



## THE USE OF ALTERNATIVE FUEL IN CEMENT INDUSTRY IN SUDAN

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Received 20<sup>th</sup> September 2025; Accepted 24<sup>th</sup> October 2025; Published online 28<sup>th</sup> November 2025

### Abstract

**Purpose:** This present study was designed to investigate the feasibility of replacing fossil fuels used in cement industry with alternative low emission ones. **Methodology:** The area of the study addressed five major cement factories that existed in White Nile state. Various biomass types that included both agricultures, scrap tires and plastic bags were analyzed for their calorific value, moisture and ash contents, as well as volatile matter. **Findings:** The results showed that plastics (9851kcal/kg) and scrap tires (8044kcal/kg) offer high calorific values then tree wood (4048 Kcal/kg), making them promising alternative fuel. Groundnut hulls with high silicon content will produce good quality clinker leading to significant cost savings and environmental benefits. Socio-economic aspects showed that driven by economic and environmental incentives, key informants and stakeholders encouraged the use of biomass as alternative fuel. **Contribution and Practical Implications:** This research highlights the potential of using waste as a source of alternative fuel to reduce greenhouse gas emissions and energy costs in cement industry, while also addressing local environmental challenges.

**Keywords:** Cement industry, Waste as alternative fuel, Cost-effectiveness, Environmental benefits.

### INTRODUCTION

In Sudan's River Nile State, cement production has expanded rapidly, making it an important industry for the country's economy. The five major factories in the region produce over 90% of the country's cement. However, the industry's reliance on fossil fuels such as coal and pet coke poses environmental challenges. The cement industry is a significant contributor to global CO<sub>2</sub> emissions, primarily due to the calcination of calcium carbonate and the burning of fossil fuels (Zieri and Ismail 2018 a). It is responsible for 5% of global CO<sub>2</sub> emissions. The cement industry is an energy-intensive industry with energy typically accounting for 30–40% of production costs (Chatziaras *et al.*, 2014). To reduce its carbon footprint and improve cost efficiency, the sector has begun exploring alternative fuels. Agricultural waste, scrap tires and plastics offer a promising solution due to their high calorific values, environmental benefits, and economic potential. Many cement plants globally have integrated alternative fuels, achieving substitution rates of 10–50%. Alternative energy sources, such as biomass, have gained attention due to their lower environmental impact. Biomass, including agricultural residues, animal waste, and invasive species like mesquite, has the potential to substitute a significant portion of the fossil fuel energy used in cement kilns (International Finance Corporation, 2017). Several studies have shown that biomass can reduce both the carbon footprint and operational costs of the cement industry. However, a more in-depth techno-economic analysis is necessary to quantify the benefits and challenges of using these materials in cement production.

### MATERIALS AND METHODS

#### Area of Study

The River Nile State is home to five major cement factories: Berber, Atbara, Elshamal, Alsalam, and Altakamol.

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These factories are responsible for 90% of the country's cement production, with designed production capacities ranging between 2,000 to 5,300 tons per day. The area is rich in agricultural residues and invasive mesquite trees, which are promising sources of biomass fuel.

**Data Collection:** Both primary and secondary data were utilized in this research. Primary data included field visits, laboratory analysis of biomass samples, and key informants and stakeholder interviews. Secondary data was sourced from factory reports and government publications.

**Sample Collection:** Samples of mesquite wood (an invasive species), sesame and wheat straws, groundnut hulls, and cow dung were collected from various locations around the factories: Mesquite wood was collected from areas near the River Nile and agricultural schemes, while agricultural residues were collected from local farms. All samples were prepared by grinding and sieving for calorific analysis. Waste tires and plastics were collected, shredded and analyzed for calorific value, ash content, moisture, and volatile matter. The results were compared with coal and pet coke, the primary fossil fuels used in the cement industry. Cost-benefit analysis was calculated by using 10% substitution plastic tiers to replace coal or pet coke.

**Laboratory Analysis:** The calorific values of the samples were analyzed using a bomb calorimeter. Moisture content, ash content, and volatile matter were determined using ASTM standard methods. The results were compared to those of conventional fossil fuels such as coal and pet coke.

### RESULTS

#### Secondary data

**Factory designing capacity clinker production and CO<sub>2</sub> emissions:** The five 5 factories capacity production (tons/day) is shown in table 3.1.1 The order of production was; Atbara (5300) then Altakamol cement and Berber cement (4800) and (4500) respectively), Elshamal (4200) and least in Alsalam

(2000) ton/day. Total clinker and cement production was comparable with cement production, varied from about 1 to 2, 3 and 4 million tons/year (table 3.1.2). Tons of CaCO<sub>3</sub> used were calculated from clinker production, to release equivalent tons of CO<sub>2</sub> (table 3.1.3). Increased and decreased throughout the years, the quantities were equivalent CO<sub>2</sub> emissions and with increase of CaCO<sub>3</sub> used for clinker production within the range of 2.8 to 0.9 million tons, however, year 2023 showed the lowest peak of less than 1 million tons of CO<sub>2</sub> equivalence.

**Table 3.1.1. Factories designing capacity (ton/day)**

Factory name	Locality	Designing capacity (ton/day)
Atbara cement company LTD	Atbara	5300
Alsalam Cement	Adamar	2000
Berber cement Co. LTD	Berber	4500
Altakamol cement	Berber	4800
Elshamal for cement production	Adamar	4200

Source: General administration of industry and environment – River Nile State

**Table (3.1.2). Clinker and cement productions (ton/year) (2011 - 2023)**

Year	Clinker production	Cement production
2011	2,450,787	2,761,147
2012	3,087,979	2,793,398
2013	3,409,944	3,192,648
2014	3,113,316	3,192,648
2015	-	3,466,938
2016	3,877,485	3,891,828
2017	4,952,301	4,252,243
2018	3,276,029	4,019,491
2019	3,206,460	3,869,405
2020	3,078,599	3,163,341
2021	2,691,530	2,852,190
2022	2,184,971	2,383,698
2023	1,576,734	1,610,826

Source: General administration of industry and environment – River Nile State

**Table 3.1.3. Estimation Carbon dioxide (CO<sub>2</sub>) emissions from calcination of calcium carbonate (CaCO<sub>3</sub>) from cement industry at River Nile State**

Year	CO <sub>2</sub> emissions (Tons/CO <sub>2</sub> e)	CaCO <sub>3</sub> (Tons)
2011	1,419,373.291	4,043,798.55
2012	1,788,403.037	5,095,165.35
2013	1,974,869.067	5,626,407.6
2014	1,802,866.361	5,136,971.4
2015	-	-
2016	2,245,645.437	6,397,850.25
2017	2,868,125.124	8,171,296.65
2018	1,897,312.195	5,405,447.85
2019	1,857,021.309	5,290,659
2020	1,782,970.610	5,079,688.35
2021	1,558,799.599	4,441,024.5
2022	1,265,425.954	3,605,202.15
2023	913,165.496	2,601,611.1

## Laboratory analyses

**Calorific Value and Properties:** Waste tires and plastic bags waste showed much higher calorific values compared to traditional fuels. Waste plastics, with a calorific value of 9851 Kcal/kg, are the most energy-efficient among the tested alternatives, followed by waste tires with 8044 Kcal/kg. These values exceed the energy content of coal, showing potential for significant substitution (Table 3.1). The calorific value of mesquite wood was found to be 4048 Kcal/kg, making it a suitable alternative fuel for coal and pet coke. Agricultural residues, including sesame and wheat straws, had lower calorific values (3000 - 4000 Kcal/kg) but could be used for co-energy combustion. The high silicon content in groundnut hulls would result in good quality clinker production (table 3.2).

**Moisture and Volatile Matter:** Moisture content was very low across all crop residues as well as mesquite wood making them good source for co-energy combustion (below 30%). Volatile matter content was higher in agricultural residues compared to mesquite wood, indicating easy burning during combustion (table 3.2.1).

**Ash Content and Mineral Composition:** The ash content of the biomass was relatively low, particularly in mesquite wood and sesame straw, indicating their minimal residues after combustion. The high level of calcium content in mesquite wood, makes it suitable for cement kilns (table 3.2.2).

**Table 3.1. Comparison of calorific values for traditional and alternative fuels**

Fuel Type	Calorific Value (Kcal/kg)
Coal	6100
Pet Coke	8200
Waste Tires	8044
Plastic Waste	9851

**Table 3.2. Calorific value for the different biomass in the area**

Sample	Calorific value (CV) (Kcal/Kg) Mean ±SD
Mesquite (A)	4063.90 ± 32.50 <sup>c</sup>
Sesame straw	4027.40 ± 73.65 <sup>c</sup>
Wheat straw	3861.30 ± 75.24 <sup>c</sup>
Cow(pure)	3249.90 ± 135.18 <sup>d</sup>
groundnut hulls	3866.10 <sup>d</sup> ± 109.32 <sup>d</sup>
Palm frond	4022.20 ± 64.64 <sup>c</sup>

<sup>abcd</sup>Values within the same column bearing different superscripts vary significantly at (P < 0.01).

**Table (3.2.1) Moisture and volatile matter (%) for alternative fuels under study**

Sample	Moisture (%)	Volatile matter (VOCs)%
Mesquite	4.90 ± 0.56 <sup>a</sup>	10.18 ± 2.155 <sup>c</sup>
Sesame straw	5.45 ± 0.77 <sup>a</sup>	12.66 ± 0.89 <sup>b</sup>
Wheat straw	3.633 ± 2.06 <sup>b</sup>	12.68 ± 0.71 <sup>b</sup>
Cow dung	4.13 ± 1.12 <sup>b</sup>	25.89 ± 0.20 <sup>a</sup>
groundnut hull	4.106 ± 2.48 <sup>b</sup>	15.56 ± 0.39 <sup>b</sup>
Palm frond	6.063 ± 1.37 <sup>a</sup>	15.34 ± 0.79

<sup>ab</sup>Values within the same column bearing different superscripts vary significantly at (P < 0.01).

**Table 3.2.2. Ash and mineral contents for the biomass samples**

Sample	Ash (%)	Si	Al	Fe	Ca	Mg
Mesquite tree	2.19	5.28	1.46	1.15	36.55	4.50
Sesame straw	2.17	11.81	2.63	1.46	48.71	9.37
Wheat straw	1.98	28.08	7.37	3.64	13.70	4.30
Cow	14.02	83.21	0.93	0.18	7.57	0.36
groundnut hulls	3.47	97.30	0.0	0.0	0.2	1.80
Palm frond	3.15	78.8	1.12	1.83	4.87	2.08

## Substitution Potential for fossil fuels

**Scrap tires and plastic:** The following table presents the substitution potential of waste tires and plastics, showing how much of each material is required to replace one ton of coal or pet coke in cement kilns.

**Table 3.3.1: Amount of alternative fuel needed to replace coal and pet coke**

Fuel Type	Fuel to Replace 1 Ton of Coal (tons)	Fuel to Replace 1 Ton of Pet Coke (tons)
Waste Tires	0.76–0.95	1.03–1.27
Plastic Waste	0.65–0.80	0.95–1.20

**Economic Analysis:** The economic analysis evaluates the cost savings of using waste-derived fuels. Given their high calorific value and low acquisition costs (often acquired for free or at minimal cost), waste tires and plastics present significant economic advantages (table 3.3.1.2).

**Table 3.3.1.2: Economic comparison of alternative fuels versus coal and pet coke**

Fuel Type	Acquisition Cost (\$/ton)	Savings vs. Coal (%)
Coal (6100)	100	0
Pet Coke (8200)	200	-100
Scrap tires (8044)	25	75
Plastic waste (9851)	30	70

The use of scrap tires and plastics can reduce fuel costs by 70–75% compared to coal, contributing to substantial savings in cement production. Additionally, the potential to earn carbon credits from lower emissions enhances the overall economic benefit.

**Biomass ranking potential for fossil fuel replacement:** For the different biomass source, the calorific value was calculated, ranking as medium or low and estimated according to the required quantities per day (table 3.3.2). It was shown that the calorific values were nearly the same for mesquite wood, sesame straw and palm fronds (~4000kcal/kg) with medium requirements (~18000Kg). For wheat straw, cow dung and groundnut-hulls the calorific values ranged around 3,000 kcal/kg with medium requirement for wheat straw and groundnut hulls but ranged from medium to low for cow dung which showed the highest requirement (~20000Kg) than both wheat straw and groundnut hulls (19000Kg).

**Table (3.3.2) Calorific value, ranking and quantities required per day**

Sample	Calorific value kcal/kg	Ranking	Quantity / kg/day
Mesquite wood	4048.25	Medium	18526.5
Sesame straw	4027.40	Medium	18622.4
Wheat straw	3861.30	Medium	19423.5
Cow dung	3249.90	Medium- low	23077.6
Groundnut hulls	3866.10	Medium	19399.4
Palm fronds	4022.20	Medium	18646.5

### Economic analysis about saving cost

Cost of 1 ton of fossil fuel (coal) = (126 \$)  
 Calorific value (CV) of coal = 6000 KCal/Kg  
 1Kg of coal cost 0.126 \$

Assume 1ton of alternative fuel cost 30.6 \$ (about quarter of coal cost)

1Kg of alternative fuel cost 0.0306 \$  
 1 kg of clinker needs 720 KCal  
 [1Kg of coal has 6000 KCal]

720 KCal is needed for 1 Kg clinker, then need 0.12 Kg of coal for 1 Kg of clinker :

$720/6000=0.12$  Kg coal/ 1 Kg clinker

0.12 Kg of coal / 1 Kg of clinker \* 0.126 \$ \* 1000 = 15.12 \$ for 1 ton of clinker

CV of alternative fuel = 4000 KCal/Kg

$720/4000 = 0.18$  Kg of alternative fuel / 1 Kg of clinker

0.18 Kg (alternative fuel) \* 0.0306 \$ \* 1000 = 5.508 \$ for 1 ton of clinker

### Substitution rate is 10%

0.12 Kg (coal) / Kg clinker \* 1000 = 120 Kg(coal) / ton clinker

120 Kg (coal) \* 6000 = 720000 KCal / ton clinker

10% = 72000 KCal/ton clinker

$72000/4000 = 18$  Kg(alternative fuel)

18 Kg(alternative fuel) \* 0.0306 \$ = 0.5508 \$

Cost of 10% of coal for 1 ton clinker = 12 Kg \* 0.126 = 1.512 \$

Saving cost = 1.512 \$ - 0.5508 = 0.9612 \$

0.9612 \* 5000 (capacity/ day) = 4806 \$

4806 \$ \* 300 = 1,441,800 \$ / year

**Then annual saving for 10% substitution = 1,441,800 \$**

- (1 dollar is equivalent to 2450 SDG)

In SDG the saving would be 3,532,410 (1,441,800 x 2450)  
 Significant saving could be achieved when using biomass fuel in cement industry

## DISCUSSION

Plastic waste is considered as one of the most available alternative fuel resources in cement industry due to their worldwide production and high calorific value, which ranges from 29 to 40 MJ/kg. Plastic wastes are available as municipal waste as well as industrial waste. The preferable particle size is less than 5 cm, while the accepted particle size for the incineration process is 10 cm, and a shredder is needed when larger parts are offered in the kiln (Zieri and Ismail, 2018 b). In this study the results indicated that waste tires and plastics are viable alternatives to coal and pet coke in the cement industry. Their high calorific value ensures they can meet the energy demands of cement kilns, while their low cost leads to significant savings. Similarly it was found Refuse-derived fuel (RDF) consisted largely of combustible components of such waste, as nonrecyclable plastics, paper cardboard, labels, and other corrugated materials. In Thailand a total of 23 cement kilns were reported under operation, under construction and planning covering a clinker capacity of 38 Mton/y. These plants have a potential to substitute 40% of its own energy demand by RDF (Sciubidlo and Nowak, 2018).

The high calorific value of mesquite wood makes it a good competitive as a fuel in the cement industry. The second advantage is that tree as an invasive species could be better controlled by its application in cement industry. The high silicon content of groundnut hulls, palm fronds and cows' dung will provide a better kiln quality. Similarly, in some cement plants in Brazil, 42% of the fuel used comes from biomass or waste, which reduced emissions of 156,000 tonnes of CO<sub>2</sub> in 2007 (Lafarge, 2008) (Seboka, *et al.*, 2009). Other biomass sources in this study could be used as heat co-generation. In Malaysia, part of the coal used in the cement plants of Rawang and Kanthan has been replaced by biomass (palm kernel shells). It was found to save over 60,000 tons of CO<sub>2</sub> per year and uses by-products from the local production of palm oil which would otherwise be wasted. Key persons showed willingness to adopt biomass as alternative fuels although they were conservative about crop residue availability due to their seasonality. Stakeholders were aware about the environmental, economical and health impacts of the alternative fuels and some were willing to invest in such enterprises.

## Conclusion

It could be concluded substituting fossil fuels with waste can reduce CO<sub>2</sub> emissions by up to 30%. Additionally, diverting waste from landfills helps mitigate environmental pollution. The substitution rate could be increased by at least 30% in the short term, with long-term goals of up to 50% substitution. Policymakers and business men could be incentivized to use of alternative fuels through subsidies or carbon credits, promoting the widespread adoption of waste-derived fuels. Further research on the technical and economic optimization of waste fuel processing and delivery to cement kilns will enhance the feasibility of this alternative.

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