravel to facilitate transportation, blending and milling into powder.

As shown in Figure 2, there are two processes of raw material grinding and blending. Those are known as the ‘wet’ process and the ‘dry’ process. In the wet process, the materials are ground and homogenised as slurry. This method was traditionally preferred to achieve homogeneity of feedstock, but following improvements in dry mixing and blending of powder materials most modern cement factors now use the dry process because it requires less energy per tonne of clinker.

Using the dry or wet process, different types of cement are made for various applications. The most common cement used in civil construction today is Ordinary Portland Cement (OPC), but there are specialist cements such as rapid heat cement, high alumina cement, oil-well cement, quick set cement, etc. For example, the raw material for Portland Cement needs to be predominantly calcareous, rich in calcium oxide (CaO) and with smaller amounts of siliceous (SiO₂), aluminous (Al₂O₃) and iron-rich (Fe₂O₃) content. Most often, between 70-99 percent of this calcareous component comes from limestone deposits. Clay, sand or other minerals are also

⁷ **Pumice** is a volcanic rock.

⁸ **Gypsum** is a very soft mineral composed of calcium sulfate dihydrate.

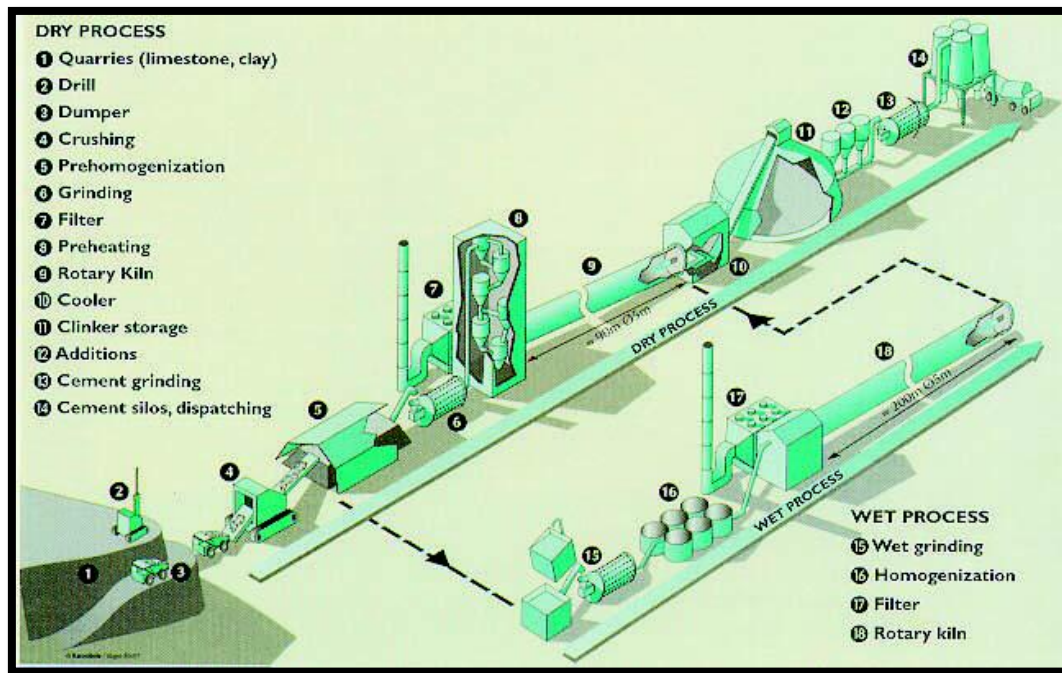
⁹ **Pozzolan** is a siliceous rock which react with calcium hydroxide to form calcium silicates.

¹⁰ **Ground granulated blast furnace slag** is a by-product of iron and steel making.

milled with limestone in the correct proportions to achieve the following proportion in the cement clinker (Chatterjee, 1983):

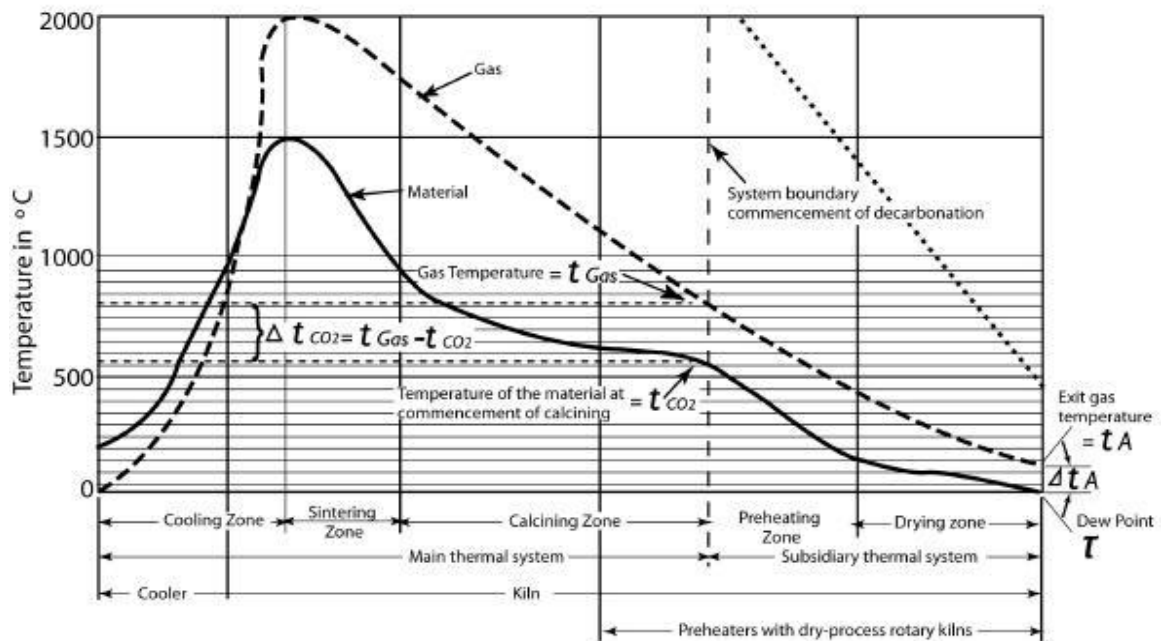
CaO	63-67 %
Al ₂ O ₃	4- 7%
Fe ₂ O ₃	2-4 %
SiO ₂	21-24%
Trace amounts	2-3%

Figure 2. Cement Production Steps in the Dry and Wet Process
(European Cement Association, 1998)



Once the correct proportions of these chemical compounds are achieved, the material is fed into pre-heating cyclones to be heated to decompose some of the CaCO₃ and prepare it for further reactions that will take place. In the kiln, as shown in Figure 3, the temperature of the material reaches around 1,450°C and the air temperature is as high as 2,000°C. During this process of chemical reactions, a black/grey solid mass is formed through partial or total fusion of the raw materials. This is known as clinker (Peter, 2001).

Figure 3. Temperature Profile of Pre-Heating Cyclones and Kiln (Hansen, 1990)



3. CHEMICAL REACTION OF CLINKER PRODUCTION

The pre-heated material in the cyclones is dropped into the kiln for complete reaction. As shown in Figure 4, most modern cement kilns are rotary shafts with a diameter ranging from 3.5m to 5.5m and a length of between 50 to 200m. Coal, gas, fossil fuels or alternative fuels are continuously injected into the kiln to burn and produce heat of about 1,450°C in the clinker production zone.

A typical Portland cement clinker consists of at least two-thirds mass of calcium silicates $(CaO)_3SiO_2$ and $(CaO)_2SiO_2$ and the remainder consists of aluminium oxide (Al_2O_3) , iron oxide (Fe_2O_3) and other oxides (Peter, 2001). Once the clinker is formed it drops into a cooler where air is blown in at one end to remove the heat from the partly-softened and molten material and turn it into small pebbles. The clinker is then ground in a cement mill – with or without “extender minerals” such as pumice, gypsum, pozzolan or ground furnace slag – to produce cement.

To carry out these operations a large amount of electrical and fossil fuel energy is used, which will be discussed in the next section.

Figure 4. Kiln Source



3.1 ENERGY CONSUMPTION OF THE CEMENT INDUSTRY

Cement production is one of the largest users of fossil fuels. According to energy consumption benchmarking carried out in Canada, the energy cost of cement production is between 25-35 percent of the total direct cost of cement production. A similar analysis carried out in Poland estimated energy costs to be between 30-40 percent of the total costs of cement production (Mokrzycki, Uliasz-Bochenczyk and Sarna, 2003). Messebo Cement factory in Ethiopia reports that it spends up to 60 percent of its total cost of production on imported furnace fuel, which is exceptionally high compared with the industry standard (Addis Fortune, 2007). This figure is probably distorted by cheap labour and other costs. Nonetheless, this high proportion of energy cost has been a major driver for the industry to search for cost-effective and alternative fuels.

Fuel consumption at a cement plant depends on the type of process the plant uses. As shown in Table 3, total energy consumption used during the wet cement production process is much higher than in the dry kiln process.

**Table 3. Typical Fuel Consumption of Three Kiln Types
(Energy Innovation Initiative in Canada, 2001)**

Kiln Type	Average Fuel Consumption GJ/tonne clinker
Wet Kilns	6.0
Dry Kilns – Single stage pre-heater	4.5
Dry Kilns – Multi-stage pre-heater	3.6

Ruth *et al* (2000) estimate that the most efficient and modern kilns could use as little as 3,200 MJ of energy per tonne of clinker produced. Assessing the Polish cement industry, Mokrzycki (2003) derived average energy consumption of Polish factories

at around 4,100MJ per tonne of clinker. On average, Mokrzycki (2003) states that the energy required for the production of one tonne of cement is about 120 kg of coal. Another study carried out in Pakistan suggests that about 85 kg of furnace oil is used to produce a tonne of cement (Kazmi, 1996). Ethiopia's cement factories use imported furnace fuel, probably with similar energy efficiency to that of Pakistan.

The scope of this report is to assess the use of fuel directly injected into the rotary kiln to generate flame and heat of around 1,450°C. This heat activates the decomposition of calcium carbonate and facilitates solid state reactions between aluminium, iron, silicon and calcium oxides to produce a new chemical structure substance called clinker. To achieve these reactions, three types of fuels are commonly used.

3.2 TYPES OF FUELS USED IN CEMENT KILNS

In the context of the cement industry, there are three sources of fuels used in kilns. These are fossil fuels, biomass, and non-renewable wastes.

1. **Fossil Fuels:** Fossil fuels represent the main sources of energy used in cement production. Principal fossil fuels used are coal, petcoke and petroleum-based fuels such as natural gas and heavy furnace fuel.
2. **Biomass:** These materials are, in principle, 'renewable' because they can be re-grown at a rate equal to, or greater than, the rate of harvesting; they are 'carbon-neutral' because plants absorb carbon dioxide as they grow. Biomass waste such as forest products, fuelwood, foliage, shavings, agricultural crops, cotton stokes, rice straw, sugarcane, flower farm waste and wheat straw are widely used as renewable and carbon-neutral fuels. Industrial-scale animal wastes, such as bones, fats, meats and other animal wastes, also fall under the biomass category.
3. **Non-renewable wastes:** These materials are wastes or materials at the end of their service lives. They can be burnt in the cement kiln to recover energy and conserve fossil fuels that would have otherwise been used. Some, such as plastics and rubber wastes, can also cause environmental hazards when dumped in landfills. Rubber tyres, plastics, hydraulic oil, grease and hydrocarbon-based household or industrial wastes can be used as an energy source in cement factory kilns.

The European Cement Association (1998) states that "[w]aste is used in cement manufacturing as an alternative fuel and raw material, thereby providing a significant contribution to waste management. Unlike incinerators, the cement manufacturing process "absorbs" all of the elements present in the burnt waste. In this way, it cuts both its production costs and global greenhouse gas emissions. Today, on average, alternative fuels provide about 17 percent (up to 72 percent in some regions) of thermal energy consumption in European cement plants" (European Cement Association, 1998).

Though there are no clear specifications for determining what would be a good waste fuel, Lafarge Cement, for example, has developed the following specifications to protect the environment and conserve the efficiency of their cement kilns (Mokrzycki *et al*, 2003):

- Calorific value – over 14.0 MJ/kg (weekly average)
- Chlorine content – less than 0.2 percent
- Sulphur content – less than 2.5 percent
- Polychlorinated Biphenyls (PCB) content – less than 50ppm
- Heavy-metal content – less than 2,500 ppm, out of which:
 - Mercury (Hg) – less than 10ppm, and
 - Total cadmium (Cd) and thallium (Tl) less than 100ppm

Most hydrocarbon-based materials are safe to burn in the kiln to provide energy as long as they meet the above guidelines. Results in Table 4 give a rough range of calorific values for different cement fuels materials.

Table 4: Calorific Values of Different Fuels (Source: Hansen, 1990)

	Low Heat Value (LHV)	High Heat Value (HHV)
	MJ/kg	MJ/kg
Coal	27.8	29
Coal Fines	20.4	21.5
Petroleum Coke	29.7	32.8
Liquid Hazardous Waste-Derived Fuel	22.6	25.8
Waste Tyre	31.5	33.0
Wood	19.7	20.7
Hog Fuel Sawdust	19.7	21.2
Municipal Waste	13.2	15.1

As a result of these calorific value differences, the fuels cannot be replaced by each other at a one-to-one ratio. An adjustment has to be made to compensate for the loss of calorific value. For example, an approximate 1:1.4 coal-to-wood ratio is needed to replace coal with wood to achieve similar heat energy in the kiln.

Though the scope of this chapter is principally interested in the use of biomass, it discusses non-renewable waste materials as a source of fuels in the cement industry for two reasons:

First, finding a sustainable supply of biomass with uniform calorific value could be challenging from a supply as well as a logistical perspective. This may discourage cement factories from investing in modifications of their systems to burn biomass fuels only.

Second, the cost of biomass could be higher and there may not be clear cost benefits. Alternative waste fuels are often free, except the cost of collection, transportation and processing of these materials. In some cases, waste may even be 'negative cost', where waste producers pay cement factories to take away their wastes.

3.3 REAL-LIFE EXAMPLES OF BIOMASS USE IN CEMENT KILNS

Burning biomass in cement kilns is occurring more often due to volatile energy prices and environmental benefits. The following are a few examples reported in various publications.

- **Kenya:** A cement firm operating in Kenya and Uganda claims to have cut its "annual carbon dioxide emission by reducing its use of fossil fuels in cement making by 20 percent. The company, which is partly owned by Lafarge Cement, plans to reduce its use of coal by using wood from its own plantations as well as coffee, rice and cashew nut husks. It is targeting a reduction of 132,000 tonnes of CO₂ per annum by 2010." (Reuters, March 11, 2008; Lafarge, 2007).
- **Uganda:** Uganda's Hima cement factory burns coffee husks as a CDM project. This project is expected to save the factory about \$3.1 million in foreign exchange per annum (Cement World, 21 May, 2008).
- **Malaysia:** Investigations performed to evaluate the feasibility of using biomass fuels as a substitute for fossil fuels in Malaysia's cement industry have reached the following conclusions (Evald and Majidi, 2004):
 - The economic feasibility of using biomass in the cement industry is very good, with a 263 percent financial internal rate of return (FIRR)
 - The cement sector is an obvious choice for the use of solid biomass because of the ease of replacement of coal.
 - For the cement industry, the combination of a very large volume of fuel substitution involving a relatively small investment cost allows for significant savings from the use of alternative fuels.
- **Germany:** Heidelberg Cement claims to have increased the use of alternative fuels up to 78 percent in one of its plants and 66 percent in another. It uses tyres, plastics, paper residues, animal meal, grease and sewage sludge to replace fossil fuels. It states that the company had to invest EURO 8 million in one plant and another EURO 4 million on storage equipment, homogenization and dosing installations for flexible use of alternative fuels (Hridelberg Cement, 2009a).
- **Indonesia:** Heidelberg Cement's Indonesian subsidiary was approved as the first CDM project in Indonesia in 2005. The company claims to have increased the use of alternative fuels, in particular rice husks and residues from palm oil production, replacing coal (Hridelberg Cement, 2009b).

- **Poland:** Six cement plants in Poland currently use alternative fuels. Lafarge Poland Ltd. has been using combustible fractions of municipal wastes, liquid crude-oil derived wastes, car tyres, waste products derived from paint and varnish production, expired medicines from the pharmaceutical industry, bone meal provided from meat processing plants, coke from the chemical industry and emulsified oil from a refinery (Mokrzychi *et al*, 2003).
- **India:** Cement companies in India are using non-fossil fuels including agricultural wastes, sewage, domestic refuse and used tyres, as well as a wide range of waste solvents and other organic liquids (Bernstein and Roy, 2007). The Indian Cement firm ACC is using cow dung, old shampoo, soap, plant sludge and municipal waste as alternatives to fossil fuels (Cement World, 2008).
- **USA:** In the United States, approximately 5 percent of fuel used in the cement industry comes from renewable and non-renewable waste fuels such as wood, tyres and other non-hazardous and hazardous materials. Various sources suggest the availability of millions of tonnes of wood that could be used in cement factories to reduce greenhouse gas emissions and minimise forest fires (Mackes and Lightburn, 2003).
- **UK:** Cemex cement factory in Rugby uses alternative fuels such as tyres and 'climafuel', which is derived from household and commercial wastes. The 'climafuel' can contain at least 50 percent biomass, displacing nearly 180,000 tonnes of fossil fuel CO₂ (Cemex, 2009; Cement News, January 2009). The Lafarge plant at Hope uses bone meal (MBM) which is expected to reduce 30,000 tonnes of CO₂ emissions per year (Cement World, October 2008).
- **Austria:** Austria's cement factories were amongst the earliest to start burning tyres (since the 1980s), and have been burning solid waste such as plastics, paper, textile and composite materials since 1993. All nine cement plants in Austria use solid waste to various degrees (European Cement Association, 2009). One of the factories, Wietersdorfer & Peggauer cement plant, claims to have used alternative fuels substituting up to 70 percent of fossil fuels (Zieri, 2007).
- **Tunisia:** A feasibility study carried out to study the use of municipal solid waste (MSW) as a replacement for natural gas in the cement industry was found to be unattractive economically due to the high cost involved in collection and sorting of the MSW and government subsidies on natural gas imports (Lechtenberg, 2008).
- **Canada:** St. Mary Cement in Ontario, Canada, wants to replace 13 percent of its fuel consumption with wastes such as paper sludge left over from recycling and plastic films. A factory in British Columbia uses renewable synthesis gas products from its gasifier, enabling it to replace 6 percent of its fossil fuel consumption (Dufton, 2001)

- **Portugal:** Cement producer Cimpor Cimentos de Portugal is using hazardous hydrocarbon waste in its plant in Souselas, Central Portugal (Cement World, 2008).

The list of cement factories using biomass and waste fuels is longer, but the above diverse examples are sufficient to strengthen the argument that:

1. Biomass and alternative fuels can be used in the cement industry.
2. Biomass, as well as non-renewable waste fuels, can be an economical alternative to fossil fuels.
3. There is well-established materials preparation, feeding and burning technology that can be purchased by cement factories to adopt a co-firing technology.

It is clear that using biomass in the cement industry is possible and achievable. In the following section some of the benefits are discussed.

4. BENEFITS OF USING BIOMASS AND ALTERNATIVE FUELS

The use of renewable biomass can generate environmental and economic benefits.

4.1 ENVIRONMENTAL

Biomass is a renewable energy resource that can be replaced by growing trees, crops or other vegetation to maintain the level of sequestered carbon in the environment. In addition to capturing carbon dioxide, planting vegetation protects land fertility, prevents solid erosion, reduces sedimentation at dams and water reservoirs, provides ecosystems for wildlife and insects, and, of course, produces wood for high-value timber use as well as biomass.

4.1.1 HOW BURNING BIOMASS HELPS THE ENVIRONMENT

Plants absorb carbon dioxide during photosynthesis. This cycle continues as long as trees are planted to absorb carbon dioxide, to 'cancel out' the carbon dioxide released from combustion of the cultivated biomass. That is why sustainable biomass is considered to be carbon-neutral, with no net increase of carbon dioxide into the atmosphere.

4.2 BENEFITS OF USING ALTERNATIVE WASTE FUELS

The use of waste as alternative fuels in the cement industry has numerous environmental benefits, such as:

- Alternative fuels reduce the use of fossil fuels.

- Contributes towards lowering emissions of greenhouse gases from materials that would otherwise have to be incinerated (with corresponding emissions) or left in the landfill to decompose (and generate methane).
- Maximises the recovery of energy from waste. All the energy is used directly in the kiln for clinker production.
- Maximises the recovery of the non-combustible part of the waste and eliminates the need for disposal of slag or ash, as the inorganic part is incorporated into the cement.
- Improves waste management and public health. High temperatures in the kilns, long residence times and the ability to absorb inorganic residue/ash allow the complete destruction of combustible hazardous waste while recovering the energy they contain in an environmentally sound manner (Hansen, 1990; Van Loo, 2006). For these reasons, the cement industry is recognised by some European governments as an essential part of their waste management policy (European Cement Association, 1998).
- The only viable means of safe, permanent disposal of this combustible waste is by thermal treatment. Cement kilns are not only ideally suited for the safe disposal of this material, but they also can recover the energy to reduce use of fossil fuel.

4.3 ECONOMIC BENEFITS OF USING BIOMASS AND ALTERNATIVE WASTE FUELS

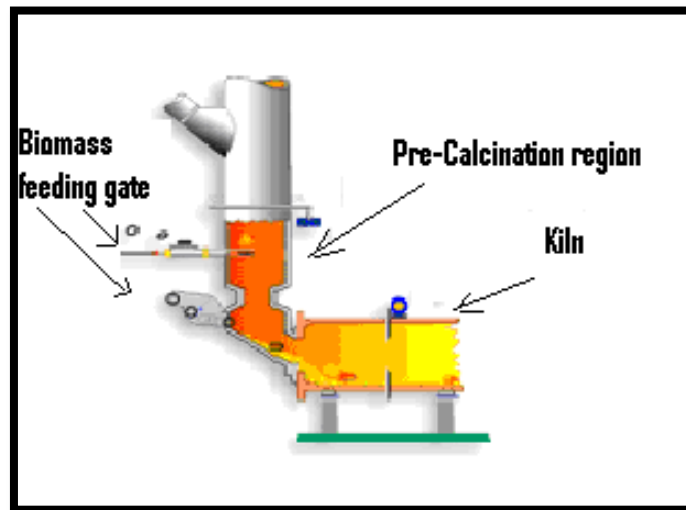
- Between 30-40 percent of the total cost of cement production is accounted for by energy needs. This means a significant reduction in cost can be achieved by using renewable and waste fuels. For example, the study carried out in Malaysia estimates that a 263 percent FIRR can be achieved (Evald and Majidi 2004). Hence, burning biomass and waste as a source of energy could save significant costs.
- Burning biomass and waste can save foreign currency by replacing imported fuels.
- Provides energy security for land-locked countries such as Ethiopia and hedges against volatile global energy markets.

5. TECHNOLOGY

Biomass burning in cement kilns is a well-established technology, which can be purchased or custom-made in developing countries. Existing feeding systems of alternative fuels into kilns are robust and it is possible to feed in biomass ranging from small pellets to full-sized tyres. For ease of handling and achieving uniform calorific input into the kiln, it is important to reduce biomass materials to

manageable sizes. For example, solid woody biomass needs to be chipped into small sizes, pre-dried, and unwanted materials such as stone and metal bits removed (Nicholls *et al*, 2008).

Figure 5: Rubber Tyre Feeding System through Bottom of Pre-Calcination Region (Derksen, 2009)

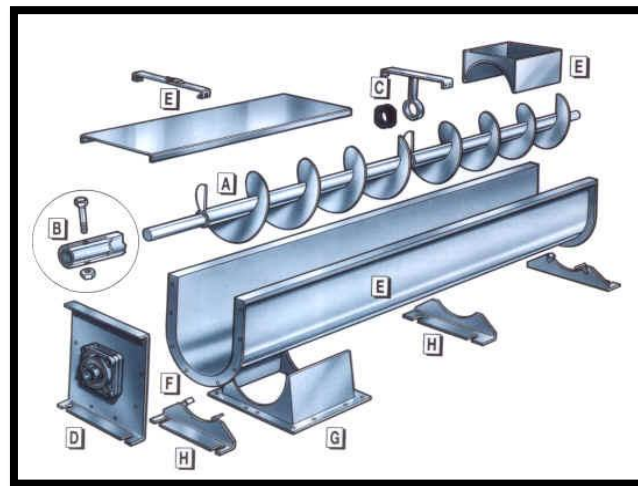
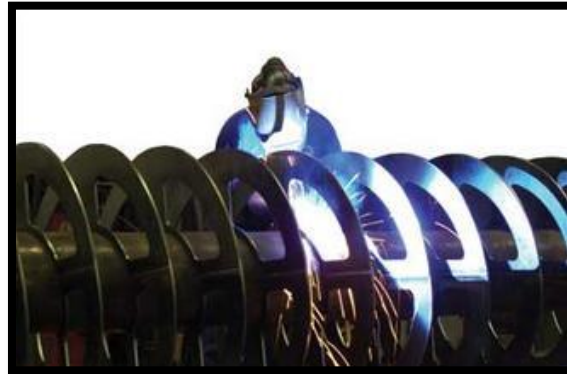


Alternative and biomass materials can be fed in 3 principal ways:

1. As shown in Figure 5, large-size biomass and alternative waste fuels such as tyres can be fed into the kiln in specially-made gates at the bottom of the pre-calcining region.
2. It is possible to grind wood along with cement raw materials to feed as pulverised fuel. However, this process may cause two potential problems (Mackes and Lightburn, 2003):
 - Due to the low ignition temperature of wood, fire may start during the milling process unless special precautions are put in place.
 - It may also affect the efficiency of the mill if the moisture content of the wood is high. Though it may make it easier to feed into the kiln, grinding the biomass adds to costs.
3. Companies that use coal as a main source of energy can blend biomass or alternative materials with coal to feed it into the kiln using a coal-feeding system.

Of the three methods described, feeding through specially-made gates at the pre-calcination region is the safest choice. There are already rotary valves or screw feeders on the market that can be easily installed. The screw feeder has certain advantages over the rotary valve as coarse materials can easily be pushed into the pre-calcining region and the feed rate of the biomass can be regulated by the speed of the screw. Figures 6a and 6b shows examples of large and small screw feeders.

Figure 6: Example of Screw Conveyor to Feed the Whole Tyre (Skidmore, 2008)



Conveyer belts are used to transport biomass materials from storage to feeding hoppers. From the hoppers, a screw conveyor feeds the biomass into the pre-calcination region.

5.1 POTENTIAL BARRIERS

Burning alternative fuels is beneficial to cement companies as well as the environment. But there are barriers to successful utilisation of biomass in the cement industry:

- **Supply:** obtaining a constant and sufficient amount of biomass.
- **Consistency:** the variability in calorific value of biomass may affect the efficiency and output of kiln production.
- **Harvesting:** although extensive biomass resources are available in many countries, often such biomass is spatially dispersed and difficult to aggregate together.

- **Cost:** the capital costs for the preparation and densification of biomass at harvesting sites, as well as modifications of the cement factory, may not justify biomass use.
- **Accessibility:** infrastructure barriers, roads, and transportation.
- **Skill barriers.** Mulugeta (2008) states that despite wood-based fuels being used by more than 90 percent of the population in Ethiopia, there are no biomass research centres in the country that study sustainable biomass development, help to upgrade skills, or that can replenish stocks.
- **Scepticism:** Management and decision-makers may regard burning household waste in modern factories with some degree of scepticism. Hence, champions are needed to overcome this resistance to change.
- **Unwanted materials:** Biomass often contains unwanted materials, such as metal wastes that may damage machines and that need to be removed using metal detectors. The European Cement Association (2009a) also classify nuclear waste, infectious medical waste, entire batteries, and untreated mixed municipality waste as unsuitable for the cement industry and public health.

5.2 ADVERSE EFFECTS ON THE ENVIRONMENT

- **Deforestation:** Industrial-scale usage of biomass may add to already-present stresses on biomass resources, thereby inadvertently encouraging deforestation (Mangoyana, 2009).
- **Hazardous substance release:** In many developing countries, there may not be stringent regulations, or enforcement of regulations, regarding air quality. This may invite companies to take a less responsible approach to burning chlorine-containing wastes such as PVC pipes and PVC packaging that may lead to formation of toxic dioxins (polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans) or industrial wastes containing toxic metals such as mercury, cadmium or chromium (Court, 2005; WHO, 2007).
- **Health:** In the absence of proper treatment, transportation of household and industrial waste could spread germs and disease.

6. ECONOMIC AND ENVIRONMENTAL JUSTIFICATION FOR USING BIOMASS IN ETHIOPIA

A total of 24 companies have permits to invest in cement production in Ethiopia, out of which 13 have begun installation and construction work (All African News, April

2008). By 2011, the total amount of cement production in Ethiopia is estimated to be 17 million tonnes per annum (Taye, 2008). This is going to increase the competition and price pressure on cement factories, squeezing their profit margins. This volume will enable the country to jump from its current position of 78th in the world ranking of cement producers to one of the top 30, placing it above the UK, Canada and Australia.

This will exert considerable pressure on energy supply in the country. The country will probably have 24 cement factories within a short time, increasing cement production from the current level of approximately 1.6 million tonnes to 17 million tonnes. That means the country will have to import approximately 1.4 million tonnes of furnace fuel. At the current market price of US\$400 per tonne, the country may need to spend billions of dollars on furnace fuel alone. This is simply unaffordable in the context of a total national export value of US\$1.5 billion dollars per year.

6.1 STRATEGIES AND BENEFITS IN ETHIOPIA

1. **Farm Wastes:** Coffee waste, cotton, oil processing, chat, sugarcane, flower farms and processing plants can be used as seasonal sources of biomass.
2. **Commercial Plantations:** Cement factories can start commercial plantations of trees on their own lands. The factories' land could be used to plant trees at the commercial level to harvest for cement production. According to Ethiopian investment law, land for tree plantation is free and no lease fee is paid on it.
3. **High-value products:** In addition to biomass fuel, high-value timber can be sold to maximise the return on investment.
4. **Public Health:** The capital city, Addis Ababa, has no proper waste management system. Household as well as industrial waste is dumped on open land, causing environmental problems and health risks. Heavy pollution of Koka Lake is a result of waste influx from tanneries, flower farms, industrial facilities and household waste (Aljazeera, February 21, 2009). Having the capability to burn alternative waste could encourage municipalities to invest in waste-processing plants and industries to collect and supply hydrocarbon-based wastes to the cement industry. This would contribute to public health, reduce methane emissions and save energy costs.
5. **Hazard management:** Liquid hazardous wastes that are often generated from industrial hydraulics and automotive lubricant can be blended with furnace oil to be burnt in the kiln, preventing the pollution of drinking water and poisoning of aquatic life (Hansen, 1990).
6. **Financial incentives:** As international concern over global warming and greenhouse gases arise, government and international organisations may provide financial support for the utilisation of biomass, reducing the burden

on the industry. Biomass-switching in the cement industry also has a rich pedigree in the Clean Development Mechanism (CDM).

7. CONCLUSIONS

The use of biomass and waste fuels is a growing area based on sound economic and environmental benefits. Biomass fuel-switching is possible, achievable and beneficial to the environment and companies that are willing to embrace it. Once implemented, companies can also benefit from the generation of carbon credits through the Clean Development Mechanism. Countries such as Ethiopia could save foreign currency, create jobs and start a sustainable biomass industry. This would help to reduce deforestation and soil erosion, while simultaneously offering social benefits to rural communities.

8. SUMMARY

With the growing realisation of the impact of fossil fuels on global warming, there is a renewed interest in the utilisation of biomass as a renewable and carbon-neutral energy source. This chapter reviews the available literature with regard to the use of biomass in clinker production in the cement industry, which is one of the largest sources of greenhouse gases. The chapter reports experiences of different countries that are using biomass and non-renewable waste fuels in cement production plants. The technology of preparation, feeding, and burning of biomass in cement kilns is widely available and could be purchased to implement a co-firing of biomass along with fossil fuels.

Taking Ethiopia as an example, the chapter makes recommendations for formulating a strategy for integrated biomass technology to achieve not only economic benefits but also to deliver long-term energy security and sustainable development. Published data confirms that this investment is economically justifiable and environmentally beneficial.

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