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# POTENTIAL OF REFUSE DERIVED FUEL (RDF) FROM MUNICIPAL SOLID WASTE AS CO-FIRING FUEL IN CEMENT PLANT OF NEPAL

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!

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# List of Figures

# List of Tables

# Contents

# ABBREVIATIONS

| | |
|---|---|
| **RDF** | Refused Derived Fuel |
| **MSW** | Municipal Solid Waste |
| **PPC** | Portland Pozzolant Cement |
| **S0x** | Sulfur Oxides |
| **NOx** | Nitrogen Oxides |
| **TPD** | Tonne per Day |
| **TEPC** | Trade and Export Promotion Center |
| **GHG** | Green House Gases |
| **MT** | Metric Tonne |
| **KMC** | Kathmandu Metropolitan City |
| **NPR** | Nepalese Rupees |
| **ADB** | Asian Development Bank |
| **SWMTSC** | Solid Waste Management and Technical Support Centre |
| **SCM** | Supplementary Cementitious Materials |
| **FY** | Fiscal Year |
| **WCA** | World Coal Association |

# 1 INTRODUCTION

## 1.1 Background

Cement production is a critical industry for infrastructure development worldwide, yet it is also one of the most energy-intensive and polluting industrial activities. Energy is one of the most crucial raw materials in the cement industry, and coal, traditionally relied upon for its heating value, also serves as a significant raw material, particularly in the production of Portland Pozzolana Cement (PPC). In Nepal, the dependence on coal for cement production has notable implications for energy security and the overall economy.The country's coal import is through the Indian border and only one dry port is available.The daily coal demand for cement related industry is 35000 TPD but only 20 percent of coal is supplied into country due to transport issue[1].

The cement industry is one of the most energy-intensive industries in Nepal. Considering the total production capacity of cement industries in Nepal, cement industries make up a significant portion of Nepal's energy demand. The cement industry is one of the potential industries to grow in the future, mainly because of the availability of untapped limestone and increasing developmental activities. At present around 124 cement industries have been registered in the Department of Industry and 55 of those are in operation[1]. It is estimated that the annual gross consumption of cement in Nepal at present is around 2,500,000 MT[2]. The annual increment of demand for cement in Nepal is considered to be around 20 percent[1]. Nepalese industries are mostly dependent on imported fuel from India and South Africa. Any disruption in the supply chain may cause huge loss for Nepalese industries. This complicated energy scenario can be considered under Energy security which is defined based on the availability, accessibility, affordability and acceptability of energy.

In addition to economic concerns, the environmental impact of coal usage is significant, contributing to high greenhouse gas emissions and other pollutants. This scenario underscores the need for alternative energy solutions that can enhance energy security and reduce environmental impacts. Refuse Derived Fuel (RDF) emerges as a promising alternative. RDF is produced from non-recyclable and non-decomposable waste materials, including plastics, paper, and organic waste, through processes such as shredding, screening, and drying [3].

Nepal faces a major challenge with non-decomposable and non-recyclable solid waste, which poses a significant burden on dumping sites. This waste management issue highlights a substantial opportunity for waste-to-energy solutions. The integration of RDF in cement production can address both the waste management problem and the dependency on coal, leveraging the waste's potential to generate energy [4]. Utilizing RDF can help mitigate the environmental impact of cement production by reducing greenhouse gas emissions and reliance on coal, while also providing a sustainable method for waste disposal [5].

## 1.2 Problem Statement

The cement industry's heavy reliance on coal results in significant environmental and economic challenges, including high greenhouse gas emissions and escalating fuel costs. Coal combustion in cement kilns contributes substantially to GHG emissions, exacerbating climate change and air pollution. The volatile global coal market further impacts the economic stability of cement production, increasing operational costs. .The country's coal import is through the Indian border and only one dry port is available. The daily coal demand for cement related industry is 35000 TPD but only 20 percent of coal is supplied into the country due to transport issues.[1].

The municipal solid waste crisis in Kathmandu Valley is concerning, with a staggering daily generation of 1,200 metric tonnes, predominantly disposed of at landfills like Banchare Danda. This overwhelming volume poses environmental and health hazards, necessitating innovative solutions like Refuse Derived Fuel (RDF) to alleviate the strain on landfill capacity and reduce harmful emissions.Co-firing refuse-derived fuel (RDF) with coal offers a potential solution, as RDF can reduce greenhouse gas emissions and mitigate environmental impacts [5].

Despite the potential benefits of RDF, there is a significant gap in the current understanding of its full potential and implications when used as a coal substitute in cement kilns. This gap is particularly pronounced in the context of Nepal, where the cement industry is both a major energy consumer and a critical component of economic development. The lack of comprehensive research on the optimal composition of RDF, its co-firing ratios with coal, and its overall economic and environmental impact underscores the need for detailed investigation.

Addressing this gap through focused research projects is crucial to developing a feasible and sustainable alternative fuel solution for the cement industry. This study will not only help reduce reliance on imported coal but also contribute to more sustainable waste management practices and lower greenhouse gas emissions, aligning with global environmental initiatives. Therefore, there is a compelling need to investigate the integration of RDF in cement production to enhance energy security, economic stability, waste to energy conversion and environmental sustainability in Nepal.

## 1.3 Objectives

### 1.3.1 Main Objectives

The main objective of this study is to determine the technical and financial potential of using RDF derived from MSW for clinker production in cement industry in Nepal.

### 1.3.2 Specific Objectives

1. Determine the potential of producing RDF from MSW of Kathmandu Valley
2. Estimate optimal composition of RDF by using Aspen Plus software.
3. Perform proximate and ultimate analysis of RDF produced using optimal composition.
4. Determine Optimal coal-to-RDF ratio for required calorific value, cement composition and quality.
5. Conduct Economic Analysis of using RDF in cement production.
6. Assess Environmental benefits of using RDF as cofiring fuel.

## 1.4 Limitations

Our study will be conducted on the case study of selected industries. Therefore, deviations in results may occur if the technologies utilized in other industries differ from those observed in the sample industries. Additionally, the composition of Municipal Solid Waste (MSW) and the potential Refuse Derived Fuel (RDF) that can be generated from it will be estimated based on data from the Kathmandu Valley. As a result, alterations in the results can be expected when extrapolating to other urban areas of the country. Furthermore, MSW samples will be collected for a selected time period, and seasonal variations throughout the entire year may not be fully representative in this study.

While RDF has the potential to reduce fuel costs, the initial investment in technology or change in contemporary technology, infrastructure, and emission control measures can be substantial, making its economic feasibility uncertain and dependent on specific circumstances [5]. Furthermore, the availability and consistency of RDF as a fuel source can be limiting factors, as variations in the composition of waste materials used to produce RDF can lead to fluctuations in its calorific value and combustion characteristics, impacting kiln performance and efficiency [3].

# 2 LITERATURE REVIEW

## 2.1 Introduction

The use of refuse-derived fuel (RDF) from municipal solid waste (MSW) as a co-firing fuel in cement plants has gained considerable interest due to its potential to reduce reliance on traditional fossil fuels and address waste management issues. This literature review aims to explore the feasibility and benefits of RDF utilization in cement plants, focusing on the specific context of Nepal. It will cover the status of municipal solid waste in Nepal, the chemistry of cement, the status of coal use and energy security in Nepal, the status of coal use in the cement industry of Nepal, and RDF as a potential replacement.

## 2.2 Status of municipal solid waste in Nepal

Municipal solid waste (MSW) management is a critical aspect of urban development, impacting public health, environmental sustainability, and overall quality of life. Municipal Solid Waste (MSW) more commonly known as trash or garbage consists of everyday items we use and then throw away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. This comes from our homes, schools, hospitals, and businesses[6].

The increasing amount of MSW has become a huge issue in developing countries, like Nepal. In Nepal, rapid urbanization and population growth have intensified the challenges associated with MSW management. Nepal, with its increasing urban population and limited resources, faces significant challenges in managing municipal solid waste effectively. The generation of MSW in Nepal has been increasing at an alarming rate, primarily due to urbanization, population growth, and changing consumption patterns[7]. Despite this increase, the infrastructure and institutional capacity for waste collection, transportation, treatment, and disposal remain inadequate[7]. The reliable estimates of MSW generation are vital for effective waste management planning and help taking better financial, regulatory and institutional decisions. In addition, the solid waste should be characterized for source, generation rates, type of wastes produced and their composition.

The study found that about 30% of surveyed households in the municipalities practice segregation of waste at source; which means that waste generated from about 70% of households in municipalities goes to the stream for collection and disposal by the municipalities in the form of mixed waste[8]. Kathmandu Metropolitan City (KMC) has been facing an increasing problem over the last two decades. Population growth and urbanization has been putting greater stress on the city's solid waste management system. The city has already exhausted one sanitary landfill site and is currently disposing its solid waste at a second sanitary landfill site. Recycling activities are very limited and informal which puts further stress on the landfill site. The practice of sanitary waste management at the household level also seems to be missing[9]. The KMC's solid waste management system is largely ineffective and unsustainable[9].

One of the primary challenges in MSW management in Nepal is the lack of proper waste segregation at the source. Studies by [10] have shown The considerable portion of MSW in Nepal is organic waste, which, if segregated and managed properly, could be utilized for composting or biogas production[10]. However, the absence of effective segregation practices exacerbates the burden on landfill sites and hampers efforts towards resource recovery and recycling.

Furthermore, the inadequate infrastructure for waste collection and transportation aggravates the problem of indiscriminate dumping and open burning of waste, leading to environmental pollution and health hazards. The situation is particularly dire in informal settlements and peri-urban areas, where access to waste collection services is limited.

The studies suggest that per capita generation of solid waste of Nepal ranges from 0.3 kg/-day to 1.0 kg/day[8]. The total amount of solid waste generated in Nepal is estimated to be 700,000 tons per year[11]. The study of MSW generation at 60 new municipalities carried in 2016 by Solid waste management technical support center(SWMTSC) with a total sample size of 3330 households is 120 gm/capita/day.The maximum waste generated in Nepal is in the capital city itself. Kathmandu municipality generates about 566 tons of waste each day. This figure is more than 3.5 times the waste generated in Pokhara which is next in the list with 117 tons a day. Similarly, Lalitpur Sub Metropolitan generates 84 tons of waste per day and is the third largest. In contrast, Dhulikhel and Bhadrapur produce the least waste per day with a figure of under 3 tons each day[12]. An experiment was conducted for waste segregation in 336 households using three-stage cluster sampling methods in four different strata in Kathmandu, Nepal The quantity of waste is 523.8 metric tons a day and per capita waste generation is 0.66 kg capita/kg[13].

## 2.3 Chemistry of Cement

The main raw materials of cement are calcium silicates, aluminates, and ferrites, which are derived from raw materials such as limestone ($CaCO_3$), clay or shale ($SiO_2, Al2O_3, Fe_2O_3$), which provides silica ($SiO_2$), alumina ($Al_2O_3$) and iron oxide ($Fe_2O_3$)[14] [15]. The key chemical reactions that occur during cement production, particularly in the formation of clinker, are central to understanding its properties and performance.

$$\text{Raw Materials}(\mathrm{CaCO_3, SiO_2, Al_2O_3, Fe_2O_3}) \xrightarrow{> 1400\,^{\circ}\mathrm{C}} \text{Clinker Phases}$$

$$\mathrm{C_3S}\,(\text{Alite}) + \mathrm{C_2S}\,(\text{Belite}) + \mathrm{C_3A}\,(\text{Aluminate}) + \mathrm{C_4AF}\,(\text{Ferrite})$$

**Raw Materials and Their Reactions**

The main raw materials used in cement production are:

- **Limestone ($CaCO_3$):** Provides calcium oxide (CaO)
- **Clay or Shale ($SiO_2, Al_2O_3, Fe_2O_3$):** Provides silica ($SiO_2$), alumina ($Al_2O_3$), and iron oxide ($Fe_2O_3$).

The chemical reactions during the clinker production process can be summarized as follows:

1. **Decomposition of Limestone:**

$$\mathrm{CaCO_3} \xrightarrow{\Delta} \mathrm{CaO} + \mathrm{CO_2}$$

Limestone decomposes to form calcium oxide (quicklime) and carbon dioxide when heated above 600°C.

2. **Formation of Clinker Phases:**

   The major clinker phases formed in the kiln at temperatures around 1400-1450°C include:

   Tricalcium Silicate ($C_3S$ or Alite):

   $$3\,\mathrm{CaO} + \mathrm{SiO_2} \longrightarrow 3\,\mathrm{CaO}\cdot\mathrm{SiO_2}(\mathrm{C_2S})$$

   Dicalcium Silicate ($C_2S$ or Belite):

   $$3\,\mathrm{CaO} + \mathrm{SiO_2} \longrightarrow 2\,\mathrm{CaO}\cdot\mathrm{SiO_2}(\mathrm{C_2S})$$

   Tricalcium Aluminate ($C_3A$ or Belite):

   $$3\,\mathrm{CaO} + \mathrm{SiO_2} \longrightarrow 3\,\mathrm{CaO}\cdot\mathrm{AL_2O_3}(\mathrm{C_2A})$$

   Tetracalcium Aluminoferrite ($C_4AF$):

   $$4\,\mathrm{CaO} + \mathrm{Al_2O_3} + \mathrm{Fe_2O_3} \longrightarrow 4\,\mathrm{CaO}\cdot\mathrm{Al_2O_3}\cdot\mathrm{Fe_2O_3}(\mathrm{C_4AF})$$

3. **Hydration Reactions:**

   Once the clinker is ground to a fine powder and mixed with gypsum, it becomes cement. When cement is combined with water, it undergoes hydration reactions, forming the final hardened structure[15]. The primary hydration reactions include:

   (a) **Hydration of Alite ($C_3S$):** Alite hydration produces calcium silicate hydrate (C-S-H), which provides strength, and calcium hydroxide.

   $$2\,\mathrm{C_3S} + 6\,\mathrm{H_2O} \longrightarrow 3\,\mathrm{CaO}\cdot 2\,\mathrm{SiO_2}\cdot 3\,\mathrm{H_2O}(\mathrm{C{-}S{-}H}) + 3\,\mathrm{Ca(OH)_2}$$

   (b) **Hydration of Belite ($C_2S$):** Belite hydration is slower but eventually contributes to long-term strength.

$$2\,C_3S + 4\,H_2O \longrightarrow 3\,CaO\cdot 2\,SiO_2\cdot 3\,H_2O(C{-}S{-}H) + Ca(OH)_2$$

(c) **Hydration of Tricalcium Aluminate ($C_3A$):** The hydration of $C_3A$ can lead to the formation of various hydrated aluminates.

$$C_3A + 6\,H_2O \longrightarrow C_3AH_6$$

(d) **Hydration of Tetracalcium Aluminoferrite ($C_4AF$):** Hydration of $C_4AF$ forms hydrated calcium aluminoferrites, contributing to the initial set and strength.

$$C_4AF + 10\,H_2O \longrightarrow C_4AFH_{10}$$

## 2.4 Impact of Ash Content from RDF Co-firing

Sources and Volume of Ash in RDF: RDF, a processed fuel derived from municipal solid waste (MSW), offers environmental and economic benefits in cement manufacturing[16][17]. However, its high ash content, ranging from 20-50% compared to coal's 5-30%, necessitates careful management. The heterogeneous composition of MSW, including organic materials and non-combustible elements like glass and metals, contributes to this higher ash volume.

### 2.4.1 Challenges of Managing High Ash Content:

- **Kiln Operation:** Excessive ash content can lead to operational issues. Clinker dusting, the escape of fine ash particles, can impact equipment and air quality. Additionally, high ash content can cause clogging in the kiln and reduce thermal efficiency by absorbing heat needed for clinker formation.[18]

- **Cement Quality:** Uncontrolled ash levels can negatively affect cement quality. It introduces oxides like silica, alumina, and iron oxides crucial for clinker phases like alite and belite[19][20]. Grinding clinker with high ash content also requires more energy due to increased hardness.

- **Enviromental Impact:** The composition of ash from RDF can influence emissions of pollutants like $SO_x$ and $NO_x$. Improper ash management can lead to environmental contamination if these pollutants are not adequately controlled.

### 2.4.2 Methods for Mitigating Challenges:

Several strategies can be employed to mitigate the challenges associated with high ash content in RDF:

- **Pre-processing RDF:** Grinding RDF to a finer size improves combustion efficiency and reduces unburnt material contributing to ash content. Separating inert materials like glass and metals from the RDF feedstock can significantly decrease the overall ash volume entering the kiln. Advanced techniques like heavy metal removal from the ash can further minimize potential pollutant emissions.

- **Optimizing Kiln Operation:** Careful blending of RDF with low-ash fuels like coal and adjusting the proportions of RDF and other raw materials in the kiln feed are essential strategies. However, another crucial approach involves:

  - **Limestone and Clay Blending:** The chemical composition of the raw materials fed into the kiln significantly impacts clinker formation and ash behavior. By adjusting the proportions of high-grade or low-grade limestone and clay in the blend, manufacturers can:

    - **Manage Ash Content:** High-grade limestone, with a higher calcium oxide (CaO) content, can dilute the ash from RDF, effectively reducing its overall impact on the system. Conversely, low-grade limestone with more impurities like silica ($SiO_2$) can be used in situations with lower ash content in RDF to maintain the desired chemical balance for clinker formation.

    - **Optimize Clinker Chemistry:** Clays with varying alumina ($Al_2O_3$) content can be used to adjust the clinker mineralogy, potentially compensating for the influence of ash composition on clinker quality.

- **Ash Management Strategies:** Beneficial reuse of ash in construction materials or soil amendments can be explored, depending on its composition. However, proper disposal is crucial for ash that cannot be beneficially reused to prevent environmental contamination.

- **Alternative Cement Formulations:** Utilizing Supplementary Cementitious Materials (SCMs) like fly ash or slag can compensate for potential reductions in clinker quality caused by higher ash content from RDF. Ongoing research into alternative cement formulations and clinker production methods offers promising solutions for effectively utilizing high-ash fuels like RDF in a sustainable manner.

## 2.5 The Impact of Chlorine on Cement Manufacturing

### 2.5.1 Benefits:

- **Faster Setting Time:** In the past, small amounts of calcium chloride ($CaCl_2$) were added to speed up setting time, particularly beneficial for precast concrete applications[21]. Improved Early Strength: Calcium chloride also contributed to a slight increase in early strength development.

- **Improved Early Strength:** Calcium chloride also contributed to a slight increase in early strength development[21].

### 2.5.2 Drawbacks:

- **Steel Corrosion:** Chlorides can penetrate concrete and damage the protective layer around steel reinforcement, leading to rust and reduced structural integrity[22].

- **Weaker Hydration:** High chlorine content can disrupt the cement's hydration process, resulting in weaker hydration products and compromising overall strength and durability[19].

- **Destabilized Clinker Phases:** At high concentrations, chlorides can negatively impact desirable clinker phases like Portlandite, further reducing cement performance[23].

### 2.5.3 Modern Solutions for Minimizing Chlorine:

- **Raw Material Selection:** Careful selection of raw materials with low inherent chlorine levels is a key strategy[24].

- **Chloride-Resistant Cements:** For unavoidable chloride exposure (e.g., coastal structures), specially formulated cements with supplementary cementitious materials (SCMs) can help mitigate their negative effects.

## 2.6 Impact of Heavy Metals in Cement Manufacturing

### 2.6.1 Causes of Heavy Metal Contamination

The presence of heavy metals throughout the cement manufacturing process poses a significant environmental and health challenge. These contaminants can enter the production cycle through various pathways:

- **Raw Materials:** Limestone, clay, and shale, the fundamental building blocks of cement, naturally contain trace amounts of heavy metals [24] [22]. While these levels may be minimal, their cumulative effect throughout the production process can become significant.

- **Alternative Fuels:** The growing use of Refuse Derived Fuel (RDF) as a sustainable alternative fuel source necessitates careful management to minimize the introduction of additional heavy metals. The composition of RDF can vary greatly depending on the waste stream it originates from, and some materials may contain higher concentrations of heavy metals compared to traditional fossil fuels.

- **Additives:** Even certain additives employed in cement production, though used in small quantities, can harbor trace levels of heavy metals. Strict quality control measures are essential to ensure these additives do not contribute significantly to overall heavy metal content.

### 2.6.2 Effects of Heavy Metals

The presence of heavy metals can negatively impact both the production process itself and the surrounding environment:

- **Distrupted Clinker Formation:** Heavy metals can interfere with the formation of crucial clinker minerals like alite ($C_3S$) and belite ($C_2S$) during the high-temperature kiln process [19]. This disruption can lead to the creation of unwanted phases that compromise the final cement's strength and durability. A weaker cement product can have a negative impact on the overall lifespan and safety of concrete structures.

- **Emissions and Environmental Contamination:** Volatile heavy metals like mercury, present in some raw materials and fuels, can volatilize during kiln operations. This volatilization can cause operational issues within the kiln and contribute to increased air emissions [24]. Furthermore, leaching of heavy metals from inadequately managed stockpiles or through improper waste disposal practices can contaminate surrounding soil and water bodies. This contamination poses risks to ecosystems and human health through exposure. Potential health risks associated with heavy metal exposure include respiratory problems, neurological damage, and chronic illnesses like cancer [23] [22].

### 2.6.3 Mitigating Strategies

The cement industry can achieve sustainable production practices by effectively managing heavy metals:

- **Raw Material Selection:** Implementing a rigorous selection process to prioritize raw materials with naturally low heavy metal content is a critical first step. Collaborations with geologists and material scientists can help identify suitable sources with minimal heavy metal content.

- **Advanced Emission Control Technologies:** Utilizing advanced technologies like scrubbers and filters specifically designed to capture heavy metals can significantly reduce emissions during the kiln process. Investing in research and development of even more efficient emission control technologies can further minimize environmental impact.

- **Responsible Management of Alternative Fuels:** Careful selection and processing of alternative fuels like RDF, along with stringent regulations and responsible management practices throughout the entire supply chain, are crucial for minimizing heavy metal introduction into the kiln[25]. This may involve pre-processing RDF to remove materials with high heavy metal content or blending RDF with cleaner fuels to maintain a balanced overall heavy metal input.

- **Alternative Cement Formulations:** Research into alternative cement formulations and clinker production methods that are less susceptible to the negative effects of heavy metals presents a promising opportunity. Utilizing Supplementary Cementitious Materials (SCMs) like fly ash or slag can potentially compensate for potential reductions in clinker quality caused by higher ash content from RDF, while also offering additional environmental benefits.

## 2.7 Energy Security and status of coal use in cement industry of Nepal

As there is the literal meaning of energy security, there are numerous explanations of energy security provided by various organizations and agencies.Energy security for the developing countries refers to enough energy supply to meet all requirements at all times of its citizens at affordable and stable prices [26]. Whereas, for developed nations, energy security refers to resilient energy systems and securing the amount of energy required for people's life, economic and social activities, defense and other purposes for acceptable prices [26]. According to the International Energy Agency, the uninterrupted physical availability of energy at a price which is affordable, while respecting environmental concerns [27]. Energy security is a critical concern for both developed and developing nations, encompassing the accessibility, affordability, reliability, and sustainability of energy sources. In recent decades, the global focus on energy security has intensified due to factors such as geopolitical tensions, environmental concerns, and economic fluctuations.

Nepal, a landlocked country nestled in the Himalayas, faces unique challenges in ensuring energy security. The nation predominantly relies on hydropower for electricity generation, with abundant water resources offering significant potential. However, seasonal variations, inadequate infrastructure, and geopolitical complexities limit the reliability of this energy source. Consequently, Nepal has sought to diversify its energy mix to enhance security and meet growing demand. Despite the fact that the annual energy demand and the annual energy consumption of Nepal is increasing , the dependency on coal is increasing annually. The cement industry plays a vital role in Nepal's economic development, providing essential construction materials for infrastructure projects. Traditionally, the industry has relied on imported coal as a primary fuel source for kiln operations. However, concerns over energy security, environmental sustainability, and cost-effectiveness have prompted a reevaluation of coal usage. In FY 2078/79 (2022), the energy consumption of Nepal was 640 PJ. 9.09% of total energy consumption is obtained from coal [28]. Nepal's clinker

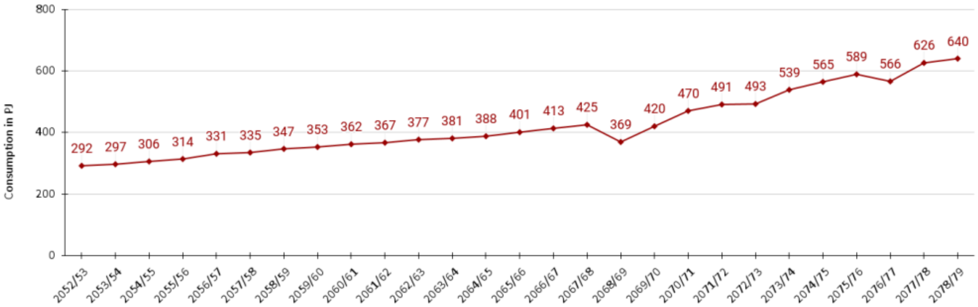
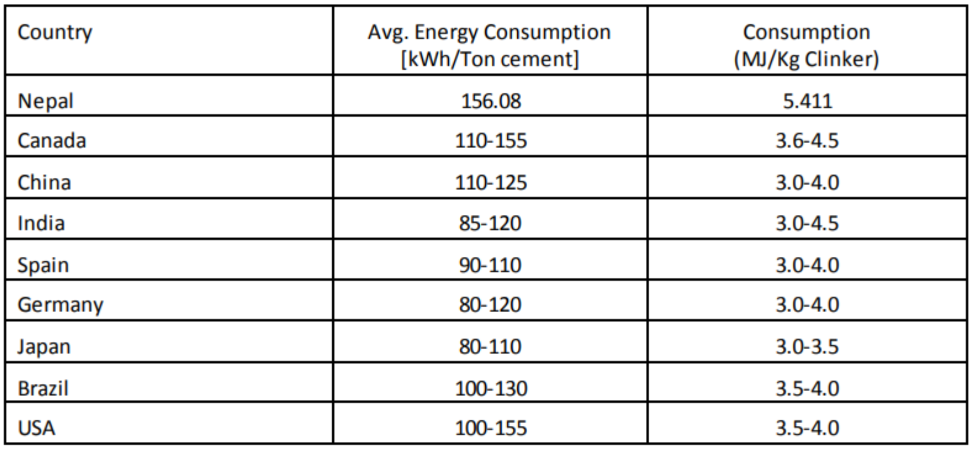


Figure 1: Total Energy Consumption throughout the year
**Source:** Source: (Energy Synopsis Report 2023 (FY 2078/79). Ministry of Energy, Water Resources and Irrigation, Nepal)



| Country | Avg. Energy Consumption [kWh/Ton cement] | Consumption (MJ/Kg Clinker) |
|---|---|---|
| Nepal | 156.08 | 5.411 |
| Canada | 110-155 | 3.6-4.5 |
| China | 110-125 | 3.0-4.0 |
| India | 85-120 | 3.0-4.5 |
| Spain | 90-110 | 3.0-4.0 |
| Germany | 80-120 | 3.0-4.0 |
| Japan | 80-110 | 3.0-3.5 |
| Brazil | 100-130 | 3.5-4.0 |
| USA | 100-155 | 3.5-4.0 |

Figure 2: Comparison of Average energy consumption in cement industry
**Source:** Source: (Shrestha, Ghimire, & Singh, 2016)

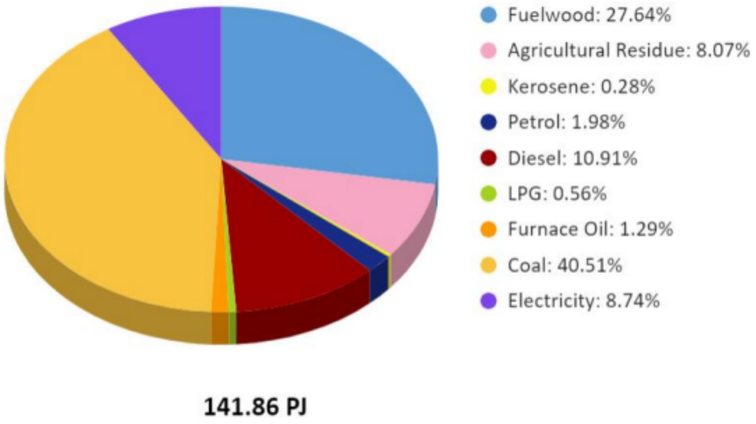
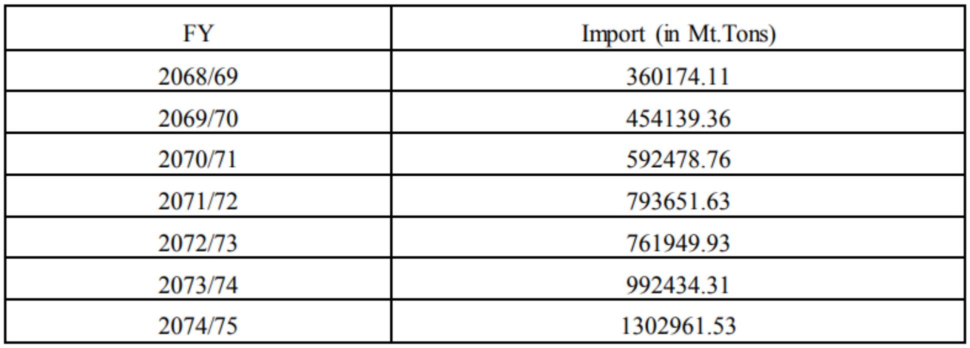


Figure 3: Energy Consumption by fuel Types in industrial sector
**Source:** Source: (Energy Synopsis Report 2023 (FY 2078/79) Ministry of Energy, Water Resources and Irrigation, Nepal.)

manufacturing industry heavily relies on third countries for the sufficient coal required for the production. Coal is imported from South Africa, Australia, Russia and also from India. Around 80 percent of coal is imported from south africa alone and the rest from other countries[1]. According to the World Coal Organization, it takes 200 kg for the production of 1 tonne of cement i.e 20% coal is required to produce onetonne of cement. The country's coal import is through the Indian border and only one dry port is available.The daily coal demand for cement related industry is 35000 TDP but only 20 percent of coal is supplied into country due to transport issue[1].Recent studies highlight the evolving dynamics of coal use in Nepal's cement sector. According to the TEPC, coal import in the country has steadily increased over the past decade, driven by rising production demands and limited domestic alternatives. This trend has raised concerns regarding energy security and environmental impact, prompting calls for sustainable alternatives and policy interventions. While coal remains a necessary evil for the time being, Nepal's cement industry is demonstrably committed to finding more sustainable solutions. By embracing alternative technologies, improving infrastructure, and potentially receiving government support, the industry can pave the way for a greener and more competitive future. The promising alternative to coal is Refuse-Derived Fuel (RDF), which can be used as a cofiring material in cement production. RDF is a type of waste material that can be converted into a fuel source, reducing the reliance on coal and decreasing greenhouse gas emissions. This technology has been successfully implemented in other countries and could be a viable option for Nepal's cement industry [7].



| FY | Import (in Mt.Tons) |
|---|---|
| 2068/69 | 360174.11 |
| 2069/70 | 454139.36 |
| 2070/71 | 592478.76 |
| 2071/72 | 793651.63 |
| 2072/73 | 761949.93 |
| 2073/74 | 992434.31 |
| 2074/75 | 1302961.53 |

Figure 4: Coal import status in Nepal
**Source:** Source: (TEPC, 2019)

## 2.8 RDF

The potential of refuse derived fuel (RDF) as a co-firing fuel in cement plants has garnered significant attention due to its environmental and economic benefits. RDF, produced from non-recyclable waste materials through processes like shredding, screening, and drying, includes combustible components such as plastics, paper, and organic waste, processed into a uniform fuel for energy recovery in industrial processes [3]. Cement production, which involves heating raw materials to form clinker at temperatures around 1400°C, traditionally relies on coal as the primary fuel source [29].

One critical consideration in using RDF in cement kilns is its impact on emissions. Studies have shown that co-firing RDF with coal can reduce greenhouse gas emissions due to the lower carbon content of RDF compared to coal [5] . However, concerns about the release of harmful substances, such as heavy metals and chlorine, must be addressed to ensure compliance with environmental regulations [30]. Effective emission control technologies and pre-treatment processes are essential to mitigate these risks and ensure the environmental sustainability of RDF usage [31].

The quality of clinker produced when using RDF is another significant factor. The presence of different oxides (e.g., CaO, SiO2, Al2O3, Fe2O3) and other elements in RDF can influence the clinker formation process and the final properties of the cement [32]. Maintaining the appropriate chemical composition of the raw mix is crucial for producing high-quality clinker [4]. Studies have demonstrated that RDF can partially replace coal without adversely affecting clinker quality. For example, some research has found that RDF could be used in varying proportions, depending on its composition, to achieve desirable clinker characteristics and reduce reliance on traditional fossil fuels [33].

Economic analyses are essential to evaluate the cost-effectiveness of using RDF in cement production. Conducting a cost-benefit analysis can help determine the potential savings from reduced fuel costs and the economic benefits of waste diversion from landfills [34]. The importance of considering both direct and indirect economic factors, such as savings on waste disposal fees and potential revenue from selling emission credits. The economic viability of RDF usage in cement production is underscored by studies demonstrating significant fuel cost savings and reduced emissions [35] .

Several case studies illustrate the successful implementation of RDF in cement kilns. For instance, a cement plant that integrated RDF into its fuel mix achieved significant fuel cost savings and reduced emissions, providing valuable insights into the practical challenges and solutions associated with RDF co-firing [36] . These case studies underscore the potential for RDF to serve as a sustainable alternative to coal in cement production.

While challenges related to emissions and clinker quality exist, advancements in pre-treatment technologies and emission controls can address these issues [37]. Further research is needed to optimize RDF usage and fully understand its long-term impacts on cement production processes and the environment [38]. The integration of RDF into cement production not only offers environmental benefits but also presents a cost-effective solution for waste management [39].

# 3 METHODOLOGY

## Introduction

This section outlines the project design, specific methodologies to be employed, and detailed steps to execute the project. It also highlights the roles and responsibilities to ensure successful achievement of the project objectives.

## 3.1 Methodology Overview

The methodology is structured into several key phases: waste sampling and segregation, RDF production, parameter analysis and comparison, simulation, industrial testing, and economic analysis. Each phase is meticulously planned to ensure comprehensive data collection and analysis, which will guide the formulation of RDF and its integration into cement production.

### 3.1.1 Specific Overview

1. **Waste Sampling and Segregation**

| **Objectives** | **Method** |
|---|---|
| Determine the quantity of solid waste required for the study. | Conduct a survey at municipal waste dump sites to estimate the volume and types of waste generated. |
| Collect representative samples from different sections of the dump site. | Use stratified random sampling to ensure comprehensive coverage of the dump site, collecting samples from various locations and depths. |
| Separate collected waste into categories such as organic waste, plastics, metals, and paper. | Manual sorting and categorization based on physical characteristics, followed by weighing and recording. |
| Identify and select waste types suitable for RDF production, excluding non-combustible and hazardous materials. | Analyze the segregated waste for calorific value, moisture content, and non-combustibility to finalize selections. |

Table 1: Waste Sampling and Segregation Objectives and Methodology

2. **Manufacture of RDF from MSW derived feedstock**

| **Objectives** | **Method** |
|---|---|
| Analyze and decide the composition of each waste material for RDF formation. | Laboratory testing of each waste type for calorific value, moisture content, oxides, chlorine content, volatile matter, heavy metals, microplastics and inert material proportion. |
| Adjust and maintain moisture content and other relevant parameters before pulverized RDF formation. | Drying and conditioning processes to standardize moisture content across waste batches. |
| Shred waste batches into optimal particle sizes for pulverized formation. | Utilize industrial shredders with variable settings to achieve consistent particle sizes. |

Table 2: Pre-Processing of MSW Objectives and Methodology

3. **Parametric analysis of RDF**

| **Objectives** | **Method** |
|---|---|
| Measure and analyze parameters such as ash content, volatile matter, calorific 8value, moisture content, emissions( CO, NOx and SOx), heavy metals, chlorine content and presence of microplastics in the RDF. 7 | Conduct laboratory tests using standard testing procedures for each parameter. |
| Determine the most viable RDF composition for use in the cement industry. | Compare analyzed parameters of RDF pellets with those of coal to identify suitable compositions. |

Table 3: Parameter Reading and Comparison with Coal Objectives and Methodology

4. **Optimal composition simulation using Aspen Plus and RDF feeding mechanism development for rotary kiln**

| **Objectives** | **Method** |
|---|---|
| Simulate the replacement of coal with RDF in cement kiln operations. | Use simulation software( Aspen plus, Ansys) to model various RDF and coal mixtures, focusing on calorific value, emissions reduction, and clinker quality. |
| Optimize key parameters for RDF usage. | Run multiple simulations to identify the optimal co-firing ratio and parameter settings for efficient kiln operation. |

Table 4: Simulation Objectives and Methodology

5. **Industrial Testing**

| **Objectives** | **Method** |
|---|---|
| Test the simulated RDF compositions in an actual cement plant. | Conduct trials using a combination of RDF and coal, and compare the results with coal-only operations. |
| Compare industrial test results with lab findings. | Measure temperature, emissions, and clinker quality from the industrial tests and analyze the data for consistency and efficiency. |

Table 5: Industrial Testing Objectives and Methodology

6. **Techno Economic Analysis**

| **Objectives** | **Method** |
|---|---|
| Evaluate the economic viability of using RDF. | Calculate costs associated with RDF production, potential savings from reduced coal usage, and additional economic benefits from waste diversion and emission reductions. |
| Assess the overall financial impact of adopting RDF. | Compile and analyze data from cost-benefit analysis to present a comprehensive financial viability report. |

Table 6: Economic Analysis Objectives and Methodology

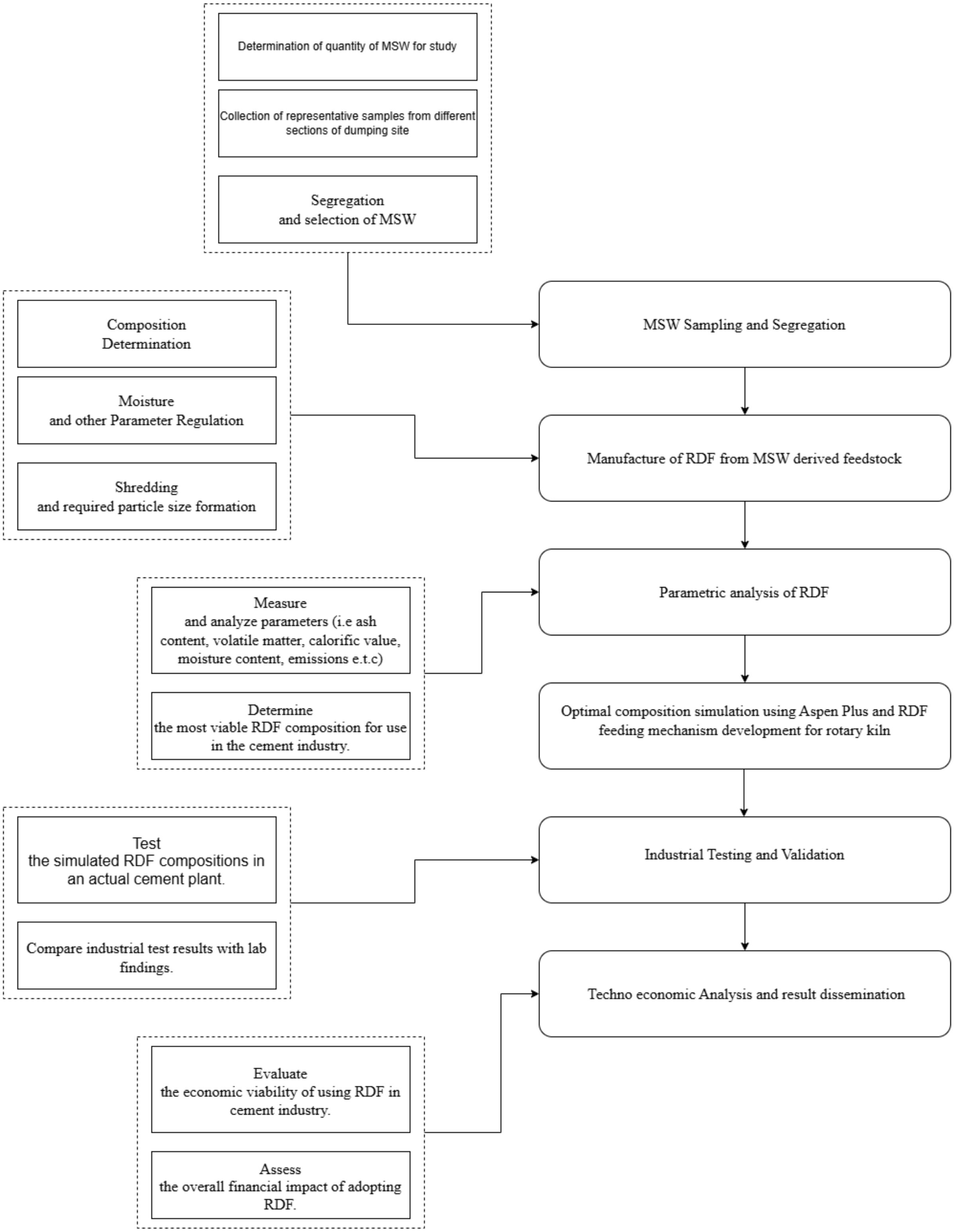


Figure 5: Project Methodology

# 4 STUDY PROCEDURE

## 4.1 Introduction

The research will be carried out in the stages described below, and the estimated budget expenditure for reaching the set goals are also tabulated.

## 4.2 Project Timeline

| SN | Task | Start Date | End Date | Total Days |
|---|---|---|---|---|
| 1 | Literature Review | 28th May | 28th Jan | 245 |
| 2 | Waste Sampling and Segregation & Segregation | 19th June | 19th July | 30 |
| 3 | RDF Generation | 19th July | 10th Sept | 53 |
| 4 | RDF Testing | 10th Sept | 10th Nov | 61 |
| 5 | Test Result Analysis and Validation | 10th Nov | 30th Dec | 50 |
| 6 | Thesis writing and Presentation | 30th Dec | 15th Jan | 16 |

Table 7: Estimated progression table

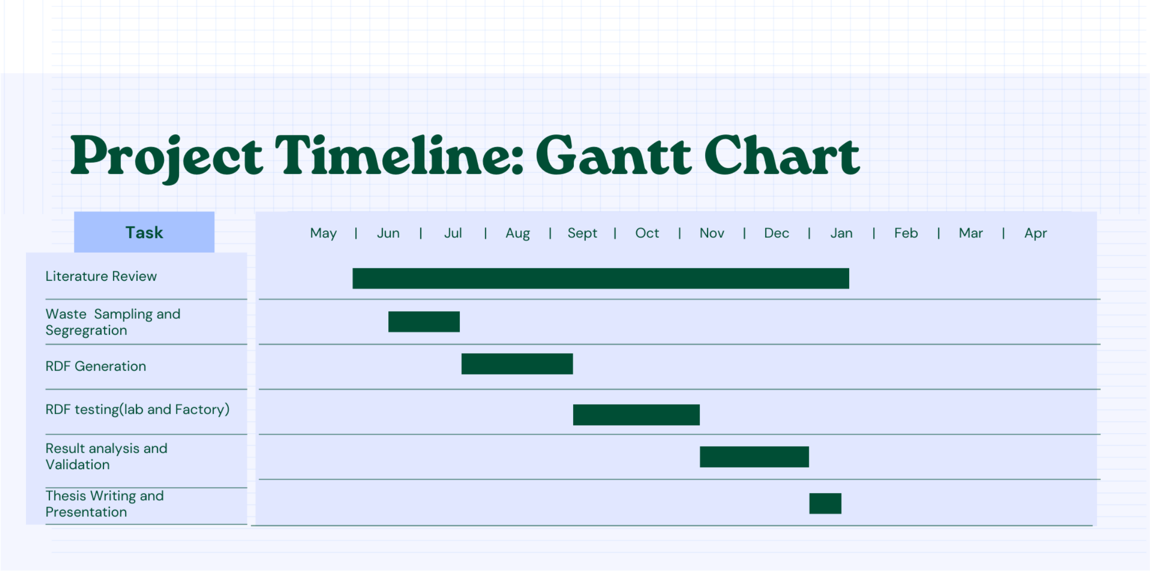


Figure 6: Gantt Diagram of project

## 4.3 Budget estimation

| SN | Expenditure Areas | Amount (NRs.) |
|---|---|---|
| 1 | Equipment Rental | 10,000 |
| 2 | Travel and Accommodation | 20,000 |
| 3 | Waste Segregation | 10,000 |
| 4 | RDF Generation Cost | 30,000 |
| 5 | Industrial Testing Fee | 25,000 |
| 6 | Stationary Items | 15,000 |
|  | Total | 1,10,000 |

Table 8: Cost estimation table

## 4.4 Expected Outcome

1. Estimated RDF production potential from MSW of Kathmandu Valley.
2. Accessed optimal composition of RDF.
3. Parametric results of proximate and ultimate analysis of RDF produced.
4. Optimal coal-to-RDF ratio for required calorific value, cement composition and quality.
5. Economic and Environmental feasibility of using RDF in cement production as a means for co-firing fuel

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