Potential of Refused Derived Fuel (RDF) production in waste dumpsites promoting Circular Economy and Impact on the Quality of Cement using RDF in Cement Production

A **Thesis**

Submitted for the partial fulfilment of the continuous assessment

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I, Somnath Poddar hereby declare that this thesis titled "Potential of Refused Derived Fuel (RDF) production in waste dumpsites promoting Circular Economy and Impact on the Quality of Cement using RDF in Cement Production" is submitted for the partial fulfilment of the continuous assessment of Master of Technology in Environmental Biotechnology to the School of Environmental Studies (SOES), Jadavpur University, Kolkata – 700032 is a record of original work done by me under the guidance of Prof. Sadhan Kumar Ghosh & Dr. Reshmi Das

This thesis is written in my own words, with reference to several published scientific papers which have been adequately cited from the original sources. It is also to be declared that this thesis does not contain any fictional or misreported data or results.

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Abstract

Purpose: Plastic waste is one of the greatest threats to the environment due to its in-destructive nature. The latest Annual Report of CPCB for the year 2018-2019 mentions that the estimated plastic waste generation during the year 2018-19 is 9.5 million tons per annum.

The cement industry is an energy-intensive industry with the rank 2nd in terms of energy consumption among the industries in India. The energy requirement in the cement manufacturing industry is mainly due to pyro processing and this energy requirement is fulfilled mainly by burning fossil flue.

This burning of fossil fuels is the reason for high GHG emissions in cement plants and there is a scarcity of raw materials present in the environment. Refused-derived fuel (RDF) which is substituting the energy & raw material requirements, is not homogeneous in nature and its composition can affect the quality of cement.

So, the main objective of the research work is to analyze the impact of RDF on the hydration qualities of cement. The potential of the waste dumpsite and legacy dumpsite in production RDF and the socio-economic, health, and safety issues of scavengers working in waste management.

Methodology: The Work is based on a literature review, questionnaire survey on scavengers working at waste management facilities, sampling of plastic waste in dumpsites of Kolkata, Murshidabad & Odisha, and Collection and testing of cement samples to identify the impact of RDF on the quality of cement.

Findings: In total 16 dumpsites, from Kolkata, Murshidabad, and Odisha are analyzed and around 10.96% of the mixed waste is found to be non-recyclable plastic waste. A total of 6542 tons of municipal solid waste is dumped every day in the sixteen biggest dumpsites in Kolkata, Murshidabad, and Odisha. According to the sampling result, out of 6542 tons of municipal waste around 650 tons (@10.96%) are non-recyclable plastic waste. So, the potential of these sixteen dumpsites for producing RDF from MSW is around 650 Tons per day.

The survey on informal scavengers involved in waste picking gives us an idea about the socioeconomic and health, safety problems. The gender ratio is found to be 4:1. Almost 70% of those scavengers have an experience of 6 to 15 years in waste management. Almost 40% of total scavengers are illiterate, 60% of scavengers suffer from different injuries and 50% of scavengers have skin-related problems, 60% of scavengers have Musculoskeletal symptoms. Addiction is also a major problem among scavengers as 75% of them have some kind of addiction. The average income of the scavengers is around 7000 Rs per month.

It was observed that the test result for those cement samples is within the limits prescribed by BIS. So, it can be said that there is no such negative impact of using RDF as AFR for co-processing in a cement kiln. Using RDF as a co-fuel in cement will help to tackle the plastic waste management problem to a greater extent.

Introduction

Chapter 1

This chapter gives a brief introduction to plastic waste generation, its management technology (Co-processing), and Refused Derive Fuel (RDF). It also puts light on the health impact on the scavengers at the RDF plant and a brief introduction of the impact of RDF on the quality of clinker.

1.1 Background

Plastic has made a significant contribution in almost every field such as horticulture, transportation, packaging, electrical and electronic products, medical applications, automobiles, furniture, and several daily use products like toothbrushes, debit cards, credit cards, gadgets, manufacturing of pipes and cables, etc. The packaging industry has the largest plastic consumption due to its being secure, clean, lightweight, durable, flexible, resistant to water, etc. Despite all the mentioned properties, the non-biodegradability of plastics has been the root cause of waste management issues. Apart from packaging industries, other major sources of this plastic waste are Municipalities and dumpsites/landfill sites.

Urbanization and economic development are inextricably linked with solid waste generation. Consumption of goods and services increases dramatically with an increase in standards of living and disposable incomes, resulting in a corresponding increase in waste generation. Waste plastic has become the biggest threat to the environment due to its in-destructive nature and potential to remain in the environment for a quite long time and eventually end up in the ocean. In the presence of heat and water, the plastic disintegrated into very small particles known as Microplastic and Nano plastic. These forms of plastic can mix with water & soil and degrade the soil & water qualities. The main sources of these plastics are land-based facilities like Municipalities and Industries. Globally around 300 million tons of plastic are produced yearly, in which around 8 million tons of plastic waste are dumped into the ocean. In India according to the latest report by CPCB for the year 2018-19, the waste plastic generated during 2018-19 is 9.5 million tons per annum which works out to be only 26 000 tons per day. The majority of this generated plastic waste around 87% is mismanaged in India and India has become the 12^{th} largest contributor to marine littering.

The negative impact of plastic waste on land, Marin environment, flora, and fauna is enormous. Most sea animals mistakenly consume plastic getting confused with food and subsequently ingesting them. This result in death due to starvation and suffocation and microplastic can be found in humans due to the intake of sea foods. Most of the substances in plastics are potential carcinogens and endocrine disruptors. People may get infected via ingestion; skin contact and inward with these toxins. Humans are widely exposed to BPA which is used in the fabrication of water bottles, due to leaching into food and water supplies and is responsible for heart disease, male impotence, fertility problems, and other conditions. Phthalates, which are used to impart flexibility and toughness to plastic material, can damage the lungs, kidneys, liver, and reproductive system, and cause neurodevelopment disorders

Plastic waste management is one of the main priorities of govt. now a day. The actions and activities for disposal, management, or reduction of waste from generation to its final disposal are known as plastic waste management. There are several management techniques, some conventional and some new techniques. Conventional techniques are those techniques that are widely used for reducing the quantity of plastic waste.

Incineration, Recycling, and Landfilling are some examples for widely used conventional plastic waste management techniques. Plasma Pyrolysis, Polymer Blended Bitumen Road, Liquid Fuel, and plastic waste Co-processing in cement kilns as an alternate fuel option are some examples of new techniques that are not so popular but have a huge potential for managing huge amount of plastic waste.

Among the energy-intensive industries, the cement industry holds the rank 2nd in terms of energy consumption in India. The energy requirement in the cement manufacturing industry is mainly due to pyro processing and this energy requirement is fulfilled mainly by burning fossil flue. the cement kiln has a huge potential for utilizing NRPW as a source of energy via the co-processing of RDF in the cement kiln.

1.2 Co-processing in cement plant

Co-processing is a procedure in which RDF is prepared from the non-recyclable part of MSW that is to be used as a source of energy in a cement kiln to substitute conventional fuels Coal, Natural gas, Pet coke, etc, and raw materials (WBCSD, 2014). A wide range of waste streams such as agricultural residues, combustible and segregated parts from Municipal Solid Wastes (MSW) based Refuse Derived Fuel (RDF), Industrial hazardous and non-hazardous wastes, Non-Recyclable Plastic Waste, tire wastes can be used as Alternative fuel and Raw material (AFR) in cement kiln.

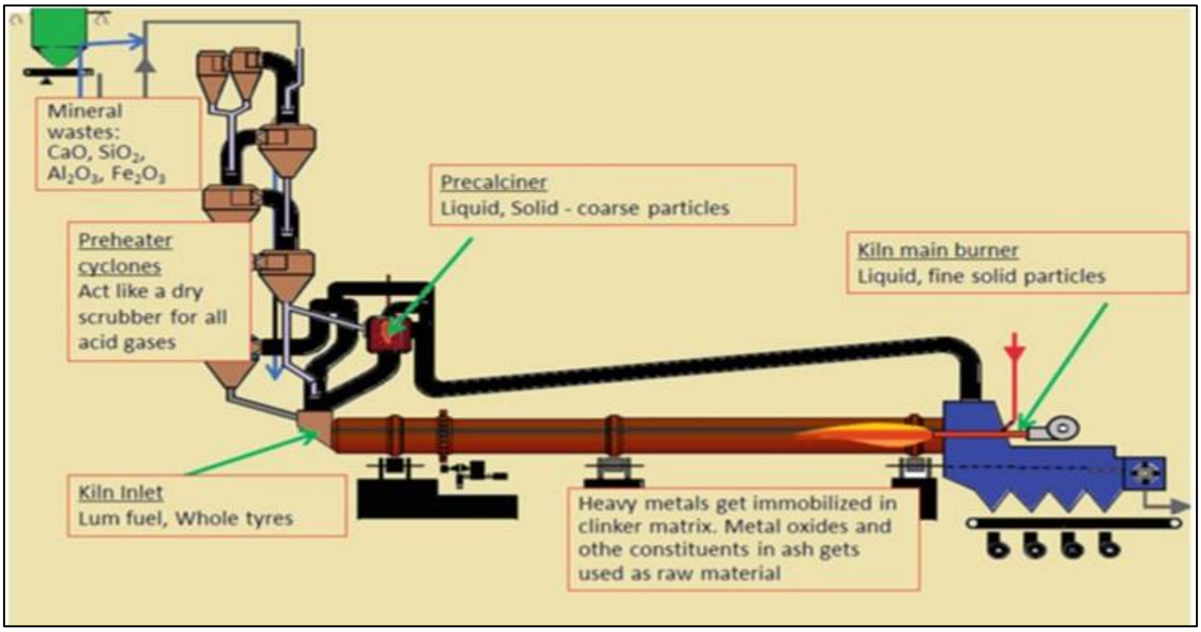


Figure 1: Feed point for different waste streams in a cement kiln

The feed point for the introduction of waste in a cement kiln depends on the characteristics of the waste for co-processing, and their specific feed points as shown in Fig. 01. The different types of waste are mentioned below:

- Granular waste: fed through the kiln inlet. Examples are waste tyres, drums filled with waste, and bags.

- Coarse solid waste: fed through the calciner. Examples are solid chunks and roughly shredded plastic and RDF material.
- Fine solid waste: fed through the main burner. Examples are powdery material and finely shredded plastics, and RDF.
- Liquid wastes: fed through the pre-calciner and main burner [atomization required]. (Ghosh S.K et al., 2022)

Currently, for India, the thermal substitution rate is about 4-5% as compared to >40% in Europe and >70% in Norway. So, India has a huge potential for utilizing waste material as an energy source and raw material in a cement kiln.

The economic & environmental benefits of Co-processing of RDF in a kiln are much greater than other plastic waste management techniques such as Incineration, Pyrolysis, and Gasification.

- Complete destruction of waste streams due to high temperatures (1450-2000 ◦c), alkaline environment, oxygen excess, and long residence time
- The specific temperature range (1450-2000 ◦c) doesn't allow the formation of dioxins and furans.
- The ash component of RDF is fully utilized for the raw material requirement for clinker formation. So, these processes don't leave any residue that needs to be landfilled.
- Here the waste substitutes the fossil fuel resulting reduction in greenhouse gas emissions and all the emissions are within the range of CPCB.
- Preservation of fossil fuels and non-renewable natural resources by recovering the mineral value and energy of the waste materials.

The long residence time and high temperature in the cement kiln about 1450 ◦c makes the cement kiln well suited for utilizing a wide range of waste streams with more efficiency in energy and raw material recovery in an environmentally friendly manner (Saha P.K et al., 2017) The mineral part of the waste is utilized as the raw required for clinker production and the energy required for clinker production is provided by combustible part of the waste. Resulting in 100% utilization of the input waste without any additional residue production.

According to the UNEP Basel Convention, comparing other waste treatment options Co-processing is a cost-efficient, practical, safe, and environmentally preferred option.

1.3 Research project "Ocean Plastic Turned into an Opportunity in Circular Economy- OPTOCE 2" and the Introduction.

The project "Ocean Plastic Turned into an Opportunity in Circular Economy – OPTOCE", conducted and managed by SINTEF, is a regional effort to address the main reason for microplastics in the Ocean, namely inadequate treatment capacity for plastic wastes on land. OPTOCE aims to investigate and document the increase in the treatment capacity for non-Recyclable parts of Plastic Wastes (NRPW) by the involvement of cement manufacturing, resulting reduction of marine littering.

The objective of the OPTOCE project is to increase the capability of the treatment options for NRPW and put a light on the NRPW situation in the country and will identify the possibility to solve waste problems by engagement of local energy-intensive industries. Some main objectives of this project are given below.

- Evaluate current plastic waste problems and management practice in the pilot demonstration area (and country if possible), including possible environmental impacts.
- Evaluate the feasibility/environmental benefits of using the local cement industry to recover energy/co-process NRPW compared to current plastic waste management practice in the pilot demonstration area.
- Estimate t/y of NRPW co-processed and coal saved in pilot sites in 2022 compared to current plastic waste management practice (the year 2019/2020) and provide an estimate of future co-processing potential by scaling up the practice to all cement plants in the country.

Documented the number of cement plants co-processing NRPW in the country by 2022 and provide an estimate of future potential by involving all "feasible" cement plants.

1.3.1 Major activities for the research studies

The study will be conducted in cooperation with the Norwegian research institute SINTEF under the OPTOCE (Ocean Plastic Turned into an Opportunity in Circular Economy) project. The whole project is subdivided into 2 research studies given below.

Research title 1: Identifying and quantifying the major sources of NRPW in India, Evaluating the different recovery and reuse options for treatment of NRPW (Co-processing, Incineration, Pyrolysis, using NRPW in road construction, etc), and conducting an in-depth investigation of co-processing of NRPW/RDF in Indian cement industry

Research title 2: Making a brief qualitative assessment of Co-processing of AFR by the cement industry in India has any negative impacts on scavengers, especially children and women (environmental, economic, social, and health & safety aspects); also assessing success cases of cement plants collaborating with local communities and employing women.

Major activities to be conducted

Research title 1:

1. Extensive literature review to identify the major sources of non-recyclable plastic waste (NRPW) in India

2. Select site(s) and investigate how much of the plastic in the MSW is non-recyclable
3. Make an estimate of the quantity of NRPW generated in India (national estimate) based on investigations in selected sites and then rationally extrapolate the findings.
4. Conduct an in-depth investigation of co-processing of NRPW and Refuse Derived Fuels (RDF) utilization in India,

Research title 2:

1. An extensive literature review on the role and operations of scavengers in (informal) waste management in India.
2. Conduct interviews with scavengers and document how they are currently making their living out of waste and eventually how they perceive any negative impacts of the involvement of the cement industry.

Develop a questionnaire for conducting surveys of selected stakeholders such as rag pickers/ scavengers, associations representing the informal waste sectors, NGOs, and other experts. Such an assessment should cover the environmental, economic, social, and health & safety aspects.

1.4 Introduction to refused derived fuel (RDF)

The definition given the by U.S. Environmental Protection Agency (EPA), "RDF is the product of processing municipal solid waste to separate the combustible and non-combustible portion into a form that can be effectively fired in an existing or new boiler." Non-recyclable but combustible waste material that has a calorific value that can be used to substitute traditional fuels such as coal. Plastic and biodegradable materials can be used as RDF for cement kilns, therefore, achieving zero waste, and more efficient resource recovery from solid waste in the form of clean technology, RDF can be utilized (Grace P. Sapuay,2015).

Effective utilization of the energy and material value in the wastes can be achieved through co-processing, resulting in the conservation of natural resources by decreasing the use of raw materials. Table 1 shows the benefits of RDF used as an alternate fuel in cement industries.

Table 1: The benefits of using RDF as an alternate fuel in cement industries

Indicators	**Benefit**
RDF Specifications	RDF of size less than 50 mm is required in Cement plants. In an oxygen-rich atmosphere of the cement kiln, these particles disintegrate completely within 4-5 seconds.
Feeding of RDF	For the proper feeding of RDF, a separate feeding mechanism is needed.
Impact on Product	There is not much negative impact of RDF on the quality of cement as in a cement kiln there is complete combustion of RDF at very

	high temperatures around 1400°C and a residence time of 4-5 seconds in an oxygen-rich atmosphere. Reduction of use of non-renewable fossil fuels like coal is possible as RDF has a calorific value of around 3000 Kcal.
Environmental Impact	Improper landfilling causes emissions and leachate runoff resulting in pollution of air, water, and soil around it. RDF produced from dumped waste will reduce the amount of waste resulting in a reduction in pollution. RDF also replaces fossil fuels, conserving natural resources.
Residual Disposal	The alkaline raw materials present in the cement kiln neutralize the acidic gases generated in the kiln during the combustion process and are absorbed into the cement clinker. There is no additional waste is generated during the process.

(Source: Guidelines on Usage of Refuse Derived Fuel in Various Industries, MOHUA 2018)

1.5 Health and Economic impact on scavengers in RDF plant

With an increase in population, there is an increase in waste generation resulting the waste management becoming an important global and environmental priority. Accumulation of waste in open-air dumpsites has a negative impact on the health of people who work in the sites apart from its contribution to different environmental hazards. 'Invisible environmentalists' is a term coined by The United Nations Environmental Programme for the waste pickers for their silent contribution to waste management. Collecting recyclables from the dumpsites and selling them, is a way to earn livelihood for the waste pickers. 50% of the recycled plastics are collected by informal waste pickers in the world (UNEP 2013). These actions also help in the reduction of air pollution due to the reduced greenhouse gas emissions and conserve natural resources that contribute to a circular economy. Some non-recyclable but reusable goods, such as wood, C&D waste, and household goods such as furniture are also collected by the waste pickers from landfills.

Recently, academia has shown considerable interest in the circular economy (CE) concept (Ghisellini et al., 2016; Bocken et al., 2016; Geissdoerfer et al., 2017; Babbitt et al., 2018; Kalmykova et al., 2018; Alcayaga et al., 2019). This concept rejects the idea of products & materials ever becoming waste and instead envisions "an economic system that introduces the reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes and replaces 'end-of-life' concept. It operates to accomplish sustainable development at the micro-level (products, companies, consumers), meso level (eco-industrial parks), and macro-level (city, region, nation, and beyond), thus simultaneously creating economic prosperity, social equity, and environmental quality, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers" (Kirchherr et al., 2017).

The waste pickers or scavengers are the base-of-the-pyramid workforces of any typical informal recycling sector (IRS) (Velis, 2017). Waste picking is the least rewarding but the most labour-intensive first step of recyclable recovery from mixed wastes. Waste pickers have to face systematic marginalization despite the environmentally and economically relevance of the work (Aparcana, 2017; Kariuki et al., 2019), (Aparcana, 2017; Asim et al., 2012; Sembiring and Nitivattananon, 2010; Wilson et al., 2006). The work of waste picking is regarded as dirty resulting in social discrimination in society, and there is an uncertainty of daily income & due to exploitation, this income can be less than the nation's minimum salary (Kariuki et al., 2019; Kaseva and Gupta, 1996; Kuria and Muasya, 2010; Wilson et al., 2006).

Waste picking from the different dumpsites and landfill sites or any RDF-producing plant is considered dirty work and due to these unhygienic working conditions, waste pickers are often subjected to different health, economic & social problems. Women and children are one of the major parts of these scavengers working at dumpsites. Most of these waste pickers and scavengers are living in marginalized (slum areas), where there is no water supply, and live in households with no connection to the drainage system. There are households connected to water supply, that have to consume untreated water, while only a few of the scavengers have used filtered water to consume. Psychological or psychiatric problems are common among waste pickers due to smoking and alcohol consumption. It is found that there are more men than women who have addiction-related issues. Waste picking is an accident-prone job and is often caused by metals, glass pieces, and syringes during their work at dumpsite as many of them don't use or don't have hand-gloves, protective boots, and full-sleeved shirts as Personal Protection Equipment. The most referred diseases were: seromuscular problems, episodic diarrhea, arboviruses, hypertension, intestinal worms, bronchitis, and diabetes. Regarding nutrition, huge numbers of waste pickers don't get enough meals per day, and at least one of the meals has to be taken inside the open dump.

The uncertainty in the workplace, along with mental & physical stress and socioeconomic condition, and exposure to different forms of discrimination, are other factors that impact workers' overall well-being and health. Due to informal employment, most of these workers don't have the access to social protection as on average, the earnings are low and risks are high. The significant presence of women in this profession may be explained by their need to survive, poor education and raising children alone are one of the major reasons. As a result, working as a scavenger at a dumpsite or RDF plant with mixed solid waste appears as an alternative earning option for women who faced unemployment or are unfit for the formal job market.

1.6 Impact of using RDF in Co-processing on the quality of clinker and cement.

When utilizing waste as a source for energy & raw material management, and with the increase in the amount of solid recovered fuels (SRF) utilization in the cement industry for heat generation, the co-incineration of SRF has become an important tool in modern waste management. Apart from that, the utilization of quality-assured SRF is state-of-the-art technology in the European cement industry according to the best available techniques (BAT) in the cement, magnesium oxide, and lime manufacturing industries published by the European Commission 2013.

In Co-processing, waste materials are utilized as Alternative Fuels and Raw materials (AFRs). The same importance has to be given to AFRs as the one that is applicable to natural fuels, for example, coal, other fossil fuels, and raw materials. The same technical and scientific considerations have to be implemented for ARFs as implemented for natural raw materials and fuels used in cement manufacturing. With the increase in usage of AFRs in cement kilns, the relevance of these principles becomes more important.

Calcium oxide (CaO), silicon dioxide (SiO2), aluminum oxide (Al2O3), and iron (III) oxide (Fe2O3) are the 4 main chemical components of cement clinker. Apart from raw material clinker production also required large amounts of energy. There is a requirement of 3.0 to 3.8 GJ of thermal energy (under optimal conditions and depending on the technology used) for the production of 1 metric ton of cement clinker in modern rotary kiln plants. These raw materials are mixed in a specific proportion and burnt at 1400 to 1450 °C in a rotary kiln to form a clinker which is then grounded and mixed with 2 to 8% gypsum. This is called ordinary Portland cement (OPC).

Tests on the raw materials, fuels, intermediate products, and final cement products are essential for the quality control of cement. Different kinds of tests are required to be performed depending upon the material. As mentioned above there are 4 different elements that constitute the raw material in the cement manufacturing process, namely Calcium oxide (CaO), silicon dioxide (SiO2), aluminum oxide (Al2O3), and iron (III) oxide (Fe2O3). Table 2 shows different natural and alternative raw materials that substitute these elements utilized in cement manufacturing.

Table 02: Natural raw materials and their substitute Alternative materials in cement manufacture (Source: Ghosh S.K et al., 2022)

Calcium	**Iron**	**Silica**	**Alumina**	**Sulphate**	**Fuel**
Natural Raw materials and Fuels					
•*Limestone* • *Chalk* • *Clay* • *Marble* • *Marl* • *Seashell*	• Iron Ore • Clay • Shale	Clay • Fly ash • Sand • Sandstone • Shale	• Bauxite • Cement rock • Clay • Fly ash • Fuller's earth • Shale	• Natural / Mineral Gypsum	• Coal • Petroleum Oil • Petroleum Gas • Petcoke • Lignite
Alternative Raw materials and Fuels					
• *Alkali Waste* • *Slag* •*Lime sludge*	• Mill Scale • Blast Furnace Flue dust • Ore washing	• Slag • Ore washing • Rice-husk Ash	• Copper slag • Ore washings Slag • Red mud	• FGD Gypsum • Chemical Gypsum	• Agro-waste • RDF • Plastic Waste • Hazardous Waste

• Red mud • Iron Sludge				• Non-hazardous waste • Used Tyres and Rubber waste

In the cement industry, alternative fuels such as solid recovered fuels (SRF) are used to substitute the primary fuels required for the clinker burning process. The quality-assured sub-group of refuse-derived fuel (RDF) is made of mixed municipal waste, non-hazardous solid waste, and commercial waste is known as SRF (ASI, 2011b; Sarc et al., 2014). However, from a technical perspective, “mixed recovery” is a term coined for co-processing of RDF as it is a mixture of energy and material recovery. (Viczek et al., 2020a). As the RDF ash is incorporated into the clinker this process is known as mixed recovery. In RDF ash there are various chemical compounds that are considered to be valuable raw materials for cement production, and their incorporation into a new product, such as the clinker, can be termed recycling at the material level.

There is considerable research on the application of municipal solid waste incinerator (MSWI) ash which substitutes the raw material and also supports the material recovery option for the cement industry. (Clavier et al., 2019; Kikuchi et al., 2008; Lam et al., 2011; Saikia et al., 2007; Sarmiento et al., 2019). Various studies have shown that RDF ashes contain various elemental compositions for cement manufacturing and can be used to substitute for traditional raw materials (Clavier et al., 2020).

It is found after analyses of 80 SRF samples produced from mixed commercial waste, there are approximately 77% of the ash contains the four main chemical components required for the production of cement clinker. (Viczek et al., 2020a) fig 02 shows the percentage of chemical components present in solid recovered fuels (SRF) ash. Wherein the percentage of SiO_2 in ash is 31.50% followed by CaO and AL_2O_3 with 28.50% & 13.20% respectively.

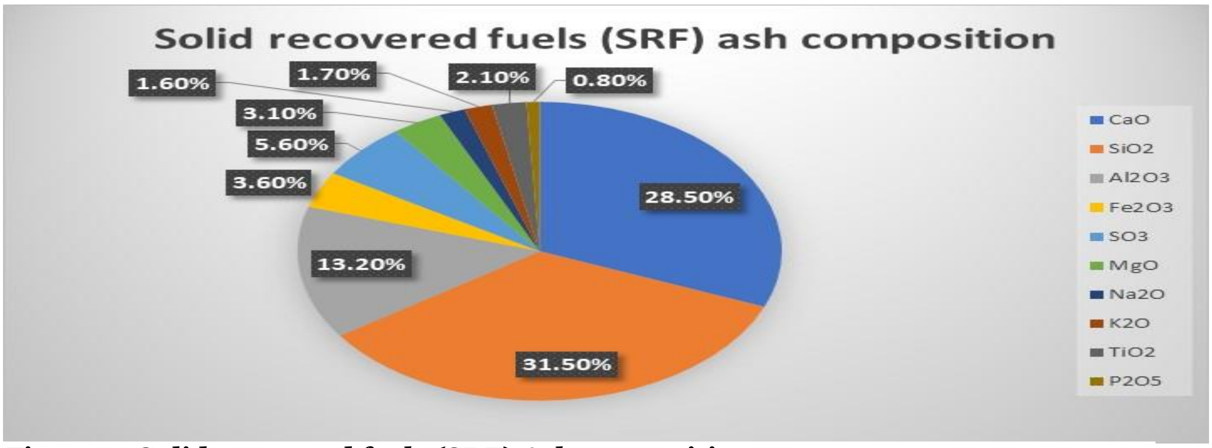


Figure 2: Solid recovered fuels (SRF) Ash composition

Literature review

Plastic Waste and Co-Processing in Cement Kiln

Chapter 2

This chapter is based on national and international literature reviewed and contains:

Global & National plastic waste generation

Global & national scenario of Cement production

Different applications of NRPW

Co-processing & circular economy

2.1 Definition & type of plastic

The material contains an essential ingredient polymer like polyethylene terephthalate (PET), high-density polyethylene (HDPE), vinyl, low-density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS) resins or multi-materials such as acrylonitrile butadiene styrene (ABS), polyphenylene oxide (PPO), polycarbonate (PC) & polybutylene terephthalate (PBT) can be defined as plastic (LCA study of plastic waste product, CPCB, March 2018 & PWM Gazette 2018).

There are different types of plastics according to their chemical composition and use, some of them are recyclable and some of them are non-recyclable. Some of the types are given below in Table 03.

Table 03: Types of plastic, Applications, and Recyclability

Types of plastic	Labelling	Recyclable or not	Applications
Thermoplastics			
High-density polyethylene (HDPE)	2	YES	Gas Pipes, Industrial Wrapping and Film, House Wares, Containers, Toys.
Low-density polyethylene (LDPE)	4	YES	Toys, Coatings, Containers, Cable Insulation, Film, Bags, Pipes
Polyethylene Terephthalate (PET)	1	YES	Synthetic Insulation, Food Packaging, Bottles, Film.
Polyvinyl chloride (PVC)	3	YES	Pipes, Toys, Cable Insulation, Credit Cards, Medical Products, Window Frames, Flooring, Wallpaper, Bottles.
Polypropylene (PP)	5	YES	Battery Cases, Electrical Components, Crates, Car Parts, Film, Battery Cases, Microwave Containers.
Polystyrene (Styrofoam)	6	NO	Thermal Insulation, Tape Cassettes, Disposable Cups, Plates, Electrical Appliances
Others	7	NO	Thermoset plastic, Melamine plates, Helmet
Thermosetting Plastics			
Epoxy resins	7	NO	Car components, Sports equipment, Boats, Adhesives.
Phenolic (phenol-	7	NO	Electrical appliances, Adhesives, Car-parts.

formaldehyde, urea-formaldehyde)			
Polyurethane	7	NO	Furniture foam, Adhesives, appliances, car parts, electrical components, trainer soles.
Furan resins	7	NO	Manufacture sustainable bio-composite construction, cement, adhesives, coatings, and casting/foundry resins.

Source: (LCA study of plastic waste product, CPCB, March 2018)

2.2 Global Plastic Production

Share of different types of plastic into the total plastic introduced into the marker since 1950 is shown below in Fig 03. Wherein Polypropylene has the highest share of 26%, followed by Low-density polyethylene, High-density polyethylene with 25% & 20% share respectively, in total Global plastic production since 1950.

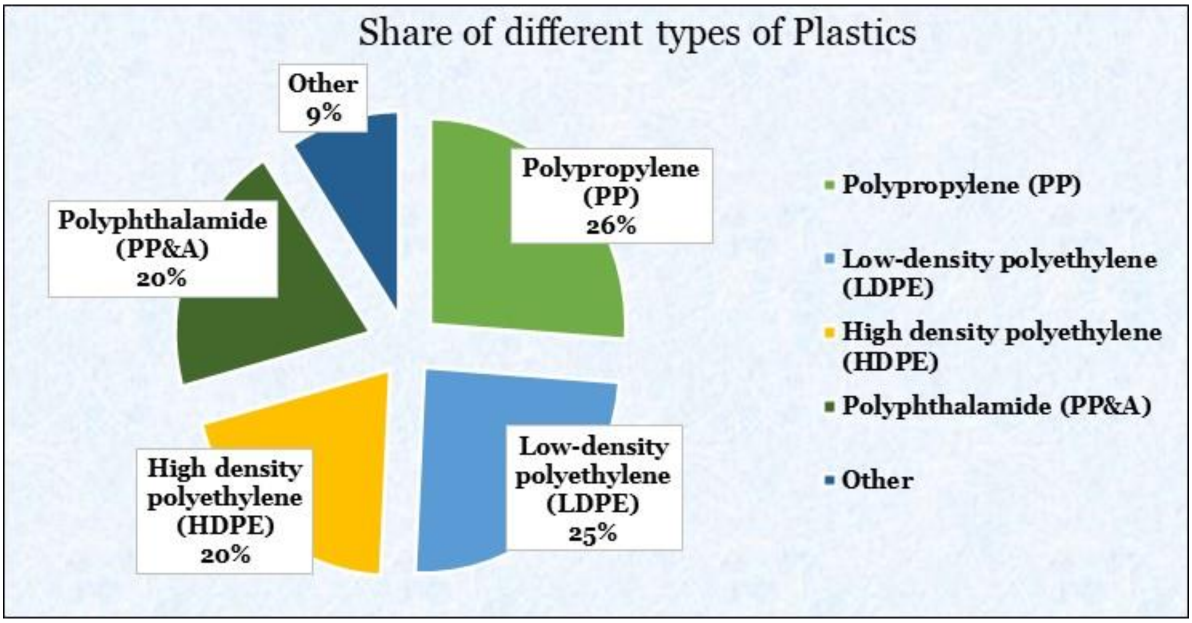


Figure 3: Share of different types of Plastics (Source: UNEP,2020)

According to the polymer type, the plastics production (million tonnes) between 1950-2018 is shown in Fig 04. Wherein In 2019, the total plastic production is around 368 million metric tons worldwide (Statista, 2021).

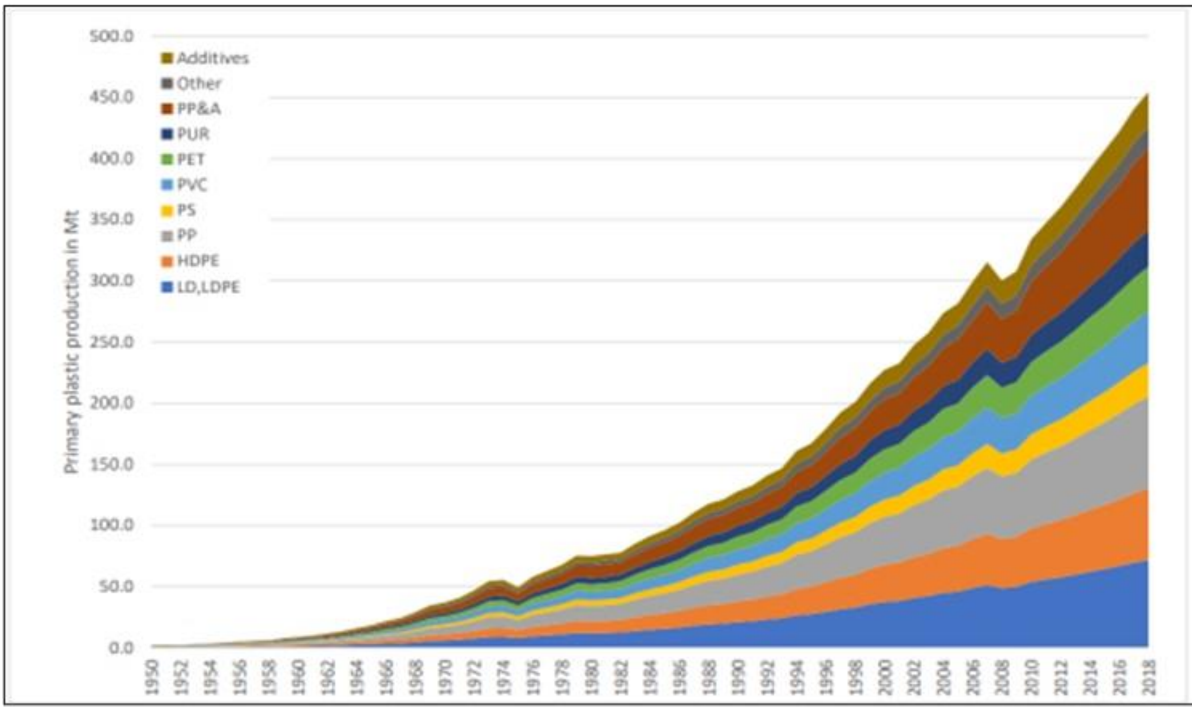


Figure 4: According to the polymer type, the global plastics production (million tonnes) between 1950-2018 (Geyer, 2020; UNEP, 2020)

The global plastic production from 2010 to 2020 increased to almost 370 million metric tons from 270 million metric tons. It is projected that the production of the global thermoplastic in 2050 will be 590 million metric tons an increase of more than 30 percent compared with 2025 with projected global thermoplastic production of 445.25 million metric tons. (Statista 2022)

2.3 Quantification of Global and Domestic generation of plastic waste (India) and their composition.

Rapid industrialization, Economic conditions, public habits, etc (UNEP, 2020) are some important parameters that must be considered to estimate plastic waste generation in a country or for the world.

In 2016 the total global plastic waste generated is about 242 million tonnes which is 12 % of total municipal solid waste generated that year. 3 regions primarily generate this plastic waste-

57 million tonnes from East Asia and the Pacific,
45 million tonnes from Europe and Central Asia, and
35 million tonnes from North America. (What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, world bank)

Table 04: Plastic waste generation in major countries after the year 2015

Countries	Plastic waste (Mt)	Reference Year
US	34.5	2015
China	61	2016
Countries	**Plastic waste (Mt)**	**Reference Year**
Indonesia	9.6	2018
Canada	3.2	2016
Japan	8.9	2018
Sweden	1.6	2016
Australia	2.5	2016
Israel	0.9	2018
UK	1.5	2016
Denmark	0.25	2017
Switzerland	0.78	2019
Zimbabwe	0.3	2019

(Source: UNEP, 2020)

In the year 2015, Asia generated the largest quantity of plastic waste in the world, 82 million tonnes then Europe generated 31 million tonnes, followed by Northern America generated 29 million tonnes, The Caribbean, Latin America, and Africa each generated 19 million tonnes of plastic waste. (Lebreton et al., 2019)

According to the SPCBs/PCCs annual report, India is the 5th largest producer of plastic waste generating 3.5 million tonnes of plastic waste in 2020. As plastic waste generated during the year, 2019-20 is approximately 34,69,780 TPA according to the details provided by 35 States/UTs. (Annual Report 2019-20 on Implementation of Plastic Waste Management Rules, 2016, CPCB)

The state in India which generated the maximum quantity of plastic waste is Maharashtra followed by Tamil Nadu & Punjab. The percentage distribution of Plastic waste generation in different States/UTs is shown below in Fig 05.

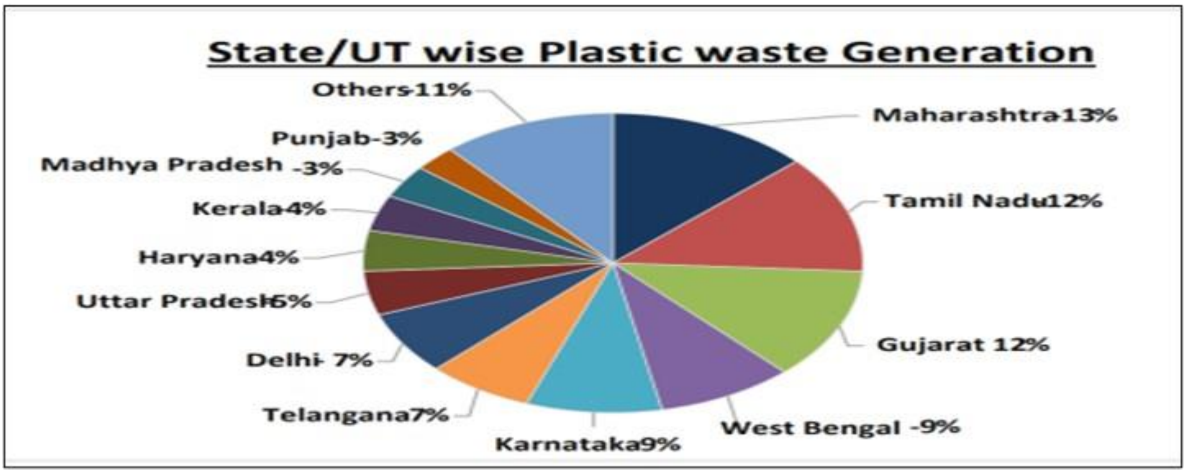


Figure 5: Plastic waste generation (Percentage distribution) in different States/UTs (Source: Annual Report 2019-20 on Implementation of Plastic Waste Management Rules, 2016, CPCB)

The highest per capita plastic waste generator states in India are Goa, Delhi & Kerala, whereas the lowest per capita plastic waste generator states are Nagaland, Sikkim & Tripura. The per capita waste generation (State-wise) for the year 2019- 20 is given below in Fig 06.

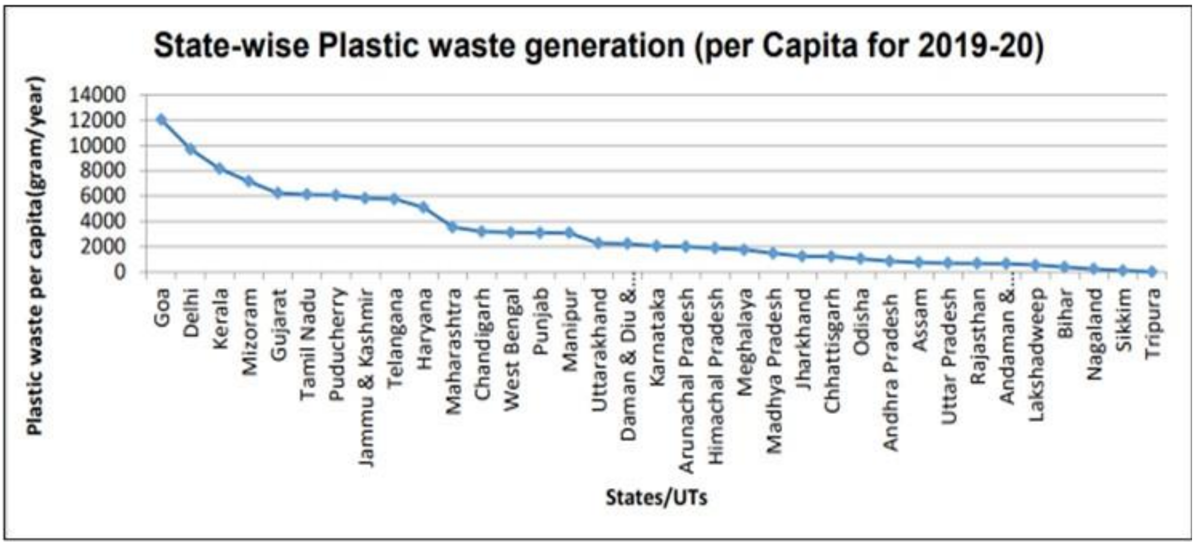


Figure 6: State-wise per Capita Plastic waste generation (for 2019.20) (Source: Annual Report 2019-20 on Implementation of Plastic Waste Management Rules, 2016, CPCB)

Plastic consumption in the year 2018-2019 was 16940 KT, and Fig 07. is showing the Percentage distribution of different Plastics, wherein Polypropylene (PP) has the greatest share of 30% with 5082 KT annual consumption followed by PVC and HDPE plastics with 19% & 14% annual consumption for Thermoplastics. For Thermosets Urethanes has the highest % of share, 44% which is about 665 KT. (Industry estimate by PLASTINDIA foundation, 2019).

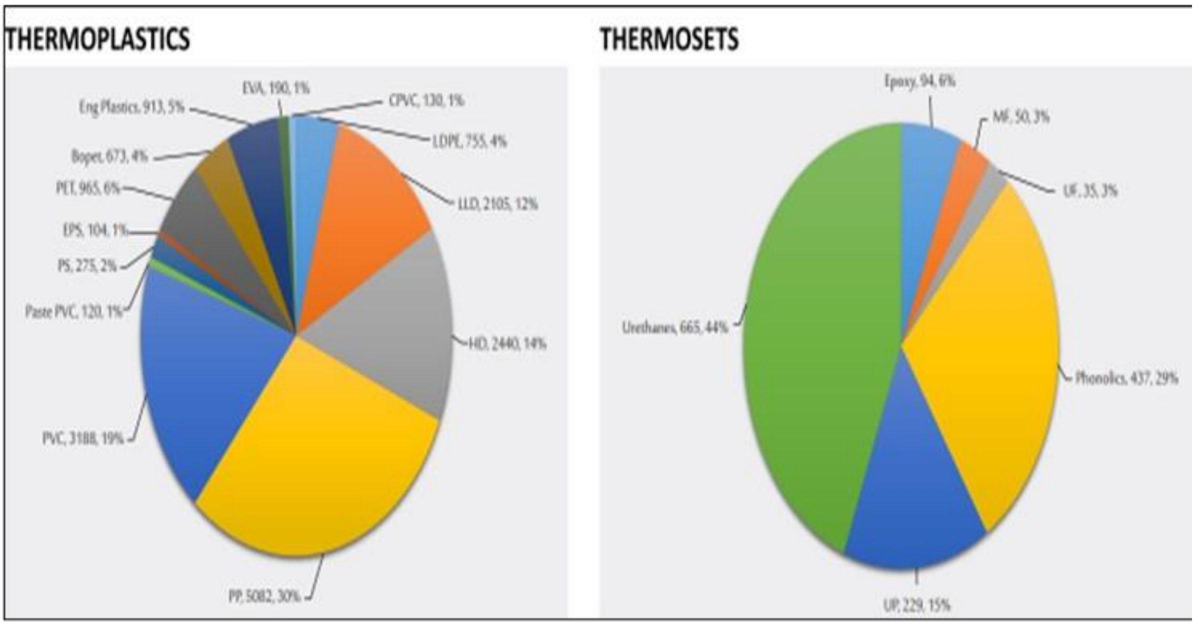


Figure 7: Percentage distribution of different Plastics (Source: Industry estimate by PLASTINDIA Foundation, 2019)

2.4 Definition, types of cement, and global scenario

One can trace back the history of cement to Roman Empire. The credit of invention of Portland cement can be given to a British stone mason, Joseph Aspdin of Leeds, Yorkshire, England in 1824 (P. E. Halstead, 1961).

The primary cement manufacturing process is mining essential raw materials, mainly limestone and clay. In most cases, the limestone and clay are excavated by drilling and blasting from open cast mines or other appropriate processes. Then, the limestone and clay are transported by dumpers. Through crushers, limestone and clay are crushed and stored at the desired place. Silty clay, Zafarana clay, and Kaolin are three types of clay used in cement manufacturing (Christopher Hall, 1976).

According to UNEP cement is a inorganic finely ground material that, forms a paste, when mixed with water, which sets and hardens due to the hydration reactions, after hardening, it will retains its strength and stability underwater (UNEP, 2011) and the intermediate product in cement manufacturing is clinker, which is the main substance in cement. The raw materials are burned and in a process of the calcination of limestone in the kiln the clinker is formed. (IFC, 2016)

Cement manufacturing Process Description

Wet Process, Semi-wet Process, Dry Process, Semi-dry Process are four main types of processes used in cement manufacture. steps are shown in Fig 08:

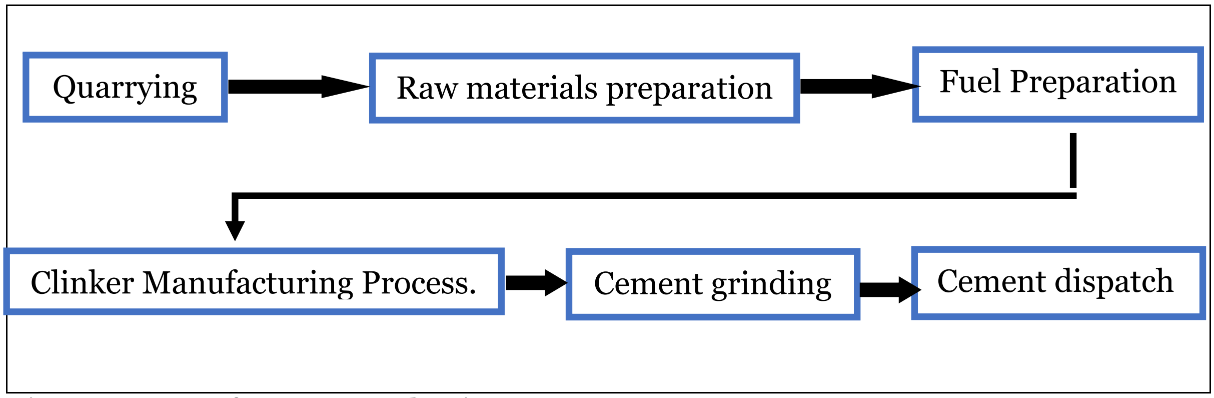


Figure 8: Step of cement production

Types of cement and global scenario

Calcium, Silica, Alumina, and Iron are the main ingredient necessary for cement production. These raw materials are burnt in a rotary kiln at 1400 to 1450 °C after proper mixing to produce clinker which is subsequently cooled and ground to powder and 2 to 8% gypsum is mixed. This is how ordinary Portland cement (OPC) is made. 33 Grade, 43 Grade, and 53 Grade are the different grades of OPC.

There are a different of types of cement available. The cement made by mixing of OPC with fly ash is called Portland pozzolana cement (PPC), when Blast Furnace Slag is mixed with OPC cement is known as Portland slag cement (PSC), and when OPC, Fly Ash, GBFS are mixed the cement is called Portland composite cement (PCC) etc.

Sulphate-resistant Portland Cement, Portland limestone cement (PLC), Masonry Cement, High-Alumina Cement, Oil Well Cement, Super Sulphated Cement, White Portland cement, Rapid Hardening Portland Cement, etc., are some other types of cement. Types of cement available in different countries like India, UK & Europe, USA, and Australia are given in Table 05.

Table 5: Standards for cement products from different countries

Country	Cement Product	Standard
India	33-Grade OPC 43-Grade OPC 53-Grade OPC Portland slag cement (PSC) Portland pozzolana cement (PPC) Portland composite cement (PCC)	IS 269 (2013) IS 8112 (2013) IS 12269 (2013) IS 455 (1989) IS 1489 (1991) IS 16415 (2015)
Australia	Portland and Blended Cement	AS 3972
UK & Europe	Different types of Cement	EN 197–1
USA	OPC	ASTM C150
	Blended cement	ASTM C595

(Source: S. K. Ghosh et al., Sustainable Management of Wastes Through Co-processing)

2.5 Different applications (reuse options) of Non-Recyclable plastic waste (NRPW)

From 1950 to 2015 total of 8.3 billion tonnes of plastic is introduced into the market out of which a total amount of plastic waste generated is 5.8 billion tonnes. Of that, approximately 12% of plastic waste is incinerated, 9% recycled, rest of the waste is dumped into landfills or left in the environment. (UNEP 2020) Different sources of plastic waste from different products are shown in Fig 09.

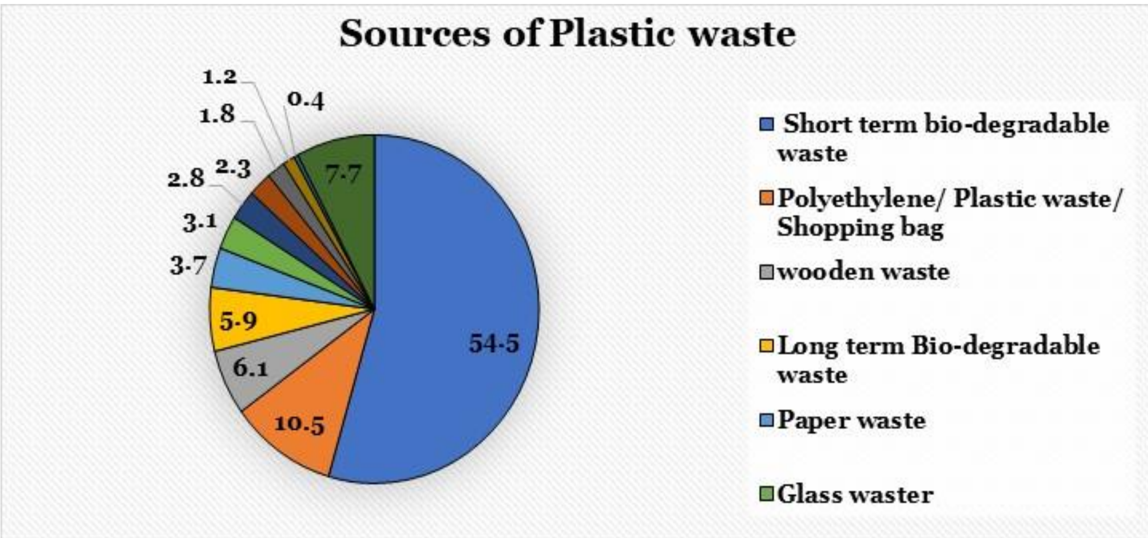


Figure 9: Sources of plastic waste (Source: Hikmath et al., 2020)

In the 80s, other than landfilling and open burning of plastic waste, incineration and recycling are introduced. Since then, incineration and recycling of plastic wastes have reached 19% & 25% respectively. (UNEP 2020) But a considerable amount of plastic waste (56%) is dumped into landfills or left in the environment.

An overview of Plastic waste management is given in Fig 10.

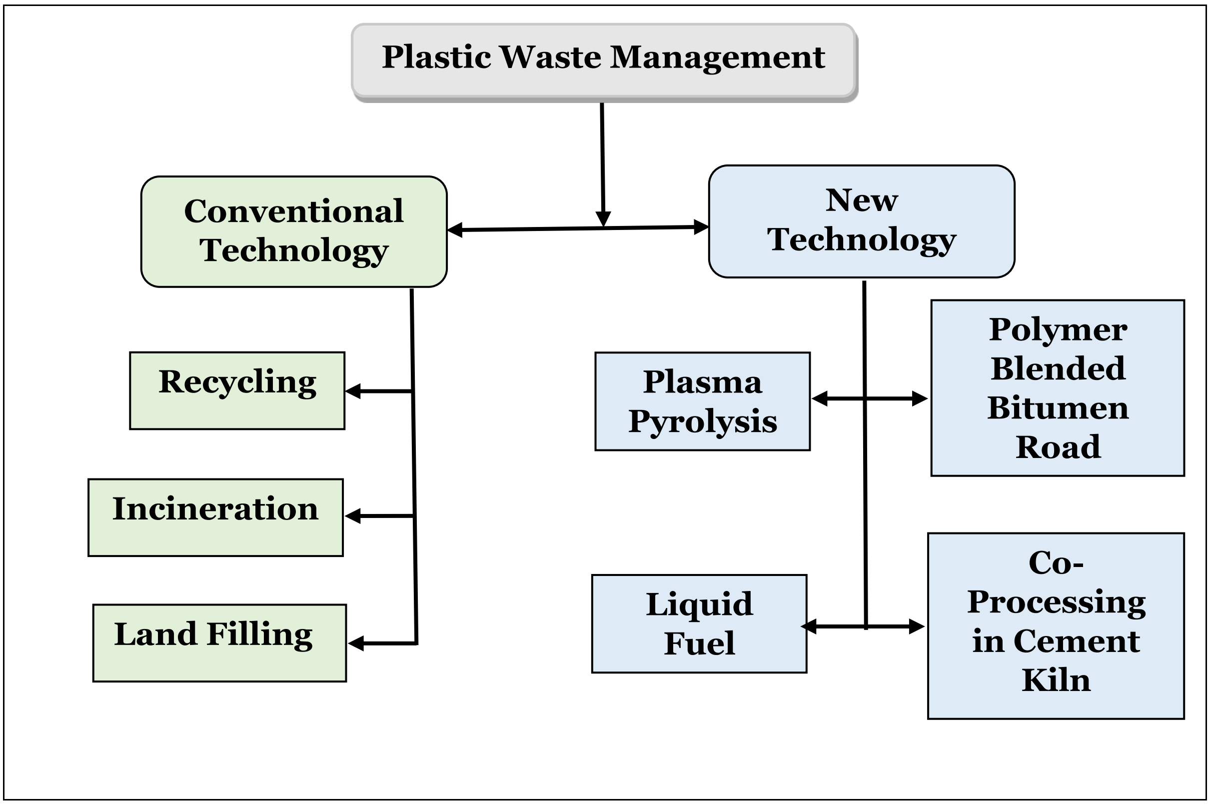


Figure 10: Overview of Plastic waste management (Hikmath et al., 2020)

Recycling, Incineration & Landfilling are some examples of conventional plastic waste management technologies. Plastic waste management is intended to reduce the impact of plastic waste on the environment, with the development of new technologies new more economic, environment-friendly processes are introduced. Here we discussed new technologies such as Co-processing in a cement kiln, Incineration, Plasma pyrolysis, and Polymer blended bitumen road.

2.6 Co-processing in cement kilns

In the co-processing process, suitable waste materials (RDF produced from the non-recyclable part of plastic waste) are used to substitute the raw material and coal requirement in a cement kiln. (UNEP, 2011) Through co-processing, 100% energy & material recovery from the RDF is possible, where RDF is called AFR (Alternative Fuel and Raw material) (S. K. Ghosh et al., 2019)

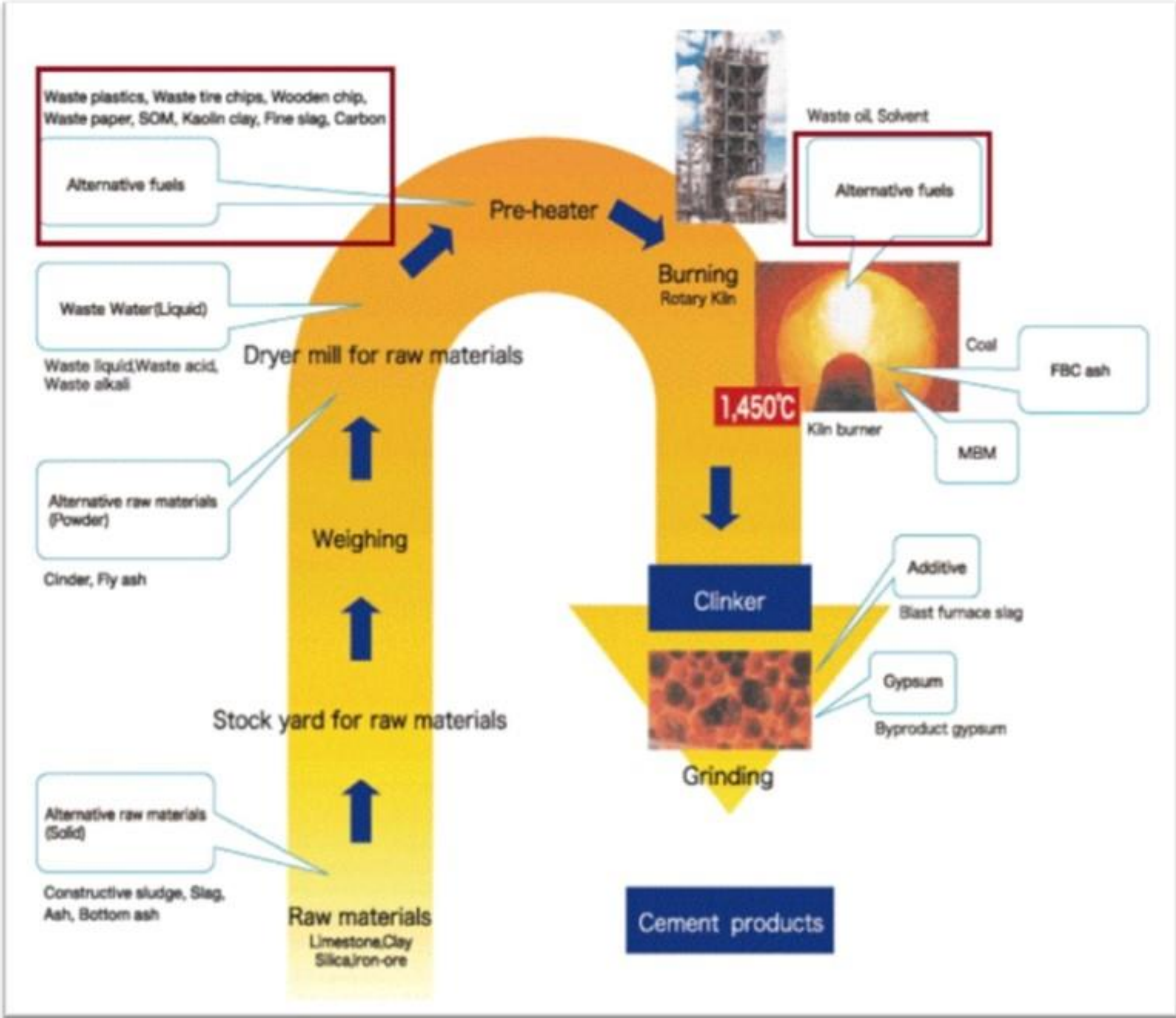


Figure 11: Co-processing in Cement Kiln (Ghosh D.S. et al., 2019)

The process flow diagram of the co-processing of alternative raw materials in the cement kiln is shown in fig 10, from the storage section of raw materials, and alternative raw materials, are weighed, dried, and faded to the pre-heater. Different streams of alternative fuels are introduced into the kiln. In a kiln through a process of clinkerization at a temperature of 1450◦ C achieved by burning primary fuels like pet coke and coal with alternative fuels, Clinker is formed which is then cooled and ground to manufacture cement. (Ghosh D.S. et al., 2019)

Different waste streams can be used as AFR in co-processing in cement kiln after going through proper shredding, drying, impregnation, bailing, segregation, and blending, this process is known as Pre-processing. (Ghosh S. K. et al., 2022) The different waste streams that can be used as feedstock in co-processing in a cement kiln are given in Table 06

Table 6: feedstock in co-processing in a cement kiln

TYPE	NAME OF FUELS
SOLID FUELS	Used tyres/ Tyre chips, paper waste, battery cases, rubber residues, domestic refuse, dried sewage sludge, plastics wastes and residues, wood waste, rice husks, pulp sludge, refuse-derived fuel (RDF), oil-bearing soils, coconut shell, nut shells, non-cattle feed harvest rejects, etc.
LIQUID FUELS	Used oils, Paint Sludge from the automobile sector, petrochemical waste, chemical wastes, Tar, distillation residues, waste solvents, Petroleum refining sludge, wax suspensions, asphalt slurry, etc.
GASEOUS FUELS	Refinery waste gas, pyrolysis gas, landfill gas, natural gas, etc.

Source: (Source: S. K. Ghosh et al., 2019; Dharmendra Singh Ghosh et al., 2019)

Around 450 Mt of raw materials and 50 million tonnes (Mt) of coal annually are consumed in India resulting in 7% of India's CO2 emissions. (Saha P.K. et al., 2017) In India Thermal Substitution Rate (TSR) is 2,5% on average; where the Norway's TSR almost 70% and EU's 40%. The average TSR of 109 Mt cement from 36 cement plants, was 3,55% (the highest single plant substitution is around 18% TSR) as a status report, published by CII in May 2015. (Saha P.K. et al., 2017)

2.6.1 Guidelines for use of alternative fuel and raw material in cement kiln

For about four decades Co-processing of AFRs is being practiced globally. Over this long period, due to undertaking co-processing initiatives, there have been many learnings and experiences. Many practices have come into place in the process. Appropriate guidelines are built through the help of these learnings and best practices. In this chapter these guidelines, learnings and best practices are discussed. Through these guidelines it is ensured that unsuitable wastes are not being co-processed and it is to validate that the co-processing activity doesn't influence emissions from co-processing.

The concerns of co-processing of AFRs in cement kilns are the following:

- Emissions during handling/pre-processing and co-processing.
- Spills, accidents, and exposure during handling.
- Contamination of the product. Source: (Ghosh S. K. et al., 2022)

When Co-processing is to be practiced elsewhere, native issues should be adopted. The fuel and stuff chemistry; the convenience of RDFs and waste materials; availability of apparatus for controlling, handling, and feeding the waste materials; infrastructure offered at the cement production plant; and site-specific health, safety, and environmental issues are some typical local issues that require to be addressed. a number of these considerations could also be site-specific and may be variable from plant to plant. Hence, these recommendations ought to be perceived as general ones. The local permit, therefore, must specify the ultimate details of the pre-processing and co-processing practices that would be allowed.

Table 7: Requirements by the cement plant or waste / AFR materials handling agency

Categories of requirements	Requirements
Compliances to international, national, and local Regulation Legislation and conventions	Approved EIA and applicable national and native permits regulative compliance at national and local levels Performance of the BAT/BEP and compliance to the relevant conventions admire city and Stockholm
Facility approval and Reliable Resource support	Facilities for pre-processing and co-processing which can be approved Reliable electricity and water supply Appropriate laboratory and system facilities
Pollution including emission control	Appropriate pollution management devices and continuous emission watching systems at stacks for guaranteeing compliance to relevant rules Preventing hydrocarbon and organic compound formation by acquisition / cooling the exit gas to below two hundred °C quickly
Calibration	Calibration of activity and observation instrumentality and instruments frequently through baseline monitoring processes
Training and Competence of personnel on technology, HSE, and emergency response	Personnel with needed skills to manage health, safety, and environmental problems with the venturesome wastes Regular coaching of the personnel to handle safety equipment, procedures, and emergencies
Responsibility matrix	Well-defined organizational structure with clearly defined responsibilities
Defined acceptance, quality control, and authorization procedure	Safe receipt, storage, pre-processing, and co-processing of dangerous wastes Authorization for collection, transportation, and handling of hazardous wastes Waste acceptance and co-processing management through applicable laboratory and instrumentation facilities Adequately outlined control procedures for product quality
Records keeping and reporting	Maintenance of the records of venturesome wastes and emissions Regular speech act of performance standing through open reports news system for workers to expeditiously touch upon errors

Certification of management systems	Implementation of ISO 9001, ISO 14001, ISO 50001, ISO 45000, EMAS, or similar systems to confirm quality, environmental and energy management, activity health and safety, and continuous improvement
Complaints handling system and Auditing	Regular audits through freelance agencies and emission watching and reportage through third-party agencies Engagement with local people and authorities to deal with comments and complaints

Source: (S. K. Ghosh et al., 2019)

Banned wastes:

Here are some waste mentioned which are banned for co-processing. Both pre-processing and co-processing are also banned for some waste streams. Local circumstances, legal requirements, and company policies may result in some companies disqualifying additional materials. Materials Banned for pre-processing and co-processing

1. Radioactive waste.
2. Unknown/unidentified wastes.
3. Asbestos.
4. Infectious and biological active medical waste.
5. Explosives.

Materials Banned for co-processing after pre-processing

1. Batteries.
2. Electronic waste.
3. Unsorted municipal waste.
4. Mineral acids and corrosives.

2.7 Pre-processing of Non-Recyclable plastic waste

To achieve successful co-processing of AFRs, pre-processing of wastes to produce AFRs is an important function. If one wants to categorize, wastes can be found in liquids or sludge forms and also in solids. In a few cases, they can also be in gaseous forms. Wastes are heterogeneous materials. There are generally very large variations in physical as well as chemical characteristics. For example, municipal solid waste (MSW) generated from one family is incredibly completely different than that generated from another household. Even the waste composition can vary for the same household on a day-to-day basis. The composition also is different from source to source and from season to season, if dry waste is segregated from the MSW. After the separation of recyclable materials, Dry waste and other non-recyclable materials can be a very good fuel with calorific value. This material varies in size, calorific value, ash content, moisture content, chloride content, etc. from batch to batch due to its heterogeneous nature. If this waste is introduced into the cement kiln without treatment for use as an alternative fuel, it can cause serious disturbances in the process and affect the quality of the clinker produced in the kiln.

Therefore, before the waste materials are fed into the furnace, they must be processed to achieve uniform physical and chemical properties. This processing of waste materials with different quality considerations, which are converted into AFR with uniform quality considerations, is called pre-processing.

Pre-processing of waste refers to preparing waste to make it suitable for co-processing in cement kilns. Waste is converted from an unwanted discarded material to a useful resource, so-called AFR (GIZ, 2020)

The pre-processing involved various unit operations such as mixing, milling, drying, impregnation, size separation, remixing, and dewatering. Mechanical treatment is mainly carried out in the pre-processing. If necessary, however, chemical treatment processes such as neutralization, flocculation, and sedimentation are sometimes carried out. (Ghosh S. K. et al., 2022)

Pre-processing of Solid Wastes

Various unit operations such as mixing, separating, crushing and drying are implemented for solid waste pre-processing. A typical flow chart of this system is shown in Figure 13.

Pre-processing of solid wastes contains the following steps:

- The primary step, the inward material received from the market is checked and waste is accepted for storing within the storage shed supported the results of the evaluation.
- Materials having totally different chemistry properties are held on separately.
- The composition of the batch mixture of different solid waste streams obtainable in the stores to attain the required uniform characteristics of the AFR, based on the characteristics of the individual streams, is determined.

- As per the batch combine composition employing a payloader the waste materials are fed into the hopper of the device and therefore the shredding operation started.
- The output of the device then is sent to a wind sifter. whereas this conveyance of title is in progress, the sensing element and therefore the eddy current centrifuge take away the metallic element and non-ferrous metal fractions from the sliced material (Ghosh S. K. et al., 2022)

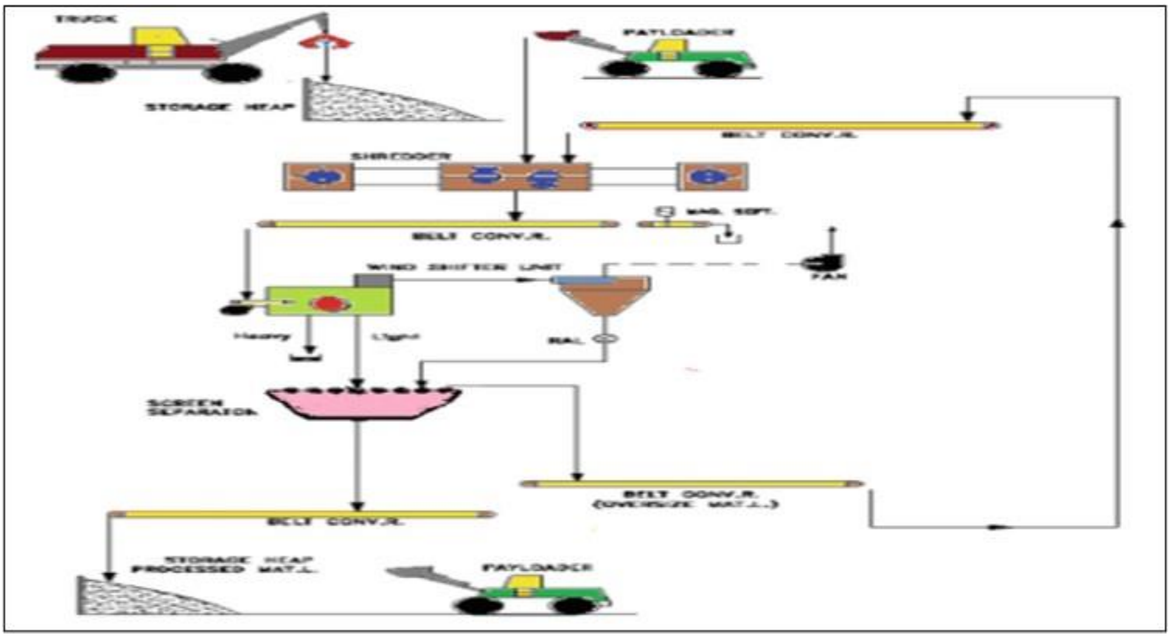


Figure 12: Typical flow sheet for the pre-processing of solid wastes

2.8 Refuse Derived Fuel (RDF)

Mechanical and combined mechanical biological treatment can convert solid waste from municipalities and industry into alternative fuel so-called RDF. The principle of RDF manufacturing is the recovery of combustible fractions from the waste and removing recyclable materials such as metal and glass, and the converted raw waste is a usable form of fuel that has uniform particle size and higher calorific value than raw MSW. A generic process flow of solid waste to RDF production is given in fig 13.

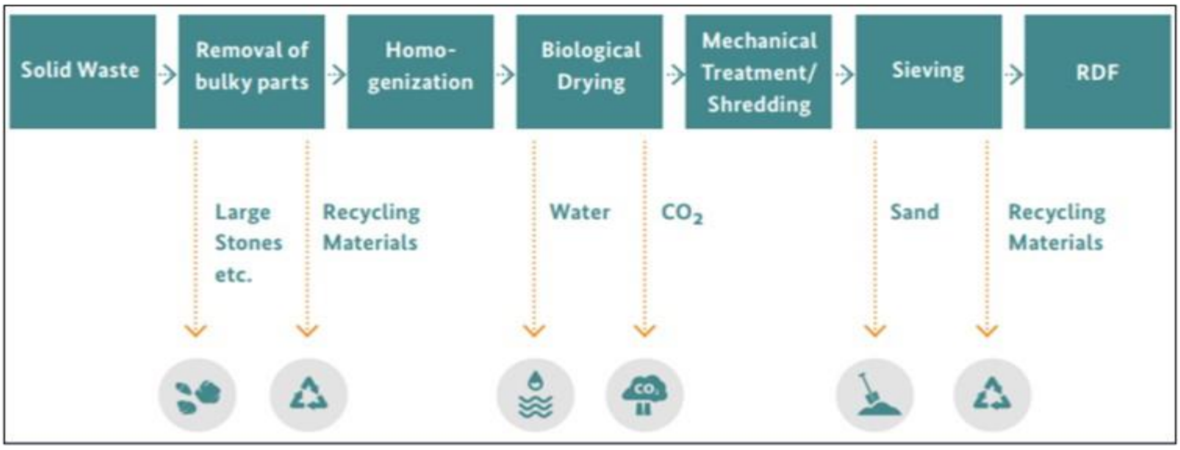


Figure 13: Process diagram of MBT for RDF production (GIZ, 2017)

According to the guidelines on the use of fuel from waste in various industries, the combustible portion of MSW, such as dirty paper, dirty clothes, contaminated plastics, multi-layer packaging materials, other packaging materials, leather parts, rubber, tires, polystyrene (thermocol), wood, etc. which has a significant calorific value and can be used as an alternative fuel in various industries according to the waste-to-wealth principle. These fractions can be processed and turned into RDF. (CPHEEO, 2018)

2.9 Impact of using RDF in co-processing on the quality of clinker and cement

calcium oxide CaO, silicon dioxide SiO_2, aluminum oxide Al_2O_3, and iron (III) oxide Fe_2O_3 are the four chemical compounds of cement clinker production. Apart from raw material clinker production also required large amounts of energy. The manufacturing of 1 tonne of cement clinker requires between 3.0 and 3.8 GJ of thermal energy in modern rotary kilns (under optimal conditions and depending on the technology used). (Viczek S.A. et al., 2020).

When SRF, RDF is co-incinerated in a cement kiln for energy and material recovery the process is known as Co-processing. Through co-processing we can achieve 100% energy and material recovery as the organic part of RDF contribute to the energy need in the cement kiln and the mineral content in form of ash contribute to the raw material requirement in clinker production (Source: S. K. Ghosh et al., 2019) since the ash content various chemical compound that is the valuable raw material for cement production, so the ash is incorporated into a new product like clinker, can technically be considered as material recycling. (Viczek et al., 2021)

RDF is not homogenous in nature. A different batch of RDF can comprise different materials in different ratios. So, for this study at 1^{st}, we have to consider the composition of different batches of RDF. Plastic, wood, glass, textile, paper & cardboard (P&C), composite materials, sewage sludge, and used tires can be the major component of RDF used in co-processing in cement kiln. (Viczek et al., 2021; Aldrian et al., 2020). 2ndly the composition of ash has to be analyzed. Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, Na_2O, P_2O_5, SO_3, SiO_2, and TiO_2 are common compounds in the RDF ash. (Aldrian et al., 2020)

These oxides in the ash contribute to the raw material requirement of cement production. When the % of each oxide is known then the Raw mix design of cement is corrected accordingly and if there is any presence of harmful oxides in the ash to the qualities of cement then necessary steps must be taken.

Literature review

Co-Processing A Transition to A Circular Economy

Chapter 3

This chapter gives the reader a full idea about the co-processing of plastic waste in cement kilns the how it is promoting the circular economy.

3.1 Introduction

For 150 years the industrial evolution was dominated by the linear economy model. The linear economy model is based on the model "take-make-use-destroy".

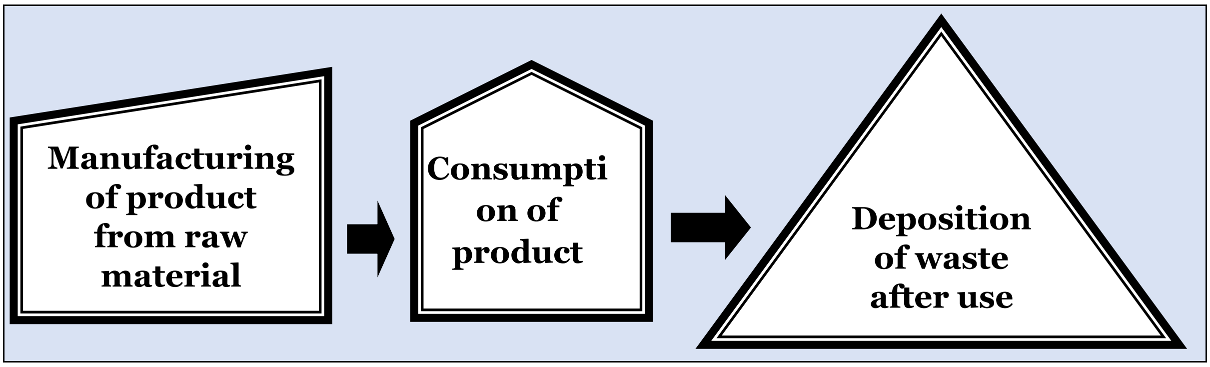


Figure 14: linear economy ("take-make-use-destroy") model block diagram.

The impact on societal capital, including human resources, and the conservation of natural resources are not the main priority of this model. On the other hand, by the circular economy model reduction of waste and consumption of resources can be monitored more closely. Reusing existing materials as raw materials can decrease the need for new ones, and this practice can be accomplished by rethinking how the product functions in a closed loop (Govindan K, 2018).

Circularity is part of the Sustainable Materials Management (SMM) approach that EPA and other federal agencies have been pursuing since 2009. A circular economy approach under the umbrella of SMM demonstrates continuity in our focus on reducing the life cycle impacts of materials, including impacts on the climate, the use of harmful materials, and decoupling material consumption from economic growth. The National Recycling Strategy identified the need to implement a circular economy approach for all: reduce waste generation with respect for local communities and implement materials management strategies that engage communities with environmental justice concerns. (U.S. Environmental Protection Agency)

To tackle urgent problems of resource scarcity and environmental degradation the proposed Circular economy (CE) concept is among the most suitable sustainable development strategy. the negative impacts of production and consumption lead to rapid environmental deterioration around the world, which has led to the development of policies and strategies for reducing this impact. the recycling principle of a circular economy is adopted by a number of countries by introducing acts and laws.

The increasing demand for natural resources, which puts pressure on the environment, is leading to a shift from a linear economy to a circular economy. The objectives of the circular economy are to reduce the consumption of natural resources, reduce greenhouse gas emissions and the use of hazardous substances, reduce the amount of waste that has to be transferred to suppliers of renewable and sustainable energy, and reduce the pressure on suppliers. The value destruction in the overall system can be reduced by a circular economy, which increases the value creation in every link of the system (Bastein et al.2013). In addition, a circular economy reduces the generation of waste from recycling and reusing products, bringing both environmental and economic benefits, extending the useful life of products, and increasing the opportunity to create more jobs. work. According to a recent report, reduced resource use in the European Union will create between 1.4 and 2.8 million new jobs by 2020 (MacArthur 2012). In addition, a circular economy could have a positive impact on reducing carbon emissions by 2030**.** (MacArthur 2015).

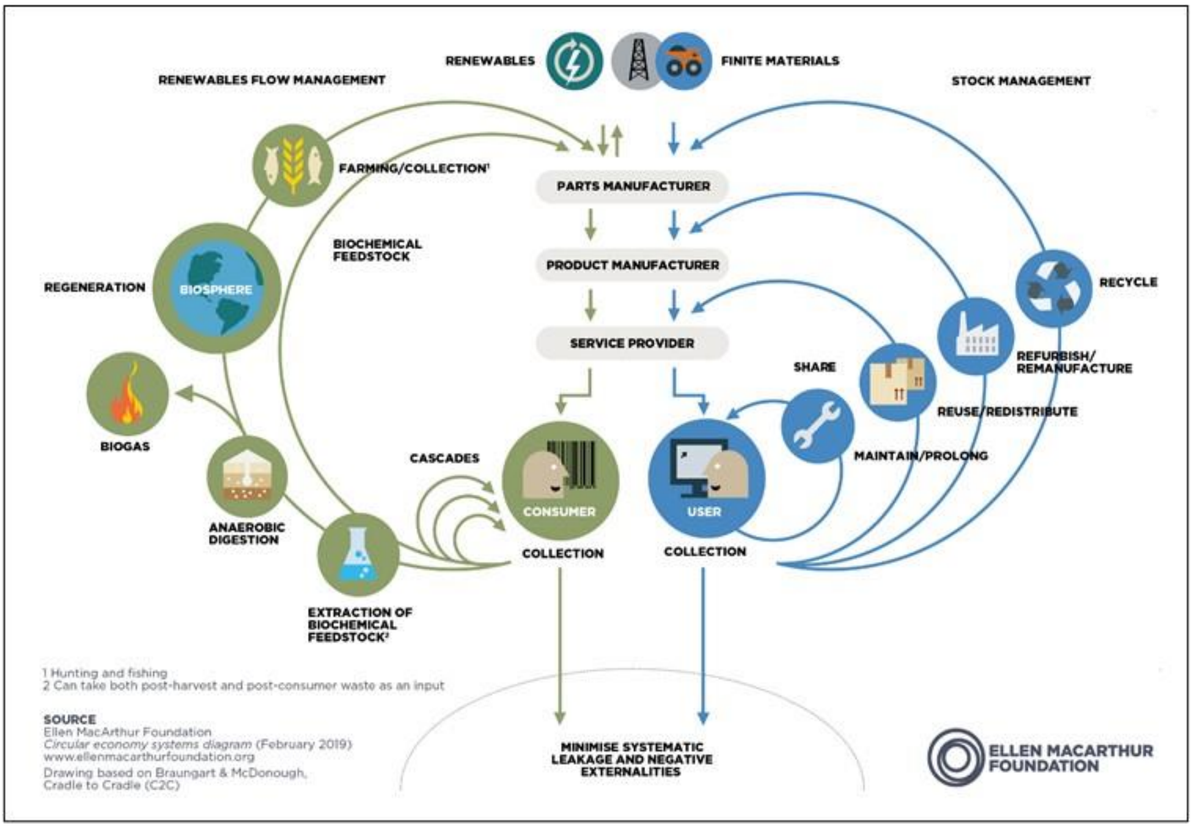


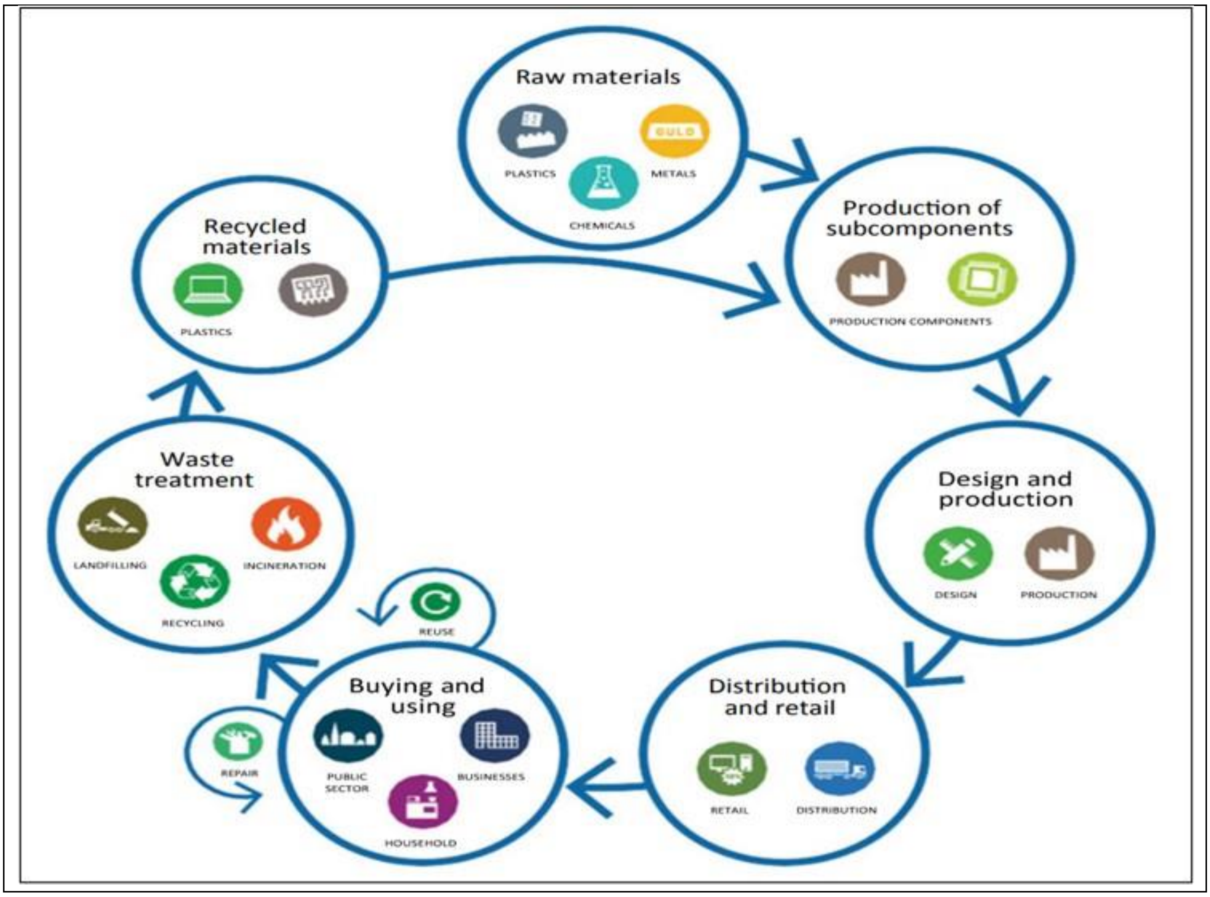
Figure 15: Outline of circular economy (MacArthur 2019)

A product must be designed to extend its useful life; however, with the market saturation for their devices, companies are designing single-use products with shorter lifespans, accelerating their replacement cycle. Longer shelf life not only saves material resources but also allows for a distribution of the product's carbon footprint. for a long period of time (Ghosh S.K, 2019).

3.2 Definition of circular economy

For economic development, the circular economy is a systems-level approach and a paradigm shift from the traditional concept of the linear extract-production-consumption-disposal-depletion (epcd2) economic model to a better approach to achieving zero waste through resource conservation that requires the Changing the concept of production processes and material selection leads to a higher life cycle, saving of all kinds of resources, recovery of materials and/or energy in processes and at the end of the life cycle for a specific use of the product as a starting material for a new production process in the value chain with closed material loops that improve resource efficiency and resource productivity, benefit the economy and society, create employment opportunities and ensure environmental sustainability. (Ghosh S.K, 2019)

Figure 16: Circular economy value chain of electronic and electric equipment



CE offers opportunities to create wealth, growth and jobs while reducing environmental impact. In principle, the concept can be applied to all types of natural resources, including biotic and abiotic materials, water and land. (EEA, 2016)

The circular economy as "an industrial system that's restorative or regenerative by intention and style" replaces the 'end-of-life' idea with restoration, shifts toward the employment of renewable energy, eliminates the use of virulent chemicals, that impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, among this, business models." the general objective is to "enable effective flows of materials, energy, labor, and data in order that natural and social capital will be rebuilt"(Ellen MacArthur Foundation 2013).

The circular economy is an economy "where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste minimized." The transition to a more circular economy would make "an essential contribution to the EU's efforts to develop a sustainable, low-carbon, resource-efficient, and competitive economy" (European Commission 2015).

The circular economy is based on three principles, driven by design:

- Eliminate waste and pollution
- Circulate products and materials (at their highest value)
- Regenerate nature

3.3 Co-processing of plastic waste in cement plant – A transition to the circular economy

With an increase in plastic product generation and consumption is leading to a greater plastic waste generation which has also difficulties with its management. In India, the majority of plastic waste are left untreated and find its place at dumpsite or gets into different water streams and finds its way into marine littering.

The cement industry is responsible for a more than 7% of the CO2 generation and has large carbon footprint. The same value for India is also around 7%. The cement industry also contributes to environmental pollution by releasing emissions such as particulate matter, SOx, NOx, VOC, etc. In order to be sustainable, the cement industry undertakes various initiatives to address these concerns: environmental, economic and social. The following measures will be takenCorporate sustainability initiatives. (1) reducing carbon footprint, (2) reducing waste, (3) investing in renewable energy, and (4) charities supporting the cause of sustainability

A model has been proposed to solve this problem. The following model shows a brief life path of plastics turning into waste, leading to landfills and oceans. The model also suggests with proper collection and segregation in a material recovery facility, it is possible to use those plastics as fuel, thereby preventing their way to oceans and landfills which results in the promotion of a circular economy and enhance resource circulation.

Recyclable plastic can be collected by kabadiwala and rag-pickers and sent to recycling plants for recycling. NRPW from the common dustbin, landfill, roadside dumping, marine litter, and industrial waste can be collected by ULBs and cab be stored in a materials recovery facility provided by the government or can transfer to a private company that converts this plastic waste into Refuse Derived Fuel (RDF). This final product can be transferred to a cement plant where it can be used as AFR in a cement kiln. The reuse of plastic waste for co-processing in cement plants promotes a circular economy. Figure 17 demonstrates the proposed model for the prevention of marine littering through the implemented legislation on co-processing and marine littering.

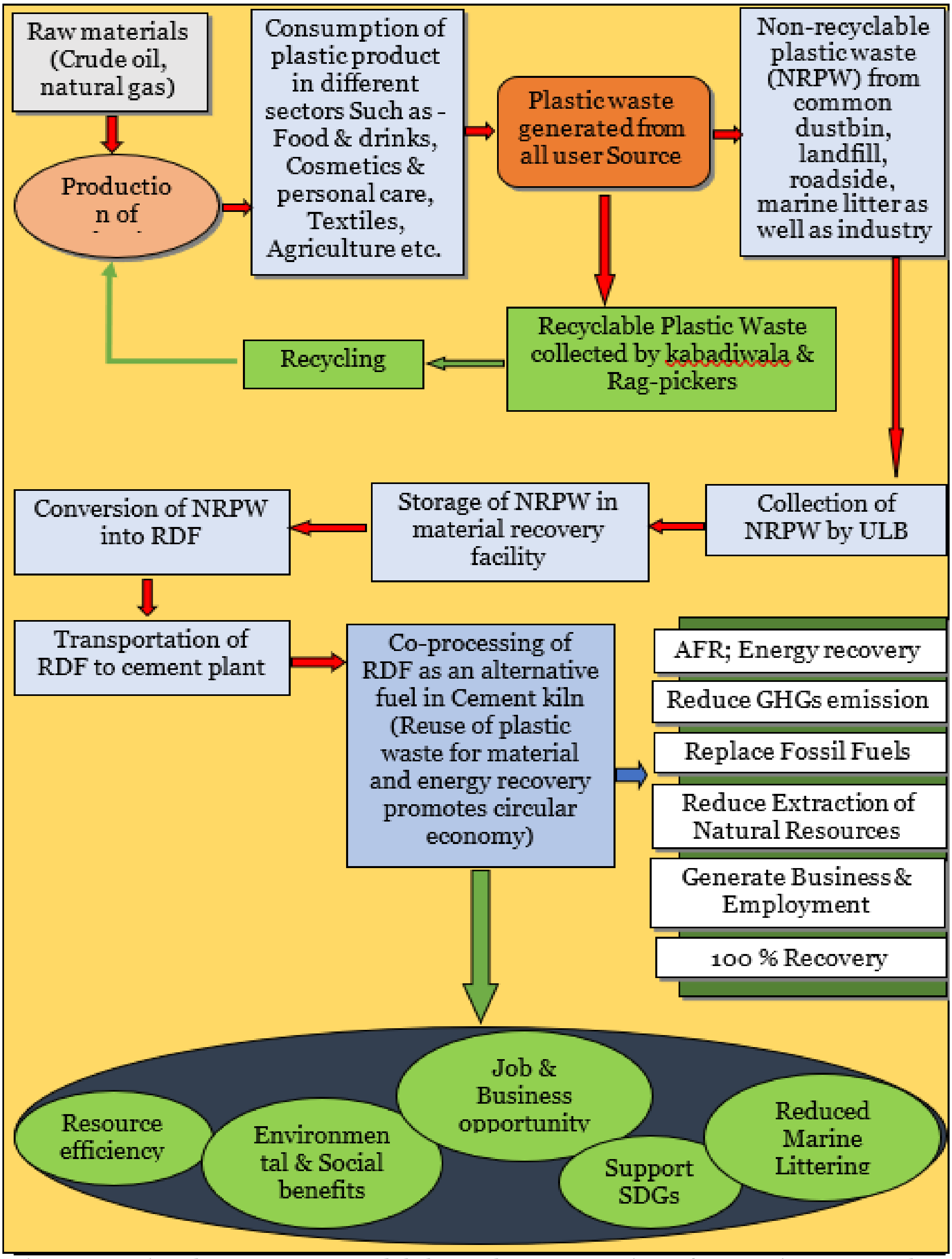


Figure 17: Circular Economy model through co-processing of NRPW in cement plant

Research gap, Research questions, Objectives, and Work package

Chapter 4

4.1 Research gap

As per the literature review, some points are found that are to be discussed yet:

1. Socio-economic, health, and safety issues of scavengers working in the waste management sector.
2. Potential of RDF production from the fresh waste dumped on a daily basis to a dumpsite or from a legacy dumpsite in India.
3. Co-processing is a contributor to the circular economy.
4. Impact of RDF on the quality of clinker and cement.

4.2 Research questions, Objectives, and Work package

RQ1: Is there any negative impact on the socio-economic, health, and safety conditions of scavengers working in a waste management system?

Research Objective	Work package
Identify the impact on the scavengers in waste management	Literature review
	Questionnaire preparation as per the requirement.
	Field survey with prepared questionnaire

RQ2: What is the potential for RDF production from waste dumpsites and legacy dumpsites?

Research Objective	Work package
Identify the potential for RDF production	Literature review
	Field visit and waste composition analysis

RQ3: Is there any negative impact on the quality of cement due to the RDF utilization in the cement kiln?

Research Objective	Work package
Identify the impact on the quality of cement	Literature review
	Field survey to identify the widely available cement brands
	Identifying cement brands doing co-processing with RDF and cement brands not doing co-processing
	Testing of cement samples in lab
	Analysis of data

Field Study and Data Collection

Chapter 5

In this chapter there are discussion on various studies conducted to identify:

Socio-economic and health impact on scavengers

Potential of RDF production from Dumpsite

5.1 IMPACT ON SCAVENGERS FROM RDF PROCESSING

In this study different environmental, economic, social, and health & safety aspects of scavengers working in waste management sectors are studied and discussed. Scavengers and ragpickers plays important role in the plastic waste management system. Municipal waste management contains several steps such as, collection, transportation, segregation of recyclables, dumping or using non-recyclable plastic waste for co-processing in cement kiln, scavengers or rag pickers have their definite role at each of these steps and also perform different operations to manage this solid waste.

In the view of municipal solid waste management (MSWM), informal waste management refers to the waste recycling activities of scavengers and waste pickers. Developing countries, including India, are majorly collected by the informal waste sector. In India, the survey sites have been chosen on the basis of the population density of the region. Among The selected seven sites, four sites are in Kolkata and outer Kolkata, others are in Berhampore, Murshidabad district.

Kolkata is one of the 4 metropolitan towns of India and is the capital of the country of West Bengal. The metropolis is targeted on range 22 zero 34íNorth and longitude 88 zero 24í East, is about 30 km from the Bay of Bengal, and the river tides at Kolkata vary over 4m. According to the 2011 Indian census, Kolkata is the seventh-maximum populous metropolis in India, with a populace of forty-five lakh (five million) citizens withinside the metropolis limits, and a populace of over forty-one crore (14.1 million) citizens withinside the Kolkata Metropolitan Area. KMC record says that on common 4,000 MT of waste is generated in KMC Area each day.

In Kolkata, two open dumpsites and two clean city compactors have been chosen for survey in Baruipur and Jadavpur, Palbazar respectively. In mahamayatala, the data was gathered through interviews with household waste collectors.

Murshidabad is in the center of West Bengal lying between 23°43'N and 24°52'N latitude and 87°49'E and 88°44'E longitude with HQ at **Berhampur**. Berhampore falls in Murshidabad district situated in West Bengal state, with a population of 137864 (2020). Being located in a residential area, the waste generation is also observed to be high amounts.

In the sites, the waste picker samples are collected randomly. On the basis of environmental, economic, social, and health & safety aspects, the interview of scavengers has been done. The simple random sampling method has been chosen for this study.

4.1.1 Methodologies adopted for interview

This study used a systematic literature review to identify and examine the environmental, social, and economic risks and health outcomes associated with informal waste collection. Outcomes related to informal waste collection

-

- These steps involved identifying items, selecting items, determining the suitability of items, and finally determining which
- For the purpose of this study, informal has been defined as being without municipal or government regulation. The criteria included publications and sources with information regarding informal waste pickers, as well as all other similar terms (e.g., collector, scavenger, and recycler), social and economic hazards associated with informal waste picking, health outcomes associated with informal waste picking, especially woman and child waste pickers and English language articles.
- For the interview, a close-ended questionnaire has been formed to ask the scavengers about the aspect of social, economic, and health hazards due to involvement in this occupation. On the site, the scavengers have been chosen randomly and asked the questions to follow the questionnaire. The primary data was recorded for further study.

5.1.2 Interview of Informal scavengers

In the view of municipal solid waste management (MSWM), informal waste management refers to the waste recycling activities of scavengers and waste pickers. In developing countries, like India, the major collector of non-recyclable plastic waste are mostly scavengers or ragpickers working without any formal recognition by any government agencies (local municipal corporation, Block office) and NGOs known as the informal waste sector.

In India, the survey sites have been chosen on the basis of the population density of the region. Among The selected seven sites, four sites are in Kolkata and outer Kolkata, others are in Berhampore, Murshidabad district.

A total of 53 informal scavengers or ragpickers are interviewed. Details of these interviews are shown in Table 08.

Table 8: Details of the scavenger's interview

Site location	**Ward no.**	**Served population Waste generation**	**Type of site**	**Date of survey**	**No of interviews**
Baraipur	17		Open dumpsite		7
Maheshtala			Open dumpsite		8
Jadavpur	96	113251	Clean city waste compactor	19/04/22	6

Palbazar	104		Clean city waste compactor	19/04/22	7
Murshidabad			Open dumpsite	08/03/22	8
Berhampore			Open dumpsite	08/03/22	6
Mahamayatala			Collected waste vehicles	09/05/22	11

5.1.3 Results of Interview conducted with Informal scavengers

5.1.3.1 SOCIO-ECONOMIC ASPECT

GENDER- In this occupation, the male proportion is always high than the female. Especially, in the study area, Maheshtala, the female waste pickers are mainly observed otherwise, the proportion of males is high in other sites. As shown in Table 09 among the total interviewed 53 scavengers there are 42 scavengers are male and 11 women scavengers.

So, the gender ratio of total interviewed scavengers is,

- **42: 11 = 3.81: 1, approx. 4: 1**
- Which means for every 1 woman, there are 4 men working as informal scavengers.

Table 9: the proportion of males & females among scavengers

Location of the interview	No. of interview with scavengers	Male	Female
Palbazar	7	6	1
Jadavpur	6	6	
Mahestala	8		8
Mahamayatola	11	11	
Baharampur	6	5	1
Baruipur	7	7	
Murshidabad	8	7	1
Total	**53**	**42**	**11**

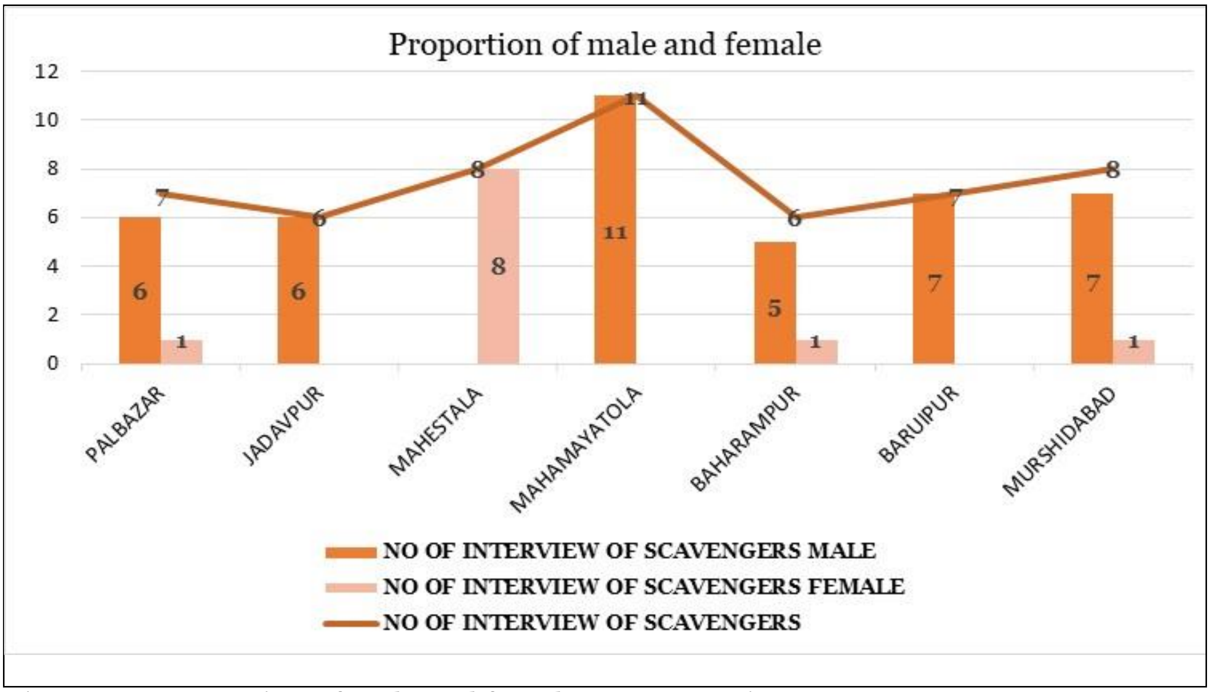


Figure 18: Proportion of male and female scavengers in waste management

YEARS OF EXPERIENCE – In the studies, the women and male waste pickers have been observed engaging with this occupation average of above 10 years. Though most male population are engaged with 15 years and above. In this job, the waste pickers are mostly engaged due to the easy getting job, lack of skill, lack of education, etc. For the same reason, in Palbazar, the above 20 years experienced waste picker has been found for this study.

Table 10: The engagement in occupation in various sites

Location of the interview	**No of interviews of scavengers**	**Engagement in occupation**				
		Below 5 years	6- 10 years	11-15 years	16-20 years	Above 20 years
Palbazar	7	1	2	3		1
Jadavpur	6	2	2	1	1	
Mahestala	8	1	4	1	2	
Mahamayatola	11	2	6	2	1	
Baharampur	6		1	5		
Baruipur	7		2	4	1	
Murshidabad	8		2	3	3	
Total	**53**	**6**	**19**	**19**	**8**	**1**

AGE-GROUP- In these studies, the adults above 18 years and teenage below 18 years also engaged in this job due to poverty and family size. In Mahestala, Mahamayatala below 18 years are also engaged to help their parents, and they also get daily wages, but in less amount than adults. Mostly in the major cities, the >30 age group people are engaged in this waste picking. 30 aged Women's engagement in these sites is mainly observed.

Table 11: The age group of scavengers

Location of the interview	No of interviews of scavengers	Age groups				
		BELOW 18 YEARS	18-30 years	30-40 years	40-50 years	Above 50 years
Palbazar	7		1	2	3	1
Jadavpur	6			3	2	1
Mahestala	8	1	1	4	1	1
Mahamayatola	11	1	3	3	2	2
Baharampur	6		3	2	1	
Baruipur	7		2	3	2	
Murshidabad	8	1	2	3	2	
Total	**53**	**3**	**12**	**20**	**13**	**5**

HABITAT- In the poor habitat system, the slum area, temporary settlements near dumpsites are common for waste pickers. In the habitat, there is a lack of hygiene, and no such facilities for pure drinking water, and food which indicates the vulnerability of the waste pickers. In Maheshtala and Mahamayatala, maximum waste pickers are in rented houses.

EDUCATION - As this job is not required as such no education criteria, the engaged maximum people are illiterate or primarily educated. In study areas, it has been observed that the no of illiterate is also high while only 13 scavengers got an opportunity in secondary education. They are mainly engaged for their family responsibility and large family size while there is not required such education in this job. In this case, a major issue is notable that despite being a megacity, there is a lack of getting opportunities for education among waste pickers in Kolkata.

Table 12: shows the literacy ratio among scavengers in various sites

Location of the interview	No of interviews with scavengers	Education		
		Illiterate	Primary education	Secondary education
Palbazar	7	5	1	1
Jadavpur	6	1	4	1
Mahestala	8	4	2	2
Mahamayatola	11	4	2	5
Baharampur	6	1	3	2
Baruipur	7	4	3	
Murshidabad	8	4	3	1
Total	**53**	**23**	**18**	**12**

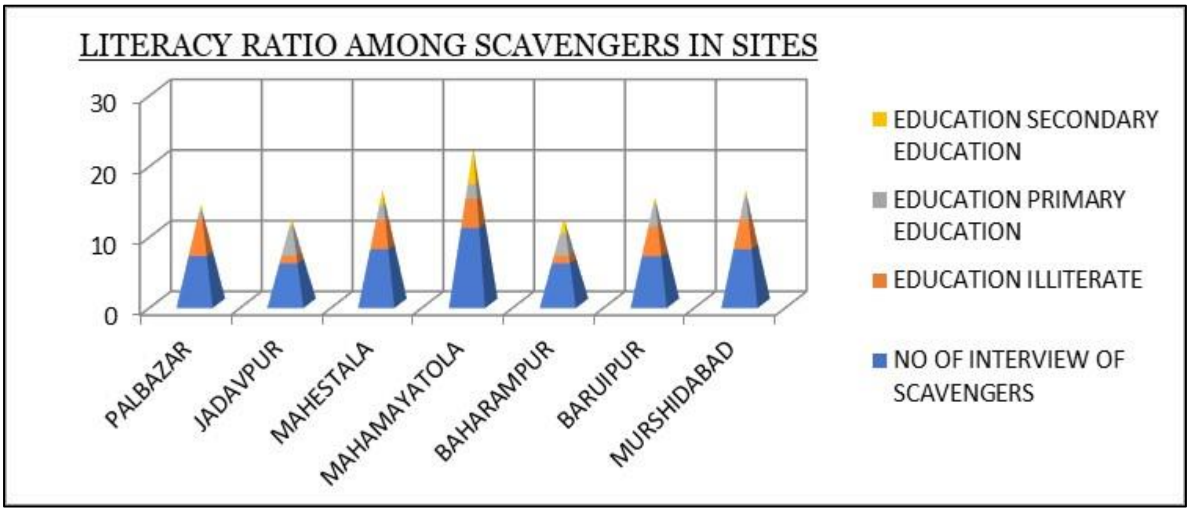


Figure 19: Literacy ratio of scavengers

4.1.3.2 HEALTH ASPECT

PHYSICAL HAZARDS-

In the physical hazards, the most common diseases are skin diseases, injury, respiratory diseases, and musculoskeletal symptoms among waste pickers. In most of the sites, skin diseases and injuries are around 75%, the physical weakness is about 60% which is a high range due to involvement in the physical hard-working job.

Table 13: showing the health aspect of scavengers in various sites

Sl no.	Survey area	Health impact				
		No. Of scavengers served	Injury	Musculoskeletal symptoms	Skin diseases	Addiction
1	Palbazar	7	2	5	4	5
2	Jadavpur	6	5	6	4	3
3	Mahestola	8	5	5	2	3
4	Mahamayatola	11	8	3	5	9
5	Baharampur	6	2	3	2	5
6	Baruipur	7	4	5	5	6
7	Murshidabad	8	6	7	5	7
	Total	**53**	**32**	**34**	**27**	**40**

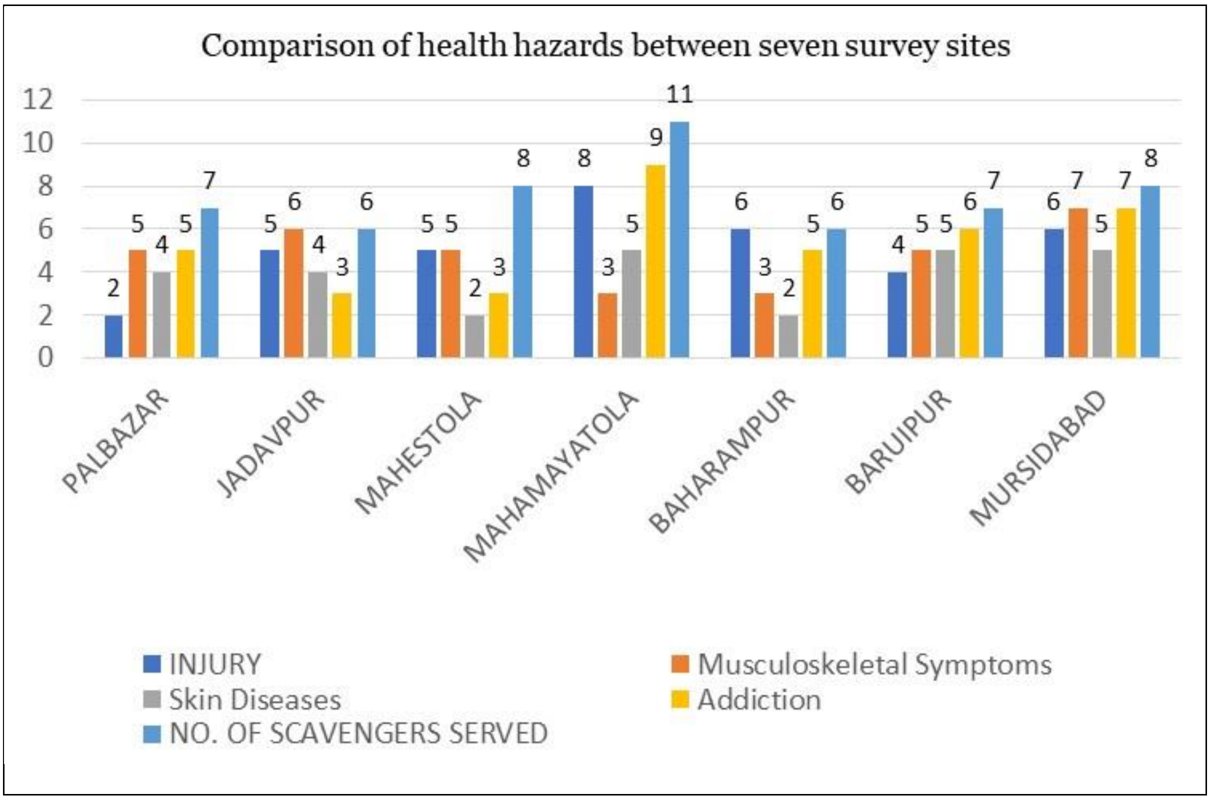


Figure 20: Health hazards faced by scavengers

MENTAL DISORDERS

In these studies, it has been observed that mental disorder like anxiety and tension is the most common factor among waste pickers as their low-income, uncertain job, and most importantly high- priced daily foods in major cities. Among the urban poor, the existence of low income, and poor livelihood is the reason for getting addictions like smoking, drinking, etc, which is not good at all for their health and society. On the site Mahamayatala, the responded male is more badly addicted due to poverty and lack of education.

4.1.3.3 ECONOMIC ASPECT

AVERAGE INCOME - Among seven sites, the average monthly income of waste pickers is around 6000-6500rs. Due to contractual jobs, the fixed wage is not sufficient at all for scavengers. In southern Kolkata, mainly in Baruipur, the wages of the scavengers are high among the seven sites.

Table 14: The average income of scavengers at various sites

Sl no	Location of the interview	Average income	Average income
		5001-7000	7001-9000
1	Palbazar	4	3
2	Jadavpur	5	1
3	Mahestala	6	2
4	Mahamayatola	8	3

5	Baharampur	1	5
6	Baruipur	1	6
7	Murshidabad	3	5
	Total	**28**	**25**

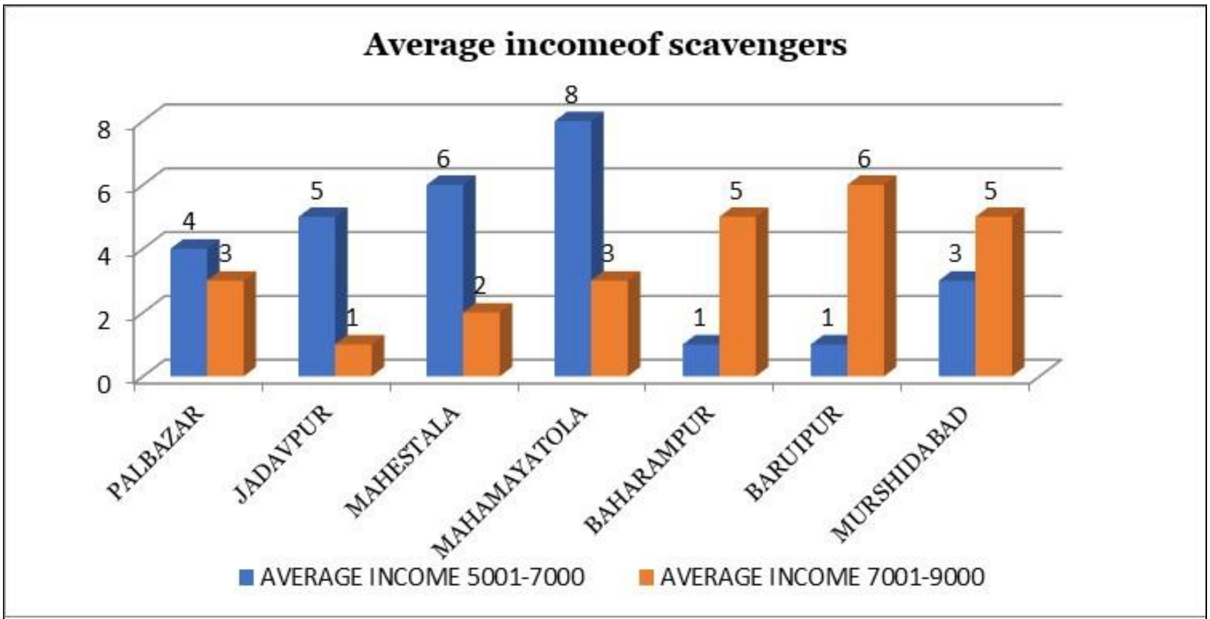


Figure 21: Average income of scavenges

MEDICAL EXPENSES AND WELFARE SCHEMES

Due to getting involved in unhygienic and unhealthy jobs, the medication expenses are getting regular and high. The average expenses are around 250-500 Rs in most of the sites whereas also the rate is also low, below 250 Rs in Mahamayatala. The welfare scheme, Swastha Sathi Card among scavengers is common in most of the sites.

5.2 Sampling of plastic waste in different dumpsites in *Kolkata, Murshidabad, Odisha.*

This work package is about a field study on the sampling of plastic waste in different dumpsites in and around Kolkata, West Bengal and Odisha. Different dumpsites of Kolkata and surrounding are selected for sampling study named as **Baruipur, Maheshtala, Berhampur,** and **Murshidabad** and dumpsite in Odisha named as **Bhubneshwar, Cuttack, Berhampur, Angul, Sambalpur, Keonjhar, and Sundargar.** Samples were collected from all the dumpsites after sampling and stored in the lab for further study.

Coning and quartering method [IS 436-1-1 (1964)] is used for sampling of mixed solid waste.

Sampling Plan of Collection of Waste Plastics from Dumpsites

- Selection of proper Dumpsite
- Taking Pictures of the overall dumpsite
- Communicate with the authority in charge of waste collection and preceding.
  Sampling is to be conducted in Coning and Quartering Sampling Procedure

[Ref: 1. Solid biofuels — Sample preparation; BS EN 14780:2011; BSI Standards Publication 2. Swachh Bharat Mission; Municipal Solid Waste; Management Manual; Part II]

Coning and quartering method – The size reduction of a powdered or granular sample by creating a conical heap that is spread out into a flat circular cake. The cake is divided radially into 4 equal parts and two opposite parts are combined. The other two parts are discarded. To obtain the quantity desired for some final use the process is repeated as many times as necessary (e.g., as the laboratory sample or taste sample).

1. A definite 64 kg fresh municipal solid waste is to be collected.
2. Samples from all heterogeneous sampling points shall be mixed thoroughly. [Initially, the fresh waste consists of concentration variations in different points; they are to be mixed well to get almost equal concentrations in different points of waste collected]
3. Then the sample is placed on a clean plastic sheet (10'×10′) which is spread on a plain surface in the form of a heap. (Ref: A Sampling Protocol for Composting, Recycling, and Re-use of Municipal Solid Waste; Martin J.H.; et al.)
4. The total waste taken for sampling is to be divided into 4 parts, using straight lines, perpendicular to each other, where each possesses a similar weight (16 kg each)
5. Waste from opposing corners of the divided heap is removed to leave half of the original sample. The remaining portions (16+16 = 32 kg) are to be thoroughly mixed.

6. The mixed waste is to be separated into 4 parts (8 kg each) in a similar fashion and 2 diagonal portions are taken removing the other 2 portions.
7. Remaining portions (8+8= 16kg) are to be mixed well.
8. The Same process followed up to the total 4kg of MSW remains.
9. The amount of plastic waste is to be separated from the total mixed waste of 4 kgs and weighed properly. And the plastic wastes are to be sorted into a different container.
10. Weighing: Before and after washing & cleaning.
11. Plastic wastes are to be washed and dried properly to segregate the residues and impurities. After drying up completely, plastic waste is to be weighed and residue fraction can be measured from plastic waste.
12. After sorting out the plastic waste, they are to be identified and separated further for non-recyclable plastics.
13. Few clear videos and photos are to be captured of the overall sampling and segregation procedure.
14. All the packets of cleaned plastics are kept with labels and dates, and locations for testing.

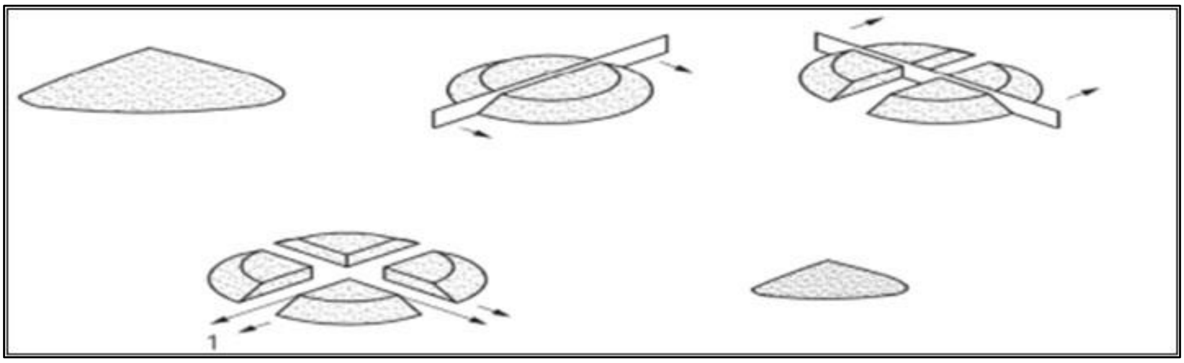


Figure 22: Coning and Quartering Method [BS EN 14780:2011; P-14]

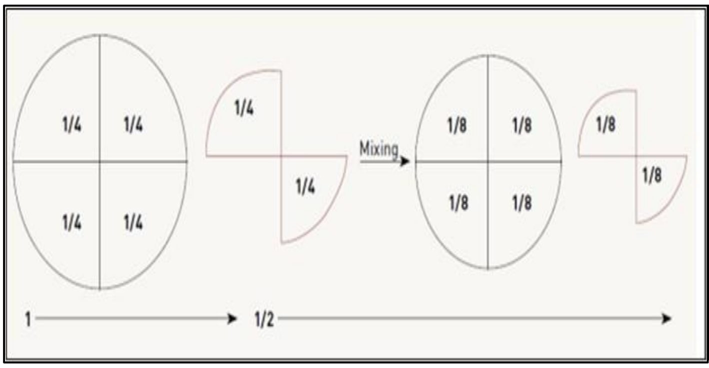


Figure 23: Characterization of Municipal Solid Waste through Quartering Method [Swachh Bharat Mission; Municipal Solid Waste; Management Manual; Part II, 2016]

Sampling Tools & Equipment

- Weighing machine (100 kg precision)
- Digging Hoe (Kodal)
- Containers
- Gloves for waste handling
- Labours

5.2.1 Sampling at Baruipur dumpsite of West Bengal

- **Location of the Dumpsite**: kirtonkhola, ward-08, Baruipur, 19 km from Jadavpur university
- **Age of Dumpsite:** Over 60 years
- **No. of words covered:** 17 (Baruipur municipalities)
- **Types of waste compositions:** Mixed waste
- **No. Of scavenger/waste pickers Formal/Informal):** 110 (20/90)
- **Area of dumpsite:** 2.03 acre
- **Total solid waste accumulated daily:** 33 to 34 tons
- **Types of vehicles- used for disposal of waste:** Tractors, Lorry, Dumper, compactors, paddle tricycles, battery-operated trippers, and fuel-operated trippers

5.2.1.1 Sampling of plastic waste at the dumpsite:

- 2 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
  - ❖ Mixed waste #sample-01 (8.5 kg): 2.5 kg
  - ❖ Mixed waste #sample-02 (4 kg): 0.5 kg

Figure 1: Total 64 kg of mixed solid waste was mixed well for sampling and placed in a clean fresh surface

Figure 2: The mixed solid waste taken; divided into 4 parts, each having 16 kg

Figure 3: Waste from opposing corners of the divided heap was removed to leave half of the original sample

Figure 4: The remaining waste was mixed thoroughly again placed in a clean fresh surface

Figure 5: The mixed waste was divided into 4 parts in similar fashion

Figure 6: Wastes from opposite corners were mixed & plastic wastes are separated

Figure 24: Sampling at Baruipur dumpsite of West Bengal

5.2.2 Sampling at Maheshtata dumpsites of West Bengal

- **Location of the Dumpsite:** Budge Budge Trunk Rd, Balarampur, Maheshtala, West Bengal 700140
- **Age of Dump site:** 16 years
- **Area of dumpsite:** 49 bigha
- **No. of words covered:** 35
- **Total solid waste accumulated daily:** 180 metric ton
- **Waste composition:** Mixed waste, kitchen garbage
- **Types of vehicles:** Paddle Tri-Cycle, Tractor, Eicher car, Tata 407, Ashok ley land, Tata ACE, JCB, JCB Hydra, Excavator, Tata V30, Dumper, Hyva compacter, Tri Cycle van.
- **No of scavengers working at the dumpsite:** 19 (Informal)

5.2.2.1 Sampling of plastic waste at the dumpsite:

- Plastic waste from total 4.5 kg of mixed solid waste is separated and weighed properly.
- Quantity of plastic waste from
  - Mixed waste #sample-01 (4.5 kg): 1 kg


Figure 1: Total 64 kg of mixed solid waste was mixed well for sampling and placed in a clean fresh surface


Figure 2: The mixed solid waste taken; divided into 4 parts, each having 16 kg


Figure 3: Waste from opposing corners of the divided heap was removed to leave half of the original sample


Figure 4: The sample was missed thoroughly again placed in a clean fresh surface


Figure 5: The mixed waste was separated into 4 in similar fashion


Figure 6: Diagonal portions were taken removing other 2 portions.


Figure 7: Wastes from opposite corners were mixed & plastic wastes are separated


Figure 8: The plastic waste separated was collected, labelled and weighed

Figure 25: Sampling at Maheshtata dumpsites of West Bengal

5.2.3 Sampling at Lalbag Murshidabad dumpsites of West Bengal

- **Location of the Dumpsite:** Lalbag municipality Murshidabad
- **Age of Dump site:** 3 years
- **Area of dumpsite:** 5 acres
- **No. of words covered:** 16
- **Total solid waste accumulated daily:** 32 metric ton
- **Waste composition:** Mixed waste, kitchen garbage
- **Types of vehicles:** Paddle Tri-Cycle, Tractor, Eicher car, Tata 407, Ashok ley land, Tata ACE, JCB, JCB Hydra, Excavator, Tata V30, Dumper, Hyva compacter, Tri Cycle van.

5.2.3.1 Sampling of plastic waste at the dumpsite:

- Quantity of plastic waste from
  - Mixed waste #sample-01 (4 kg): 0.495 kg
  - Mixed waste #sample-02(4 kg): 0.685 kg

Figure 26: Sampling at Lalbag Murshidabad dumpsites of West Bengal

5.2.4 Sampling at Berhampur dumpsites of West Bengal

- **Location of the Dumpsite:** Berhampur
- **Age of Dump site:** 30 years (Approx.)
- **Total solid waste accumulated daily**: 120 TPD
- **Types of vehicles-** used for disposal of waste: Tractors, Lorry, Dumper, Pay Ladder

5.2.4.1 Sampling of plastic waste at the dumpsite:

- 2 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
    - Mixed waste #sample-01 (4 kg): 0.42 kg
    - Mixed waste #sample-02(4 kg): 0.435 kg

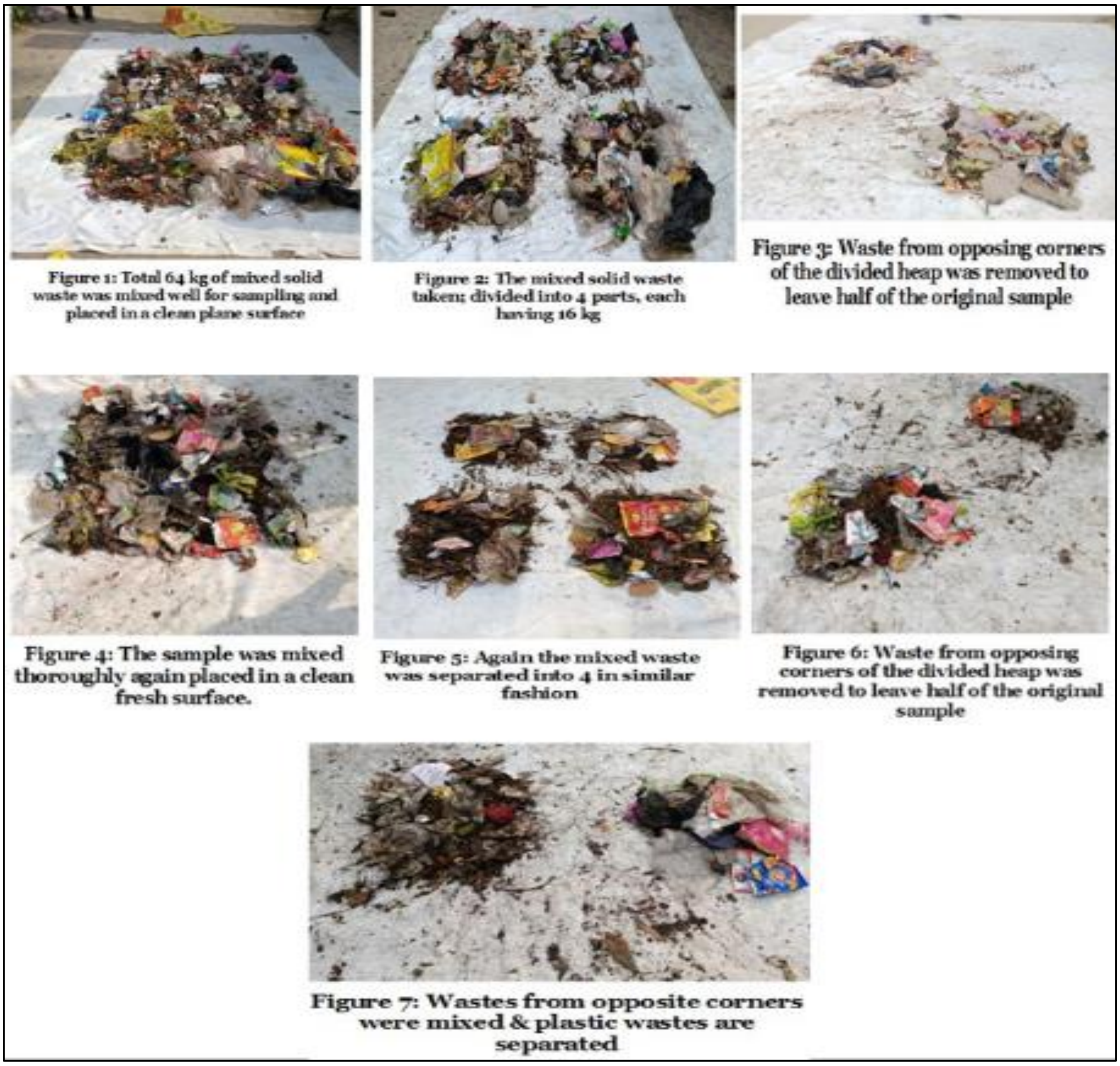


Figure 27: Sampling at Berhampur dumpsites of West Bengal

5.2.5 Sampling at Bhubneshwar dumpsite of Odisha

- **Location of the Dumpsite:** Bhuashani
- **Age of Dump site:** 15 years (Approx.)
- **Total solid waste accumulated daily**: 190 TPD
- **Types of waste compositions:** Mixed solid waste
- **Types of vehicles-** used for disposal of waste: Tractors, Lorry, Dumper, Pay Ladder

5.2.5.1 Sampling of plastic waste at the dumpsite:

- 2 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
  - Mixed waste #sample-01 (8.275 kg): 1.42 kg
  - Mixed waste #sample-02(7. 924 kg): 0.90 kg

Total 64 kg of fresh MSW is collected and placed on the sheet

Total waste is divided into 4 equal parts, each having 16 kg

Waste from opposing corners of the divided heap was removed to leave half of the original sample

The sample was missed thoroughly again placed on a clean fresh surface and the whole process is repeated

plastic wastes are separated from the mixed waste

The plastic waste separated was collected, labelled, and weighed

Figure 28: Sampling at Bhubneshwar dumpsite of Odisha

5.2.6 Sampling at Cuttack dumpsite of Odisha

- **Location of the Dumpsite:** Chakradharpur
- **Age of Dump site:** 14 Years (2008 onwards)
- **No. of wards:** 59 Nos
- **Area of the dumpsite:** 27 Acre
- **Total solid waste accumulated daily**: 150 TPD
- **Types of waste compositions:** Mixed solid waste
- **Types of vehicles-** used for disposal of waste: Battery-operated vehicles, Tracks, Hyva

5.2.6.1 Sampling of plastic waste at the dumpsite:

- 2 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
  - Mixed waste #sample-01 (4.67 kg): 0.695 kg
  - Mixed waste #sample-02 (5.87 kg): 0.790 kg

Figure 1: Collection of freshlydumped waste

Figure 2: Total 64 kg of mixed solid waste was mixed well for sampling and placed on a clean fresh surface

Figure 3: The mixed solid waste is taken; divided into 4parts, each having 16 kg

Figure 4: Waste from opposing corners of the divided heap was removed

Figure 5: The sample was missed thoroughly again placedon a clean fresh surface

Figure 6: The mixed waste was separated into 4 in a similarfashion

Figure 7: Diagonal portionswere taken removing the other 2 portions

Figure 8: Wastes from opposite corners were mixed &plastic wastes are separated

Figure 9: The plastic waste separated was collected, labeled, and weighed

Figure 29: Sampling at Cuttack dumpsite of Odisha

5.2.7 Sampling at Berhampur dumpsite of Odisha

- **Location of the Dumpsite:** Mahuda
- **No. of wards:** 42 Nos
- **Total solid waste accumulated daily**: 100 TPD
- **Types of waste compositions:** Mixed solid waste
- **Types of vehicles-** used for disposal of waste: Battery-operated vehicles, Tracks, Hyva

5.2.7.1 Sampling of plastic waste at the dumpsite:

- 2 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
    - ❖ Mixed waste #sample-01 (8.985 kg): 0.935 kg
    - ❖ Mixed waste #sample-01 (10 kg): 1.035 kg

Figure 1: Total 64 kg of mixed solid waste was mixed well for sampling and placed on a clean surface

Figure 2: Mixed waste is divided into 4 equal parts each having 16 kg

Figure 3: Waste from opposing corners of the divided heap was removed

Figure 4: The sample was missed thoroughly again placed on a clean fresh surface in square shape

Figure 5: Again, divided into 4 equal parts

Figure 6: Diagonal portions were taken removing the other 2 portions

Figure 7: At last, the NRPW is separated, labeled & packed

Figure 30: Sampling at Berhampur dumpsite of Odisha

5.2.8 Sampling at Angul dumpsite of Odisha

- **Location of the Dumpsite:** Mahuda
- **No. of wards:** 23 Nos
- **Area of dumpsite:** 2 acres
- **Total solid waste accumulated daily**: 15 TPD
- **Types of waste compositions:** Mixed solid waste
- **Types of vehicles-** used for disposal of waste: Battery-operated vehicles, Tracks, Hyva

5.2.8.1 Sampling of plastic waste at the dumpsite:

- 1 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
  - Mixed waste #sample-01 (8.275 kg): 0.80 kg

Total 64 kg of fresh MSW is collected and placed on the sheet

Total waste is divided into 4 equal parts, each having 16 kg

Waste from opposing corners of the divided heap was removed to leave half of the original sample

The sample was missed thoroughly again placed on a clean fresh surface and the whole process is repeated

plastic wastes are separated from the mixed waste

The plastic waste separated was collected, labelled, and weighed

Figure 31: Sampling at Angul dumpsite of Odisha

5.2.9 Sampling at Sambalpur dumpsite of Odisha

- **Location of the Dumpsite:** Sikirdi
- **Age of Dumpsite: 7 Years (2015 onwards)**
- **Total solid waste accumulated daily**: 37 TPD
- **Types of waste compositions:** Mixed solid waste
- **Types of vehicles-** used for disposal of waste: Battery-operated vehicles, Tracks, Hyva

5.2.9.1 Sampling of plastic waste at the dumpsite:

- 2 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
  - ❖ Mixed waste #sample-01 (4.19 kg): 0.220 kg
  - ❖ Mixed waste #sample-02 (4.69 kg): 0.330 kg

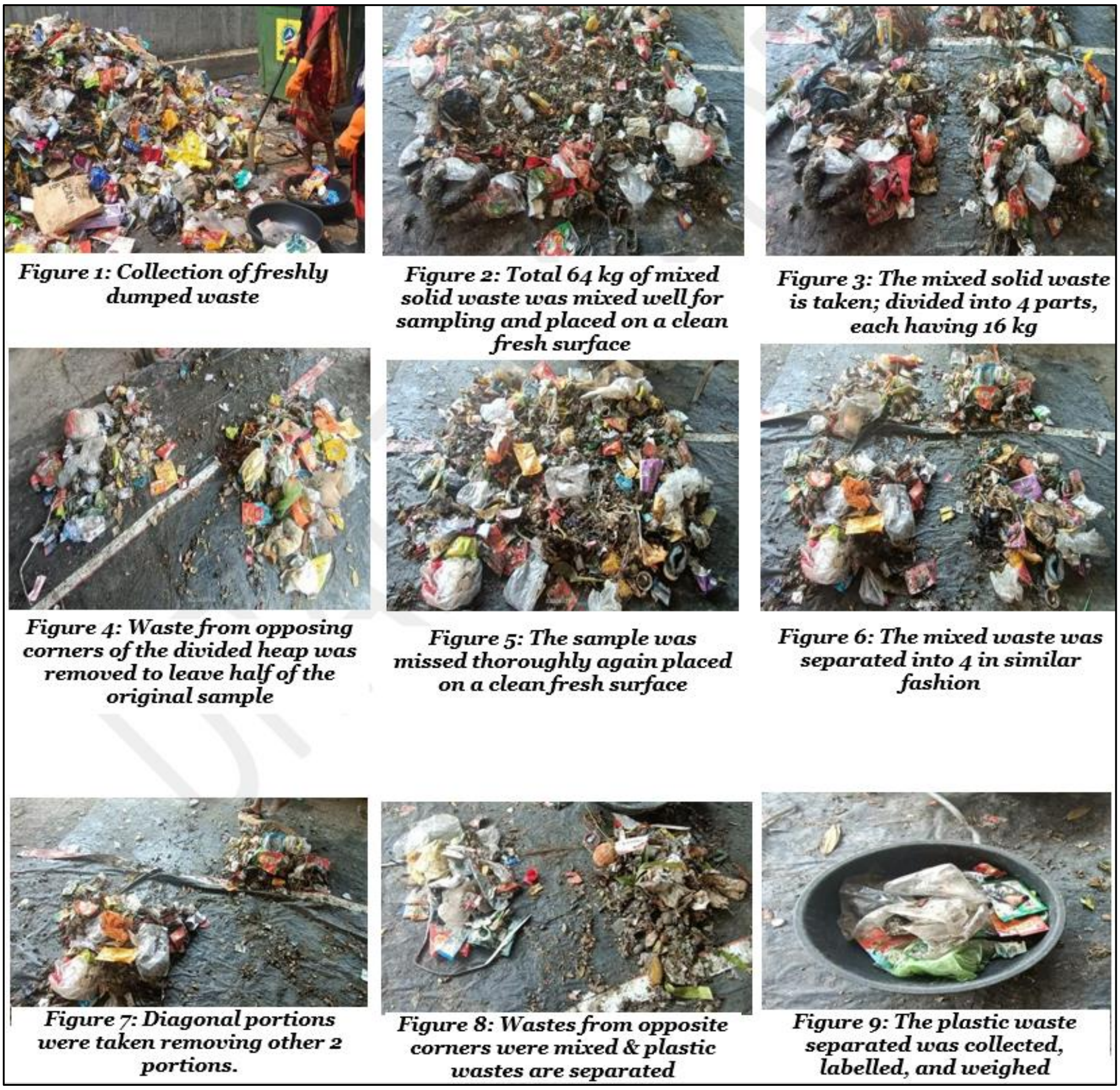


Figure 1: Collection of freshly dumped waste

Figure 2: Total 64 kg of mixed solid waste was mixed well for sampling and placed on a clean fresh surface

Figure 3: The mixed solid waste is taken; divided into 4 parts, each having 16 kg

Figure 4: Waste from opposing corners of the divided heap was removed to leave half of the original sample

Figure 5: The sample was missed thoroughly again placed on a clean fresh surface

Figure 6: The mixed waste was separated into 4 in similar fashion

Figure 7: Diagonal portions were taken removing other 2 portions.

Figure 8: Wastes from opposite corners were mixed & plastic wastes are separated

Figure 9: The plastic waste separated was collected, labelled, and weighed

Figure 32: Sampling at Sambalpur dumpsite of Odisha

5.2.10 Sampling at Keonjhar dumpsite of Odisha

- **No. of wards:** 21 Nos
- **Types of waste compositions:** Mixed solid waste
- **Types of vehicles-** used for disposal of waste: Battery-operated vehicles, Tracks, Hyva

5.2.10.1 Sampling of plastic waste at the dumpsite:

- 2 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
    - Mixed waste #sample-01 (7.93 kg): 1.52 kg
    - Mixed waste #sample-02(7.86kg): 0.98 kg

Figure 1: Total 64 kg of mixed solid waste was mixed well for sampling and placed on a

Figure 2: The mixed solid waste is taken; divided into 4 parts, each having 16 kg

Figure 3: Waste from opposing corners of the divided heap was removed

Figure 4: The sample was missed thoroughly again placed on a clean fresh surface in square shape

Figure 5: Again, divided into 4 equal parts

Figure 6: Diagonal portions were taken removing the other 2 portions

Figure 7: The plastic waste separated was collected, labeled, and weighed

Figure 33: Sampling at Keonjhar dumpsite of Odisha

5.2.11 Sampling at Sundargar dumpsite of Odisha

- **No. of wards: 19 Nos.**
- **Types of waste compositions: Mixed solid waste**
- **Total solid waste accumulated daily: Around 35 TPD**
- **Types of vehicles-** used for disposal of waste: Battery-operated vehicles, Tracks, Hyva

5.2.11.1 Sampling of plastic waste at the dumpsite:

- 1 sampling of plastic waste had been taken from mixed solid waste.
- Quantity of plastic waste from
  - ❖ Mixed waste #sample-01 (7.93kg): 1.2 kg

Figure 34: Sampling at Sundargar dumpsite of Odisha

5.2.12 Results of sampling at dumpsites in Kolkata, *Murshidabad*, *Odisha*.

Table 15: Data for sampling of waste at different dumpsites in Kolkata, Murshidabad, Odisha.

Sl. No.	Location of the dumping ground with GPS	Date of Visit	Sample No.	Type of the fresh solid waste taken	Weight of NRPW in 16 kg of solid waste	Weight of NRPW in 64 kg of solid waste	Average weight of NRPW in 64 kg of solid waste (Kg)
1.	Promodnagar [22.646, 88.369]	21.12.2020	1	Mixed	0.3	4.8	7.015086 Kg (10.96%)
			2	Mixed	0.325	5.2	
2.	Baidyabati [22.788, 88.317]	22.12.2020	1	Dry	0.45	7.2	
			2	Mixed	0.268	4.3	
			3	Mixed	0.316	5.06	
3.	Budgebudge [22.473, 88.189]	11.01.2021	1	Mixed	0.305	4.08	
			2	Mixed	0.277	4.44	
4.	Sonarpur-Rajpur [22.422, 88.425]	14.01.2021	1	Mixed	0.212	3.4	
			2	Mixed	0.237	3.8	
			3	Mixed	0.237	3.8	
			4	Mixed	0.277	4.4	
5.	Dhapa [22.538, 88.422]	18.01.2021	1	Mixed	0.362	5.8	
			2	Mixed	0.33	5.28	
6.	Baruipur [22.35, 88.43]	23.03.2022	1	Mixed	0.48	7.68	
			2	Mixed	0.453	7.248	
7.	Maheshtala [22.51, 88.25]	29.03.2022	1	Mixed	0.562	8.992	
			2	Mixed	0.536	8.576	
8.	Berhmpore [24.124, 88.261]	09.04.2022	1	Mixed	0.42	6.72	
			2	Mixed	0.435	6.96	
9.	Murshidabad [24.175, 88.28]	09.04.2022	1	Mixed	0.495	7.92	
			2	Mixed	0.685	10.96	
10.	Bhubneshwar (Bhuashani)	21.06.2022	1	Mixed	2.74	10.98	
			2	Mixed	1.817	7.268	
11.	Cuttack (Chakradharpur)	21.06.2022	1	Mixed	2.38	9.52	
			2	Mixed	2.15	8.61	
12.	Berhampur (Mohuda)	22.06.2022	1	Mixed	1.66	6.65	
			2	Mixed	1.65	6.624	
13.	Angul (Panchamahalla)	22.06.2022	1	Mixed	1.54	6.18	
			2	Mixed	1.74	6.96	
14.	Sambalpur (Durgapalli)	23.06.2022	1	Mixed	1.68	6.72	
			2	Mixed	2.25	9.00	
15.	Keonjhar	23.06.2022	1	Mixed	3.06	12.26	
			2	Mixed	1.99	7.97	
16.	Sundargar	25.06.2022	1	Mixed	2.42	9.68	
			2	Mixed	2.62	10.49	

In total 16 dumpsites, from Kolkata, *Murshidabad, and Odisha* are analysed to identify the percentage of NRPW in the MSW dumped there. These data are shown in table 15.

The sixteen dumpsites have an average amount of 7.015086 Kg of Non-recyclable plastic waste from a sample of 64 Kg of solid mixed waste which is around 10.96%. It gives an idea that the municipal solid mixed waste of Kolkata, Murshidabad, and Odisha has approximately 10.96% of non-Recyclable plastic waste.

Table 16: Data for incoming waste per day at different dumpsites in Kolkata, Murshidabad, and Odisha.

Sl. No.	Dumpsite	Incoming waste (Tons/day)
1.	Promodnagar	315
2.	Baidyabati	50-60
3.	Budgebudge	30-35
4.	Sonarpur-Rajpur	25-30
5.	Dhapa	5000
6.	Baruipur	33-34
7.	Maheshtala	180
8.	Berhmpore	150
9.	Murshidabad	32
10.	Bhubneshwar	520
11.	Cuttack	150
12.	Berhampur	00
13.	Angul	20
14.	Sambalpur	37
15.	Keonjhar	00
16.	Sundargar	00
Total		**6542 (approximate)**

A total of 6542 tons of municipal solid waste is generated from the sixteen biggest dumpsites in Kolkata, Murshidabad, and Odisha per day. According to the sampling result out of 6542 tons of municipal waste around 717 tons (@10.96%) is non-recyclable plastic waste. This waste can be used in cement plants as an alternative fuel.

As per the test result shown below the average Gross Calorific Value of RDF is 2892 Kcal/ kg. which with in permissible limit mentioned in the CPCB guidelines

Waste plastic calorific test results from Qualitek Labs Private Limited

Analysis Details:

Discipline: Chemical
Group: Solid Waste

Analysis start date: 15/03/2022
Analysis end date: 17/03/2022

Sr. No	Test Parameters	Unit of measurement (UOM)	Test Method	Specifications	Test Result
1.	Gross Calorific Value	Kcal/ kg	QLB/STP/EW/067	NA	2892

Remarks:

1.0- NA- Not Applicable

Reviewed by:
Name: Dr. Md. Motiar Rahaman Khan
Designation: Manager Q.A.

Authorized by:
Name: Partha Ulal
Designation: Group Leader (Environment & Water)

End of Test Report

Figure 35: Calorific value of RDF

5.3 Discussion & Conclusion from Test results

Economic, Social, Health & Safety impacts on informal scavengers in waste management.

Our survey observed that more men are working as informal scavengers in waste management than women (gender ratio 4:1) in the respective study areas. Almost 70% of those scavengers have an experience of 6 to 15 years in waste management. But it was also observed in a few areas such as Mahestala, Mahamayatola, and Murshidabad scavengers below 18 years (minimum age for working in waste management) are also involved in work and their participation is almost 5% of the total observed scavengers. Almost 40% of total scavengers are illiterate, 30% of scavengers have a primary level education, and around 20% of scavengers have the opportunity of secondary education.

Due to involvement in dirty work like waste picking, 60% of scavengers suffer from different injuries and 50% of scavengers have skin-related problems. As waste picking is a labour-intensive job, around 60% of scavengers have Musculoskeletal symptoms. Addiction is also a major problem among scavengers as 75% of them have some kind of addiction to alcohol, smoking and tobacco. On the other hand, anxiety and hypertension are common among the scavengers due to their low income, and uncertainty in the job.

The average income of the scavengers is around 7000 Rs per month in observed cities where around 52% of the scavengers have their monthly income between 5000-7000 Rs and the rest around 48% of the scavengers have their monthly income between 7000-9000 Rs. But around 250-500 Rs per month is the expense of medications due to the unhygienic and unhealthy job nature.

Sampling of plastic waste in different dumpsites in *Kolkata, Murshidabad, Odisha.*

In total 16 dumpsites, from Kolkata, Murshidabad, and Odisha are analysed to identify the percentage of NRPW in the MSW dumped there. The sixteen dumpsites have an average amount of 7.015086 Kg of Non-recyclable plastic waste from a sample of 64 Kg of solid mixed waste which is around 10.96%. It gives an idea that the municipal solid mixed waste of Kolkata, Murshidabad, and Odisha has approximately 10.96% of non-Recyclable plastic waste.

A total of 6542 tons of municipal solid waste is dumped every day in the sixteen biggest dumpsites in Kolkata, Murshidabad, and Odisha. According to the sampling result out of 6542 tons of municipal waste around 650 tons (@10.96%) are non-recyclable plastic waste.

So, the potential of these sixteen dumpsites for producing RDF from MSW is around 650 Tons per day.

5.4 Summary of chapter

The survey on informal scavengers involved in waste picking gives us an idea about the socioeconomic and health, safety problems. To strengthen waste management in the observed cities, it is very important to address the problems faced by the scavengers during their involvement in waste management works.

Data collected from the field study in dumpsites of Kolkata, Murshidabad, and Odisha tells us that there is a huge potential for producing RDF from the non-recyclable part of plastic waste dumped at those dumpsites for co-processing of plastic waste in cement kilns. As per the CPCB guidelines on the use of waste as an alternative fuel and raw material in cement plants, The GCV of the RDF produced from the NRPW from the MSW is 2892 Kcal/ kg, which is within the permissible limit.

Production of RDF in Waste Dumpsite

Chapter 6

In this chapter the RDF production and supply chain from waste dumpsite and legacy dumpsite is discussed in details.

The quality para meters of RDF are also discussed here

6.1 RDF supply chain and Potential of RDF production from waste dumpsites

Solid Waste Management is an integral part of Environment Management thus waste collection should be done scientifically. The waste collection process is complex, involving many Manpower, technologies, and infrastructure. The technologies involve collecting, handling, transportation to the dumping yard, treatment, and final disposal. Waste after generation in a co-mingled way is needed to be identified and separated into respective categories such as biodegradable and non-biodegradable. Collection of waste includes both the gathering of solid waste and recyclable materials and the activity of transport of these materials starting from the site of the location to the place where the collection vehicle is emptied.

It is essential to know the composition and characterization of MSW for implementing proper waste disposal and management plans and practices for the recovery of resource and energy potentials before deciding on the appropriate method of its disposal (Nilanthi et al., 2007).

It was identified in our study the percentage of non-recyclable plastic waste in the fresh municipal solid waste dumped in landfill sites is around 10% to 11%. According to the Ministry of Housing and Urban Affairs, the annual municipal solid waste generation is about 42.0 million tons and per day around 1.15 lakh metric tons (TPD). The 423 Class -1 cities alone produce 83,378 TPD solid waste, which is around 72.5% of the total waste generated each day. (MOHUA 2020)

According to MOHUA, the municipal waste composition is given below in fig 37.

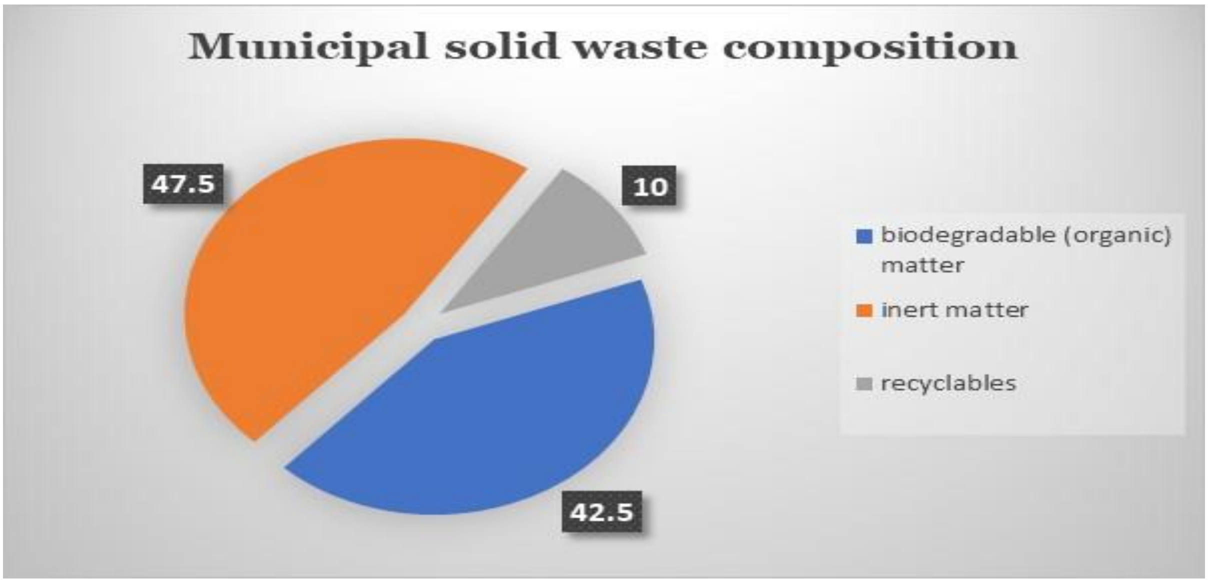


Figure 36: Municipal solid waste composition according to MOHUA.

So, considering 10%-11% of NRPW in total MSW the potential of RDF generation in India is around .46 million tons per year and around 12604 tons per day. If necessary, steps are taken to proper channelize this huge amount of RDF, which will help to boost the economy by saving valuable non-renewable fossil fuels and help to tackle the waste management problems.

The waste supply chain from source to RDF production is shown in the figure 38.

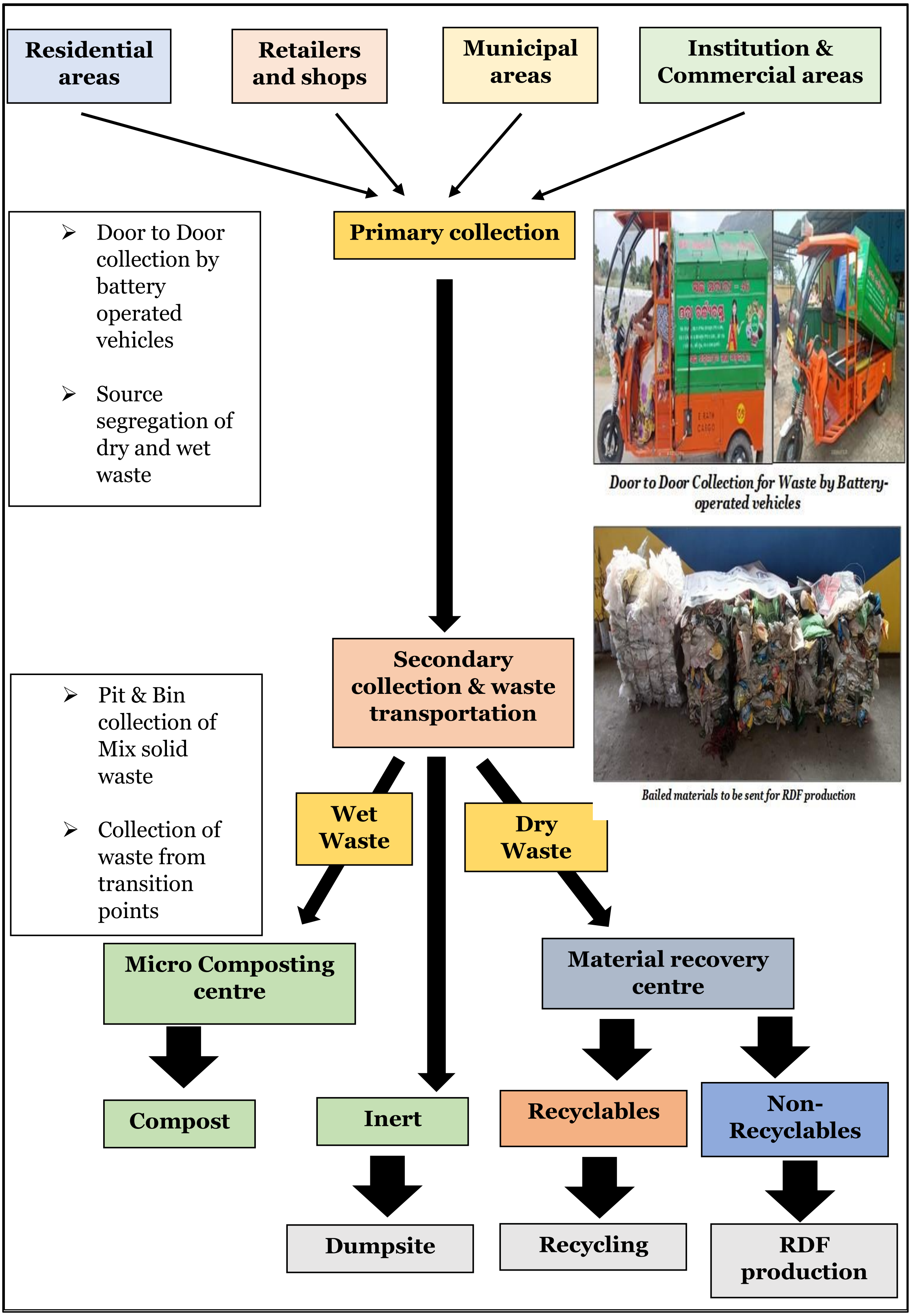


Figure 37: Supply chain for RDF production from fresh MSW.

6.2 RDF supply chain and Potential of RDF production from legacy dumpsites

Legacy waste-

Legacy wastes are the wastes that have been collected and kept for years on some barren land or aplace dedicated to a Landfill (an area to dump solid waste).

Environmental Impact of Legacy Waste-

- Legacy wastes not only occupy large space but also become a breeding ground for pathogens,flies, malodours, and the generation of leachate, which may lead to water contamination.
- They also contribute to the generation of greenhouse gases and pose a risk of an uncontrollable fire.

Need of Bio-mining of Legacy waste in India.

India's cities are struggling to manage their waste as these dumpsites have already exceeded their capacityand cannot take in any more waste. They have also not managed to find land for installing waste-processing facilities.

As much as 1,250 hectares of precious land is lost every year in India to dispose of municipal solid waste, according to the Swachh Bharat report (2020). The National Green Tribunal has estimated that more than 10,000 hectares of valuable urbanland are locked up under 3,159 legacy waste dumpsites in India.

These dumpsites have emerged as pollution hubs in the middle of human settlements, as cities have grown over the decades. It has, therefore, become a necessity for the city authorities to reclaim the existing dumpsites in an environmentally sound and economically viable manner.

The Centre has earmarked Rs 1,41,600 corer under its flagship Swachh Bharat Mission 2.0 (SBM 2.0), with a goal of achieving "garbage-free cities".

The focus of the mission is on the remediation of all legacy dumpsites in the country by bio-mining.

The Potential applications of legacy waste

Legacy waste has the potential to create a sustainable business model (SBM) which will support the circular economy concept of "Waste to wealth".

1. The non-recyclable plastic wastes recovered from the bio-mining of legacy dumpsites can be utilized in refuse-derived fuel (RDF) production.
2. These RDFs can be used to substitute natural non-renewable fossil fuels such as coal in a cement kiln or in any other energy-intensive industries.
3. The fine fraction can be used for several constructions and geotechnical applications such as soil cover in scientific landfills etc.

The supply chain for RDF production from the legacy waste is shown in the figure 39.

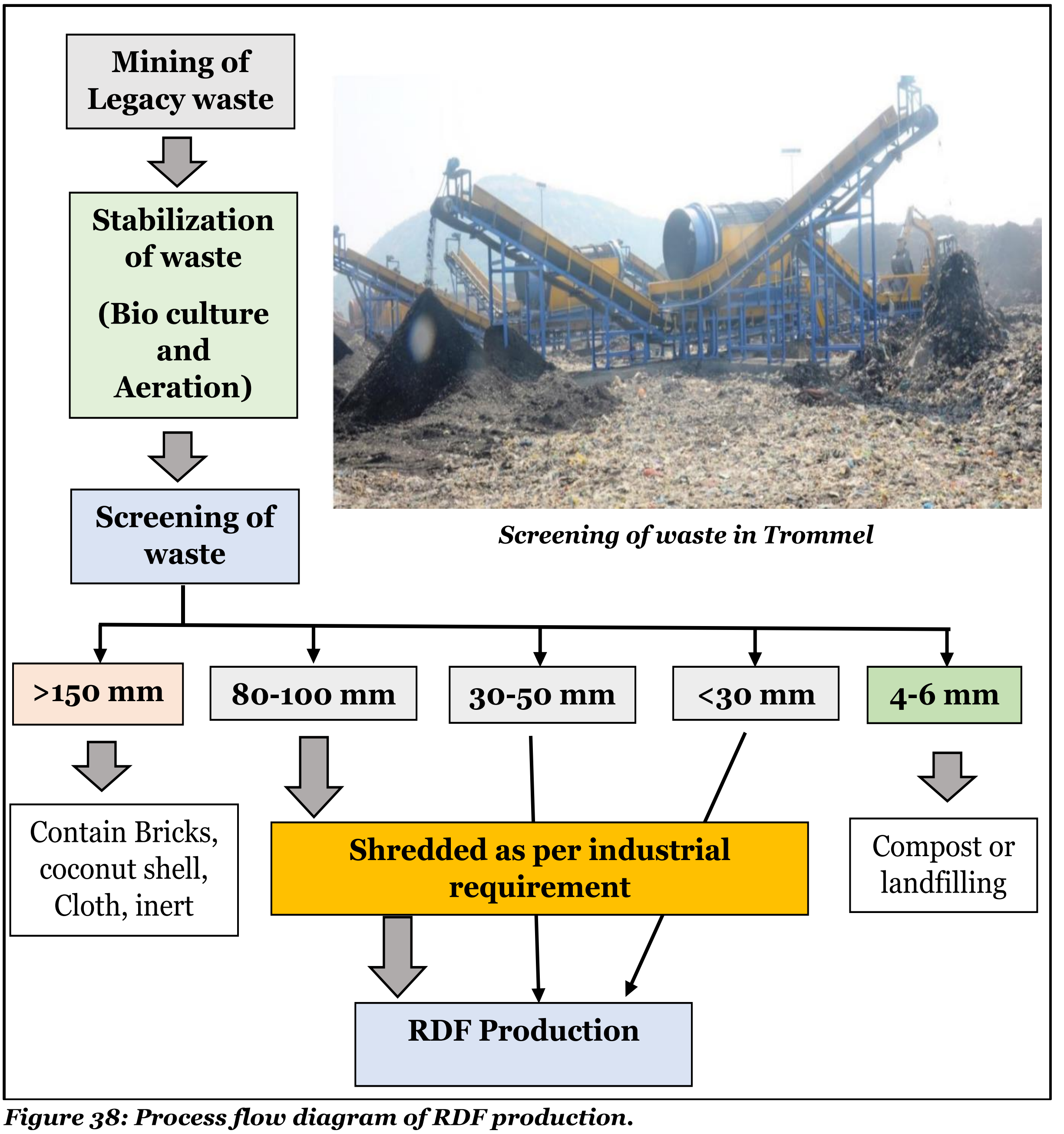


Figure 38: Process flow diagram of RDF production.

6.3 RDF production, calorific value, moisture, ash, and chloride content in non-recyclable plastic wastes.

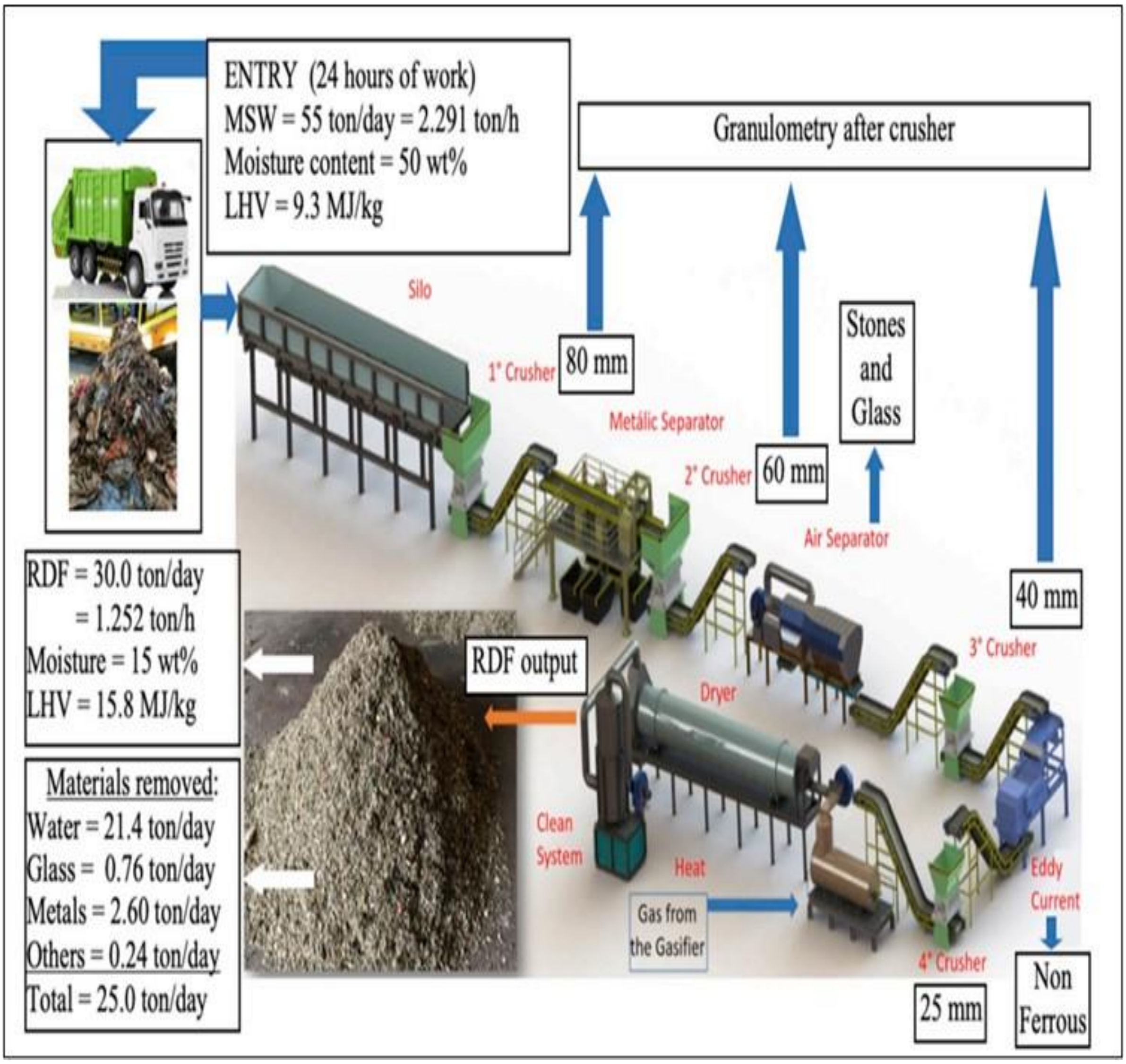


Figure 39: Scheme of the solid waste processing line (SWPL)

The production of RDF from municipal waste starts with weighing, unloading and storing the waste in a silo. The silo contains a conveyor belt that makes repetitive reciprocating motions and is perforated for drainage, and the MSW (pre-flush) water is collected. The waste is then transferred to a pre-shredder designed to accept any type of municipal waste from the silo without pre-selection or selection. The particle size of the RSU at the exit of the crusher is 80 mm. All the crushed residue falls into one Metal conveyor belt under the crusher. The biomass was transported to a selective waste collection platform with a rubber conveyor belt, and the recyclables, metals and glass were separated manually. At the end of the rubber conveyor belt was a magnetic separator to remove ferrous metals that were not removed by the selective collection staff. The tailings were then transferred to a secondary crusher which reduced the particle size to 60mm. Then by a High-density air separator material, such as glass, rocks and organic materials, is removed from the waste using a metal conveyor belt.

The waste is then fed to the tertiary crusher to reduce the particle size to 40mm. Aluminum is separated. Of the non-metallic materials (plastic, paper, rubber, etc.), the particle size was reduced to 25 mm using an eddy current separator using a quaternary crusher. The MSW was fed into a rotary dryer using a metal conveyor band where the moisture content has been reduced to about 15% by weight, the dryer also has the function of blending and homogenizing the RDFs to produce a uniform fuel.

There are different grades of RDF available. These grades depend on the size, ash content, moisture content, chlorine, sulfur, and calorific value of the respective RDF products are given in Table 17.

Table 17: Different grades of RDF and their properties

Sl.no.	Parameters	RDF - Grade III	RDF - Grade II	RDF -Grade I
01	Intended Use	For co-processing directly or after processing with other waste materials in a cement kiln	For direct co-processing in cement kiln.	For direct co-processing in cement kiln
02	Size	< 20 mm depending upon use in ILC or SLC, respectively		
03	Ash – maximum permissible	<15 %	<10 %	<10 %
04	Moisture – maximum permissible	< 20%	<15 %	<10 %
05	Chlorine – maximum permissible	< 1.0 %	< 0.7	< 0.5
06	Sulphur – maximum permissible	<1.5 %		
07	Net Calorific Value (NCV) – in Kcal/kg (Average figure of every individual consignment)	>3000 KCal/kg net	>3750 KCal/kg net	> 4500 KCal/kg net
08	Any other parameter	RDF – any offensive odour to be controlled.	RDF – any offensive odour to be controlled.	RDF – any offensive odour to be controlled.

(Source: Central Public Health and Environmental Engineering Organization (CPHEEO), 2018)

As per the MSW manual, the desirable characteristics of RDF for Co-processing in cement kilns are:

a) For the 2D material size of RDF should be < 120 mm and for 3D material < 70 mm subject to process limitations of specific plants.
b) Chlorine content of RDF depends on particular raw mix and fuel mix preferably < 0.7%,
c) Sulpher contents also depend on particular raw mix and fuel mix and should < 2%.
d) restricted items like PVC, explosives, batteries, biomedical waste, radioactive waste, etc. must not be present in RDF (Source: CPHHEO, 2018)

6.4 Conclusion.

Municipal Solid waste generated on a daily basis or already dumped as legacy waste for years in a dumpsite has a greater negative impact on countries economy, human health, and the environment. The amount of waste generated in India is around 1.15 lakh metric tons (TPD). Which has the potential for RDF production is around 12604 tons per day, annually .46 million tons. There is a huge scope of RDF production from waste in India. If necessary, steps are taken it will create new job opportunities and boost the circular economy by converting “Waste to Wealth”

In legacy dumpsites, there is a huge amount of legacy waste dumped for years occupying the precious land area and causing numerous environmental, health, and economic problems. Bio-mining of legacy waste to recover different types of waste which can be used for different purposes is one of the options to tackle this problem. There is a huge possibility of RDF production from legacy waste as it was found that around 25%-35% of waste is non-recyclable plastic waste which can be used in RDF production.

For proper utilization of this RDF in energy-intensive industries, the quality of RDF is an important factor. The produced RDF should fall within the limits suggested by CPCB and the characteristics of RDF should fulfil the requirement of the industries.

Impact of using RDF in Co-processing on the quality of Clinker and Cement.

Chapter 7

In this, there are some tests formed according to the BIS standards on cement samples with RDF and without RDF.

After comparing the test results the impact of RDF on the hydration and hardening qualities of cement is identified and discussed.

Impact of using RDF in Co-processing on the quality of clinker and cement

Due to its ductile and durable nature plastic can be moulded into various types of objects for numerous numbers of uses. (UNEP, 2020). Global fossil fuel-based plastic production dramatically increased, to greater than 454 million tonnes in 2018 where in 1950 it was 2 million tonnes (UNEP, 2020). Economic conditions, rate of industrialization, public habits, etc are some important parameters that are influencing per capita plastic waste generation in. In 2016 the total global plastic waste generated is about 242 million tonnes which is around 12 % of total municipal solid waste generated that year (UNEP, 2020).

To tackle the plastic waste problem different countries have adopted different plastic waste management techniques. Co-processing of non-recyclable plastic waste in cement kilns is a growing sector for waste management. In the Co-processing of non-recyclable plastic waste in cement kiln, primary fossil fuels are substituted by alternative fuels such as solid recovered fuels (SRF) in clinker burning process. Various studies have shown that RDF ashes contain various elemental compositions for cement manufacturing and can be used to substitute for traditional raw materials (Clavier et al., 2020).

7.1 Quality parameters of cement. (BIS)

According to BIS, the parameters that are to be checked to determine the quality of cement are given below in Table 18.

Table 18: Test parameters and the experiments on cement

Sl. No	Test Parameters	Experiments
01	**Quality check of cement at field (Field test)**	• Date of Packing • Color of Cement • Lumps test • Temperature test • Floating test
02	**Hydration quality check of cement**	• Fineness of cement • Soundness of cement (For free lime) • Standard consistency • Initial & Final setting time
03	**Quality check of hardened cement**	• Compressive strength

Here we are identifying the impact of RDF ash on the hydration and hardening qualities of cement.

Permissible limit for different tests according to Indian Standards are given in table 19.

Table 19: Permissible limit for tests according to Indian Standards

Sl.No.	Test Parameters	Permissible limit (BIS)	
		OPC	PPC
1	**Hydration quality**		
1.1	Fineness of cement	Not more than 10%	Not more than 5%
1.2	Soundness of cement (For free lime)	Not more than 10 mm	Not more than 10 mm
1.3	Initial setting time	Not less than 30 minutes	Not less than 30 minutes
1.4	Final setting time	not more than 600 minutes	not more than 600 minutes
2	**Hardened cement**		
2.1	Compressive strength	a) 72 minutes ± 1 hour, not less than 16 MPa, b) 168 minutes ± 2 hours not less than 22 MPa, and c) 672 minutes ± 4 hours not less than 33 MPa.	a) 168 minutes ± 2 hours not less than 22 MPa, and b) 672 minutes ± 4 hours not less than 33 MPa.

7.2 Test method

In this study, we are evaluating whether there is any impact on the quality of clinker and cement. The tests are framed according to BIS 4031, 1998 and the tests selected for identifying the impact on the hydration and hardening cement qualities are shown in table 19.

Table 20: Experiments on cement sample for identifying the impact on the hydration and hardening qualities of cement.

Sl. No.	Experiments on cement sample	Qualities of cement tested
01	Fineness test (Sieve test) **IS-4031 part 1 (1996)**	The fineness test is used to measure the surface area of cement particles per unit mass and denote the proper grinding of cement. cement **smaller particles** react much **quicker** than **larger particle**.

		Excess fineness will lead to quick setting and give no time for mixing placing and transportation of cement.
02	Standard consistency test **IS Code 4031 (Part 4 – 1988)**	Finding out the standard consistency of cement paste with Vicat apparatus is one of the vital works in the testing of cement. Standard consistency of cement is necessary because the percentage of water added to cement affects the other properties such as the setting time of cement and the strength of cement. For proper completion of the chemical reactions, it is necessary to add an adequate amount of water not less than this standard consistency. Again, greater amount of water will also reduce the strength by increasing water-cement ratio.
03	Initial setting time **IS 4031(Part 5):1988**	To identify the initial setting time as there is a time requirement for proper mixing, transportation, and placing of mortar.
04	Final setting time **IS 4031(Part 5):1988**	The time at which cement paste loses the plasticity and became hard is the final setting time of cement. For the safe removal of scaffolding or form the final setting time must be known.
05	Soundness test (For free lime) **IS Code 4031 (Part 3 – 1988)**	The set cement must not produce any appreciable change in volume. If the cement shows large expansion after setting, resulting disruption of the set and hardened mass and possess a big threat to the durability of structures. Soundness is the ability to resist volume expansion.
06	Compressive strength test **IS 4031(Part 6):1988**	Strength is one of the most important properties of cement. With increase in compressive strength flexural strength, resistance to abrasion, and so on also increases. To identify the suitable grade of cement compressive strenghth test of cement is a important test.

7.3 Cement manufacturer selection

In this test, we are comparing the qualities of cement sample made with RDF ash through co-processing with cement sample which isn't made with RDF ash through co-processing. For this purpose, the cement brands must be identified which are doing co-processing and which brands are not.

The survey is conducted in local cement supplier stores to identify the cement brands which are easily and widely available at those stores and noting the cement manufacturing plant name for identifying whether they are doing co-processing or not is also a purpose of this survey. A total of 21 different cement supplier stores are visited and 9 different widely available cement brands are identified at those stores. Manufacturing plants of those cement brands are noted for further study.

After reviewing the Annual Environmental Sustainability report of different cement plants, a total of 6 brands of which 3 brands are doing co-processing with RDF and the other 3 brands are not, details of these brands are shown in table 21.

Table 21: Details of selected cement brands for the study

Sl. No	Doing Co-processing with RDF	Cement sample no.	Cement plant	Source
1.	No	Cement Sample 01	Cement Limited Jhargram	Sustainability Report 2020-21
2.	No	Cement Sample 02	Purulia	Sustainability Report 2020-21
3.	No	Cement Sample 03	Cement LTD, Burdwan	Sustainability Report 2020-21
4.	Yes	Cement Sample 04	Rawan Cement Works, Chhattisgarh	Sustainability Report 2020-21
5.	Yes	Cement Sample 05	Cement Plant Sankrail	Sustainability Report 2020-21
6.	Yes	Cement Sample 06	Mejia Cement Plant	Sustainability Report 2020-21

7.4 Sample preparation & Sample size

There are 3 main parameters that define the qualities of cement. These parameters and related tests are mentioned in table 19.

So, here is the sample preparation procedure discussed for each of the testes

Hydration quality check of cement

- **Fineness of cement**

For fineness, the test totals 18 samples of cement, in which 9 samples are of 3 cements made by co-processing of RDF and 9 samples are of 3 cement which is not made by co-processing of RDF.

For each sample 100 gm of cement is taken and rubbed with hands as there should not be any lumps in the fineness sample. Then the sample is tested for the fineness of the cement.

- **Standard consistency**

For the standard consistency, the test totals 18 samples of cement, of which 9 samples are of 3 cements made by co-processing of RDF and 9 samples are of 3 cements which is not made by co-processing of RDF.

For each sample 300 gm of cement is taken and rubbed with hands because *the* standard consistency *test sample should be free of lumps then it* is mixed with a known percentage of water by weight of cement the time of mixing of cement and water must be done in between 3 minutes to 5 min and should be completed before any sign of setting.

- **Initial & Final setting time**

For the Initial & Final setting time test total of 18 samples of cement for each test, in which 9 samples are of 3 cements made by co-processing of RDF and 9 samples are of 3 cements which are not made by co-processing of RDF.

For each sample 300 gm of cement is taken and rubbed with hands because *the* Initial & Final setting time test sample should be free of lumps then it is mixed with a known percentage of water by weight of cement the time of mixing of cement and water must be done in between 3 minutes to 5 min and should be completed before any sign of setting.

- **Soundness of cement (For free lime)**

For the Soundness of cement (For free lime) test total of 18 samples of cement for each test, in which 9 samples are of 3 blocks of cement made by co-processing of RDF and 9 samples are of 3 cement which is not made by co-processing of RDF.

100 gm cement is mixed with 0.72 (P) % of water to make cement paste of specific consistency. where "P" is the standard consistency.

Quality check of hardened cement

- **Compressive strength**

For the Compressive strength, the test totals 54 samples of cement for each test, in which 27 samples are of 3 blocks of cement made by co-processing of RDF and 27 samples are of 3 cement which is not made by co-processing of RDF. There are 3 samples is to be tested for each cement on the 3^{rd} day, 7^{th} day, and 28^{th} day. So, a total of 9 samples for each cement.

The temperature of room and water should be 27 ± 2°C. Potable/distilled water shall be used in preparing the cubes.

For each cube the material should be mixed separately and the amount of cement, sand, and water are given below:

200 gm Cement with 600 gm Standard Sand mixed with Water ((P/4) +3.0) percent of the combined mass of cement and sand, where P is the standard consistency.

7.5 Experiment

<u>Fineness test of cement</u>

Experiment Objective- The fineness test is used to measure the surface area of cement particles per unit mass and denote the proper grinding of cement.
cement **smaller particles** react much **quicker** than **larger particle**.
Excess fineness will lead to quick setting and give no time for mixing placing and transportation of cement.

Apparatus Used-

Weighing machine | **IS Sieve No. 9 (90 microns)** | **Sieve shaking machine** | ***Trowel, Tray***

Figure 40: Apparatus used for fineness test

Test Procedure-

A sample of cement is collected and rubbed with your hands. The Fineness test sample should be free of lumps

100 gm of cement sample has been taken and noted its weight as W1

100 gm of cement is dropped in 90 µ sieve and the lid is closed.

Now, the sieve has been shaken by Sieve shaking machine 15 minutes.

After that, the retained cement on the 90 µm sieve is weighed and noted

Figure 41: Test procedure for fineness test

To calculate the fineness of the cement formula is given below:

Fineness = (W2/W1) * 100

Where W1= weight of sample taken for testing

W2= weight of sample retains on the sieve after testing

Standard consistency test of cement

Experiment Objective- Finding out the standard consistency of cement paste with Vicat apparatus is one of the vital works in the testing of cement. Standard consistency of cement is necessary because the percentage of water added to cement affects the other properties such as the setting time of cement and the strength of cement. For proper completion of the chemical reactions, it is necessary to add an adequate amount of water not less than this standard consistency. Again, greater amount of water will also reduce the strength by increasing water-cement ratio.

Reference: Consistency Test of Cement IS Codes IS: 5513-1976, IS: 4031 (Pat 4) 1988,

Apparatus Used-

Vicat apparatus and Plunger | **Weighing machine** | **Trowel, Tray** | **Stop Watch**

Figure 42: Apparatus used for standard consistency test

Test Procedure-

1. About 300 gm cement is taken and mixed with known amount of water.

For this test 26% water is added and then increased by 2% until achieving standard consistency.

2. Mixing of cement and water should be done within 3 to 5 minutes.

3. Cement paste is filled into the Vicat apparatus and the top surface is levelled.

4. For testing the standard consistency of the cement plunger is attached to the apparatus and the mould filled with cement paste is placed on a non-porous plate.

5. Now, the plunger is lowered to touch the top surface of mould with cement paste, and released to penetrate the cement paste.

6. The process with varying % of water to cement is repeated until the penetration is around 33 to 35 mm from the top mould.

Figure 43: standard consistency test

To calculate the Standard consistency of cement formula is given below

Standard consistency- the % of water at which cement permits the Vicat plunger to penetrate to a point 33 to 35 mm from the top of the Vicat mould.

Initial & Final setting time

Experiment Objective- Setting time is one of the important parameters for any cement. The cement paste must not lose its plasticity too early or too late. Quick setting of cement can be a problem for transportation and placement of cement.

- Delayed final setting time of cement will be problem as it will delay the constatation work and strength gain.
- For proper concrete transportation, placing, and curing the initial setting time is an important factor to know.
- For the safe removal of scaffolding or form the final setting time must be known.

Reference: Initial & Final setting time Test of Cement IS Codes IS: 4031 (Part 5) – 1988.

Apparatus Used-

Vicat apparatus

Needle for Initial setting time

Needle for Final setting time

Weighing machine

Trowel, Tray

Stop Watch

Figure 44: Apparatus used for initial & final setting time

Test Procedure-

1. **400 gm of cement is mixed with water** about **0.85x P is added (P is the standard consistency of cement)**
2. **Time is noted immediately after water is added to the cement and this time is T1. This mixing must be done within 3 to 5 minutes.**
3. Now, the **Vicat apparatus** mould (**diameter of 80 mm and height of 50 mm**) is filled with cement paste and the t**op surface** of **mould** is levelled.
4. For determining the initial setting time of cement, the needle for the initial setting time is attached to the Vicat apparatus and the mould with the cement paste is placed below it.
5. The needle is lowered to touch the top of cement paste filled in mould.

6. The needle is released and allowed to penetrate the cement paste.
7. The process is repeated until the needle fails to penetrate the cement paste for about 5 mm to 7 mm from the mould bottom. The time is noted as T2
8. Needle having an angular ring attachment is used for determining the final setting time of cement.
9. Final setting time is the time when the attachment is fail to put any impression on the cement sample. The time is noted as T3

Calculation of Initial and Final Time:

Initial setting time of cement= Time when needle fails to penetrate 5 m from the bottom of mould. (T2) – The time when added to cement (T1)

Final setting time of cement= Time when angular need ring impression stop on cement paste (T3) – Time when water added to cement (T1)

Soundness of cement (For free lime)

Experiment Objective- The set cement must not produce any appreciable change in volume. If the cement shows large expansion after setting, resulting disruption of the set and hardened mass and possess a big threat to the durability of structures. Excess Free lime is the cause of unsoundness in cement and could be combined with acidic oxide at the kiln. High a proportion of magnesium content or calcium sulphate content can also cause unsoundness in cement. The Le-Chatelier method and the autoclave method are methods for determining the Soundness of cement.

To speed up the tendency of expansion the cement specimen is boiled for a certain time. Soundness means the ability to resist volume expansion.

Apparatus Used-

Le Chatelier Apparatus

Weighing machine

Trowel, Tray

Water Bath

Measuring scale & Glass Sheets

Figure 45: Apparatus used for soundness test of cement

Test Procedure-

1. Cement pastes mixed with water 0.78 times of standard consistency into a lightly oiled mould and placed on a lightly oiled glass sheet. [refer IS: 4031 (Part 4)-1988].
2. Another piece of glass sheet is used to cover the mould and a weight is put on the top the sheet, the whole assembly is put under water at a temperature of 27 ± 2°C and keep there for 24 hours.
3. The distance separating the indicator points is measured to the nearest 0.5 mm. the mould is submerged again in water at the temperature prescribed above.
4. The water is boiled, with the mould for three hours. Then the mould is removed from the water, allowed to cool, and the distance between the indicator points is measured.
5. The expansion of cement is the difference between these two measurements. This must not exceed 10 mm for ordinary, rapid hardening and low heat Portland cements. If in case the expansion is more than 10 mm as tested above, the cement is said to be unsound.

Calculation of Soundness of cement:

1. Soundness/expansion of cement = L1-L2
2. Where, L1= is the distance measured after 24 hours of immersion in water at a temp. of 27 ± 20C
3. L2= is the distance measured after 3 hours of immersion in boiling water.

Compressive strength of cement

Experiment Objective- Compressive Strength is one of the most important properties of cement. With increase in compressive strength flexural strength, resistance to abrasion, and so on also increases. To identify the suitable grade of cement compressive strength test of cement is an important test.

Apparatus Used-

Compression Testing Machine **Weighing machine** **Trowel, Tray**

Cube Mould **Standard Sand** **Vibration Machine**

Figure 46: Apparatus used for compressive strength of cement

Test Procedure-

1. At 1st the apparatus is cleaned with dry jute and ensured that the temperature of the room in which the test is to be conducted should be 27 ± 2°C
2. Then the cement is mixed with the sand by trowel for 1 min on a Non – porous surface. It should be ensured that cement doesn't contain any lumps.
3. Then the required amount of water is added and well mixed for 3 minutes to make the paste uniform in colour.
   The quantity of water required for the test is **(P/4 + 3)**
   % where **P** is **Standard consistency**

4. Then mould is cleaned with dry jute and the oil is applied to make the removal of the dry sample easy.
5. Now the prepared mortar is poured into a steel cube mould.
6. Once the mortar cube sets, after 24 hours it is dismantled from the steel mould.
7. Then the test specimens are submerged underwater. This process is termed as **curing**.
8. The test specimen is kept in water for 28 days, and the water is changed every 7 days.
9. Three cubes, on the 7th day, on the 14th day, and on the 28th day are to be tested.
10. The test specimen is placed in a compression testing machine.
11. The loading was applied axially on the specimen **at the rate of 35 $N/mm^2/min$** without any shock.
12. The cube fails at a specific load and the reading is noted.

Calculation of Compressive strength of cement

$$\text{Compressive strength of Cement} = \frac{\text{Max load carried by the specimen (N)}}{\text{Top surface area of specimen } (mm^2)}$$

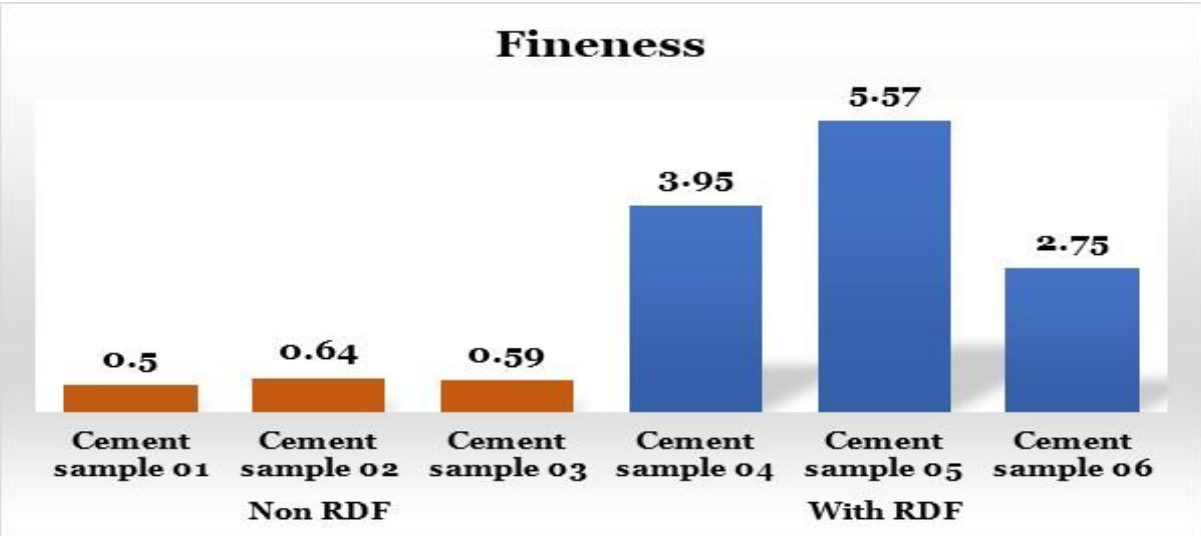
5.6 **Result**

Fineness test of cement

Table 22: Test result for Fineness test for RDF & Non-RDF cements

Sl. No.	Type of cement	Name of Cement Brand	Weight of Cement Sample	Average Weight Cement Samples Retained on 90µm Sieve
01	Non-RDF	Cement Sample 01	100 gm	0.50 gm
02	Non-RDF	Cement Sample 02	100 gm	0.64 gm
03	Non-RDF	Cement Sample 03	100 gm	0.59 gm
04	With-RDF	Cement Sample 04	100 gm	3.95 gm
05	With-RDF	Cement Sample 05	100 gm	5.57 gm
06	With-RDF	Cement Sample 06	100 gm	2.75 gm

Figure 47: Fineness of for RDF & Non-RDF cements



Standard consistency

Table 23: Test result for Standard consistency for RDF & Non-RDF cements

Sl. No	Type of cement	Name of Cement Brand	Weight of Cement Sample	Water added (gm)	Penetration from Bottom (mm)	% Water added
01	Non-RDF	Cement Sample 01	300gm	93 gm	5 mm	31%
02	Non-RDF	Cement Sample 02	300gm	96 gm	6.5 mm	32%
03	Non-RDF	Cement Sample 03	300gm	102 gm	6 mm	34%

04	With-RDF	Cement Sample 04	300gm	102 gm	6.60 mm	34%
05	With-RDF	Cement Sample 05	300gm	105 gm	6.50 mm	35%
06	With-RDF	Cement Sample 06	300gm	105 gm	5.50 mm	35%

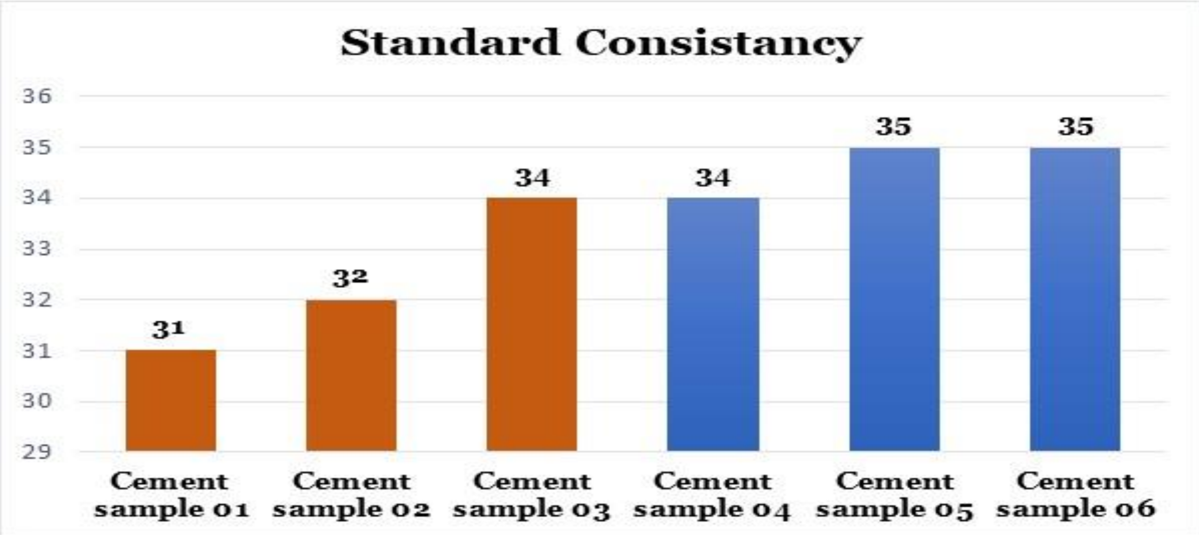


Figure 48: Standard consistency of for RDF & Non-RDF cements

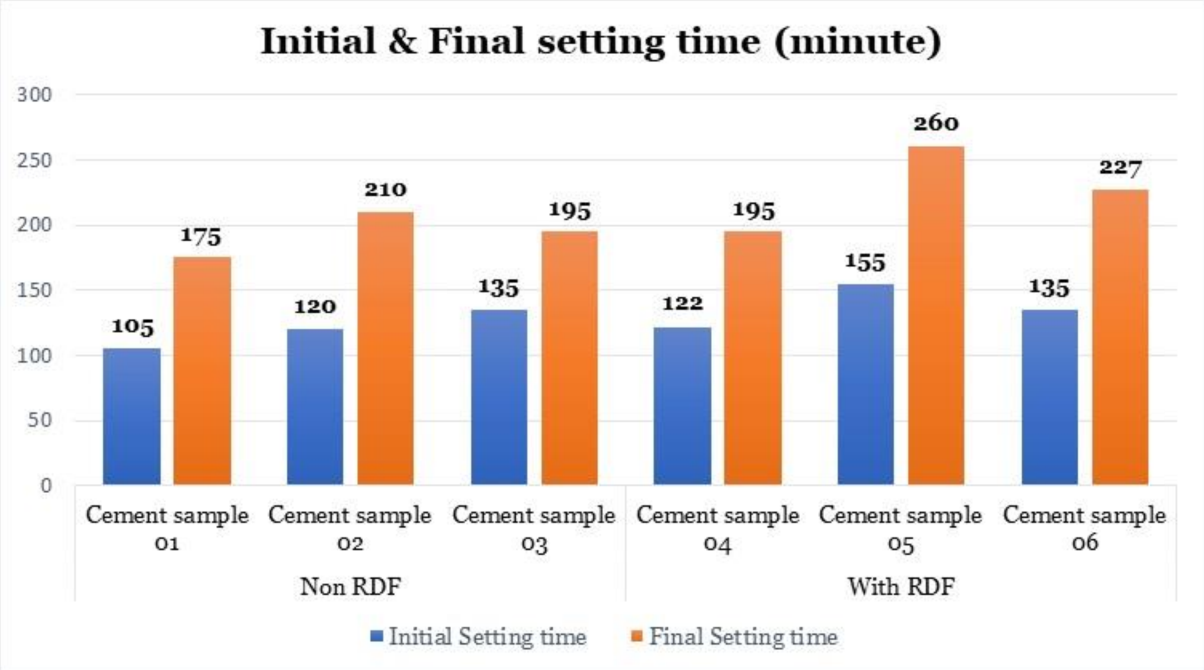
<u>Initial & Final setting time</u>

Table 24: Test result for Initial & Final setting time for RDF & Non-RDF cements

Sl. No	Type of cement	Name of Cement Brand	Weight of Cement Sample	Water added (gm)	Penetration from Bottom (mm)	Time for Initial set (minute)	Time for Final set (minute)
01	Non-RDF	Cement Sample 01	400 gm	0.85* 31% = 26.30 gm	5.50 mm	105 minutes	175 minutes
02	Non-RDF	Cement Sample 02	400 gm	0.85* 32% = 27.20 gm	5 mm	120 minutes	210 minutes
03	Non-RDF	Cement Sample 03	400 gm	0.85* 34% = 28.90 gm	5 mm	135 minutes	195 minutes
04	With-RDF	Cement Sample 04	400 gm	0.85* 34% = 28.90 gm	6.5 mm	122 minutes	195 minutes
05	With-RDF	Cement Sample 05	400 gm	0.85* 35% = 29.70 gm	5.5 mm	155 minutes	260 minutes

06	With-RDF	Cement Sample 06	400 gm	0.85* 35% = 29.70 gm	5.5 mm	135 minutes	227 minutes

Figure 49: Initial & Final Setting Time of for RDF & Non-RDF cements



Soundness of cement (For free lime)

Table 25: Test result for Soundness of cement (For free lime) of cement for RDF & Non-RDF cements

Sl. No	Type of cement	Name of Cement Brand	Weight of Cement Sample	Water added (gm)	Expansion (mm)
01	Non-RDF	Cement Sample 01	100 gm	0.78* 31% = 24.18 gm	8 mm
02	Non-RDF	Cement Sample 02	100 gm	0.78* 32% = 24.96 gm	5 mm
03	Non-RDF	Cement Sample 03	100 gm	0.78* 34% = 26.52 gm	7 mm
04	With-RDF	Cement Sample 04	100 gm	0.78* 34% = 26.52 gm	6 mm
05	With-RDF	Cement Sample 05	100 gm	0.78* 35% = 27.30 gm	4 mm
06	With-RDF	Cement Sample 06	100 gm	0.78* 35% = 27.30 gm	6 mm

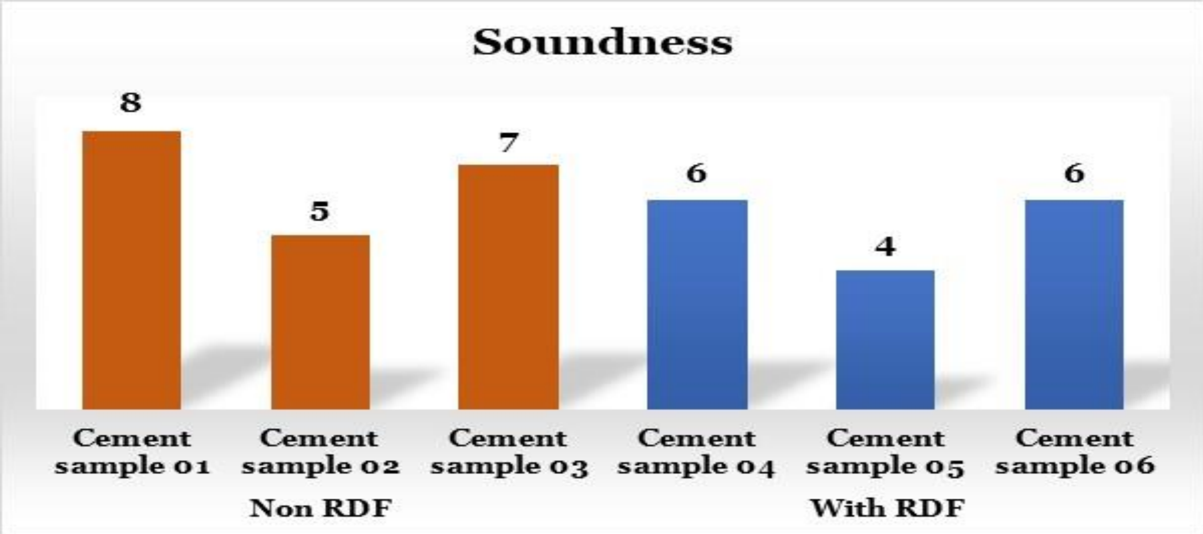


Figure 50: soundness of cement for RDF & Non-RDF cement

Compressive strength of cement

Table 26: Test result for Compressive strength of cement for RDF & Non-RDF cements

Sl.No	Type of cement	Name of Cement Brand	Age of the cube (Days)	Average top surface area (mm²)	Average Peak Load carried (KN)	Avg. Compressive strength (N/mm²)
01	Non-RDF	Cement Sample 01	3 days	4914 mm²	83.60 KN	17.01 N/mm²
			7 days	mm²	KN	N/mm²
			28 days	mm²	KN	N/mm²
02	Non-RDF	Cement Sample 02	3 days	4914.01 mm²	84.26 KN	17.14 N/mm²
			7 days	mm²	KN	N/mm²
			28 days	mm²	KN	N/mm²
03	Non-RDF	Cement Sample 03	3 days	4907 mm²	82.71KN	16.85 N/mm²
			7 days	mm²	KN	N/mm²
			28 days	mm²	KN	N/mm²
04	With-RDF	Cement Sample 04	3 days	4935.06 mm²	79.66 KN	16.14 N/mm²
			7 days	mm²	KN	N/mm²
			28 days	mm²	KN	N/mm²
05	With-RDF	Cement Sample 05	3 days	4942.09 mm²	79.10 KN	16 N/mm²
			7 days	mm²	KN	N/mm²
			28 days	mm²	KN	N/mm²
06	With-RDF	Cement Sample 06	3 days	4907 mm²	78.80 KN	16.05 N/mm²
			7 days	mm²	KN	N/mm²
			28 days	mm²	KN	N/mm²

The rest of the tests are yet to be done.

5.7 Analysis & Discussion

Fineness of cement

According to BIS standards, the fineness of cement must not exceed 10%.

As per our experiment on 3 cements with RDF and 3 cement without RDF, it is shown that for all the cements the fineness value is within the specified range of IS 12600: 1989.

It is also observed that the fineness value of non-RDF cements are in the range of 0.50-0.64, indicating greater fineness than the cement made with RDF.

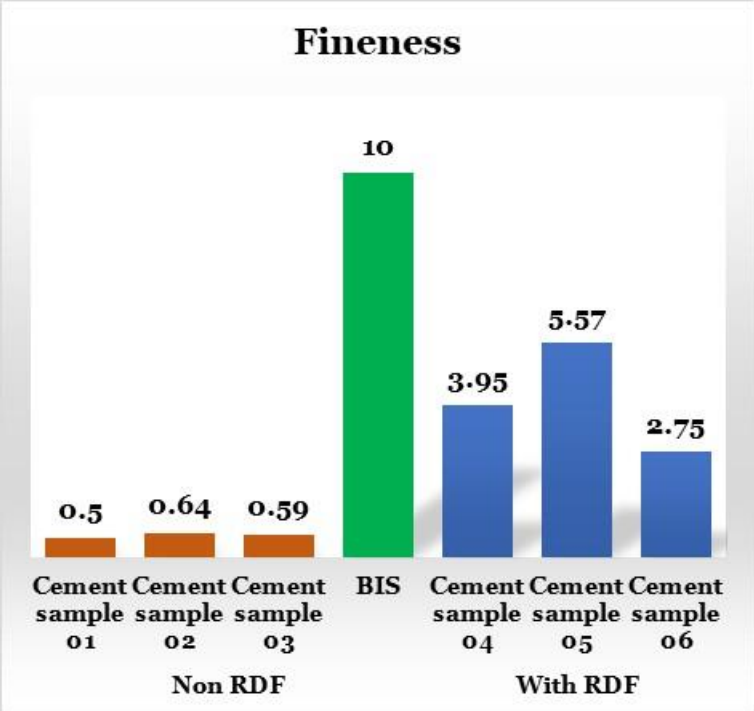


Figure 51: Comparison of fineness value with BIS standards

The greater fineness of cement provides a more surface area for hydration reaction resulting in faster development of strength. Drying shrinkage of concrete is a cause of the greater fineness of the cement.

Soundness of cement

According to BIS standards, the soundness of cement must not exceed 10mm.

As per our experiment on 3 cements with RDF and 3 cement without RDF, it is shown that for all the cements the soundness value is within the specified range of IS 12600: 1989.

It is also observed that the average soundness value of non-RDF cements is 6.66, and the average soundness value cements made with RDF is

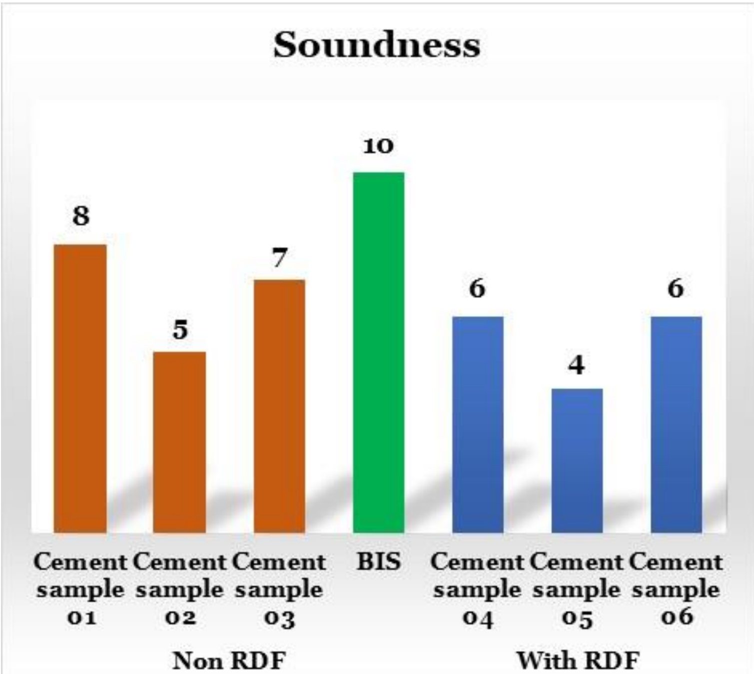


Figure 52: Comparison of soundness value with BIS standards

5.33 indicating the presence of a greater amount of free lime in non-RDF cement than the cement made with RDF.

Unsound cement undergoes a large expansion after setting causing disruption of the set and hardened mass. The use of unsound cement put a serious threat to the durability of the structure.

Initial & Final setting time

According to BIS standards, the Initial setting time of cement must not be less than 30 minutes and the Final setting time must not be greater than 600 minutes.

As per our experiment on 3 cements with RDF and 3 cement without RDF, it is shown that for all the cements the Initial & Final setting time value is within the specified range of IS 12600: 1989.

It is also observed that the average Initial & Final setting time value of non-RDF cements are 120 minutes & 193.33 minutes, and the average Initial & Final setting of cements made with RDF are 137.33 minute & 227.33 minutes, indicating the presence of a greater amount of silica in cement composition of cement made with RDF than the non-RDF cement.

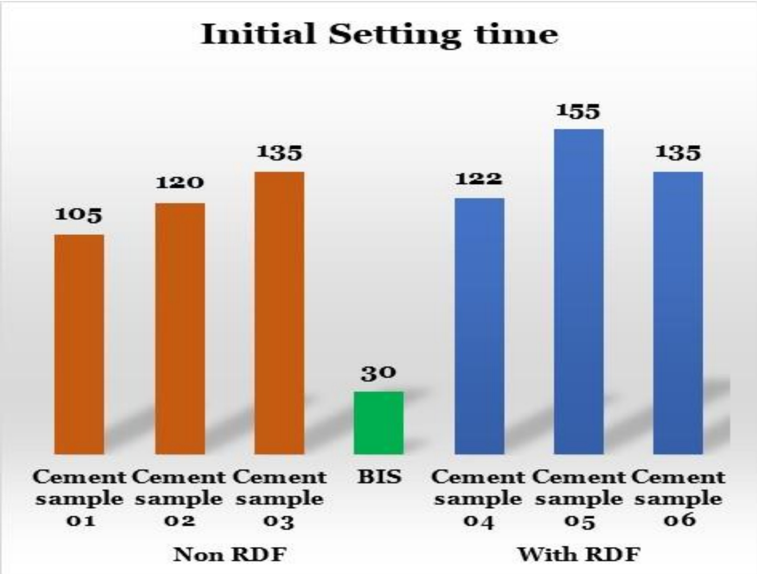
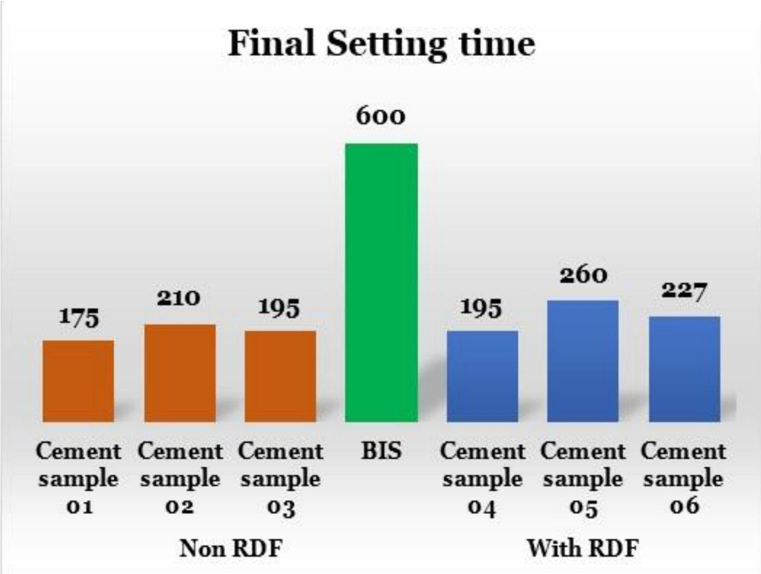


Figure 53: Comparison of initial & final setting time value with BIS standards



5.8 Conclusion

In this study, the impact of RDF ash on the hydration and hardened qualities of cement is identified. Several tests have been performed the result and discussion are given above.

The fineness of non-RDF cements is observed to be much lower than the cements produced by co-processing of RDF in cement kiln, resulting much higher rate of hydration and faster development of strength. But the drying shrinkage can be a problem for finer cements.

One of the major components of RDF ash is SiO_2, it is also observed that using of RDF ash contributes to increasing the initial & final setting time of cement produced by RDF than the non-RDF cement.

It was observed that the test result for those cement samples is within the limits prescribed by BIS. So, it can be said that there is no such negative impact of using RDF as AFR for co-processing in a cement kiln. Using RDF as a co-fuel in cement will help to tackle the plastic waste management problem to a greater extend.

Conclusion

Now a day in every industrial sector there is the use of plastic or plastic base products. This increasing trend of plastic use is leading to a larger problem of a greater quantity of plastic waste generation in the world. In the year 2016, the global plastic waste generation is about 242 million tonnes which are 12 percent of all municipal solid waste generated that year. Plastic waste management is one of the biggest challenges in front of mankind. There are different technologies such as Incineration, pyrolysis, use of plastic waste in road construction, and Co-processing of nonrecyclable plastic waste in cement kilns to tackle this plastic waste disposal problem. The majority of plastic waste generated (70- 75 %) in India is not processed and is dumped at landfill sites.

It was identified in this study, that there is a presence of 10% to 11% of non-recyclable plastic waste in the total MSW dumped into the dumpsites. The studied 16 dumpsites have the potential of producing RDF around 717 TPD. If necessary, steps are taken, so the nonrecyclable but combustible fraction of MSW can be converted to RDF and can be used to substitute the fossil fuel in the cement kiln for the production of cement. This utilization of NRPW as RDF will contribute to a more cost-effective, and environment-friendly way of plastic waste management and will eventually boost the Circular economy concept of "Waste to Wealth".

Informal scavengers, who help in the sorting and segregation of waste are an integral part of proper waste management. 'Invisible environmentalists' is a term coined by the UNEP for waste pickers for their silent contribution to waste management. Due to the unhygienic work environment and unavailability of proper safety equipment, the waste picker or scavengers often face serious health and safety issues. It is identified among the scavengers' injuries during work and skin-related problems are most common in nature. Illiteracy, uncertainty in the job, and low income are other major problems faced by these informal waste pickers and scavengers, which is leading to other health-related problems of addiction, depression, and anxiety. For the proper functioning of the waste management system, these problems need to be addressed.

RDF ash comprises different chemical compounds, that will mix with the raw materials fed into the cement kiln for cement production. This study identified that there is no such negative impact of RDF ash on the hydration & harden quality of cement. All the test result of cements made with RDF and without RDF is within the prescribed range of BIS. So, this will boost the use of RDF as an alternative fuel and raw material (AFR) for co-processing in cement kilns.

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Annexures

List of cement plants co-processing NRPW and RDF in the year 2019 (or before)

Sl. No.	Name of cement plant	Address	Type of waste co-process
1.	M/s ACC Ltd., Bargarh Cement Ltd.,	Cement Nagar, PO Bardol, Distt. Bargarh (Orissa), 768 038	Chemical ETP Sludge (Automobile industry), Grinding dust (Rolling bearing & seal industry), WTP; Sludge (Soft drink industry)
2.	ACC Ltd., Chaibasa Cement Works,	P.O. Jhinkpani Distt. West Singhbhum (Jharkhand) 833 215	Phosphate sludge (Automobiles Industry), WTP Sludge (Soft drink Industry), Spent Carbon (Soft drink Industry), Grinding muck (Textile Machine Manufacturing Industry); Spent catalyst (IOCL, Barauni Refinery); Oily rags (Automobile industry), ETP Bio Solid (Soft drink industry), Chemical ETP Sludge (Automobile industry), Chemical Sludge (Automobile industry), Grinding dust (Automobile industry) Incineration Ash (Tata Motors, Jamshedpur)
3.	ACC Ltd., Chanda Cement Works	Cement Nagar Distt. Chandrapur (Maharashtra) 442 502	Chemical ETP sludge (Automobiles Industry), ETP Bio solid (Soft drink Industry), Grinding Muck (Textile Machine Manufacturing Industry), Expired consumer products (Shampoo), Phosphate Sludge (Automobile Industry), Spent carbon (Soft drink Industry), WTP Sludge (Soft drink Industry) Oily rags (Automobile industry), Grinding dust (Automobile industry)

4.	M/s ACC Ltd., Gagal Cement Works,	P.O. Barmana, Distt. Bilaspur (HP), 174 013	
5.	ACC Ltd., Jamul Cement Works,	Distt. Durg (Chhattisgarh),490 024	ETP Bio solid (Soft drink Industry) and Spent Carbon (Soft drink Industry) Chemical Sludge (Automobile industry), Phosphate Sludge (Automobile industry), Grinding muck (Textile machine manufacturing), Oily Rags (Automobile industry), Chemical ETP Sludge (Automobile industry), Grinding dust (M/s SKF India Ltd, Bangalore), WTP Sludge (Soft drink industry)
6.	M/s ACC Ltd., Kymore Cement Works,	P.O. Kymore, Distt. Katni (MP), 483 880	ETP Sludge (KEC International Ltd.), ETP Sludge (M/s Godrej Consumer Product, Malanpur) paint sludge & petroleum refining sludge, Dismantled Lube/Fuel oil filter
7.	M/s ACC Ltd., Lakheri Cement Works,	P.O. Lakheri, Distt. Bundi (Rajasthan), 323 603	
8.	ACC Ltd., Madukkarai Cement Works,	P.O. Madukkarai Distt. Coimbatore (Tamil Nadu); 641 105	Chemical ETP sludge (Automobiles Industry),ETP Bio-solids (Soft drink Industry),Grinding Muck (Textile Machine Manufacturing Industry) , Oily rags (Automobiles Industry), Phosphate Sludge (Automobiles Industry), Plastic & Laminates (Consumer goods), Spent Carbon (Soft drink Industry), WTP Sludge (Soft drink Industry) Green mesh with resin (M/s Suzlon Energy Ltd.), Poly residue (M/s

			SRF India Ltd.); Grinding dust (Rolling bearing & seal industry) Waste/residues (sludge from process)and filters & filter material & Process residue.
9.	M/s ACC Ltd., Wadi Cement Works,	P.O. Wadi, Distt. Gulbarga Karnataka 585 225	Grinding Muck (Textile Machine Manufacturing Industry), ETP Bio Solids (Soft drink Industry) Chemical ETP sludge (Automobiles Industry), Phosphate Sludge (Automobiles Industry), Spent Carbon (Soft drink Industry) and WTP Sludge (Soft drink Industry); Solar Evaporation Pond Sludge (M/s Jubilant Organosys Ltd.), N Butanol salt (M/s Jubilant Organosys Ltd.), Green mesh with Resin (M/s Suzlon Energy Ltd.) and Grinding dust (M/s SKF India Ltd.); Oily rags (Automobile industry) & Grinding dust (Automobile industry); Benzofuran (Kumar Organic Product Ltd) Chemical ETP sludge (M/s Syngenta India Limited, Goa);
10.	M/s Anjani Portland Cement Ltd.,	Nalgonda, Andhra Pradesh.	spent carbon (pharmaceutical industries); solid & liquid spent solvent (pharmaceutical industries)
11.	M/s Ambuja Cement Ltd.,	P.O.Ambujanagar, Tal.-KodinarDistt. Junagadh, Gujarat- 362715	TDI Tar; Waste mix liquid (M/s Lupin Ltd., Ankleshwar); Waste mix liquid (M/s Bharuch Enviro Infrastructure Ltd., Ankleshwar, Gujarat); spent carbon
12.	GajAmbuja Cement Plant	P.O. – Ambujanagar	Waste mix liquid (M/s Gujarat Enviro Protection

		TalukKodinar; Distt. Junagarh Gujarat-362 715	and Infrastructure Ltd., Surat waste mixed liquid (distillation residue & process residue waste) (M/s Unimark Remedies Ltd.)
13.	M/s Ambuja Cements Ltd., Bhatapara,	PO – Rawan, Tehsil Baloda Bazar, Distt. Raipur, Chhattisgarh	Mixed waste (distillation residue, residue & waste, spent catalyst & spent carbon & date expired medicine & off-specification drugs
14.	Ambuja Cements Ltd.,	P.O. Rabriyawas, The. Jaitaran Distt. Pali (Rajasthan)	Paint sludge; ETP sludge (M/s Sona Processors (India) Ltd., Bhilwara -Textile Industry)
15.	Ambuja Cements Ltd., Suli,	P.O. Darlaghat Distt. Solan (HP)	Paint sludge (automobile industry); solid waste mix (ShivalikSolid Waste Management Ltd., Nalagarh)
16.	Bharathi Cement Corporation Pvt. Ltd.	Nallalingayapalli village, KamalapuramMandal, KadapaDistt. – 516 289, Andhra Pradesh	liquid & Solid Organic Spent Solvent
17.	Chettinad Cement Corporation Ltd., Kallur Works, Sangem K,	GaragappalliPost, Chandrapur (SO), Chincholi (TK), Gulbarga (DT), Karnataka-585 305	Solar Evaporation Pond sludge, n- Butanol salt, solid and liquid organic spent solvent & spent carbon of pharmaceutical industries, paint sludge, phosphate sludge, ETP Sludge & oily rags of the automobile industry
18.	Chettinad Cement Corporation Ltd.,	Ariyalur Trichy Road, Keelapur post, Ariyalur dist-621707, Tamilnadu	Fiber Reinforced Plastic (Green Mesh with Resin of M/s SuzlonEnergy Ltd.)
19.	M/s Chettinad Cement Corporation Ltd.,	Rani Meyyammai Nagar, Karikklai PO, Guziliamparai (via), DindigulDistt., Tamilnadu 624 703	
20.	M/s Chettinad Cement Corporation Ltd., Puliyur Cement Works,	KarurDistt., Tamilnadu	

21.	M/s Dalla Cement Factory,	Village – Dalla, Distt. – Sonebhadra, UP 231207	
22.	M/s Dalmia Cement (Bharat) Ltd.,	SF, No. 630, Thamaraikulam Village, Ariyalur - TamilNadu	Solid waste mix (M/s Gujarat Enviro Protection & Infrastructure Ltd., Tamilnadu); Bio-mass, Resin Waste, Rubber Foam waste, Tire Chips, RDF, Carbon Black, Cotton Waste, Waste mix liquid, Plastic waste
23.	M/s Dalmia Cement (Bharat) Ltd., Dalmiapuram,	Dist. Tiruchirapalli- 621651 Tamil Nadu	
24.	M/s Dalmia Cement (Bharat) Ltd.,	V&P- Chinnakomerla, Mandal-Mylavaram, Jammalandhu, Distt. Kadapa, AP	
25.	M/s J. K. Cement Works,	P.O.- Muddapur-587122, Distt.-Bagalkot, Karnataka.	ETP sludge of M/s BASF India Ltd., Karnataka
26.	M/s J. K. Cement Works, Mangrol, C/o J.K. Cement Works, ,	Kailash Nagar, Nimbahera Distt. Chittorgarh 312617	
27.	M/s J. K. Cement Works,	Kailash Nagar, Nimbahera, Distt. Chittorgarh 312617	
28.	M/s J. K. Lakshmi Cement Ltd., Jaykaypuram,	Distt. Sirohi, Rajasthan 307 01	
29.	M/s Kesoram Cement Ltd., Post-Basantnagar, .	Karimnagar Dist.- 505 187, Andhra Pradesh	spent carbon, liquid organic solvents & solid organic solvents
30.	M/s Kalburgi Cement (formerly VicatSagar Cement), Chhatrasala,	Gulbarga Karnataka	
31.	M/s Keerthi Industries Ltd., Mellacheruvu	(V &M), NalgondaDistt., Telangana 508	

32.	Lafarge India Ltd., Sonadih Cement Plant(Line -I)	PO Reseda, Via Baloda Bazar Distt. Rapur , Chhattisgarh	Waste mix solid & waste mix liquid (GEPIL, Surat); Plastic & Resin Waste (M/s GEPIL, Faridabad); Process sludge & ETP sludge, SCRAP PTA (Purified Terephthalic Acid), Empty PTA contaminated plastic liner & oil-contaminated jute & rags (M/s MCC PTA India Corporation Pvt. Ltd., West Bengal)
33.	Lafarge India Ltd., Sonadih Cement Plant (LineII) ,	PO Reseda, Via Baloda Bazar Distt. Raipur, Chhattisgarh	Waste mix solid & waste mix liquid (GEPIL, Surat
34.	Lafarge India (P). Ltd., Arasmata Cement plant,	PO Gopal Nagar, Janjgir, Champa, Chhattisgarh	Waste mix solid, waste mix liquid (GEPIL Surat)
35.	M/s Lafarge India Pvt. Ltd., Chittor Cement	Plant, Chittorgarh, Rajasthan	waste mix liquid & waste mix solid from M/s Recycling Solutions Pvt. Ltd., Panoli, Gujarat
36.	M/s My Home Industries Limited Mellacheruvu (Post &Mandal),	Dist – Nalgonda, Telangana- 508246	Liquid Organic Spent Solvent (Pharmaceutical Industries)
37.	M/s Trinetra Cement Ltd., Mahi Cement Works,	P.O. Walwana, Banswara – 327025, Rajasthan	Waste mix liquid & solid (GEPIL, Surat).
38.	M/s Sagar Cement Ltd., Nalgonda,	Telangana	spent carbon, Solid organic spent solvent & Liquid organic spent solvent of the pharma industry
39.	M/s Sanghi Cement Ltd.,	Kutch, Gujarat	spent carbon, Solid organic spent solven& Liquid organic spent solvent of the pharma industry
40.	M/s Shree Cement Ltd., AndheriDeori,	Post Box No. 33, Bangur Nagar, Beawar, District - Ajmer, Rajasthan – 305901	

41.	M/s Shree Cement Ltd.,	Village-RAS, Tehsil-Jaitaran, Distt.-Pali, Rajasthan	Paint sludge (automobile industry); ETP sludge (Textile industry); CETP sludge (Pali); ETP sludge & Phosphate sludge.
42.	Ultra Tech Cement Ltd., ,)	Andhra Pradesh Cement Works, Bhogasamudram PO: ChukkalurMandal:Tadipatri Distt. Anantapur (AP	Solid and liquid organic spent solvent
43.	Ultra Tech Cement Ltd., Aditya Cement,	Adityapuram, PO Sawa Distt. Chittorgarh (Rajasthan) -312 612	
44.	M/s UltraTech Cement Ltd., Rajashree Cement works,	Adityanagar, Malkhed Road, Dist. Gulbarga, Karnataka 585292	Paint sludge, Phosphate sludge, ETP sludge & oily rags of automobile industries, solid & liquid organic spent solvent and spent carbon o-pharmaceutical industries, n-Butanol salt of M/s Jubilant Organosys Ltd., Mysore, ETP sludge of M/s BASF India Ltd
45.	M/s Ultratech Cement Ltd., Narmada cement-Jafrabad Works,	Babarkot, Taluka- Jafrabad, Distt. Amreli, Gujarat.	Waste liquid blend and waste solid blend (Colortex Industries Ltd.)
46.	M/s Ultra Tech Cement Ltd.	P.O. Mohanpura, Tehsil Kotputli, Distt. Jaipur, Rajasthan- 303108	
47.	Ultra Tech Cement Ltd., Gujarat Cement Works,	P.O. Kovaya, Taluka Rajula, Distt. Amreli (Gujarat)-365 541	Waste mix solid & waste mix liquid (GEPIL, Surat); Waste liquid blend and waste solid blend from M/s Colourtex Industries Ltd. (Unit 2);
48.	Ultratech Cement Ltd., Vikram Cement Works,	Vikram Nagar, P.O. Khor, Distt. - Neemuch, M.P. -458 470	ETP Sludge (Textile industry); Paint Sludge (automobile industry).
49.	Ultra Tech Cement Ltd.	P.O. Reddipalayam, Ariyalur, Distt. Perambalur (Tamil Nadu)-621 704	ETP Sludge (BASF I. Ltd.), Tyre Chips, Paint sludge, Refinery sludge, and plastic waste CETP/IETP sludge (textile industry) oily rags; chemical sludge;

			phosphate sludge (M/s Ford India Ltd., TamilNadu - automobile industry); Green mesh with resin (M/s Suzlon Energy Ltd, Pondicherry); spent carbon, liquid and solid organic spent solvent of pharmaceutical industries; ETP Biosolid waste, WTP sludge and spent carbon of soft drink industries.
50.	M/s Ultra Tech Cement Ltd., Rawan Cement Works	P.O. Grasim Vihar, Distt. Baloda Bazar – Bhatapara, Chhattisgarh – 493196	
51.	M/s Ultra Tech Cement Ltd., Hiromi Cement Works,Hiromii, Bhatapara,	Distt. Baloda Bazar Chhattisgarh – 493195	
52.	M/s Zuari Cement Ltd., Sitapuram,	Dondapadu, Distt.- Nalgonda, Telangana	
53.	M/s Zuari Cement Ltd., Krishna Nagar, Yerraguntla,	KadapaDistt., AP 516 311	
54.	M/s Vasavadatta Cement,	Post &Tq- Sedam, Distt. Gulbarga Karnataka- 585 222	