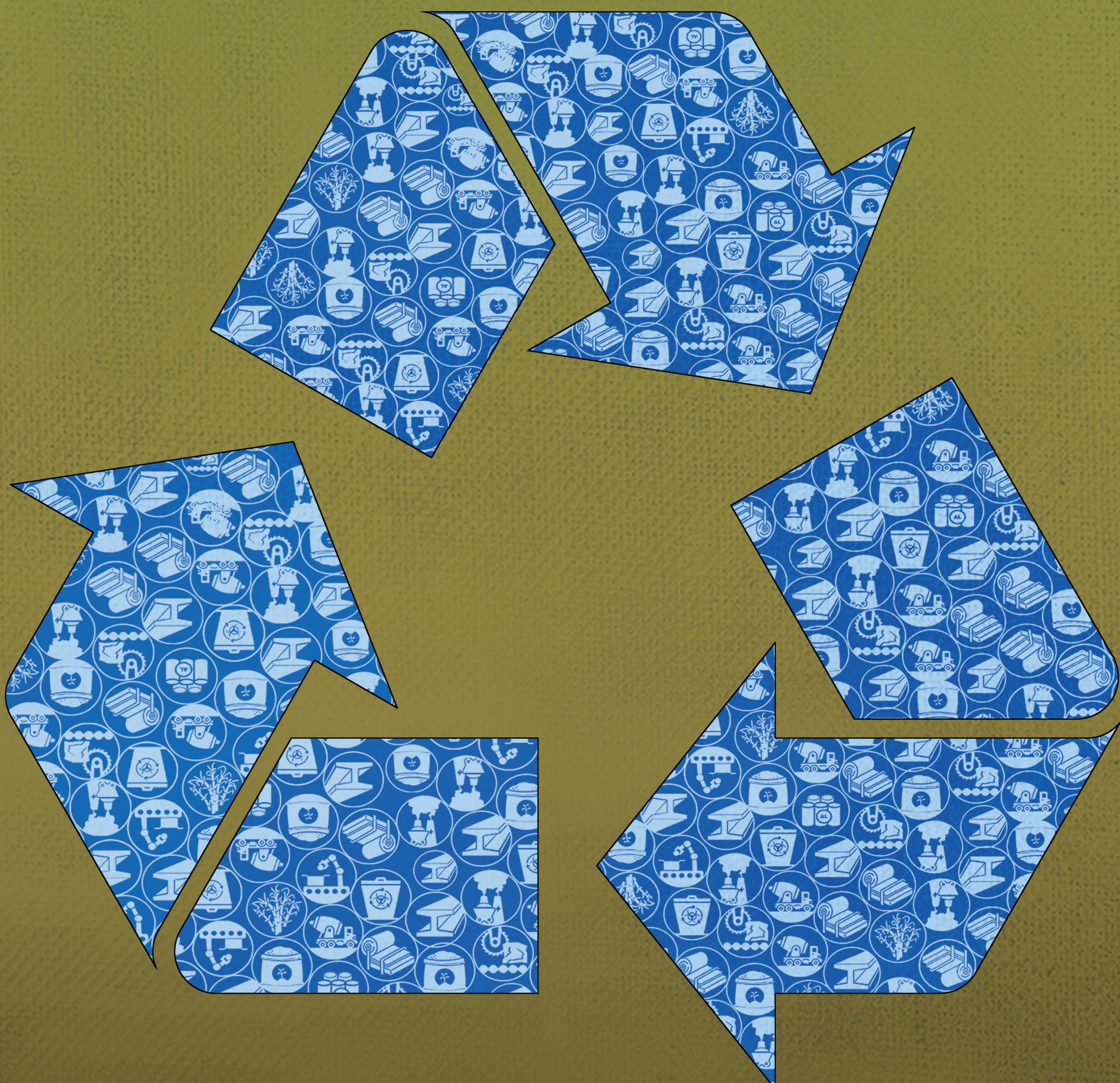
GOOD PRACTICES IN INDUSTRIAL WASTE CIRCULARITY

A COMPENDIUM



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List of abbreviations

MoEFCC:	Ministry of Environment, Forest and Climate Change
IRP:	Indian Resources Panel
CE:	Circular economy
GDP:	Gross domestic product
NGT:	National Green Tribunal
MPCB:	Maharashtra Pollution Control Board
SPCB:	State Pollution Control Board
HDPE:	High-density polyethylene
CPCB:	Central Pollution Control Board
FGD:	Flue gas desulphurization
RDF:	Refuse-derived fuel
LD:	Linz Donawitz
HW:	Hazardous waste
RCF:	Recycled fibre
AFR:	Alternative fuels and raw materials
GHG:	Greenhouse gas
MoHUA:	Ministry of Housing and Urban Affairs
DPIIT:	Department for Promotion of Industry and Internal Trade
PLI:	Production-linked incentive
OPC:	Ordinary Portland cement
PSC:	Portland slag cement
CC:	Composite cement
PPC:	Pozzolana Portland cement
CBG:	Compressed bio-gas
MT:	Metric tonne
BOF:	Basic oxygen furnace
DRI:	Direct reduced iron
EAF:	Electric arc furnace
BF:	Blast furnace
IF:	Induction furnace
RDSO:	Research Design and Standards Organisation
SAIL:	Steel Authority of India Limited
BSP:	Bhilai Steel Plant
DS:	Desulphurization slag
LF:	Laddle Furnace
ICAR:	Indian Council of Agricultural Research
IARI:	Indian Agricultural Research Institute
NH:	National highway

WBSCD: World Business Council for Sustainable Development
TSR: Thermal Substitution Rate
SCF: Segregated Combustible fraction
CPHEEO: Central Public Health and Environmental Engineering Organisation
MSW: Municipal solid waste
GCV: Gross calorific value
BEE: Bureau of Energy Efficiency
GWMC: Goa Waste Management Corporation
NGO: Non-government organization
SWMF: Saligao Waste Management Facility
NABARD: National Bank for Agriculture and Rural Development
HWTPL: Hindustan Waste Treatment Pvt. Ltd
ULB: Urban local bodies
TPD: Tonnes per day
CCP: Corporation of the City of Panaji
MC: Municipal council
MRF: Materials recovery facility
GST: Goods and services tax
MoU: Memorandum of Understanding
BIS: Bureau of Indian Standards
SoP: Standard Operating Procedure
ESP: Electrostatic Precipitator
EC: Environmental Clearance
PCC: Pollution Control Committee
CEA: Central Electricity Authority
GW: Gigawatt
TRC: Technical Review Committee
GVP: Gypsum vermiculite plaster
JPL: Jhajjar Power Limited
NALCO: National Aluminium Company
RM: Red mud
JNARDDC: Jawaharlal Nehru Aluminium Research Development and Design Centre
AERB: Atomic Energy Regulatory Board
REE: Rare earth elements
MEE: Multi-effect evaporator
IPL: Indian Potash Limited
TCD: Tonnes of cane crusher per day
KLPD: Kilolitre per day
PDM: Potash derived from molasses

TPH:	Tonnes per hour
IOCL:	Indian Oil Corporation Limited
MW:	Megawatt
UPRVUNL:	Uttar Pradesh Rajya Vidyut Utpadan Nigam
GAIL:	Gas Authority of India Limited
NCR:	National Capital Region
CAQM:	Commission for Air Quality Management
IFFCO:	Indian Farmers Fertiliser Cooperative
RSPCB:	Rajasthan State Pollution Control Board
MMTPA:	Million metric tonnes per annum
CBRI:	Central Building Research Institute
RIICO:	Rajasthan State Industrial Development & Investment Corporation
SPVs:	Special purpose vehicles
MoP:	Ministry of Power
MNRE:	Ministry of New and Renewable Energy
RPO:	Renewable Purchase Obligations
DISCOMS:	Distribution company
PNG:	Piped natural gas
AQI:	Air quality index
NAAQS:	National Ambient Air Quality Standards
GoI:	Government of India
STPP:	Super thermal power plant
ERC:	Electricity regulatory commissions
MIA:	Matsya Industrial Area
LSHS:	Low sulphur heavy stock
CFTPP:	Coal-fired thermal power plants
EII:	Energy intensive industries
TSDF:	Treatment, Storage, and Disposal Facilities
CETP:	Common Effluent Treatment Plants
H&OW:	Hazardous and other wastes
NCV:	Net calorific value
WoW:	Well-being out of waste
EPR:	Extended producer responsibility
EPE:	Expanded polyethylene

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1. Introduction to circular economy

Circular economy could be the last way out to save upon the natural resources

Till a decade ago, economies globally were largely moving linearly. The extraction of resources and their processing, consumption and final disposal into the environment were negatively impacting the environment. Apart from this chain being a capital-intensive process, the availability of the resources is also an important aspect to be looked into. With the introduction of the term circular economy in the global dictionary, focus is now shifting towards reusing and recycling of the waste as alternate resource. The circularity gap report estimates that only 7.2 per cent of the global economy is circular.[1] The circular economy is currently a major focus area not only globally but also at the national level. It works on the principle that 'waste is not only a waste but a resource'. It is a 'model of production and consumption that involves circularity (sharing, leasing, reusing, repairing, refurbishing and recycling) of existing materials and products as long as possible. In this way, the lifecycle of products is extended. In practice, it implies reducing waste to a minimum.[2] It has the potential to fuel India's growth while also providing significant environmental benefits, making a sustainable and resilient framework.

Circularity in India

Though the concept has been around since the mid-1960s, it has picked up pace in India lately. In 2015, the Government of India constituted the Indian Resources Panel (IRP) as a step to address India's resource security in a strategic perspective. IRP is an advisory body under the Ministry of Environment, Forest and Climate Change (MoEFCC).

To provide a glimpse of the existing scenario in the country, the annual material consumption as compared to 7 billion tonnes of consumption in 2015 is expected to double to 14.2 billion tonnes by 2030.[3] With the current recycling of goods standing at mere 20 per cent, there is a huge potential for the Indian economy to transform into a circular one. In Europe alone, the quantum of goods recycled is as high as 70 per cent.[4]

In September 2022, the Circular Economy Cell (CE Cell) was constituted in government think-tank NITI Aayog as a dedicated unit to work in the area of circular economy. NITI Aayog has identified 11 focus areas in waste management, to expedite India's transition from a linear to a circular economy. The focus areas include scrap metal (ferrous and non-ferrous), gypsum, toxic and hazardous industrial waste, solar panel, used oil waste etc.[5] There has been some progress towards fly ash and slag utilization, which shows in the form of the Policy Framework on Utilization of Fly Ash and Slag, 2018–19.

However, much more needs to be done for a more formalized transition to the circular economy regime in India. As the country is growing in population and urbanization, to counter the international commitments and environmental challenges shifting towards circular economy is the need of the hour and it is no longer a choice for India to practice circularity.

Why industrial waste circularity is important

There are many aspects of circularity, as per the aforementioned definition wherein refurbishing and repairing is also covered under circularity. This document mainly focuses on waste that is generated in industries or is used in industries during the manufacturing process and reuse and recycle of same.

Industry holds a prominent position in the Indian economy, accounting for about 31 per cent of GDP on average.[6] The industrial sector also plays a crucial role in the overall economic growth of a country. It contributes to increased production, fixed investment, exports and employment. Industrial development is highlighted as strategically important for the overall economic development of a country. At the same time, it is also to be highlighted that industries are one of the major consumers of the natural resources, generates a significant quantity of different types of waste including hazardous as well as non-hazardous and are a source of pollution and CO_2 emissions.

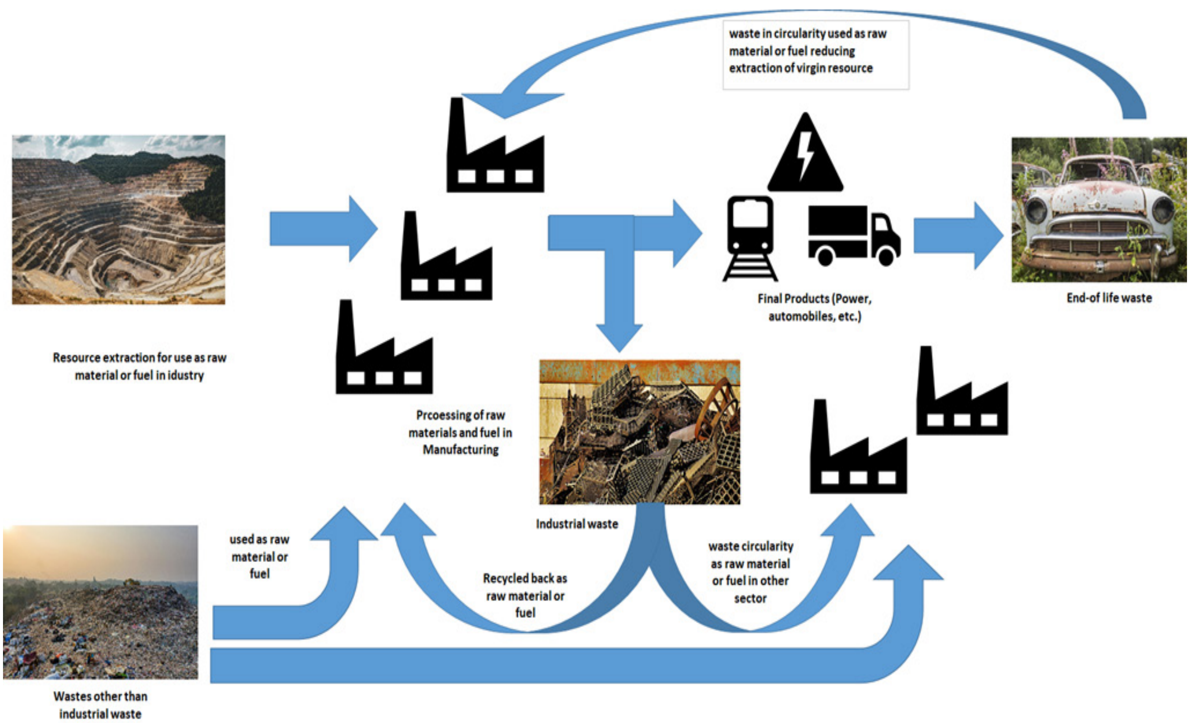
More so, in a developing economy like India, industries have a major role to play in country's development and also in attaining the net zero targets of the nation. It's also pertinent to note that India is also the third-highest emitter of greenhouse gases, and accounts for 9.2 per cent of total world emissions.[7] In this regard, industries should concentrate on reducing waste disposal to the environment and instead look for the potential options for bringing the waste into the circular stream.

The fact that most natural resources are not available in abundance and there is a limited time till when these resources can be exploited itself is an indication of the sense of urgency for the country to switch to circularity of waste in industries. Circularity can serve the objective of natural resource conservation by replacing the use of different natural resources with potential waste generated within or outside the industry. Even as companies are preparing their strategies to become net zero, they should focus on bringing the aspect of circularity in its operations to achieve decarbonization targets. At the same time, circularity also will reduce the issues and concerns of industries in terms of waste management and its disposal.

There can be different models of circularity of waste in industries, such as.

1. Waste material from an industrial sector is used as a raw material or fuel in another sector. For e.g., fly ash from power plant sector is used in cement industries.
2. Waste material of an industrial sector is used in activities other than manufacturing sector. For e.g., slag from the iron and steel sector is used in road construction.
3. Waste generated outside the manufacturing sector is used in different industries either as fuel or raw material. For e.g., processed municipal solid waste is used as fuel in the cement sector to replace fossil fuels.

Figure 1: Material flow in circular economy



Objective of the compendium

Various types of industrial wastes are generated in significant quantities in the country, which are also referred to as high volume waste. There are several instances wherein mismanagement and mishandling of such wastes has led to environmental accidents and impacted the inhabitant, flora and fauna of the region. Several court or NGT orders have been issued in each case and matters have been highlighted.

CIRCULARITY IS ONE WAY TO IMPROVE DISPOSAL AND MANAGEMENT OF UNUTILIZED INDUSTRIAL WASTE

- **NGT case against Jindal Steel Works Ltd (now JSW Steel Ltd) with application number 165/2020 on slag disposal[8]**

The case centred on JSW Steel's slag disposal practices at its integrated steel plant in Dolvi, Raigad (Maharashtra). The Maharashtra Pollution Control Board (MPCB) granted Consent to Operate for the plant, categorizing the slag as non-hazardous waste. However, the NGT intervened, directing JSW Steel to comply with consent conditions for proper slag disposal, explore slag utilization in cement manufacturing, road construction and brick production, strictly follow guidelines for handling slag from pyro-metallurgical operations, prevent soil and water pollution and adhere to environmental norms.

- **Thermal power plants are still not disposing of fly ash properly, NGT cases show[9]**

Despite the 2021 notification of the Union Ministry of Environment, Forest and Climate Change (MoEFCC) mandating 100 per cent utilization of fly ash by coal-fired thermal power plants, several cases have been registered with the National Green Tribunal (NGT), alleging its improper disposal.

In April 2023, failed compliance and inaction by coal power plants regarding pollution from fly ash slurry was brought to the attention of the NGT. In the matter of *Mohan Singh vs State of Haryana*, the applicant told the tribunal that the Panipat Thermal Plant in Haryana, owned by the state, failed to scientifically manage fly ash and its effluents.

- **Judgment of the National Green Tribunal regarding pollution caused by Madras Aluminium Company Limited (MALCO),Salem, Tamil Nadu, 24/09/2015[10]**

Judgment of the National Green Tribunal (Southern Zone, Chennai) in the matter of T.S. Sekar on behalf of the general public of Thippampatti Kattuvalavu Konnur Post, Mettur Taluk, Salem District Vs Union of India & Others dated 24/09/2015 regarding pollution caused by Madras Aluminium Company Limited (MALCO), Salem, Tamil Nadu.

The applicant seeks a direction for the industry to take appropriate pollution control measures to prevent red mud dust pollution from damaging the nearby residential houses, agricultural lands and water bodies.

- **Red mud pond wall collapses at Hindalco site in Muri[11]**

On April 10, 2019, the boundary wall of the caustic pond created by Hindalco Ltd to dispose of red mud recovered in the process of extracting aluminium collapsed, thus leading to a landslide-like situation in Muri near the railway tracks.

As an impact of the boundary breach, a few dumpers, earth movers and tractors that were parked in the area were buried in the mud slide.

- **Order of the National Green Tribunal regarding disposal of industrial waste by a sugar unit in village Khatauli, district Muzaffar Nagar, Uttar Pradesh, 22/03/2024[12]**

Order of the National Green Tribunal in the matter of Jogindra Kumar Vs State of Uttar Pradesh & Others dated 22/03/2024.

By shifting towards circularity of industrial waste, these wastes will be better managed and utilized in applications of potential. CSE has compiled a number of media clippings, court cases and NGT orders passed against mismanagement of unutilized industrial waste which has impacted the environment in one way or the other.

The matter related to a sugar unit located at village Khatauli, district Muzaffar Nagar, Uttar Pradesh and the allegation is that Triveni Engineering & Industries Ltd is generating fly ash in the boilers of the factory and dumping it illegally on both side of the road in complete violation of the environmental norms, consent conditions and Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016.

Further allegation of the applicant (Jogindra Kumar) is that several persons have suffered accidental burn injuries by stepping into heap of dumped fly ash and few such incidents have been disclosed in the application. The NGT opined that the issue raised substantial concern relating to compliance of the environmental norms.

The Uttar Pradesh Pollution Control Board was directed to file a comprehensive report in respect of the allegation made in the application and the remedial/punitive action taken by the SPCB.

- **Molasses leak from sugar factory kills thousands of fish in the Beas[13]**

In a massive ecological disaster, a large number of fish were killed in the Beas on May 17, 2018 after molasses from a sugar factory leaked into the river. The presence of molasses, a byproduct in sugar factories used for alcohol production, affected over 30 km of the river.

- **Order of the National Green Tribunal regarding air pollution due to crop burning, West Bengal, 03/03/2021[14]**

Order of the National Green Tribunal in the matter of Subash Datta Vs State of West Bengal & Others dated 03/03/2021. Grievance in the application was against air pollution due to crop burning during winter season in Districts Burdwan, Birdhum, Hooghly, Howrah, Murshidabad and New Town Action Area II of Calcutta in West Bengal, resulting in air pollution in Calcutta.

The court noted that implementation of law by the concerned executive authorities is needed and directed the Chief Secretary, West Bengal to look into the matter with the concerned departments and take appropriate action in accordance with law.

- **Order of the National Green Tribunal regarding waste dumped at Bhalswa, Ghazipur and Okhla dumpsites in Delhi, 29/01/2021[15]**

Order of the National Green Tribunal in the matter of news item published in the *Times of India* authored by Jasjeev Gandhiok & Paras Singh titled 'Below mountains of trash lie poison lakes' dated 29/01/2021.

The issue for consideration is the disposal of 'legacy' waste dumped at Bhalswa, Ghazipur and Okhla dumpsites in Delhi where huge garbage has accumulated over the period of time, adversely impacting public health and the environment, requiring emergent, scientific and environmentally safe disposal, as per applicable rules.

An inspection report of the dump sites was filed by the Joint Committee comprising the CPCB, NEERI and IIT Delhi before the NGT. The report informed the Tribunal that no concrete measures for leachate collection and treatment were being taken at the three dumpsites.

Cost of damage to environment has been calculated based on the Environmental Compensation to be levied for violation of Solid Waste Management Rules and has been assessed as Rs 155.9 crore (for Bhalswa), Rs 142.5 crore (for Ghazipur) and Rs 151.1 crore (for Okhla).

The NGT, January 29, 2021 directed the NCT Delhi and the Municipal Corporations concerned to coordinate and execute the work of remediating the legacy waste dumpsites for enforcing the rule of law and protection of environment and public health, expeditiously in terms of earlier orders of the Tribunal.

- **Dumping of marble and granite slurry in the storm-water drain of Mohi village, district Rajasmand**

In February 2023, the National Green Tribunal called for a report on the complaint received from a number of villagers of Mohi village, tehsil and district Rajasmand, Rajasthan. The allegation was that some of the marble and granite units in the area are dumping marble and granite sludge/slurry and other waste in the storm-water drain, obstructing its flow. The waste was also being dumped in agriculture and grazing land, causing damage to the environment and also making the land unusable for the cattle.

- **NGT direction to utilize marble and granite slurry[16]**

A complaint was filed at NGT against unscientific disposal of marble slurry on agricultural land near Harischandrapuram Railway Station, Kotabommali Mandal, Srikakulam district, Andhra Pradesh, causing detrimental effects on the environment and public health. The dumping of marble slurry resulted in air pollution, affecting both the health of the community and the fertility of agricultural soil due to increased salinity, micronutrient deficiency, and decreased water percolation. The committee noted that Srikakulam district has 128 granite-cutting and polishing units, and instructed the Association of Granite Cutting and Polishing Units to lift and store the waste properly within high-density polyethylene (HDPE) lined storage areas to prevent groundwater contamination. Upon NGT's orders, a joint committee comprising the Central Pollution Control Board (CPCB), State Pollution Control Board (SPCB), and District Magistrate, Srikakulam, was formed to visit the site, engage stakeholders, and devise an action plan.

CSE found that there have been number of initiatives taken by different industries or sectors in the country towards industrial waste circularity. It is to be highlighted that some industries are doing appreciable work on waste circularity. However, at present, these initiatives are either not upscaled to its maximum potential or if done there have been policy-level limitations due to which the circularity of different waste is relatively low.

There are few regulations on different industrial wastes promoting its circularity, including MoEFCC's Fly Ash Notification (1999) (last amended in 2021) and Agro Residue Utilization by Thermal Power Plants Rules, 2023; Central Pollution Control Board's (CPCB's) Guidelines for Handling and Management of Flue Gas Desulphurized (FGD) Gypsum, Slags and Red Mud; and utilization of hazardous waste in co-processing in industries, but efforts are needed to realize the potentiality of circularity of each, ensure the enforcement of the specific regulation already provided by the government and bringing regulations on circularity of other industrial wastes.

This document is intended to compile the good case studies from different sectors explaining the working of the circularity models in industrial ecology in the country, as waste from one manufacturing sector gets utilized in another sector either as raw material or fuel.

The Centre for Science and Environment (CSE), through this compendium, aims to bring different stakeholders on the same platform and deduce the policy-level interventions required with respect to different industrial wastes generated from different sectors, including municipal solid waste (MSW) used in industries. The case studies covered in this document are just some of the good initiatives taken by different industrial sectors or stakeholders in the country. But there may be many more initiatives in the industry which need to be highlighted and upscaled by overcoming the limitations and challenges and thus increasing waste circularity in the industry.

Summary

The CSE team visited different industries, facilities and agencies practising circularity of industrial waste. Based on the survey visits, the data collected and discussions with sector experts, waste-wise and sector-wise sections were prepared and are in this document. The details of the sectors and waste covered in Table 1.

Each section has information regarding the major waste of the sector explaining the case studies of circularity practised within industries. Detailing on the resources conserved through the initiative, the cost economics of replacing resource with different waste, the challenges and limitations. Also, we have examples of cement sector where not only industrial waste is getting utilized but waste from outside the manufacturing sector also gets processed and used as fuel in the industries. The major objective of the document as mentioned above is to upscale the good practices on circularity of different material or waste from within one sector industries or from outside to another industrial sector. Focusing on what resource, the waste is replacing while getting utilised in the industries a comparison has been drawn of various environmental benefits. Also, CSE has estimated the future scenarios and potential of using different wastes in the circularity.

In the **iron and steel sector**, the waste of major concern is steel slag or LD (Linz Donawitz) slag. Every year, about 12 million tonnes of LD slag is generated, of which only about 17–20 per cent is currently utilized in different applications.[17] There is huge scope for increasing the utilization of steel slag, and case studies from the iron and steel sector have been covered.

Table 1: Sectors and waste covered in the report

S. no.	Waste for circularity	Generating sector
1.	Steel slag	Iron and steel
2.	Refuse-derived fuel (RDF) from municipal solid waste	Domestic
3.	Hazardous waste	Manufacturing
4.	Fly ash	Thermal power plant
5.	Gypsum from flue gas desulphurization system	Thermal power plant
6.	Red mud	Aluminium
7.	Bagasse, press mud, molasses and spent wash	Sugar and distillery
8.	Stone slurry and marble slurry	Kota stone cutting and marble cutting
9.	Biomass	Agriculture waste
10.	Waste paper	Domestic

Note: Wastepaper and municipal solid waste (RDF) though generated in the domestic set up and are not industrial waste but serves as a resource (either fuel or raw material) for the industries. Same is the case with biomass.
Source: CSE, 2024

The **cement sector** has emerged as one of the best examples with regard to utilizing waste from different sources, including municipal waste, as raw material or fuel. The sector acts as a sink and promotes circularity of waste. It utilizes not only municipal solid waste but also hazardous waste as a replacement of coal used in clinker making. The Indian cement sector consumes about 8–9 million tonnes of coal annually, which is used for captive power generation as well as clinker making.[18] The total municipal solid waste generation in India is about 60 million tonnes per year. As per the Annual Report on Solid Waste Management (2020–21) by the Central Pollution Control Board (CPCB), about 95 per cent is collected—out of which only 50 per cent (29 million tonnes) is treated either in waste to energy or compost plants or used as refuse-derived fuel (RDF) in cement industries—around 20 per cent is landfilled and the rest is unaccounted for. Similarly, about 12.35 million tonnes of hazardous waste is generated in the country, out of which about 7.6 million tonnes is recycled or utilized in different applications.[19] This comprises 60 per cent of the hazardous waste getting into the circular stream. Therefore, there is ample scope of utilizing both municipal solid waste and hazardous waste to replace coal usage within the cement sector.

Thermal power plants in India produces fly ash, which is an unburnt residue of coal combustion in a thermal power plant. In 2021–22, about 271 million tonnes of flyash[20] was generated. In spite of clear usages of fly ash in various applications, fly ash utilization is not 100 per cent till date. CSE has documented the various usages and quantities of fly ash utilized in each application, and assessed the gap between generation and utilization and how it can be overcome.

Another waste from thermal power plants is gypsum generated from flue gas desulphurization (FGD) gypsum units. The capacity of thermal power plants with installed FGD is about 8.44 GW which is generating about 2–4 million tonnes of gypsum per year.[21] FGD gypsum has the characteristics to replace both mineral and synthetic gypsum used in the cement sector. Detailed case studies of different thermal power plants are included on circularity of FGD gypsum.

The **pulp and paper sector** is divided into wood-based, bamboo-based and wastepaper or recycled fibre (RCF)-based industries in India. Out of total production of 21.68 million tonnes in 2021, about 76 per cent of the production is through wastepaper-based industries. Wastepaper is the main raw material for these industries. CSE assessed the circularity of wastepaper in the country and found that the supply chain of wastepaper is mostly in the hands of the informal sector and, due to various secondary applications, the recovery of wastepaper back to industries from the supply chain is only about 57 per cent. This also results in import of about 35 per cent of the total wastepaper required by industries (about 6–7 million tonnes annually).[22] It has been observed that there are some good models that need to be replicated to increase the circularity of wastepaper to industries. The same has been documented.

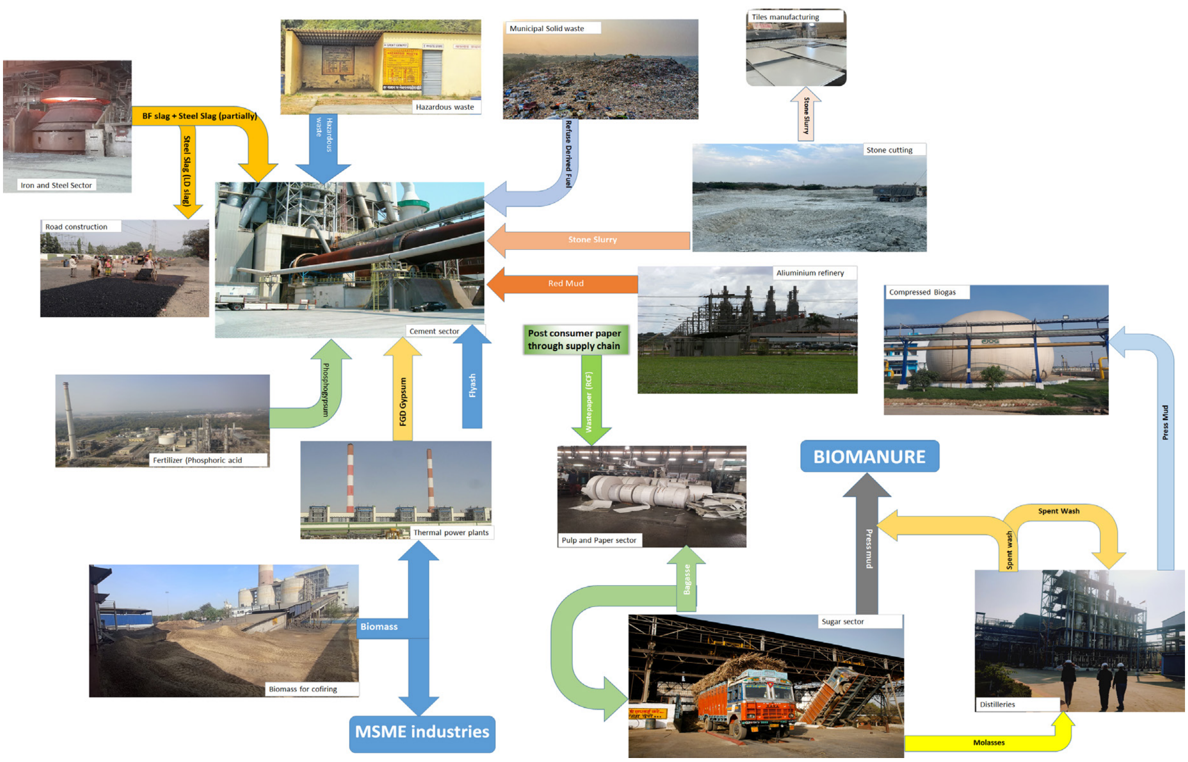
Aluminium is another manufacturing sector CSE covered. The aluminium industry is divided into two—alumina refinery and aluminium smelter. India's alumina production capacity is about 7.4 million tonnes per annum.[23] Alumina is extracted through the refining process of bauxite ore by separating other impurities such as iron and silica. The impurities removed are called bauxite residue or red mud. As a thumb rule, about 1–1.5 tonnes of red mud is generated per tonne of alumina produced.[24] During 2021–22, total red mud generation from alumina refineries is about 10.4 million tonnes. Red mud is highly alkaline in nature and thus its disposal and utilization is a concern for the industries. However, some of the industries have taken an initiative towards utilization of red mud in cement plants. CSE has highlighted the current status of circularity of red mud and the potential avenues that can be considered for its consumption in future.

Sugar and distilleries are covered by CSE in an integrated way in this compendium. The two sectors together have been a good example of a circularity of materials between them. India's sugar industry crushed about 357.4 million tonnes of sugarcane during 2022.[25] The major waste produced in a sugar unit is bagasse, press mud, spent wash and molasses. Each waste is consumed within the sugar or distillery industry and nothing goes out as waste from the industry. In the last few decades this sector has shown an enormous improvement in terms of its resource management. The case studies depict the current scenario of waste circularity in the sector.

We have also included the **stone-cutting** sector, predominantly located in the state of Rajasthan. The major waste from these industries is stone slurry, which is generally disposed of in nearby areas. However, when stone slurry is deposited in landfills, its water content diminishes significantly, leading to the formation of stone dust, which results in dispersion of dust into the environment. It has been observed that cement industries have the potential to use stone slurry along with phosphogypsum (waste from the fertilizer plant) to replace natural gypsum.

In the Indian economy, which is primarily agrarian, biomass is a potential fuel to replace fossil fuels used in industries. The government also has taken steps on **biomass co-firing** in industries and thermal power plants as an option to move away from coal and other fossil fuels. CSE has captured this initiative of the manufacturing sector as well as of power plants as a good practice, which in turn has the potential to increase the circularity of biomass as a fuel, reducing the carbon emissions into the environment. The case studies on biomass co-firing is derived

Figure 2: Prevailing good practices on industrial waste circularity as documented by CSE



from CSE's work on micro, small and medium enterprise (MSME) industries in Delhi-NCR and biomass co-firing in thermal power plants.[26,27]

Multifold benefits of industrial waste circularity

Resource efficiency

Through circularity of industrial waste, there is huge scope of saving on valuable and limited natural resources available in the environment. Promoting circular material use and circular economy activities contributes to reducing raw material extraction and thus can be a driver to resource conservation. For example, India's coal consumption is 1,156 million tonnes,[28] and if our industries can replace a specific quantity of coal with alternative fuels and raw materials (AFR), it will directly save on coal, which is an important natural resource for the country. Substituting, say, 10 per cent of coal will result in saving of about 115 million tonnes of coal reserves of the country and corresponding CO_2 emissions.

Reduced GHG emissions

Fossil fuels have been a primary source of energy for industries for centuries. Circularity helps in reducing greenhouse gas (GHG) emissions and hence has the potential to contribute to India's decarbonization journey. GHG emissions, for example, could be 44 per cent lower in 2050 compared to the current development path if India embarked on the circular economy transition.[29]

Better management of non-hazardous and hazardous industrial waste

One thing which circularity will surely improve upon is the way waste is managed in India. The country has a limited space and waste generated per day cannot be landfilled across the country. There is a need to replicate different models of waste utilization, increase the usage of waste and thereby reduce the waste getting landfilled and disposed of in an unscientific manner.

Reduced cost economics

The cost of manufacturing of any goods or products will be more if it involves raw material procurement from natural resources, its processing and making the final product. However, in the case of sourcing of resources through circularity, the costing of manufacturing is expected to reduce significantly. The cost–benefit varies on a case-to-case basis and may or may not be economically viable all the time.

Increased energy efficiency

While the waste material moves in circularity, it generally requires less energy as compared to extracting virgin raw materials or fossil fuel from the environment to produce new products. Thus, circularity of waste also brings in an add-on advantage of manufacturing processes becoming energy-efficient in nature.

Limitations and challenges of attaining circularity

Lack of regulatory push to promote industrial waste circularity

There have been a few notifications put out by the Indian government that focus on promoting industrial waste circularity. It is understood that the policies bring a push for the stakeholders to comply with the regulations, in the absence of which the objective of any initiative cannot be achieved.

For example, though the Ministry of Housing and Urban Affairs (MoHUA) brought the guidelines on usage of refuse-derived fuel (RDF) in various industries in October 2018, no notification in this regard came into effect, which kept the things open for the industries as well as other stakeholders, as there is no enforcement on any of the stakeholders to either utilize the RDF or supply RDF of certain quality.

Involvement of large number of stakeholders in the supply chain

As we have gone through the waste management systems across different industrial sectors, it has been observed that the supply chain of these wastes includes a number of levels and to ensure the circularity of waste in industries it is important that each of these stakeholders be made aware of their responsibilities. There have been leakages or diversions of industrial wastes while it moves into the supply chain, which is mostly informal in nature. However, there are also number of formal agencies and there is a need to develop an integrated ecosystem where formal and informal agencies work together to handle different wastes generated within or outside the industry to ensure the proper utilization of the waste in specific applications.

Lack of pilot interventions to exhibit the model of waste circularity

Many of the industries are currently doing good work in terms of industrial waste circularity. But since they are doing it in isolation there is no replication of these models by other stakeholders. This sometimes acts as a bottleneck as such initiatives need to be projected and upscaled to be followed by the other similar industries.

Incentives for the industries practising circularity

Industries can manage their waste either in a linear model or in a circular model. However, there is no incentive for the industries to preferably go for waste circularity and at times the linear model of waste management is more economically feasible for industries. Policymakers need to ensure that it is cost viable for industries to manage their waste in a circular stream rather than going for disposal of waste in a linear manner. For example, the sale and purchase of many of the industrial wastes comes under the purview of GST regime. To promote circularity of wastes, Government of India may consider exemption of GST on waste materials.

Recommendations

1. Mapping and inventorization of the industrial waste generated in the country

It has been understood that there is no data on the quantum of utilization of different industrial wastes barring a few—e.g., flyash—where credible data is available through CEA on the utilization of flyash for different applications. Thus, there is a need to prepare the inventory of the industrial wastes and area-wise mapping of different wastes based on the type of waste generated by the industries in any specific area. This will not only help in developing the inventory but will also assist in preparing the logistically feasible procurement network for all kinds of industrial waste.

2. Government needs to notify and mandate guidelines/ policies on different industrial waste with clear responsibilities of different stakeholder

If India has to transform into a circular economy, preparing and notifying the guidelines to utilize different industrial waste in circularity is must. The guidelines should include the framework as well as economic models along with the responsibilities of each stakeholder regarding different wastes.

Application-based standards for different industrial wastes should also be part of guidelines. Different waste is used in different applications. However, the quality of waste required for each application may differ. At present there is no qualitative classification of the waste based on the application it is intended to be used for. Thus, there is a need to bring the application-based standards for different industrial wastes.

The specification of different waste (qualitative) needs to be notified by the respective agencies like the Bureau of Indian Standards, National Council for Cement and Building Materials, Central Building Research Institute, Ministry of Steel, Ministry of Power, Department for Promotion of Industry and Internal Trade (DPIIT) Ministry of New and Renewable Energy etc.

3. Taxonomy of the green products should be inclusive of circularity aspects

While defining the products as 'green', the taxonomy should also consider if the product has been manufactured using circularity of waste as raw material or fuel feed. It is not only the carbon emissions that should be taken into account but production through circularity is also important as it prevents use of virgin natural resources, reduce air pollution through less usage of fossil fuels and better waste management.

4. Incentivization for industries to enhance and encourage practising circularity of waste from within or into the system

There needs to be provision of incentives for industries to adopt a circular solution for the waste coming into or going out of the system. Sometimes, even the development of infrastructure to enhance circularity in industries is not economically viable, and industries thus restrict their move towards circular economy. NITI Ayog along with the waste-respective stakeholders can work upon the incentive schemes for the industries to promote industrial waste circularity. For e.g. recently, the Ministry of Mines has planned to bring in a Production Linked Incentive (PLI) scheme to boost circular economy and intended to complement the Battery Waste Management Rules (BWMR), 2022. Production Linked Incentive (PLI) Schemes for 14 key sectors have been announced to enhance India's Manufacturing capabilities and Exports.[30] This is supposed to be in line with NITI Ayog's policy recommendations on the battery waste.[31]

5. Common dashboard to be developed by the government to share success stories, mapping and inventory

There is a need to share information, transfer of technologies and infrastructure development to enhance circularity in the industrial sectors. Since there are a large number of stakeholders involved from different sectors, there is need for a common platform to be built to accelerate and collaborate on circular economy initiatives within the industries. Showcasing the impact of the waste circularity is also important. NITI Aayog can develop a dashboard on circularity initiatives to document the cases across the country. Also, the mapping and inventory of industrial waste should be made available on this portal.

6. Governement should assign a central agency responsible for circularity in India

At present there is no government agency responsible for promoting circular economy in the country. Different ministries, government bodies are working on circularity but in silos. Since industrial waste circularity is an inter-related stream where waste material from one sector can be utilised in other sector, therefore there is a need to designate a central agency to look after the waste circularity in the country.

7. Capacity building of the stakeholders

Since the world of circularity is yet to reach its potential, it is important to create awareness among the industries and other stakeholders towards industrial waste circularity, avenues of its utilizations and the cost economics of promoting circularity.

Sector-wise/waste-wise recommendations are given at the end of each case study separately.

Future scenario of industrial waste circularity

For each of the wastes and sectors covered in the compendium, we have estimated the expected generation of each industrial waste by 2030 and current annual generation (average). Further, we have also estimated the quantity of waste utilized in different applications as documented by CSE along with the rationale of estimation (see *Table 2*).

Table 2: Resources conserved from use of various industrial wastes (future scenario)

Industrial waste	Steel slag		
Generating industrial sector	Iron and steel		
Current generation (annual avg.)	12 million tonnes		
Estimated Generation in 2030	52.5 million tonnes		
Application	Estimated quantity to be utilized (2030)	Rationale for estimation	Resource conserved (quantity)
Cement making			
OPC	3.3 million tonnes	Based on estimations in CSE's report *Decarbonising the Cement Sector*	Mainly blast furnace slag is currently used
	9 million tonnes	As per existing product mix	
PSC	22 million tonnes	Considering 50 per cent steel slag is used in raw mix	
CC	10 million tonnes		
Fly ash brick	47.5 million tonnes	Steel slag is used to replace both sand and lime in 50 per cent of brick manufacturing	15.86 million tonnes of sand 21.7 million tonnes of lime
Roads and highways	80–160 million tonnes	Assuming 80,000–85,000 tonnes is used per km of six-lane highway. 20 per cent of total highway construction uses steel slag	Bitumen and concrete with saving of Rs 150–1,500 per square metre
Waste	Municipal Solid waste		
Generating industrial sector	Domestic		
Current generation (annual avg.)	62 million tonnes		
Estimated generation in 2030	165 million tonnes		
Application	Estimated quantity to be utilised (2030)	Rationale for estimation	Resource conserved (quantity)
Cement making	36 million tonne RDF	Replace 50 per cent of coal used in clinker making	24 million tonnes of Coal Abatement of 7.6 million tonnes of CO2e
Industrial waste	Fly ash		
Generating industrial sector	Coal-based power plant		
Current generation (annual avg.)	271 million tonnes		
Estimated generation in 2030	437 million tonnes		
Application	Estimated quantity to be utilized (2030)	Rationale for estimation	Resource conserved (quantity)
Cement making			
PPC	185–208 million tonnes	40–45 per cent fly ash used in composition of PPC	Equivalent limestone conservation expected
Composite cement	23 million tonnes	35 per cent fly ash used in composition of CC	
Roads and highways	110 million tonnes	Average 5,000 km highway constructed and fly ash is used in 20 per cent of total km.	

Industrial waste	Gypsum		
Generating industrial sector	Coal-based power plant		
Current generation (annual avg.)	3.86 million tonnes		
Estimated generation in 2030	12–17 million tonnes		
Application	Estimated quantity to be utilized (2030)	Rationale for estimation	Resource conserved (quantity)
Cement making	16.5 million tonnes	Gypsum is used in 50 per cent of total cement production	Replacing natural with FGD gypsum, cost saving is Rs 2,150 per tonne
Industrial waste	Red mud		
Generating industrial sector	Aluminium		
Current generation (annual avg.)	10–12 million tonnes		
Estimated generation in 2030	36 million tonnes		
Application	Estimated quantity to be utilized (2030)	Rationale for estimation	Resource conserved (quantity)
Cement making	20.4 million tonnes	85–90 per cent of 5 per cent additives can be replaced by red mud in case of pet coke usage	Laterite saving of Rs 250–300 per tonne of clinker
	8.4 million tonnes	35–40 per cent of 5 per cent additives can be replaced by red mud in case of coal usage	
Industrial waste	Bagasse Press mud		
Generating industrial sector	Sugar and distillery		
Current generation (Annual avg.)	Bagasse: 90 million tonnes Press mud: 14.3 million tonnes		
Estimated generation in 2030	Bagasse: 130 million tonnes Press mud: 15.6 million tonnes		
Application	Estimated quantity to be utilized (2030)	Rationale for estimation	Resource conserved (quantity)
Steam generation in sugar industry	Bagasse: 93.6 million tonne	Sugarcane requirement is expected to be 520 million tonne by 2030. To process one tonne of sugarcane, 37 per cent of steam is required. 1 tonne steam requires 4 tonnes of bagasse	46.8 million tonnes coal 5.6 million tonnes CO_2
Manufacturing compressed biogas	Press mud: 15.6 million tonne	All press mud generated in sugar manufacturing is utilized for CBG production	Replacement of fossil fuel with green fuel in mobility through fuel blending and can replace natural gas in industrial/ commercial application

Waste	Biomass		
Generating industrial sector	Agriculture		
Current generation (annual avg.)	750 million tonnes		
Estimated generation in 2030	Data not available		
Application	Estimated quantity to be utilized (2030)	Rationale for estimation	Resource conserved (quantity)
Coal-based power plant	58–88 million tonnes	Considering 100 per cent and 50 per cent of total capacity is doing biomass co-firing of about 5 per cent	39–78 million tonnes of CO2e
Industrial waste	Hazardous waste		
Generating industrial sector	Manufacturing		
Current generation (annual avg.)	12.35 million tonnes		
Estimated generation in 2030	Data not available		
Application	Estimated quantity to be utilized (2030)	Rationale for estimation	Resource conserved (quantity)
Co-processing in cement sector	14.7 million tonnes	quantity authorized for co-processing is 29.34 million tonnes remains same and 50 per cent of capacity is utilised	12 million tonnes of coal
Industrial waste	Stone slurry 2. Phosphogypsum 3. Marble slurry		
Generating industrial sector	1. Stone cutting—Kota stone 2. Phosphoric acid plant 3. Marble stone cutting		
Current generation (annual avg.)	0.25–0.3 million tonnes (stone slurry) 6.5 million tonne (phosphogypsum) 5–6 million tonne (marble slurry)		
Estimated generation in 2030	Data not available		
Application	Estimated quantity to be utilised (2030)	Rationale for estimation	Resource conserved (quantity)
Cement making	3-7 million tonne-Kota stone slurry	All cement plants in Rajasthan start using 4–9 per cent Kota stone slurry (existing cement capacity of Rajasthan—77 million tonne per annum)	Natural gypsum Rs 1,800–2,200 per tonne, depending upon the source, saving of Rs 1,050–1,450 per tonne
	1.54 million tonne phosphogypsum	All cement plants in Rajasthan start using 2 per cent phosphogypsum	
Tile making	8–10.5 million tonne marble slurry	Tile manufacturing expected to be 80 million tonnes by 2027, utilization of marble slurry in tile making to be 10–13 per cent	Equivalent natural feldspar. Based on grade, feldspar costs around Rs 1,200–5,000 per tonne, saving in the range of Rs 100–3,900 per tonne

CASE STUDIES

2. Steel slag from iron and steel sector—Potential replacement for natural aggregates in road construction

About 15 million tonnes of unused steel slag is currently stacked in industries across the country

India is the world's second-largest producer of crude steel, with an output of 125.32 million tonnes (MT) of crude steel and 121.29 MT of finished steel production in FY23. The iron and steel sector is one of the most important sectors owing to its contribution in the infrastructure development in the country and its contribution to country's Gross Domestic Product (GDP). It currently accounts for around 2 per cent of India's GDP. The production of the sector jumped by 4.2 per cent to a record 125.3 million tonnes in 2022–23.[32]

Iron and steel can be manufactured through different routes. Hot metal or pig iron is an intermediate product in the process of manufacturing of steel—hot metal is the liquid form that becomes pig iron when it solidifies. Pig iron is used as raw material for production of crude steel through the basic oxygen furnace (BOF) route. While the share of steel manufacturing through the BOF route is about 45 per cent, about 28 per cent of steel is manufactured through the direct reduced iron (DRI) route through electric arc furnace (EAF) and 27 per cent through induction furnace (IF). There are various waste streams emerging from the iron and steel process, with slags being one of the major wastes generated from the sector.

The different types of slags generated in the iron and steel industry are blast furnace slag, basic oxygen furnace slag (BOF slag/steel slag/Linz-Donawitz (LD) slag), electric arc furnace slag (EAF slag), induction furnace slag (IF slag), desulphurization slag, stainless-steel slag and secondary refining slag.

Blast furnace slag (BF slag): BF slag is produced during hot metal or pig iron production. Depending on the cooling method, three types of iron slag are produced—air cooled, expanded and granulated—that have different types of applications. Blast furnace (BF) slag production is in the range of 300–540 kg per tonne of pig or crude iron produced.

BF slag in India is used mainly in cement manufacture as a replacement for clinker and in other unorganized work, such as, landfills and railway ballast. A small quantity is also used by the glass industry for making slag wool fibres. The annual generation of BF slag is about 24 million tonnes of which 90 per cent is utilized mainly in cement production and the remaining 10 per cent is either dumped or used in road construction.[33]

Steel slag (LD slag/BOF slag): Steel slag is generated during steel manufacturing in convertor shop. About 12 million tonnes of steel slag is generated per year in India.[34] It has shown potential for use as a raw mix component up to 10 per cent in the manufacture of cement clinker. Steel slag can also replace granulated blast furnace slag up to 10 per cent in the manufacture of Portland slag cement. About 150–200 kg per tonne of steel slag is generated per tonne of steel.

Utilization of steel slag is an issue and efforts are required for making steel slag production and utilization a part of the circular economy. Like BF granulated slag, use of BOF slag in cement making is not established and its recyclability in the steel-making process is also restricted to a certain extent. Presence of high phosphorous and sulphur content affects its recyclability.

The circularity of steel slag refers to its potential for reuse and recycling within a circular economy framework. Steel slag is a byproduct generated during the steelmaking process, primarily from the conversion of iron ore to iron in a blast furnace. It consists of various impurities, fluxes and non-metallic elements that are present in the iron ore.

Traditionally, steel slag was considered waste and was often disposed of in landfills. However, with the growing focus on sustainable practices and resource efficiency, there has been increasing interest in harnessing the circularity potential of steel slag.

EAF and IF slag: EAF and IF slag generation is around 5 million tonnes annually. The EAF route produces 200–220 kg slag per tonne of steel.

Desulphurization slag: The rate of generation of slag from desulphurization 14–16 kg/ tonne of hot metal. Generated during the desulphurization process, it is a heterogeneous slag and partially melted. The composition of slag depends on the desulphurization agents used for the process. The slag contains relatively high sulphur content. The slag is processed to metal recovery plant for separation of metallic and non-metallic parts.

Since major manufacturing route is BF–BOF route (45 per cent) therefore the quantum of BF slag and steel slag generation is huge. For steel slag there are limitations in terms of its utilization, as at present more than 15 million tonnes of steel slag is stacked in the industries across the country due to challenges with its properties and thus reduce utilization.

Challenges in utilizing steel slag (LD slag)

Steel slag is not ideal for construction applications because of high content of free lime as it absorbs moisture and calcium (Ca) to form hydroxides and carbonates respectively, thereby leading to volume expansion or swelling and subsequent crack formation in roads and buildings. Phosphorous content, high free lime content and higher specific weight are the major reasons for its lesser utilization. However, it can be weathered either naturally or by steam ageing or maturing before use for these purposes.

During natural ageing steel slag is normally exposed to rain and sun and stabilization for months before use. The natural aging process is slow and time-consuming, and thus restricts its usage. The steel-making slag can be put to effective use as coarse aggregates if quickly aged and stabilized by pre-reacting the free expansive phases.

The steel industry is finding ways and means to utilize the steel slag in other applications like construction and road making, soil conditioning and rail ballast. There are, however, problems and issues. The steel slag needs to be properly aged and ground to a very fine size before it can be explored to be utilized, which incurs substantial cost. There is lack of guidelines for use of steel slag as replacement of natural aggregates in construction activities and road-making. Use of aggregates in rail ballast is governed by RDSO standards. However, the RDSO standards do not presently allow use of steel slag.

CASE STUDY 1: Utilization of steel slag in paver block manufacturing

Name of industry: Steel Authority of India

Location: Bhilai Steel Plant, Chhattisgarh

The annual average generation of BF slag at the Bhilai Steel plant is about 6–7 million tonnes. About 95 per cent of the total BF slag is used in cement manufacturing. The remaining quantity is partially utilized within the unit and the rest is dumped in the slag yard.

The Bhilai steel plant produces about 2 million tonnes of steel slag out of which about 50–60 per cent is utilized within the unit in kaccha road preparation. The rest remains unutilized. The plant management is taking steps towards finding innovative solutions of utilizing the steel slag in productive applications.

Pilot project on paver block manufacturing: SAIL BSP is doing an in-house pilot project on manufacturing of paver blocks using steel slag. The stone chips (5–12 mm) which are natural aggregates are replaced by steel slag and the paver blocks are used for the internal use at present. The paver block is constituted of cement, sand and slag (57 per cent by weight).

One paver block weighs about 6.5 kg and covers an area of about 6.45 sq. ft. One paver block consumes around 1.8 kg of steel slag. The pilot scale project is capable of producing about 1,000 blocks per day. Thus about 1.8 tonnes per day of steel slag

Steel slag stacked at SAIL BSP

Source: CSE Survey

is utilized in paver block manufacturing. Apart from saving on natural aggregate, use of slag in place of stone chips is also an economically viable option as the cost of stone chips may vary by Rs 1,000–2,500 per tonne or even higher while the cost of processing of steel slag to the required size is about Rs 100–150 per tonne.

The cost economics of replacing stone chips with steel slag (at a plant) is estimated as follows:

Weight of one paver block	**= 6.5 kg**
Steel slag share in one paver block	**= 1.8 kg**
Steel slag consumption in 1000 paver block manufacturing	**= 1.8 tonnes per day**
Cost of stone chips @Rs 1,750 (average cost)	**= Rs 3,150 per day**
Cost of transportation @Rs 500/tonnes	**= Rs 900 per day**
Total cost of using stone chips	**= Rs 4050 per day**
Cost of using steel slag (may vary as per location of utilization)	**= Rs 270 per day**
Total cost saving by replacing stone chips with steel slag in paver block manufacturing	**= Rs 3,780 per day**
Annual cost saving	**= Rs 1.25 million**

Note: The above-mentioned cost economics is indicative and will vary on a case-to-case basis for paver block manufacturing units.

The process of manufacture of cement concrete paving blocks involves the following steps:

a) Proportioning
b) Mixing
c) Compacting
d) Curing
e) Drying

Process of manufacturing

The process of manufacture of cement concrete paving blocks involves the following steps:

- A concrete mix of 1:2:4 (cement: sand: LD slag) by volume is used for cement concrete paving blocks.

- All the raw materials are placed in a concrete mixer and the mixer is rotated for 15 minutes.
- Vibrating table may be used for compacting the concrete mix in the moulds of desired sizes and shapes.
- After compacting the blocks are demoulded and kept for 24 hours in a shelter away from direct sun and winds.
- The blocks thus hardened are cured with water to permit complete moisturization for 14–21 days. Water in the curing tanks is changed every three to four days. After curing, the blocks are dried in the natural atmosphere and sent for use.

Proportioning and mixing

Vibrating table

Curing

Drying

Finished product

CSE team at SAIL BSP

Source: CSE survey

CASE STUDY 2: Utilization of steel slag coarse aggregates in brick manufacturing, cement making and road construction

Name of industry: Tata Steel

Location: Jamshedpur Steel Plant

Tata Steel, Jamshedpur, has been doing well in terms of utilization of slag. Regarding BF slag generation, about 2–3 million tonnes per year is generated from the all Tata Steel facilities with Jamshedpur plant generating major share. The granulated form of BF is fully utilized in the cement sector. Cement industries have also started taking air-cooled slag as well.

Steel slag generated at the Jamshedpur steel plant is used for various applications. It is divided into two forms—metallic and non-metallic slag. There is no problem in selling metallic slag. It is either used for internal applications or outside sales for metal recovery.

Non-metallic steel slag is divided into three types—LD slag, desulphurization slag (DS) and laddle furnace (LF) slag. Non-metallic slag has the maximum utilization as slag of more than 6 mm size is matured through steam-induced system or steam ageing, resulting in making the slag lime free, to reduce the expanding properties of the slag to less than 2 per cent, which makes it usable to be used in construction

Table 3: Size-wise use of the non-metallic part of LD slag

Type of non-metallic slag	LD	DS	LF
Quantity generated per month (in tonnes)	110,000	15,000	15,000
Size (in mm)			
0–6	Cement/brick	Hardstand/landfilling	Cement
6–10	Road	Hardstand/landfilling	Hardstand/landfilling
10–20	Road	Hardstand/landfilling	Hardstand/landfilling
20–40	Road	Hardstand/landfilling	Hardstand/landfilling
40–65	Road	Hardstand/landfilling	Hardstand/landfilling

Source: Based on information shared by organization

activities. DS slag has too much sulphur while LF has high lime content. LF in 0–6 mm size is used by cement industries since it has more lime content. DS and part of LF is mostly used for hardstand or surface filling or levelling within the unit (see *Table 3: Size-wise use of the non-metallic part of LD slag*).

As seen in Table 3, about 50 per cent of the LD slag is utilized as 0–6 mm, out of which about 30–35 per cent is used in cement making. Out of the total non-metallic slag about 10–15 per cent (14,000–21,000 tonnes per month) is utilized in the cement sector.

20–65 mm size of non-metallic slag has the potential of being used for railway ballast making.

Tata Steel has launched the branded LD slag products Tata Aggreto and Tata Nirman in January 2018.

Open steam ageing plant for utilization of LD slag

The major challenge industry faces in utilizing LD slag is its expandable properties due to free CaO. Due to this it cannot be used in construction activities as CaO expands in the presence of moisture to form $Ca(OH)_2$, which results in instability of structures. To overcome this, Tata steel, Jamshedpur has set up an open steam ageing plant with two pits of 1,300 tonnes capacity each. The pit has steam lines installed and LD slag is exposed to steam treatment for 72 hours continuously, to get matured slag, branded by the name of Tata Aggreto. The process is called steam maturing. LD slag exposed to steam quickens the process of maturing as CaO gets converted into CaOH. Thereafter can be used in different applications. On the other hand, natural ageing is a long process and it may take up to three months for the slag to get matured. Matured slag has less than 2 per cent of expandable properties and can be used in construction activities.

Steam ageing plant at Tata Steel Jamshedpur

Source: CSE survey

Tata Aggreto is widely used as a substitute of natural aggregates in road construction, Tata Aggreto has no environmental side effects. This road-making aggregate, obtained from LD slag, reduces dependence on natural aggregates such as crushed stones and sand and consequently reduces dependence on mining and stone crushing. Tata Aggreto conserves about 16,500 MT of natural aggregates for every kilometre of National Highway constructed. It is thus an ideal green raw material for construction as it reduces our dependency on heavy mining.

Tata Nirman

Another branded product made out of LD slag is Tata Nirman. It is ideal for making fly ash bricks and clinker. It is used as an alternative to replace sand in the manufacture of fly ash bricks and partial replacement of limestone in clinker in cement making. It can also be used in making Ordinary Portland Cement by up to 5 per cent as per the guideline IS269.

The steel slag from the steel melting furnace is cooled before metallic separation. The slag is then crushed and sized to produce Tata Nirman.

Figure 3: Production of Tata Nirman

CASE STUDY 3: Development of construction sand from waste steel slag

Name of industry: **JSW Steel**

Location: **Vijaynagar**

JSW Steel did an extensive research and development project, which aimed to identify a viable and sustainable solution to the problem of steel slag. After extensive theoretical studies, laboratory testing, and field studies, JSW Steel has developed an innovative process for transforming waste steel slag into IS-383:2016 Code for aggregates for Concrete, compliant sand that is suitable for construction, as well as slag fines which can be used in cement making as well as some agricultural applications.

The project culminated in the construction and commissioning, in June 2022, of the world's first steel slag-to-sand facility (with a capacity of 800 tonnes/day) at JSW's Vijayanagar works. The annual average estimated generation of steel slag at JSW Vijayanagar is about 1.5–2 million tonnes per annum.

JSW's steel slag sand plant

Source: CSE survey; JSW

As a result of the project and the development of the Vijayanagar facility, the following benefits have been realized:

1. The possibility of recycling of approximately 0. 27 million tonnes of steel slag waste each year.
2. The avoidance of an equivalent tonnage of steel slag waste from entering local landfills.
3. Net reduction in Vijayanagar Works' carbon dioxide emissions by approximately 100 tCO_2e/annum from the reduced use of vehicles for slag disposal within the plant. (This does not include the emissions incurred for river sand excavation and transportation.)
4. Creating new jobs within the local community.

In addition to the aforementioned advantages, there is one more significant benefit associated with this project. In delivering a solution that creates a useful new source of what is already an increasingly scarce commodity, the project has created a reduction in demand for natural river sand in the region of 0.2–0.3 million tonnes. In doing so, the project has not only made a small but important contribution to the prevention of river and delta degradation and the associated loss of habitats, but it has also ensured the sustainable operation of the industry as it has been able to resolve the industry's most intractable problems.

Case study 4: Use of steel slag (LD) as runner sand in the blast furnace section

Name of industry: Steel Authority of India (SAIL)

Location: Bhilai Steel Plant, Chhattisgarh

River sand is procured from outside to be used as runner sand in the blast furnace. The size requirement of the sand is 1 mm. BSP is doing a trial to replace river sand with the LD slag.

Runners are connected channels that convey the molten metal to different storage vessels. A well-designed running system can regulate the speed of the molten metal, avoid shrinkage and minimize turbulence. Runner sand prevents molten metal from sticking to the earth material. The cost of river sand to the plant is Rs 1,300 per tonne while the processing cost of LD slag to 1 mm to 250 µ is Rs 140 per tonne. The total quantity of sand required per year in blast furnaces at the Bhilai steel plant is about 25,000 tonne, which is a natural resource and can be conserved as a whole.

Cost of river sand required per year @Rs 1,300 per tonne	=	**Rs 32.5 million**
Cost of LD slag used as runner sand @Rs 140 per tonne	=	**Rs 3.5 million**
Annual savings on the runner material	=	**Rs 29 million per year**

Trenches to extract hot metal from blast furnace and use of slag as runner material

Source: CSE survey

To enhance utilization of steel slag or BOF slag, SAIL is also taking up R&D-based studies, including:

1. Field trials on assessing suitability of weathered BOF slag as rail track ballasts.
2. SAIL as an industry partner participated in the Ministry of Steel-sponsored R&D

project 'Development of steel slag-based cost-effective eco-friendly fertilizers for sustainable agriculture and inclusive growth' through ICAR-IARI.

Future scenario of steel slag utilization

The steel production is expected to be about 300 million tonnes by 2030,[35] which will generate about 126 million tonnes of BF slag and 52.5 million tonnes of steel slag (assuming 150–200 kg of steel slag generation per tonne of steel). The potential applications for steel slag utilization and scenario as expected in year 2030 are:

Cement sector (OPC/PSC/CC): By 2030 the total cement production of the country will be about 660 million tonnes,[36] divided into Ordinary Portland cement (OPC), Pozzolana Portland cement (PPC), Portland slag cement (PSC) and composite cement (CC). As per the CSE study *Decarbonizing India: Cement Sector*, the share of blended cement (PPC, PSC and CC) is expected to increase to about 90 per cent (594 million tonnes) of which about 20 per cent share is of PSC (10 per cent, 66 million tonnes) and CC (10 per cent, 66 million tonnes) wherein 65 per cent and 30 per cent of slag are used in the constituents respectively. As per CSE estimates, about 43 million tonnes of slag is required in the manufacture of PSC and about 20 million tonnes of slag for composite cement. Currently, however, BF slag is used in these cements. Assuming 50 per cent of the slag used is steel slag (matured), the utilization of steel slag will be about 22 million tonnes in PSC and 10 million tonnes in CC. As informed by the iron and steel industries, cement industries are conducting trials for potential usage of steel slag in cement manufacturing.

Considering the CSE's proposal in its report on *Decarbonizing India: Cement sector* (2023), OPC share will reduce to 10 per cent by 2030, thus consuming about 3.3 million tonnes of steel slag. Considering the existing production scenario of the country, the share of OPC production is about 27 per cent. Assuming the same share by 2030, OPC manufactured will be about 178 million tonnes per annum. As per BIS standards (IS 269), steel slag can be used as a performance improver in OPC cement and its usage can be up to 5 per cent, i.e. about 9 million tonnes of steel slag can be used in the manufacturing of OPC cement, if its share will remain the same by 2030.

Fly ash brick manufacturing: As per CSE estimates, the number of fly ash bricks manufactured in India is about 122 billion per year. In discussion with industry experts, it is understood that about 10–20 per cent of steel slag dust can be used as raw material. It can replace both sand as well as lime (binding material) in the

Table 4: Costing of raw materials in fly ash brick making

S. no.	Raw material	Share in composition (per cent)	Cost Rs per tonne	Quantity (tonnes)	Cost per month (Rs)
1	Sand	10	150	125	18,750
2	Lime	20	5,000	250	12,50,000
Total cost per month					12,68,750

Source: CSE analysis

manufacturing of bricks. The general composition of the fly ash bricks includes 60–80 per cent of fly ash, 10–20 per cent lime, 10 per cent gypsum and 10 per cent sand, depending upon the quality of raw materials. One brick weighs about 2.6 kg.[37]

Considering steel slag is used for replacing the lime and sand in manufacturing of 5 lakh fly ash bricks per month, the cost and quantity along with savings is given below:

As per CSE's analysis, if the fly ash brick manufacturer gets steel slag whose average cost is Rs 100–150/tonne. To replace sand and lime as per the above table, the total cost of procuring steel slag (considering the same quantity as sand and limestone is required) will be Rs 56,250 per month saving about Rs 14.5 million annually for the fly ash brick manufacturing.

Even if half of the fly ash bricks are manufactured in the country using steel slag as a raw material about 47.5 million tonnes of steel slag is expected to be consumed in a year.

Average annual fly ash brick manufacturing	= 122 billion
Weight of one fly ash brick	= 2.6 kg
Total estimated weight of fly ash bricks	**= 122 billion X 2.6 kg**
	= 317 million tonnes
Sand requirement in manufacturing 317 million tonnes bricks	= 317X 0.1 (10 per cent)
	= 31.72 million tonne
Lime requirement	= 317 X 0.2 (20 per cent)
	= 63.4 million tonne

If steel slag is used to replace both sand and lime in 50 per cent of brick manufacturing,
Slag utilized = 317 x 0.3 x 0.5 (30 per cent)
= 47.5 million tonne

Subsequently,
Quantity of sand conserved = 31.72 x 0.5 (replaced in 50 per cent brick manufacturing by steel slag) = 15.86 million tonne

Quantity of lime conserved = 63.4 x 0.5
= 21.7 million tonne

Construction of roadways: The pace of National Highways (NH) construction has increased consistently between 2014–15 and 2023–24 due to the systematic push through corridor-based National Highway development approach. Considering the average length of highway constructed per day in India in last few year as 28–30 km per day. The total length of the highway constructed in a year is about 10,000–11,000 km.[38] The same may vary year on year basis. As per estimates, for every km of a six-lane road constructed the steel slag required is about 80,000–85,000 tonnes.[39] Considering the annual construction of highways is about 5,000–10,000 km (considering 20 per cent of it is six-lane highways) and if steel slag is mandatorily used in the construction of this 20 per cent of highways, the consumption of steel slag is expected to be about 80–160 million tonnes per year which is much more than the expected generation of the same.

Steel slag roads most suitable to Indian terrain, costs 30 per cent cheaper. The average development cost per square meter of a handled steel slag street is Rs 1,150 as against Rs 1,300 for a bitumen street and Rs 2,700 for a concrete or a substantial one.[40] This innovative technological initiative also addresses the problem of environmental degradation caused by waste steel slag and unsustainable mining and quarrying of natural aggregates.

Recommendations

1. Standardization of steel slag for usage in different applications

Steel slag generation is extensive from the sector, however, there are limitations and challenges in its usage due to its properties and presence of free lime content. Though, there are avenues of steel slag getting used in different applications, but its utilization has not lived up to its potential and the same needs to be upscaled.

There is a need to prepare standards for steel slag for getting used in different applications. Bureau of Indian standards and Ministry of Steel should form a committee and can draft the standards in consultation with different stakeholders.

2. Ensuring enforcement of CPCB's Guidelines on Management of Pyro-metallurgical Slags (iron and steel slags)

CPCB in the guidelines on management of slag (December 2023) has iterated that the iron and steel plants shall maximize external use or recycling of slag that cannot be used or recycled internally. Iron and steel plants shall take steps to achieve 100 per cent regular utilization of iron slag and steel slags for current generation within one year and also fully utilize the legacy steel slag by September 2027. Thereafter, the maximum allowable storage of slags at any point of time will not be more than one year's generation for steel slag.

3. Using steam ageing process for maturing of the slag by industries

Tata Steel Jamshedpur has installed induced steam ageing plant, and thus most of the steel slag generated within the process is dispatched to outside under different brand names which are replacing the natural aggregates in roads construction and building activities. There is a need that other industries should also consider this system. Ministry of Steel in consultation with Ministry of Road Transport and Highways should prepare a model of supply chain to ensure matured steel slag is considered for road construction across the country.

3. Cement sector: Policy push to elevate use of refuse-derived fuel (RDF) as fuel much needed

Out of 62 million tonnes of municipal solid waste generated in India, about 12 million tonnes can be processed to RDF

The cement industry in India accounts for about 8 per cent of global cement production. In 2021–22, domestic production of cement in India was about 360 million tonnes, which is about 20 per cent more than the 300 million tonnes produced in FY 2020–21.[41]

Limestone is the main raw material while coal is the main fuel for the manufacture of cement in India. The cement capacity in the country is mostly concentrated near the sources of limestone. According to estimates, around 1.5 tonnes of limestone and 180–250 kg of coal is required to produce a tonne of cement.[42]

Cement production in India accounts for about 5.63 per cent of India's overall GHG emissions, i.e. about 106.6 million tonnes from industrial processes and product use and 53.5 million tonnes from energy usage.[43] These emissions are generated during the conversion process of limestone into lime (50 per cent), combustion of fossil fuels to produce thermal energy (40 per cent) and through transportation and electricity usage (10 per cent). The CO_2 emission intensity of the Indian cement sector is better than the global average of 576 kg CO_2/tonne of cement produced against the global average of 634 kg CO_2/tonne of cement produced.[44]

The calcination of limestone in the clinker production process emits CO_2, which is inherent to the process and hence hard to abate. OPC has the highest clinker ratio of 0.9 and, therefore, has the highest emissions intensity at 740 kg of CO_2 per tonne of cement.[45] According to the World Business Council for Sustainable Development (WBSCD) estimate, the average clinker ratio in India is 0.77, which is expected to be reduced to 0.73 by 2030.[46] With relevant interventions such as blending cement with additives (which includes cases of material circularity), the average clinker factor in India can be further reduced to 0.63, and, as a consequence, the emissions intensity of cement will also reduce. In PPC clinker factor can be reduced from 68 per cent to 60 per cent through the use of fly ash. Similarly, in PSC, the clinker factor can be reduced from the current share of 55–25 per cent by increasing slag content.[47]

The cement sector currently has a total coal consumption of about 9 million tonnes.[48] To reduce upon the coal consumption of the sector, industries have been replacing certain quantity of its coal with alternative fuel and raw materials (AFR), which results in reduced consumption of coal, thereby preventing CO_2 emissions from the sector. Alternative fuels used in the cement industries include tyres, biomass, textile, paper, wood and other wastes from industries, sludge, insulation waste and processed municipal solid waste or refuse-derived fuel (RDF). The amount of alternative fuel used by the cement industry is defined in terms of Thermal Substitution Rate (TSR), which refers to the percentage of alternative fuel used to replace fossil fuels.

The Indian cement industry contributes to the circular economy primarily by (i) circular supply chain, (ii) recovery and recycling. It is by virtue of co-processing that the cement sector acts as a sink for different kinds of waste generated in various sectors, including municipal solid waste.

Co-processing is utilization of waste from various industries and sources by the cement industry as AFR. As the cement manufacturing process itself supports environmentally sustainable waste utilization due to high temperature incineration without leaving any residue, it can act as backbone for waste generating industries.

Within MSW management, processing of several fractions that are combustible in nature but are not recyclable, such as soiled paper, soiled cloth, contaminated plastics, multilayer packaging materials, other packaging materials, pieces of leather, rubber, tyre, polystyrene (thermocol), wood etc. has remained a challenge and these fractions unwantedly ends up at landfill sites. These fractions can be processed and converted to refuse-derived fuel (RDF) or segregated combustible fraction (SCF), which carries significant calorific value, and can be utilized as alternative fuel in industries.

The publication *Guidelines on Usage of Refuse Derived Fuel in Various Industries* was released by the Central Public Health and Environmental Engineering Organisation (CPHEEO), Ministry of Housing and Urban Affairs, in October 2018. The guidelines proposed standards for RDF for utilization in waste-to-energy plants and the cement industry. Though these guidelines are well accepted by the industry, standards for RDF are yet to come in India.

In recent years, the Indian cement industry has started using alternative fuels to further cut down emissions. The country's average TSR stands at less than 6 per cent as compared to average TSR of about 40 per cent in the European cement industry.[49] Although there is clear push from the government to utilize municipal waste for energy generation, uptake of MSW as RDF has been rather slow in industries, mainly due to lack of any regulation regarding the same. Also, there are several challenges that the sector grapples with. Uniform accessibility to good-quality RDF, disrupted supply chain and tedious procurement process of RDF are some such factors that have contributed to it.

However, some of the cement industries have been able to move past these limitations and achieve a TSR as high as 17 per cent by utilizing substantial amounts of refuse-derived fuel (RDF) in lieu of coal. The CSE team conducted on-ground surveys and documented case studies on good practices on RDF usage in the sector. Replacement of coal with RDF reduces cost by 40–50 per cent and CO_2 emissions as RDF is partly carbon neutral. Out of 62 million tonnes of MSW generated in urban India, 12 million tonnes is combustible fraction that can be potentially converted into RDF, thereby replacing 8 million tonnes of coal.

The CSE team visited several cement plants, waste management facilities, private agencies or suppliers of RDF-to-cement plants. We have observed different models of RDF transportation and utilization. We tried to document each case with its cost economics and pros and cons.

The procurement models used by industries to procure RDF/SCF from different sources include the following:

i. Industries procuring the RDF or SCF through third parties;
ii. Industries procuring RDF from the municipal corporations directly;
iii. Industries procuring segregated waste (SCF) from municipal corporation/third party and process it within their premises; and
iv. Industries procuring raw waste from the municipal corporation.

Implications of presence of chlorine in RDF and AFR

The burning of RDF with high chlorine content could be detrimental for the cement process. The presence of chlorine in alternative fuels (e.g., sewage sludge, municipal solid waste or incineration ash etc.) has both direct and indirect implications on cement kiln emissions and performance. Trace levels of chlorine in feed materials can lead to the formation of acidic gases such as hydrogen chloride (HCl) and hydrogen fluoride (HF). Chlorine compounds can also build-up on kiln surfaces and lead to corrosion. Introduction of chlorine into the kiln may also increase the volatility of heavy metals and foster the formation of dioxins.[50]

When the chlorine content is high, it weakens the concrete in terms of two, seven and 28 days' compressive strength. The chlorine compounds and alkali-silica reactions create salts. These salts generate micro-cracks and the compressive strength decreases.[51] Also, chlorine creates the oxidation of iron in concrete.

Ideally zero per cent chlorine is required by the cement industry, but that is not possible. However, if the plant is operating at 10 per cent TSR, requiring 1,000 tonnes per day, then the minimum chlorine content that will not interfere with the process is about 0.5 per cent.

CASE STUDY 1:	**Cement industry using SCF through third party**
Name of industry:	**Wonder Cement**
Location:	**Nimbahera, Rajasthan**

The plant, established in 2012, has a capacity of 11 million tonnes of clinker per annum. The coal consumption of the industry in the process is estimated to be about 5,100 tonnes per day. The cement industry currently receives segregated combustible fraction (SCF) through third parties. It has RDF storage space of 1,500 m^2 that can handle 5,000 tonnes of waste. Due to the unavailability of the required quantity of RDF, however, the plant is utilizing approximately 80–100 tonnes per day, which is far less than the input feed based on which they have planned and designed their systems. As informed, the plant can use RDF with GCV of up to 2,000 kcal/kg and an average of about 3,000 to 3,200 kcal/kg. The plant receives about 25 per cent moisture content in the SCF on an as-received basis. Though the plant is in the initial stages of utilizing RDF in the process, it is positive about its future prospect in the industry.

Pre-processing at plant

The SCF supplied to cement plants is non-homogenous, has 30–50 per cent moisture and 30–40 per cent ash content. Both moisture and ash have to be strictly regulated by the plant operators otherwise it interferes with the cement manufacturing process and can lead to significant losses for the company.

The plant currently has engaged with third parties for procurement of SCF. It is received on daily basis from different vendors. It has previously tried to work with municipalities but they have not shown enough interest or were reluctant to arrange for the SCF loading, transport and unloading logistics. The SCF is supplied from long distances such as New Delhi and Gurugram.

The plant also has a laboratory set up for evaluating the properties of the waste received by the plant. Depending on the nature of waste received, a 'homogenous mix' is prepared by mixing a wide variety of waste materials of defined characteristics to make it suitable for co-processing in cement kilns.

The plant has within its premises developed a waste-management facility called 'pre-processing platform', where different sections have been allocated for collection of different kinds of waste streams. The plant is able to achieve 3–3.5 per cent of TSR currently of which 60–70 per cent can be attributed to the replacement of coal by RDF, 25–30 per cent is by plastic scrap and 10–15 per cent from industrial waste, seasonal biomass etc.

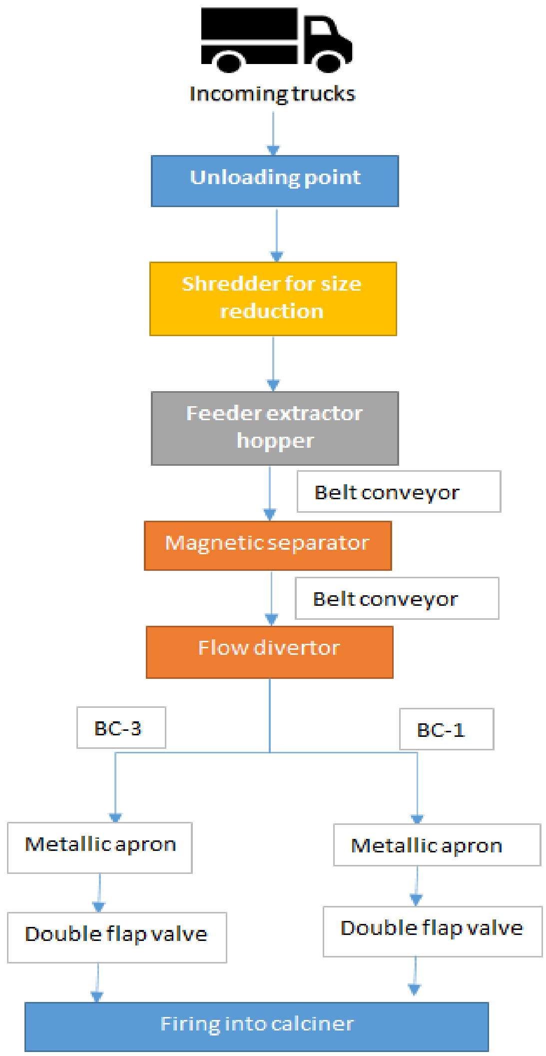
The plant has installed a primary shredder or a single shaft shredder with honeycomb screen and 160 knives that can handle 15–20 tonnes of waste per hour. The shredder is, however, able to reduce the size of the SCF to less than 50 mm because of the presence of metals, boulders and other such material in the poorly segregated SCF leads to breakage of machine blades. Replacement of machine blade costs company Rs 20,000–30,000 per blade and adds to the overall operational cost of production. Thus, single shaft shredders require input control in terms of better quality of waste.

The company is in the process of procuring another shredder with a double shaft that can process 20–25 tonnes of waste per hour. The twin shaft shredder is an advanced instrument which is rough in its working as it tears off the input material. The two shredders once installed and fully functional will be able to process approximately 600–700 tonnes per day of waste.

RDF utilization under existing scenario

The plant is currently using RDF in two of its four kilns with the AFR feeding capacity designed for 1,000 TPD. Of the total coal consumption, about 60 percent coal is fired in the calciner while 40 percent is fired in the kiln. Since coal consumption of the plant is around 5100 tonnes per day, this means that per kiln coal consumption is about 1,275 tonnes (5,100/4 kilns). However, as per the discussion with plant personnel the actual coal consumption per kiln is about

Figure 4: System designed for RDF and other AFR utilization at Wonder Cement



1,000–1,200 tonnes per day out of which about 765 tonnes per day is fired in the calciner. Considering about 3–3.5 per cent of TSR, 27 tonnes of coal is getting replaced by RDF and other alternative fuels in one kiln per day. The annual savings on coal in the current scenario is about 17, 820 tonnes at 3.5 per cent TSR.

The coal costing is 1.70 per 1,000 kcal with calorific value of about 7,200–7,500 kcal/kg (petcoke). Costing of RDF is also done in Rs per 1,000 kcal, and average value of RDF for the industry is about Rs 0.9–0.95 per 1,000 kcal (cost saving is about Rs 0.75 per 1,000 kcal) and average GCV of 1,800–2,000 kcal/kg. This kcal is the NCV of the RDF, i.e. calorific value after removing moisture.

SCF processing at Wonder Cement to RDF

Source: CSE survey

As mentioned, under the existing scenario at TSR of 3.5 per cent, average daily usage of RDF is about 80–100 tonnes per day, which results in coal saving of about 54 tonnes per day on two kilns. As per the Bureau of Energy Efficiency (BEE), the combustion of one tonne of coal typically produces approximately 1.52 metric tonnes of carbon dioxide.[52] Also, emission factor of RDF is estimated to be about 0.8 tonnes of CO2e per tonne of RDF.[53, 54]

The annual abated CO_2 emissions by using RDF in place of coal in this industry is estimated to be in the range of 686–5,966 tCO_2e. CO_2 emissions can further be reduced once the issues and challenges related to quality and availability of RDF for the industries are looked into.

Investment on machinery:*

An estimate of capital investment for the equipment and systems for a 100 tonne per day RDF processing facility includes:

- Laboratory for testing: Rs 1 crore
- Shed for storage: Rs 2 crore
- Shredding facility: Rs 4 crore
- Mechanical handling: 1 crore
- Firefighting and instrument: 2 crore

* cost of equipment is for reference and may vary based on the capacity and make.

CASE STUDY 2: Supply of RDF/SCF by Goa Waste Management Corporation to cement industries

Name: Saligao Waste Management Facility
Location: Goa

The Goa Waste Management Corporation (GWMC) is a special purpose vehicle of the government under the aegis of Department of Science, Technology Waste Management by the Goa Waste Management Act 2016. GWMC is entrusted to look after the overall management of all types of wastes in the state of Goa and, more specifically, setting up of centralized waste treatment facilities in the state as per the 2016 rules in order to create a clean and sustainable waste-free and litter-free environment in the state by ensuring disposal of all wastes in the manner provided under the law. GWMC is currently transporting RDF (segregated and unprocessed form) to various cement industries. GWMC can be seen as a combined effort of bureaucratic, regulators, Government of Goa, Ministry of the Department of Science and Technology and various NGOs and agencies working on the social

Table 5: Total refused-derived fuel (RDF) disposed of by GWMC

Sent from	Duration	Quantity (tonnes)	Estimated quantity of coal saved (tonnes)
Saligao WMF	July 2016–May 2023	131,197	87,465
GWMC baling stations (Verna/Cacora/Bicholim)	October 2013–May 2023	11,600	7,733
Municipal councils	December 2011–May 2023	60,780	40,520
Village panchayats	February 2015–May 2023	10,620	7,080
Total		214,197	142,798
Tonnes of CO_2 emissions		171,358	217,052
Emission factor		0.8	1.52
Tonnes of CO_2 emissions avoided by replacing coal		45,694	

Source: CSE analysis

aspect of waste management. This is due to the clear roles and responsibilities that GWMC is doing a great work towards waste management and can be seen as a benchmark by other states of the country to replicate the model adopted in Goa.

GWMC has set up the following two major centralized waste treatment facilities:

- 250 TPD Solid Waste Management Facility at Saligao; and
- 100 TPD Solid Waste Management Facility at Cacora.

Both the solid waste management facilities (Saligao and Cacora) have been brown field projects, i.e. reclaimed land was used for setting up of facilities after remediation of existing legacy waste dumps. All the projects of GWMC are working on public–private partnership model.

The waste management facility at Cacora is still a new set up and is operational since May 2023 only. However, Saligao facility since its inception in 2016 has treated more than 400,000 tonnes of waste. It is a good case of circularity out of waste.

Profile: Saligao Waste Management Facility (SWMF) (250 TPD)

As there was no space available to develop the facility, about 70,000 tonnes of waste was remediated in 45 days along with reused land for setting up the Saligao facility after declaring it as an industrial estate to get approvals from Industrial Development Corporation. SWMF is set up with financial assistance from NABARD.

The facility is managed by Hindustan Waste Treatment Pvt. Ltd. (HWTPL) It is designed for mixed waste receipt but separate treatment for dry and wet waste

Table 6: Profile of the Hindustan Waste Treatment Pvt. Ltd (HWTPL)

Phase 1: 100 TPD commissioned on	May 2016
Phase 2: 250 TPD 20 commissioned on	Dec 2021
Average waste received	About 250 TPD
Total electricity generated from 2016 to Dec. 2023	> 27,500,000 units
Average electricity generated	About 28, 000 units per day
Average electricity exported to grid	About 14, 000 units per day @Rs 5/unit
Inert to landfill	<3 per cent of input waste
Average compost generation	About 8 TPD

Source: GWMC, CSE survey

is available. The facility receives waste from the northern coastal belt village panchayats and urban local bodies (ULBs) and scientifically manages the waste on a day-to-day basis.

Process

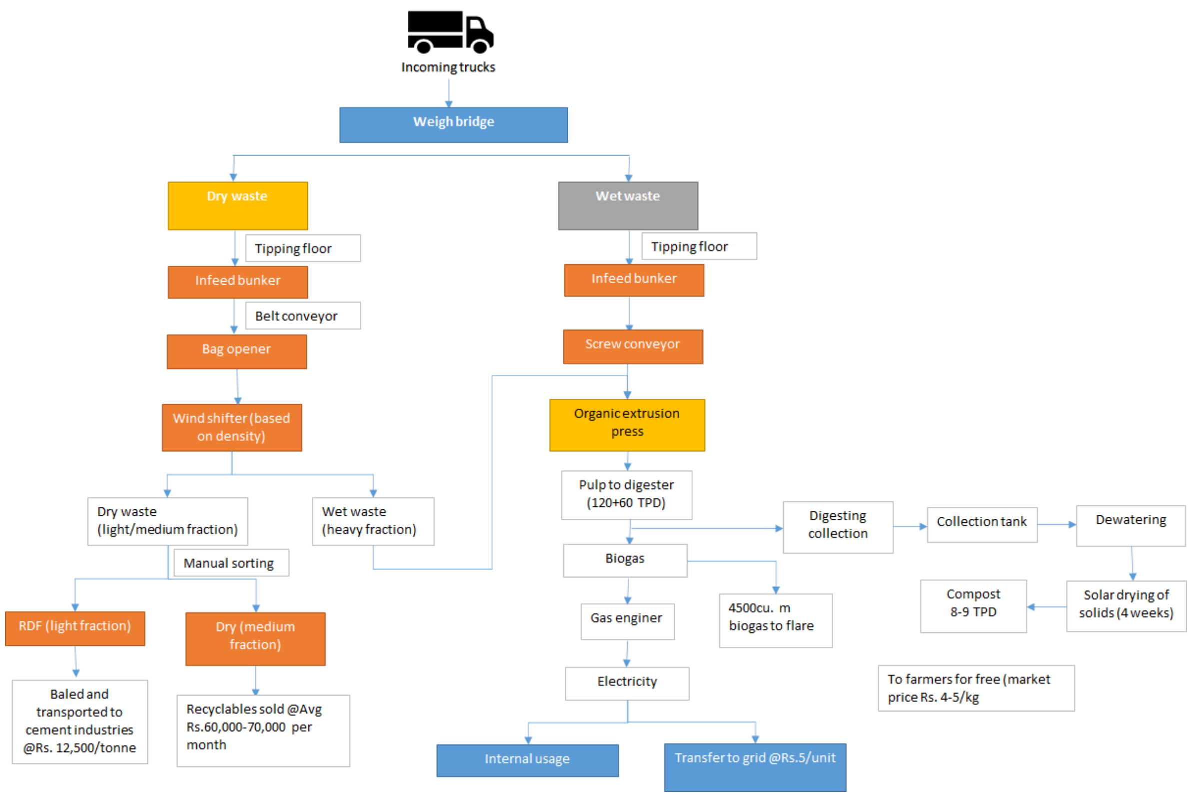
Primary door-to-door waste collection is done by local bodies, and transferred to the respective local body's sorting or storage facility. Hindustan Waste Treatment Pvt. Ltd (HWTPL) then collects dry waste from the primary storage facility and transfers it to the GWMC-operated material recovery facility (MRF) or solid waste management facility for sorting. At the MRF, dry waste is sorted in recyclables fraction and non-recyclable fraction (RDF). Recyclables fraction is sent to recycling unit and RDF is baled and sent to cement plant for co-processing. GWMC doesn't charge any tipping fee from households. However, for commercial establishments like hotels, offices etc. there is a fee of Rs 2,500 per tonne.

Urban local bodies (CCP/MC) and some village panchayats operate their own MRFs where GWMC provides assistance for transporting RDF to cement plants and bears the cost of RDF transportation. Some local bodies situated near SWMF are authorized to deposit segregated dry and wet waste in their own vehicles at SWMF.

About 245 tonnes per day waste is received from all sources. As the vehicle carrying waste enters into the facility, weighing is done through weigh bridge arrangement. Dry waste and wet waste are processed separately (see *Figure 5: Process flow of Saligao Waste Management Facility*).

Dry waste is categorized based upon the density through wind shifter into light, medium and heavy factions. Heavy fraction, i.e. wet waste, is directed to the wet-waste processing plant, where the waste is processed in the digesters of total 180 tonnes per day capacity to generate about 16,000–17,000 Nm^3/day of biogas. About 12,000 Nm^3/day of biogas is used to generate about 30,000 KW per day electricity through biogas gensets installed at the SWMF. Out of the total electricity generation about 14,000 units per day are exported to grid which generates a revenue to HWTPL at Rs 5/unit. About 4500 Nm^3/day of unused biogas is flared. The solids from the digesters is collected and allowed to solar dry for about four weeks after dewatering it. This results in compost production of about 8–9 tonnes per day. Compost is currently provided to the farmers for free. The market price of the compost is about Rs 4–5 per kg.

Figure 5: Process flow of Saligao Waste Management Facility



Source: CSE

The medium fraction goes in as dry waste including the recyclables which are sold outside. About 200 tonnes per month of recyclables are collected and sold, generating a revenue of about Rs 20,00,000–25,00,000 per month. Plastic bottles are shredded separately to produce eco pet flakes. The market price of the product is about Rs 40–45 /kg and it is used for manufacturing of new PET bottles, preparation of resin, and production of bristles in tooth brushes.

The lighter fraction is segregated, baled and transported as segregated combustible fraction to the cement industries for being processed as RDF in cement kilns. The processing & O&M cost of facility is approximately Rs 2,500/tonne of waste.

Transportation of RDF to cement plants

GWMC has executed MoU's with cement plant to cut down the transportation cost. The arrangement is made so that the vehicle of the industries coming to deliver consignment from cement industries is used to transport the unprocessed RDF or segregated combustible fraction (in baled form). For this arrangement, no charge is paid by cement plant to GWMC. However, the GWMC pays Rs 12,500

Shredding plant for PET bottles to manufacture Eco pet flakes

Source: CSE survey

per trip (Rs 500/tonne) exclusive of GST and the capacity of truck is 25 tonne. The minimum cost of transportation is Rs 12,500 per trip exclusive of GST, however GWMC has to ensure minimum loading of 15 MT in each vehicle. If not adhered, penalty of Rs 500/MT is imposed on a difference in quantity as per the cement plant weighment slip if the weight is below 15 MT.

Manual segregation of medium and light fractions at SWMF

Baled waste

Source: CSE survey

Cost paid by GWMC for transporting RDF from the baling station operated by GWMC, Village Panchayat and Municipality to cement plants is same for any distance (shortest is around 200 km and longest is around 500 km). There are no cement plants in Goa and RDF is sent to the cement plants in neighbouring states such as ACC Wadi, J.K Cement Works, Muddapur-Karnataka and Cement Divisions Unit Kesoram Industries Ltd (Unit Vasavadatta Cement), Sedam-Karnataka.

The cost of RDF or SCF is not linked to the calorific value of the material provided to cement industries. However, the net calorific value that cement plants is accepting is >2,500 Kcal/Kg.

The total RDF generation in SWMF is about 70 tonnes per day. The model is based on the industry and the RDF provider sharing the cost of transportation. This model is viable as both the parties mutually bears the logistics cost (see *Table 7: Costing and revenue generation model of Hindustan Waste Treatment Pvt. Ltd*).

Table 7: Costing and revenue generation model of Hindustan Waste Treatment Pvt. Ltd

Details	Value	Unit	Remarks
Tipping fee from households	Nil		
Tipping fee from commercial customers	2,000–2,500	Rs/tonne	
Total incoming waste per day	245	Tonnes	From all sources
Revenue from electricity export to grid	70,000	Rs/day	14,000 units @Rs 5/day
Cost of recyclables sold	60,000	Rs/day	
RDF transported to cement industries	687, 500	Rs./day	Rs 12,500@ 55–70 tonnes
Compost to farmers	Nil		8–9 TPD generated, market price Rs 4–5/kg
Eco pet flakes	40-45	Rs/kg	Avg generation of PET bottles 698 TPD
Cost of O&M	2500	Rs./tonne	

Source: CSE survey

CASE STUDY 3: Supply of RDF to cement plants by third-party agency

Name: Trashonomy Pvt. Ltd

Location: Udaipur, Rajasthan

Trashonomy Pvt. Ltd is a domestic and commercial waste management company established in 2021 in Udaipur. The facility handles 150 tonnes of waste on a per day basis. It has an area of 5,000 square feet as covered storage. Waste is collected from more than 1 lakh households at a user fee of Rs 20 per month. Waste collection cost is Rs 1,500 per tonne (include manpower, fuel etc.). The total operational cost of the plant is about Rs 10 lakh per month.

Udaipur Municipality has divided the city in four zones for domestic and commercial waste collection. The vendors collect the domestic and commercial waste separately. The domestic waste is segregated into dry and wet waste by 80 per cent of the households. Whereas, commercial waste is only 25 per cent segregated. The municipality collected 55-60 lakhs in user fees last year.

In 150 TPD of waste, 70–80 tonnes is only dry waste that comprises of 3–4 tonnes of recyclables and about 55 tonnes is converted to RDF while low-value single-use plastic, sanitary pads, clothes, diapers, organic waste, garden waste, shoes, soles, saw dust, banners, posters etc. comprises 20–25 tonnes. The waste processed into RDF is sold to Wonder Cement and Ultratech Cement.

The recyclables as mentioned above are about 3–5 per cent of total dry waste and is sold at around Rs 8 per kg. The total estimated cost at which recyclables are sold is Rs 9,60, 000 per month.

About 5,000 tonnes per month of RDF is supplied to cement industries. Supply is done in two forms—shredded and non-shredded. Trashonomy supplies 80 per cent of waste as shredded and 20 per cent non-shredded. The cost to company for shredded and non-shredded RDF is Rs 1,500 per tonne and Rs 800 per tonne respectively. Cost of transportation is Rs 1,000–1,200 per tonne

The company has a shredder of 30 TPD and a trommel of 60 TPD capacity. The trommel of 30 TPD costs Rs 50–55 lakh. Mixing is done with RDF to reduce moisture content and enhance its GCV. Mixers can be coconut shells, horticulture waste, etc.

There is a provision of penalty of 200 per cent of the cost of RDF imposed on the RDF manufacturers if glass and stones are observed in RDF supplied to the plant. For example, if cost of RDF is Rs 10,000 for a specific quantity, then penalty would be Rs 20,000 on the supply.

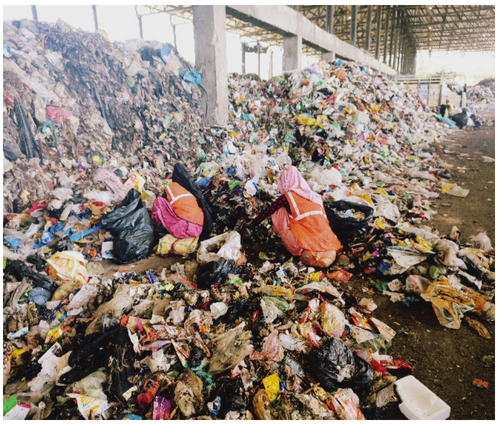
In case of GCV <2,500 kCal, 25 per cent penalty is imposed on the RDF manufacturers. There is 5–10 per cent deduction in case moisture is more than 50 per cent in the supplied material.

Major challenges for third-party agencies

The following are major challenges for third-party agencies:

- Due to the monsoon season, cement companies refuse to accept the RDF due to high moisture content (almost four months). This results in issues with storage of RDF at the waste management facility that receives the waste on a daily basis.
- Non-segregated waste from households, with polythene bags carrying organic waste.
- Lack of capacity and scientific approach of Municipal Corporations
  - ✓ Municipalities have technical and programmatic understanding gaps, SWM cells often manned by personnel from different skill sets (mostly non SWM experience or environmental science).
  - ✓ There is lack of focus on long term planning which results in dearth of reviews, concerted efforts and problem identification/dedicated follow-ups.

- Regular relocations at the SWM cell also poses several bottlenecks in decision making. Tenders designed do not fully address growing developments and are often done based on 'price competitiveness only', resulting in less incentive and money to address aspirations of labourers.
- Many bidders take work at very low costs (as the exclusions criteria and/or selection methodology are not properly designed). Ad hoc approaches are also proving detrimental to commitments for environmental sanitation.
- Awarded tenders are not monitored in a scientific manner. Many fly-by-night operators are either not willing or lack financial resources to upgrade (as they have won tenders on impractical cost in the first place).



Waste at collection station

Collection vehicle

Segregated fraction bailed to transport

Source: CSE survey

CASE STUDY 4: Processing of MSW into RDF at industry-operated material-recovery facility

Name: Ultratech Cement, MRF facility
Location: Jaipur, Rajasthan

Ultratech Cement has set up a waste processing facility at Jaipur, Rajasthan. The capacity of the plant is 350 tonnes per day. Ultratech has a memorandum of understanding (MoU) with Jaipur Nagar Nigam for supply of municipal waste to the facility. The total capital investment in setting up the facility is about Rs 20 crore.

On average 100–150 TPD of fresh waste and 30–40 tonnes per day of legacy waste is currently supplied to the plant. The waste supplied to the plant by the municipality is usually at the rate of Rs 2,000–2,500 per tonnes. Fresh waste supplied by the municipality has 40 per cent moisture.

Of the total waste received, 40–45 per cent is processed into RDF and the remaining 55–60 per cent is sent to the landfill. The processed RDF is then supplied to Ultratech's cement plant in Chittorgarh (Rajasthan) in loose form.

Process: The municipal waste is unloaded in the MSW yard from where is it stacked using the JCB. The grabber transfers the waste to the primary shredder. The shredder has magnetic separators to segregate metal waste from the municipal waste. The waste is then passed through a 'trommel' screen that rejects anything lesser than 50 mm. Reject that is more than 50 mm is then sent to the ballistic separator where heavy materials such as coconut shell, slippers etc. get separated automatically. This comparatively segregated waste is then passed through the final shredder, which shreds it to 50–70 mm size. This waste has a gross calorific value (GCV) of about 4,000 kcal/kg and net calorific value (NCV) of 3,000–3,400 kcal/kg.

The plant has a covered shed spread in 25 m^2 area for storage of shredded and segregated municipal waste.

Cost economics for third party

Revenue earning sources for third party includes:

Tipping fees for MSW: The municipal corporation pays the agencies an amount of about Rs 300–1,000 per tonne of MSW.

Processing fees: Assuming a quantity of 1,000 kg MSW, on an average 10 per cent of the total MSW (100 kg) is recyclable in nature and can give an earning of Rs 20–30 per kg. Of the MSW, 25–30 per cent (300 kg) can be processed into RDF for the cement sector and sold at around Rs 1,000 per tonne. About 600 kg of MSW is organics that is either composted or dumped. If composted, the organic part can also bring in revenue for the facility.

Revenue from cement industries: Cost at which RDF is sold.
So, practically, the source of revenue for the third party or processing agency is the tipping fee received from the Municipal Corporation, revenue earned from recyclables and then the cost of RDF sold to cement industries. The O&M cost of any RDF manufacturing facility should be inclusive of all the mentioned revenue sources.

Challenges in utilization of RDF in the industries

The following are the highlights of the challenges and issues in usage of RDF in the sector based on CSE's discussions with sector experts, industries and ground-level surveys of various facilities:

Quality and quantity issues

Most of the cement companies that CSE surveyed have engaged third-party suppliers to procure RDF, or in most cases, segregated combustible fraction (SCF). These plants are in the process of ramping up their alternative fuel and raw materials (AFR) facilities, but the uncertainty regarding the continuous and adequate supply of RDF by the vendors is there.

As in case of coal, the purchase of coal is based on working out the consistency of coal, the cement sector can afford to go ±5 per cent in terms of calorific value. Ideally, 4,000 kcal ± 200 kcal is what a cement plant needs and if cement industries can get the same consistency for RDF that will be the most appropriate situation.

Transportation factor

Another issue that needs to be worked on more is the transportation of this waste from the handler sites to the cement plants. The cement companies are procuring waste from a distance of 500-1,000 kilometres.

Risk to waste handlers

There is a substantial amount of biomedical waste in the SCF received by the plants, such as syringes, blood-infested cotton, etc. This poses a risk to employees at the cement plants or RDF-manufacturing site who are engaged in manual handling of the waste. Usually, manual handling of waste involves waste segregation, clearing the jams in machinery, etc.

Approach of Municipal Corporations

The primary concern of municipal authorities' is to get the 'burden of waste handling' off their shoulders by involving third parties. There does not seem to be any scrutiny on whether the waste is being disposed of by the third parties as disclosed by them as per the signed agreements.

Lack of coordination among stakeholders

Stakeholders are working in isolation rather than in an enabling ecosystem, which will aid in overcoming some of the challenges as mentioned. There is a need to discuss the issue and challenges to upscale RDF utilization and improving its quality and availability. Stakeholders like industries, municipal corporations, third party and related government agencies should sit across the table to ensure more coordinated efforts in the matter.

Future scenario of RDF utilization (to be estimated)

Cement production in India in 2030 is expected to be about 660 million tonnes, assuming total coal consumption to be about 0.1–0.2 tonnes per tonne of clinker and the clinker to cement ratio as 0.73. Total coal consumption in clinker production is 48 million tonnes. If RDF can replace 50 per cent (24 million tonnes) of coal consumption, roughly about 36 million tonnes of RDF will be required. This will result in reducing the carbon emissions by 7.6 million tCO_2 emissions (24 x 1.52 – 36 x 0.8).

Recommendations

1. **Standardization of RDF quality and notify the standards:** It is to be recommended that BIS along with the Ministry of Housing and Urban Affairs and MoEFCC should work out standards of RDF quality in consultation with other stakeholders (municipalities, industries, third party agencies) as there is no push for the stakeholders to process the MSW and govern the costing part of it, so that all the agencies and municipal corporations understand the requirements of the industry and follow some SoPs in processing of MSW. Once the standards are out, it is important that MoEFCC should notify them so that they can be implemented and followed by the stakeholders.

2. **Inclusion of RDF specifications in tendering by Urban Local Bodies (ULBs):** There is a need to produce RDF meeting guideline specifications as part of the tender document of the MSW treatment published by ULBs. The municipalities should also identify the right contractors, concessionaires and vendors, and not look only for the lowest bid but also consider the technical background. Tendering should be done on a techno-commercial basis, with a 75:25 ratio for technical and commercial aspects.

3. **Stakeholder interactions:** Though the supply chain of RDF to the cement industries seem to be simple, lack of communication and coordination among the industries, municipalities and third-party agencies handling waste is a major bottleneck in upscaling of RDF usage in the cement industry. All the relevant stakeholders need to develop coherence among themselves to sort the issues related to quality, logistics, costing etc.

The way forward

Overall, it is understood that the acceptability of RDF usage in the cement sector has improved significantly in the last few years. Cement plants will get on board for RDF consumption in their plants, as it also makes economic sense to them as long as the RDF provided it is of quality that does not compromise the quality of their product or harm their equipment.

4. Fly ash from TPPs: Cement making and road construction major avenues for utilization of fly ash

In spite of well-defined applications, about 11 million tonnes of fly ash remain unutilized

Coal-based power is one of the most fuel-intensive industries, and contributes significantly to ambient air emissions in India. Currently, coal- and lignite-based utility power plants account for 50 per cent of the country's total electricity generation as in February 2024.[55] The sector consumes about 82 per cent of the total coal consumed in India.[56] As per the National Electricity Plan 2023, to meet the growing electricity demand and ensure energy security the government plans to add another 31 gigawatt of coal power in the period 2022–27.[57]

This implies that our demand for coal is bound to increase further. Between 2013–14 and 2022–23, annual coal consumption by power sector rose from 395 million tonnes to about 732 million tonnes.[58]

One of the major wastes generated by the sector is fly ash. Fly ash is an unwanted unburnt residue of coal combustion in a coal thermal power plant. It is emitted along with flue gases during burning of coal in a furnace and collected using the electrostatic precipitators. The fly ash collected with the help of precipitators is converted into a wet slurry to minimize fugitive dust emissions. It is then transported to the scientifically designed ash ponds through slurry pipes lines.

A rise in coal consumption naturally increases the production of fly ash as a byproduct or residue, which not only requires large tracts of land for disposal but also leads to significant pollution. This problem is particularly severe in India, because Indian coal is low-grade, with high ash content (of the order of 30–45 per cent) and low calorific value (3,500–4,000 kcal/kg).

Health impact of fly ash

Annual fly ash generation from Indian coal power plants rose from 173 million tonnes in 2013–14 to 271 million tonnes in 2021–22. Fly ash is ultra-fine, prone to becoming airborne in the dry state. This significantly affects air quality near coal-based plants. Long-term exposure to fly ash in the air can lead to serious pulmonary illnesses like bronchitis, silicosis, fibrosis, pneumonitis, etc.

The ash contains toxic heavy metals that are known as carcinogens. Ash disposed of in the wet form in ash ponds can be equally harmful if not handled in an environmentally sound manner. Several cases of contamination of nearby surface waterbodies and groundwater due to ash pond overflows or leakages have been reported in the past. This may even lead to accumulation of heavy metals beyond permissible limits in the contaminated waterbodies.

Rules and policies governing fly ash management in India

As fly ash generation increases with coal consumption, it is important to ensure to convert this waste into a useful resource for other purposes. Fly ash is regulated in the country as per the Fly Ash Notification (1999) by the Ministry of Environment, Forest and Climate Change. Over the years, it has gone through several amendments in 2003, 2004, 2009 and 2016, in order to move towards the goal of 100 per cent utilization of fly ash produced by all coal- and lignite-based plants.

Currently, fly ash is utilized in India in cement, brick and tiles manufacturing, filling up abandoned mines, reclamation of low-lying areas and construction of roads and flyovers. The ministry has also set certain limits, in terms of geographical area, within which fly ash is to be compulsorily used for manufacturing bricks or in the construction industry.

Despite the defined avenues and rules governing the safe utilization of fly ash, ash is piling up in wet form as slurry in ash ponds and in dry form in open fields. Fugitive emissions and leakages have increased substantially over the years. The severity of the problem was exemplified by the major coal ash pond accidents that occurred during 2010–20.[59]

These accidents at massive scale finally led to the intervention of the National Green Tribunal on the matter. NGT in its order dated January 18, 2022 directed MoEF&CC for constitution of a 'Fly Ash Management and Utilization Mission'. [60]

Chronology of fly ash utilization notification:[61]

1999: The first fly ash notification was enforced in 1999. The notification made it mandatory to mix at least 25 per cent fly ash with soil in manufacture of clay bricks or tiles or blocks for use in construction activities within a radius of 50 km from coal- or lignite-based power. All local authorities were directed to modify their building bye laws to incorporate use of fly ash-based products.

The coal- and lignite-based thermal power plants were directed to make ash available free of cost for at least ten years from the date of publication of the notification, i.e. till 2009, for the purpose of manufacturing ash-based products.

The power plants were required to progressively utilize 100 per cent of the ash they generated within a period of nine years from the date of publication of the notification.

2003: The first amendment to the notification was introduced in 2003. While the 1999 notification focused on the generation side management of fly ash, the 2003 amendment focused on the demand side or agencies that can utilize ash in construction activities within a 100-km radius of a coal- or lignite-based power plant. The radius for mandatory utilization of fly ash use was increased from 50 km to 100 km. The notification also elaborated a progressive plan for percentage of fly ash by volume of total bricks, blocks and tiles. Brick manufacturers now had to comply with use of 25 per cent fly ash for manufacturing of bricks to 100 per cent fly ash bricks by the end of the fifth year of compliance.

2009: Despite six years of the 2003 amendment, construction agencies were unable to achieve the target of 100 per cent utilization of fly ash-based products and many power plants were also unable to meet their fly ash targets. This led to the government introducing another amendment that revised the deadlines for compliance by coal thermal power plants. Plants commissioned before November 3, 2009 were given five years to achieve the target, while those commissioned after that date were given a target of four years to comply with the notification. Now, all construction agencies of Central, state or local government and private or public sector were mandated to submit annual returns to the concerned SPCB or pollution committee.

2016: The January 2016 notification further increased the radius for restriction on use of fly ash from 100 km to 300 km. The government also incentivized the process by lifting the restriction of providing 20 per cent of dry ESP fly ash free of cost to power plants that were able to utilize 100 per cent of their fly ash. The notification also attempted to bring in more transparency in ash procurement and as it required power plant to upload and periodically update the details of ash available on its website. Every construction agency engaged in the construction of

EXCERPT FROM DOWN TO EARTH ARTICLE ON STATUS OF FLY ASH MANAGEMENT AND COURT INTERVENTIONS

There has been number of instances where NGT has issued order to instruct the power plants to take appropriate corrective actions on fly ash management.

One similar case filed before the NGT in May 2023, a non-operational power plant was found to be in breach of its obligation to manage fly ash.

In the matter of Ajay Shrivastava vs State of Haryana, it was brought to the tribunal's attention that Faridabad Thermal Power Station, unit of Haryana Power Generation Corporation Limited, was in violation of MoEFCC's Aravalli notification dated May 7, 1992.

The Aravalli notification restricts certain activities that cause environmental degradation in a specific area of the Aravalli range. The court observed that the thermal power station did not present any concrete plan to lift coal ash from the ash dyke.

The timeline presented to the court to carry out the safe lifting of fly ash from the dyke was found to be too long. The NGT also noted that the project proponent has not carried out the plantation proposed for fly ash pond stabilisation.

buildings within a radius of 300 km from a coal-based thermal power plant was required to use only fly ash-based products for construction.

Coal- or lignite-based thermal power plants within a radius of 100 km were directed to bear the entire cost of transportation of ash to the site of road construction, or the site for manufacturing ash-based products or for use as soil conditioner in any agricultural activity. Users within a radius of 100–300 km, however, had to bear the transportation cost equally with the generator.

2019: Certain fly-ash uses such as mine filling, reclamation of low-lying areas and as soil conditioner in agricultural use were prohibited under the environmental clearance (EC) conditions for thermal power plants. The 2019 amendment reverses such EC conditions in order to enhance utilization.

2021: The new fly ash notification of December 2021 has made provision for the 'enforcement, monitoring, audit and reporting' of the progress of fly ash utilization and implementation of the clauses of the notification by coal thermal power plants and user agencies. The Notification holds the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCB)/Pollution Control Committees (PCC) responsible for monitoring the effective implementation of mandates under it.

Status of fly ash utilization in India

Cement manufacturing, mine filling, bricks and tiles, reclamation of low-lying areas, ash dyke raising, roads and flyover construction and agriculture are some of the major avenues where fly ash is predominantly utilized. The analysis of the fly ash utilization in different sectors for 2021–22 shows that the maximum use of fly ash has been by cement sector—25 per cent—followed by in roads and flyover construction—17 per cent. It is important to note that the use of fly ash in filling up low lying areas has increased over the period and currently stands at 13 per cent of total fly ash utilization.

Government figures show that there has definitely been significant improvement in fly ash utilization over the year, but it has still not reached its 100 per cent mark. Fly ash utilization in 2013 was 57 per cent and has now increased to 95 per cent.

Coal-based thermal power plants are doing satisfactorily in terms of fly ash utilization. Therefore rather than considering unit-wise case study, we have categorized the power plants based on the percentage utilization of fly ash to highlight the scope of its utilization in different avenues (see *Table 8: Capacity break-up as per percentage utilization of fly ash*).

In the following section, we reflect on the utilization of fly ash for different purposes for following three categories of coal-thermal power plants:

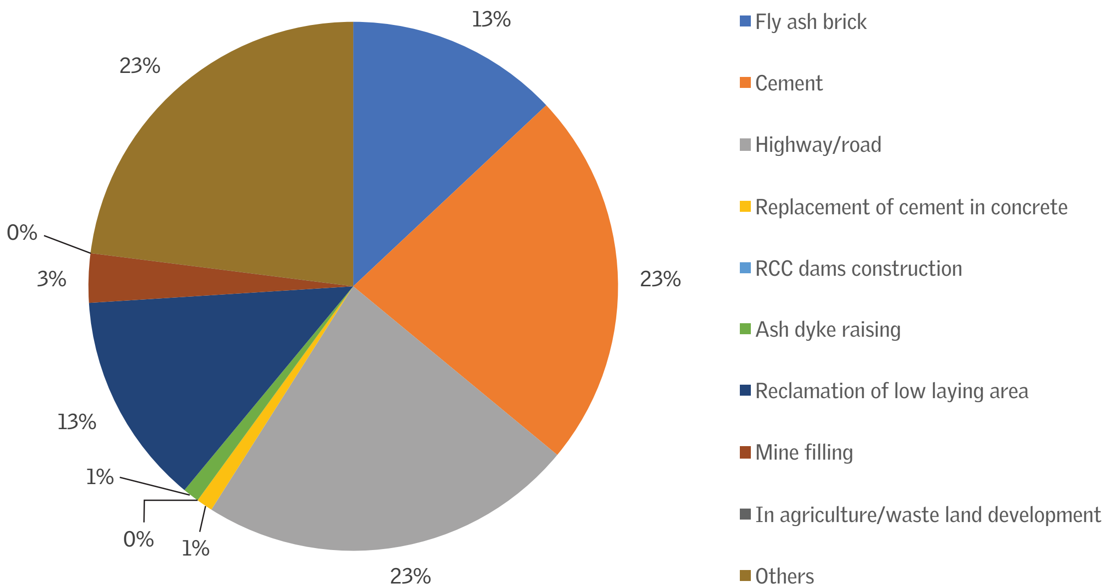
1. Coal-based thermal power plants that have achieved 100 per cent utilization of fly ash
2. Coal-based thermal power plants that have achieved fly ash utilization between 80–99 per cent
3. Coal-based thermal power plants that have achieved fly ash utilization between 50–79 per cent
4. Coal-based thermal power plants that have achieved fly ash utilization <50 per cent

Table 8: Capacity break-up as percentage utilization of fly ash

Percentage utilization	Capacity (MW)
100	83,844
80–99	40,431
50–79	63,914
<50	22, 080

Source: CSE analysis, data retrieved from CEA[62]

Figure 6: Fly ash utilization for TPPs with 100 per cent utilization (in million tonnes)



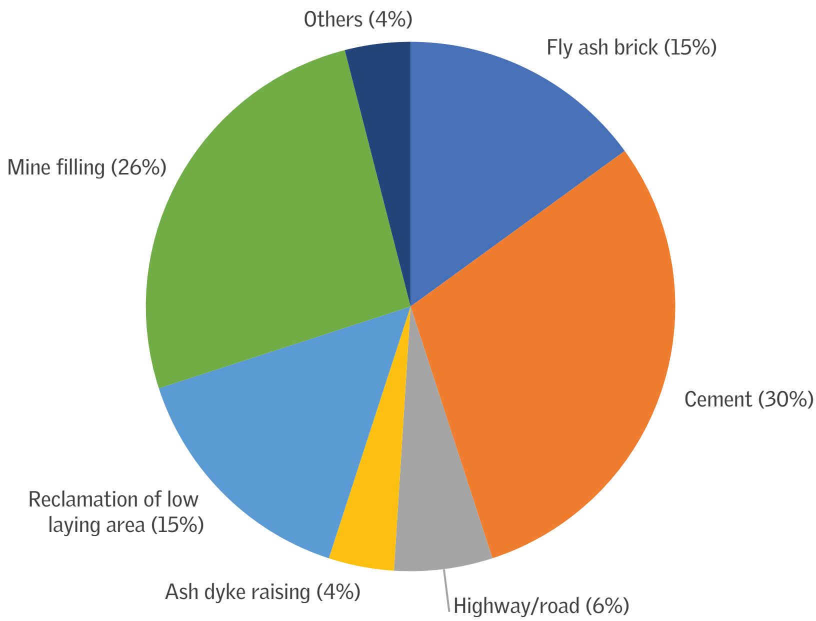
Source: CSE analysis, Data retrieved from CEA

Thermal power plants who have achieved fly ash utilization of 100% and more: Almost 84 gigawatt of installed coal-thermal power capacity has been able to achieve 100 per cent fly ash utilization. The cumulative fly ash from these plants is mainly redirected for manufacturing of Portland Pozzolana Cement (PPC) and for replacement of cement in concrete—23 per cent—while about 23 per cent is used in the construction of highways and roads followed by its use in fly ash bricks (13 per cent) and reclamation of low-lying areas (13 per cent). Mine filling is though looked at as a lucrative option by the power plants to successfully dispose of its fly ash, but only 3 per cent of the total fly ash is currently used for this purpose. Experts claim that this percentage might increase in the coming years.

It is interesting to note that 23 per cent of fly ash—almost the same amount that is redirected for cement—is used for 'other' purposes. It is, however, not clear what these purposes might be. It's important that the government defines the 'other' uses of fly ash as well because, cumulatively, it is a very high amount of ash utilization in this category.

Thermal power plants who have achieved 80–99 per cent utilization: Almost 40 gigawatt of installed coal-thermal power capacity has been able to achieve 80–99 per cent fly ash utilization. The cumulative fly ash from these plants is mainly redirected for manufacturing of Portland Pozzolana Cement (PPC)—30

Figure 7: Fly ash utilization for TPPs with 80–99 per cent utilization (in million tonnes)



Source: CSE analysis (data retrieved from CEA)

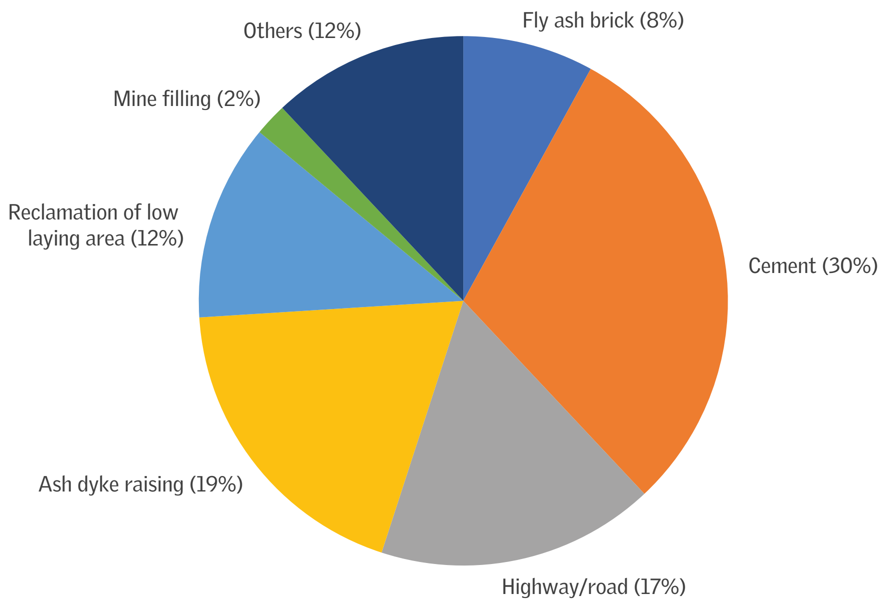
per cent—followed by its use for mine filling (26 per cent), fly ash bricks (15 per cent) and reclamation of low-lying areas (15 per cent). Only 9 per cent of fly ash is utilized in highways and road construction.

In this case, however, only 4 per cent is utilized for 'other' purpose and remains undefined by the Central Electricity Authority.

Thermal power plants who have achieved 50–79 per cent utilization: Almost 64 gigawatt of installed coal-thermal power capacity has been able to achieve 50–79 per cent fly ash utilization. The cumulative fly ash from these plants is mainly redirected for manufacturing of Portland Pozzolana Cement (PPC)—30 per cent—followed by its use for raising ash dyke—19 per cent. Highways, roads and flyover construction utilize 17 per cent of the fly ash in this category. Reclamation of low-lying area (12 per cent), bricks (8 per cent) and mine filling (2 per cent) are some other places where fly ash is being used in this category.

Almost 12 per cent of the total fly ash is used for 'other' purpose and remains undefined by the Central Electricity Authority (see *Figure 8: Fly ash utilization for different purposes in million tonnes*).

Figure 8: Fly ash utilization for TPPs with 50–79 per cent utilization (in million tonnes)



Source: CSE's analysis (data retrieved from CEA)

Thermal power with <50 per cent fly ash utilization

The total capacity under this category is about 22 gigawatt, including 18 power plants. The cumulative fly ash from these plants is mainly redirected for manufacturing of Portland Pozzolana Cement (PPC)—43 per cent—followed by its use in reclamation of low-lying area (28 per cent) and for raising ash dyke—13 per cent. About 5 per cent is used in fly ash bricks whereas mine filling utilize 3 per cent of the fly ash in this category, Highways, roads and flyover construction (2 per cent) are some other places where fly ash is being used in this category.

Almost 7 per cent of the total fly ash is used for 'other' purpose and remains undefined by the Central Electricity Authority.

Overall status

It is clear that the sector has been able to significantly increase its fly ash utilization capacity but it is as crucial to monitor where and how the fly ash is being used. Cement making is one major application wherein fly ash is currently used. As per the Central Electricity Authority of India (CEA) (2021–22), the overall consumption of fly ash in cement making is about 27 per cent. Other applications where significant quantities of fly ash are used include highways and road construction (18 per cent), reclamation of low-lying areas (14 per cent) and

Table 9: Quantities of fly ash application

Applications of utilization	Quantity of fly ash (in million tonnes)	Percentage
Fly ash brick	32	12
Cement	70	27
Highways/road construction	46	18
Replacement of cement in concrete	2	1
RCC dams construction	0.0006	0.0
Ash dyke raising	15	6
Reclamation of low-lying areas	36	14
Mine filling	19	7
In agriculture/wasteland development	0.16	0.06
Others	43	16
Total utilized	259.52	
Total generation	270.82	
Total unutilized fly ash	11	

Source: CEA, CSE analysis

fly ash bricks (12 per cent). Cumulatively, applications for which redirected fly ash are not defined amounts to about 43 million tonnes. Another 11 million tonnes of this waste lies unutilized (see *Table 9: Quantities of fly ash application*).

Future scenario

1. **Fly ash in PPC and composite cement making:** About 70 million tonnes of fly ash is utilized in PPC making, replacing limestone. Currently, an average 31 per cent of fly ash is used in the country.[63] Currently as per BIS standards, maximum fly ash addition permitted is only up to 35 per cent. While cement production is expected to reach 660 million tonnes by 2030, fly ash production during the same time is estimated to be about 437 million tonnes. As per the CSE publication *Decarbonising India: Cement Sector*, if we consider the share of PPC and composite cement in the total production as 70 per cent and 10 per cent respectively, the production of PPC will be about 462 million tonnes and composite cement will be about 66 million tonnes. As per the experts, though the current permissible limit of fly ash use in PPC is only 35 per cent, this can be increased up to 40–45 per cent with some more research. Accordingly, considering the fly ash utilization going up to 40–45 per cent, the expected usage of fly ash in PPC making will be about 185–208 million tonnes.[64]

   In case of composite cement, the fly ash utilization is about 25 per cent and can be increased to maximum of 35 per cent, which will result in fly ash utilization of about 23 million tonnes.

The utilization of fly ash will replace the equivalent use of limestone within the manufacturing of PPC, thus, will save upon 185–208 million tonnes of naturally occurring limestone.

2. **Fly ash in highways and roads:** As per the National Highways Authority of India, about 0.11 million tonnes of fly ash is utilized in the manufacturing of 1 kilometre of a four-lane highway, assuming an average of 5,000 km of highways is constructed in the country (all four-lane highways) and fly ash is used in about 20 per cent of the total kilometres constructed in the country. Thus, the fly ash requirement will be about 110 million tonnes.

Recommendations

1. **Stress on effective implementation of fly ash notification:** The fly ash notification as amended till December 2021 should be implemented to its potential. As per the CEA report on fly ash generation at coal-/lignite-based thermal power stations and its utilization in the country for the year 2021–22, about 4 per cent of the fly ash is dumped unutilized in India. Proper monitoring and auditing of the plants as per the notification is to be pushed and reports should be put in the public domain.

2. **Upscaling of fly ash-based industries to ensure increase in its utilization:** Developing fly ash-based industries and ensuring availability of fly ash for the same. Also, there is a need to upscale and create market of fly ash-based construction materials.

3. **CEA should concentrate on fly ash utilization under others category:** The other important aspect that needs attention from the CEA and the Pollution Control Boards is that about 16 per cent of the ash utilization is categorized as 'other'. However, there is no clarity on the applications for which this quantity is being used for.

4. **Thermal power plants to assess the potential of fly ash utilization:** All thermal power plants should look out for all possible modes of fly ash utilization and avenues to increase the utilization of fly ash in different applications. For unutilized fly ash, thermal power plants should explore the possibility of consuming fly ash in any construction-related activities undertaken within the plant's premises.

5. FGD gypsum from TPPs offer avenue for conservation of natural gypsum used in cement industries

India relies heavily on imported natural gypsum and about 62 per cent of gypsum consumed in the country is imported

Total installed capacity of coal-based power plants in India is about 207 GW (as of December 2023).[65] In 2015, the Ministry of Environment, Forest and Climate Change (MoEF&CC) introduced sulphur dioxide (SO_2) emission standards for the coal-fired thermal power plants. These emissions are to be controlled by deploying technologies such as flue-gas desulphurization (FGD). About 8.4 GW of the total capacity has installed FGD.[66] FGD systems are either limestone-based or seawater-based. FGD systems are efficient system that can remove up to 99 per cent of SO_2, and are thus the most preferred choice for thermal power plants that are to operate for a long time.

How FGD gypsum is generated in coal-based thermal power plants

Table 10: Coal thermal power plants where FGD has been installed

Coal thermal power plant	Organization	Capacity (MW)
Mahatma Gandhi Thermal Power Plant	Jhajjar Power	1,320
Dadri Thermal Power Plant (Units 5 and 6)	NTPC	990
Unchahar Thermal Power Plant (Unit 6)	NTPC	500
ITPCL	ITPCL	1,200
Mundra (Units 7, 8 and 9)	Adani Power Limited (APL)	2,580
Vindhyachal Thermal Power Plant (Unit 13)	NTPC	500
JSW Ratnagiri Thermal Power Plant	JSW	1,200
Dahanu Thermal Power Plant	APL	500
Trombay Thermal Power Plant (Units 7 and 8)	Tata Power	750
Total		8,440

Source: Central Electricity Authority (CEA), 2023

In plants with limestone-based FGD, flue gas is sprayed with a reagent (wet limestone) that reacts with SO_2 in the flue gas, resulting in the production of calcium sulphate di hydrate ($CaSO_4.2H_2O$), also known as gypsum. FGD gypsum is a byproduct of the wet limestone FGD, which is mineralogically similar to the gypsum found in the natural environment. FGD gypsum, due to its low effect, shall be treated as non-hazardous waste owing to the characteristics and as per the recommendations in 74th meeting of Technical Review Committee (TRC) of the Ministry of Environment Forest and Climate Change.[67]

As flue gas is generated, it is passed through an electrostatic precipitator that separates fine particles, including fly ash, from the gas. Next, a fan passes the flue gas into the absorber oxidation vessel. Inside, the gas is exposed to a water-based solution that contains fine-ground lime or limestone particulate. Scrubbing the sulphur dioxide from the flue gas by reaction with the lime or limestone produces calcium sulphite ($CaSO_3$) sludge, also referred to as FGD sludge. The cleaned flue gas is released into the air, while the sludge material is further refined for use in gypsum panels.

To make FGD gypsum, the sludge is oxidized by forcing clean, compressed air through it. In the oxidation vessel, calcium sulfite sludge is converted to calcium sulphate ($CaSO_4$), which almost immediately combines with some of the water in the slurry to form calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$). The resulting slurry is often referred to as 'unwashed' FGD gypsum.

Consumption and application of gypsum

Gypsum is a scarce resource in India. India's gypsum consumption in 2021–22 was around 9.2 million tonnes out of which it only produced 3.5 million tonnes (38 per cent) while importing about 5.7 million tonnes (62 per cent).[68, 69] The quality of FGD gypsum is at par or even better than the mineral gypsum and it has become a substitute for mineral FGD gypsum, largely in cement and construction. In India, gypsum is an integral component of cement production and the sector has to rely on costly imports or poor-quality synthetic gypsum. By adopting FGD, India's power plants would produce around 12–17 million tonnes of gypsum which can thus meet domestic shortfall and reduce the import burden.[70]

Gypsum is used in cement manufacturing to help control the rate of hardening of cement during manufacturing. Use of more FGD gypsum will ensure less natural gypsum has to be mined and can be replaced with synthetic gypsum from coal-fired thermal power plants. Thus the waste of an industry is ensured to be successfully utilized as a resource for another resource-intensive industry, thereby reducing its overall resource efficiency. Apart from cement industry, gypsum is also used in the manufacturing of gypsum boards and as a soil nutrient.

Cement gypsum: Gypsum in cement makes mortar more workable by keeping the cement in a plastic state at the early stages of hydration. It also contributes to strength acceleration in early stages of hydration.

Gypsum boards: Gypsum boards or dry wall is essentially a board with a gypsum core and a paper facing. Being fire-resistant, it is used as building material for wall, ceiling and partition systems in residential, institutional and commercial structures.

Agricultural gypsum: Gypsum is a soluble source of essential plant nutrients like calcium and sulphur and can improve overall plant growth. Gypsum amendments improve the physical properties of some soils (especially heavy soils). It helps reduce erosion losses of soils and nutrients, and the concentrations of soluble phosphorous in surface water runoff.

Limitation—uncertainty on gypsum availability

There is uncertainty over the generation of FGD gypsum and it shall continue due to varied reasons. There has been a lot of deliberation over the implementation and requirement of FGD gypsum.

1. A recent study by CSIR-NEERI found sulphur dioxide emissions from these plants do not significantly impact ambient air quality. Thus, no installation of FGD is required.
2. Huge investments of over Rs 1 crore per MW for installing FGD units by the coal-based power companies.
3. Never-ending deadlines to install FGD units: India had initially set a 2017 deadline for 211,520 MW of thermal power plants to install FGD units to cut sulphur emissions. This was later changed to varying deadlines for different regions, ending in 2022, and further extended to a period up to December 31, 2026. According to the latest guidelines, power plants that have plans to retire before December 31, 2027 will now be exempt from installing FGD units, and if the non-retiring power plants fail to adhere to the new deadlines, they will have to pay 'environmental compensation' of 20–40 paise per unit electricity generated. Considering different aspects of FGD implementation there is uncertainty over the production and availability of a certain quantity of FGD gypsum.

CASE STUDY 1: Utilization of FGD gypsum from NTPC in cement plants across India

Name of industry: National Thermal Power Corporation (NTPC Ltd)

Location: Pan India

NTPC is a power-generation company, with a profile of coal-based, gas-based, hydro as well as renewable-power-generating projects. It generates about 25 per cent of country's power, with installed capacity of about 16 per cent. Wet FGD technology is to be installed on units with a total capacity 62 GW. NTPC has currently commissioned FGD units in 2,150 MW at Khargone, Unchahar, Vindhyachal and Dadri. Generally, 1 tonne of limestone used is about 1.6 tonnes of gypsum produced.

Utilization of FGD gypsum from NTPC in cement industry

Currently, NTPC sells gypsum to the cement industry, board and brick industry. FGD gypsum is a good source of revenue generation compensating the cost of limestone.

Table 11 shows the details on the generation utilization of gypsum in a 500 MW power plant of NTPC. Almost all the gypsum generated in this plant is sold to various cement industries.

Table 11: Details of generation utilization of gypsum in a 500-MW power plant of NTPC

Year	FGD gypsum generation	Quantity sold to cement plants (MT)
2018–19	10,915	20,680
2019–20	13,413	3,977
2020–21	25,176	24,338
2021–22	12,423	16,614

Source: Guidelines for Handling and Management of Flue Gas Desulphurization (FGD) Gypsum, CPCB 2023

The following is the cost economics of operating FGD in a 500-MW thermal power plant and utilizing FGD gypsum in cement plants:

Operating hours per year (considering 300 days)	= **7,200 hours**
Limestone requirement	= **9 tonnes per hour**
Annual limestone requirement	= 64, 800
Approximate limestone cost	= Rs 2,000 per tonne
Annual cost of limestone	= **Rs 130 million**

Gypsum production	= **16 tonnes per hour**
Annual production of gypsum	= 115,200 tonnes
Approximate cost of gypsum	= Rs 850 per tonne
Revenue from selling gypsum	= **Rs 98 million**
Cost of limestone compensated	= **Rs 98 million (75 per cent)**

Other initiatives of NTPC towards utilization of FGD gypsum in different applications:

1. **Use of gypsum as soil nutrient:** NTPC, along with the Indian Council of Agricultural Research—Central Soil Salinity Research Institute (CSSRI), is working on FGD gypsum in agriculture and its management. This initiative has increased FGD gypsum utilization as a soil nutrient and in sodic soil reclamation.

2. **Use of gypsum as a plastering agent in construction:** NTPC with CSIR has been working on the aspect of using gypsum as gypsum vermiculite plaster (GVP) with fly ash plaster as direct alternate of conventional sand and cement plaster.

CASE STUDY 2: FGD gypsum usage in cement plant and gypsum board manufacturing

Name of plant: Jhajjar Power Limited (JPL)
Location: Jhajjar, Haryana

JPL has an installed capacity of 660 x 2 MW and has flue gas desulphurization system installed. FGD gypsum generation is about 0.1 million tonnes per year, depending upon the SOx loading, as more SO_2 content results in more gypsum generation. Corresponding limestone consumption is about 60,000–70,000 tonnes per year.

About 90 per cent of total gypsum generated is sold to cement industries and rest to gypsum board manufacturing. In order to ensure the consistent Gypsum offtake, M/s JPL has tied up with six cement plants including Wonder cement, Lafarge, JK Cement etc. and also with gypsum board manufacturing units available in the vicinity of the plant.

Based on the calcium carbonate content (85–95 per cent), costing of limestone is Rs 1,300–2,300 per tonne. The cost economics of compensation of limestone cost

Absorber tank of FGD at Jhajjar Power

FGD gypsum storage in Jhajjar Power Station

Source: CSE survey

Table 12: The quantity of FGD gypsum utilized by M/s JPL

Year	FGD gypsum generation	Quantity sold to cement plants (MT)	Gypsum board manufacturing (MT)
2018–19	44044	35,874	
2019–20	91190	90,556	
2020–21	63,130	62,250	
2021–22	94,849	98,310	2,703.7

Source: Guidelines for Handling and Management of Flue Gas Desulphurization (FGD) Gypsum, CPCB 2023

with revenue earned by selling FGD gypsum to cement industries is explained in the previous case study (see *Table 12: The quantity of FGD gypsum utilized by M/s JPL*).

FGD gypsum generated in the unit is directly send to the utilizers from the collection chambers below vacuum filters. The unit has a day storage capacity of 800 MT and a storage shed of 2,200 MT has been provided. Gypsum is loaded to the trailers of the procurer with the help of loader/JCB and same is covered to avoid any fugitive dust emission during transportation.

Savings through utilization of FGD gypsum in a cement industry

Cost of natural gypsum (imported)	= Rs 3,000 per tonne
Average selling price of FGD gypsum to cement plants	= Rs 850 per tonne
Cost saving by replacing natural with FGD gypsum	**= Rs 2,150 per tonne**

Future scenario

Cement production in India in 2030 is expected to be about 660 million tonnes. Looking into the composition of different cements (OPC, PPC, PSC and CC), gypsum with 5 per cent share is one component common to all. Thus, considering gypsum is used in at least 50 per cent of the total cement production by 2030, about 16.5 million tonnes of gypsum will be required. FGD gypsum generation if all the intended power plants install FGD would be about 12–17 million tonnes, which would be sufficient to meet the requirements of the cement sector.

Recommendations

1. **Power plants to achieve 100 per cent utilization of FGD gypsum:** As per the CPCB's Guidelines for Handling and Management of Flue Gas Desulphurized (FGD) Gypsum (February 2023), power plants need to utilize a minimum of 25 per cent, further increasing it to 100 per cent. It is recommended that all the power plants should plan to achieve 100 per cent utilization of FGD gypsum. CPCB and SPCB should do a monthly/quarterly assessment of the FGD gypsum utilization and applications of usage for each power plant.

2. **R&D for usage of FGD gypsum in agriculture as soil nutrient and standardization of the gypsum:** NTPC has been conducting research along with the CSSRI, on potential of utilization of FGD gypsum for soil reclamation. More such initiatives should be taken by the power plants, and once such utilization is adopted, BIS along with relevant stakeholders should work on evolving the standards for FGD gypsum utilization in such activities.

   As per CPCB guidelines, for carrying out studies or R&D within the country on FGD gypsum, no prior permission of SPCB/PCC shall be required for transporting samples of FGD gypsum up to 2,000 kg in individual cases and up to 20 MT per year. The unit shall maintain records of the same.

6. Red mud utilization from the aluminium sector: Need to explore avenues of utilization

With only 30 per cent of red mud utilization of 10 million tonnes produced annually, there is huge scope for improvement of circularity of red mud

India is the third largest producer of aluminium, with alumina capacity of 7.4 million tonnes and 4.13 million tonnes of aluminium capacity.[71] The aluminium industry consists of two parts: alumina refinery and aluminium smelter apart from bauxite mines. The refinery produces alumina (Al_2O_3) from bauxite, which is further processed to produce aluminium in the smelter. Bauxite is the primary mineral source for production of aluminium.

There are six alumina refineries, including Hindalco Industries Ltd-Muri, Renukoot, Belgaum, Utkal Alumina International Ltd, Rayagada, National Aluminium Company Ltd (NALCO), Damanjodi and Vedanta Limited. Lanjigarh, Odisha. Alumina production during 2019–20 is about 6.1 million tonnes in India,[72] while corresponding aluminium production was about 3.6 million tonnes. The average aluminium production during 2019–23 is about 3.5-4 million tonnes.[73] For each tonne of aluminium production, almost 2 tonnes of alumina and 5–6 tonnes of bauxite is required.[74]

Indian bauxite contains 40-42 per cent of alumina, the rest being a mixture of silica, various iron oxides and titanium dioxide. Thus, in the processing of bauxite into alumina by the Bayer process, a large amount of waste is generated, known as red mud or bauxite residue. About 1–1.5 tonnes of red mud is generated for one tonne of alumina production.[75]

Red mud generation during production process for alumina

The Bayer process is a cyclic process and involves addition of bauxite in the caustic solution that dissolves aluminium and forms liquor rich in aluminium. As the circuit continues, the aluminium concentration decreases in the precipitation step and the remaining spent liquor is recirculated to treat more bauxite. The process is completed in four steps: digestion, clarification, precipitation and calcination.

Digestion

The first step involves mixing of grounded bauxite with a solution of caustic soda to form a slurry and pumped into digesters where the bauxite is subjected to steam heat and pressure. Red mud is produced when the caustic soda reacts with the aluminous minerals of bauxite to form a saturated solution of sodium aluminate.

Clarification

The next step is to separate the insoluble solids from the sodium aluminate solution. These solids are settled in thickeners with the addition of synthetic flocculants. The solids in the form of a dense slurry are then washed and combined. The clarified solution is further cooled in heat exchangers and pumped into precipitators.

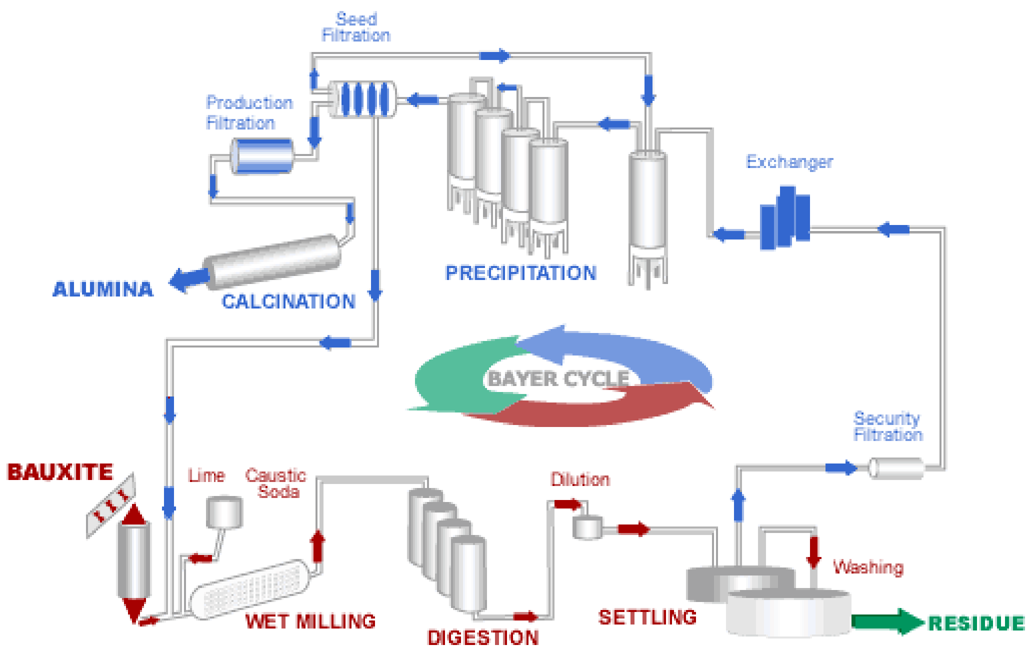
Precipitation

The crystallization of dissolved alumina from the supersaturated liquor is the slowest part of the process. Sizable amounts of aluminium hydroxide crystals are added in the precipitators as seeding to fasten crystal separation.

Calcination

The agglomerates of aluminium hydroxide (alumina) are calcined in rotary kilns or stationery fluidized-bed flash calciners at temperatures in excess of 960°C (1,750°F). This step removes excess free water to develop anhydrous pure alumina (see *Figure 9: Process of alumina production*).

Figure 9: Process of alumina production



Source: https://redmud.org/red-mud/production/

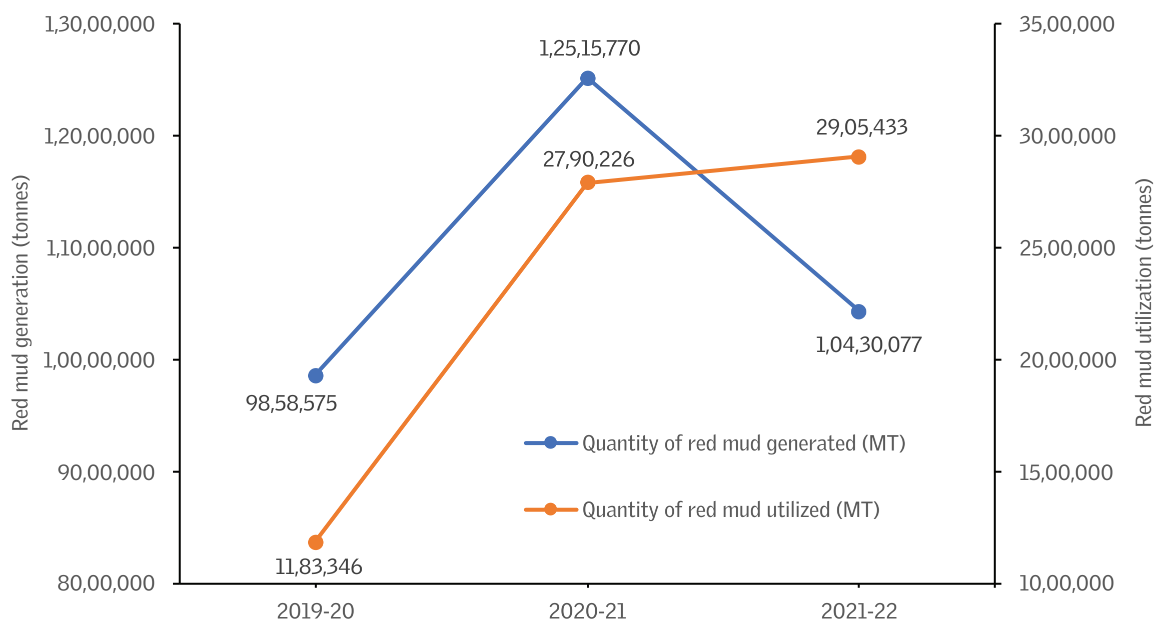
Red mud generation

The liquor exiting the thickeners during the clarification process, referred to as red mud, comprises mainly iron oxides and silica-based minerals, including quartz (SiO_2), and various calcium-based elements. To minimize loss of alumina and caustic soda in the liquor, it is directed to a series of washers (usually 5–6 in a train for each unit). The underflow from the last washer is pumped to disposal areas. Depending on the quality of the bauxite, the amount of red mud generated varies as 1–1.5 tonnes for each tonne of alumina produced.

Red mud is a highly alkaline waste with a pH range of 12–13 and may contain traces of toxic heavy metals (chromium, arsenic, cadmium etc.) and radionuclides. The red mud is fine grained in size (2–100 µm) between silt to fine sand and can form caustic dust on drying which can be easily blown with wind. These characteristics of red mud makes it a matter of concern in dealing with this waste.

Red mud generation from all the alumina refineries in India during 2019–20 to 2021–22 is about 10–12 million per year. However, the utilization of red mud is currently significantly low, in the range of 1.2–3 million tonnes only (see *Figure 10: Red mud generation and utilization from alumina refineries [2019–22]*).

Figure 10: Red mud generation and utilization from alumina refineries (2019–22)



Source: CSE analysis

RED MUD POND FAILURE IN 2019 AT MURI, INDIA

The Hindalco-owned plant is located on the banks of Subarnarekha River at Chota Muri, 65 km from Ranchi. In 2019, there was a breach of about 600 metres of the wall of the red mud pond, which resulted in spread of slurry all over the nearby agricultural land and on the railway track, resulting in disruption of rail movement. Build-up of hydrostatic pressure and low-bearing capacity of base/foundation of the pond was reported as the reason for the breach since the breached portion of the pond has been under water (red mud slurry) for a long time. Since red mud is a highly corrosive material, it corroded a portion of the wall that was weak and the pressure of the red-mud-filled material was released from the wall, causing the entire failure.

Google Images of before and after the accident

Source: Guidelines for handling and management of Red Mud generated from Alumina Plants, CPCB, 2023

Environmental issues with red mud

Red mud is classified as 'high volume low effect waste' in the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 and is required to be managed in accordance with the guidelines of Central Pollution Control Board (CPCB). Metallurgically, more than 40 per cent of the red mud is hematite or iron oxide (Fe_2O_3).

A huge quantity of red mud is stored in red mud ponds located besides the alumina refineries, which may result in following environmental impacts, if not managed properly.

1. Seepage of alkali water from red mud storage and/or disposal areas to the neighbouring soil, underground water, and water supply streams or canals;
2. Overflow and run-off of stored red mud especially during rainy season;
3. Requirement of large land space for storage of slurry;
4. Airborne dust carrying fine-sized particles containing caustic can cause air pollution, health issues and damaging the flora/fauna in neighbourhood; and
5. Dyke maintenance cost to nullify the chances of dyke/dam burst due to excessive load in the mud lake.

Current practices of red mud handling

Historically, red mud has been handled in slurry form and stored in ponds. However, industries have now adopted dry stacking of waste in place of slurry form by using the frame filter press. The filter cake, i.e. the red mud from the filter press, is collected into trucks through hoppers and disposed in the red mud stacking yards. This practice reduces the potential leakage of caustic liquor into the surrounding environment as most of it will be recovered. Additionally, it also reduces moisture content and increases the solid content of red mud to 75 per cent, which enables easy transportation with reduced costs. It also minimizes the land requirement and avoids the risks of dam failure due to hydraulic pressure.

Utilization of red mud

For 2021–22, red mud utilization by Indian alumina plants was reported to be approximately 3 million, which is only 30 per cent of the generation. Out of six plants, Hindalco's three plants reported achieving almost 100 per cent utilization of the generated red mud while NALCO is in process of installing a filter press and thus has not initiated the utilization.[76] The major portion of utilization was undertaken by sending dry red mud to cement plants.

CASE STUDY: Red mud utilization in cement making to replace laterite

Iron oxide is the major constituent in the red mud due to which it is considered as a low-grade iron ore containing 30–50 per cent iron and 14–17 per cent aluminium. This makes it an attractive candidate for clinker production in cement industries, serving as a laterite substitute. Additionally, the residual caustic soda in red mud helps control sulphur emissions when applied directly, making it a suitable choice for this purpose.[77]

Iron corrective is added with limestone into the raw mill to increase the binding property of clinker. Generally, 4–5 per cent of iron corrective (iron oxide) is added for producing 1 tonne of clinker. Laterite is the most commonly used additive as it

Table 13: Various types of material used as iron/alumina corrective along with their purity and cost

Name of material used as iron/alumina corrective	Purity in terms of iron content (%)	Cost/tonne
Iron ore	65–70	Rs 1,200–1,500
Iron sludge	50–55	Rs 700–900
Laterite	60–63	Rs 500–800
Bauxite	50–55	Rs 500–750
Red mud	55–60	Rs 450–500

Source: CSE survey

is rich in iron and alumina. There are other materials as well which are used as an iron corrective; the quantity of their usage depends on the purity of the material (see *Table 13: Various types of material used as iron/alumina corrective along with their purity and cost*).

While iron ore, bauxite and laterite are natural minerals, iron sludge and red mud are processed waste from industries.

The quantity of red mud usage as an additive depends on the type of fuel used by the cement industry. The industry using pet coke as fuel will be able to use more quantum of red mud because, apart from acting as an additive, RM will also regulate the alkali to sulphur ratio in the kiln generated due to use of petcoke. While the industry using Indian coal (which has less sulphur content) will use less amount of red mud since more usage will increase the alkali content of the clinker which reduces its strength. Red mud, however, can't be used 100 per cent as an additive and some parts of other additive are always required. Since 5 per cent of additive is required for 1 tonne of clinker production, while using pet coke, red mud can be used up to 85–90 per cent of the additive while with Indian coal its usage is limited to 35–40 per cent.

Overall, the use of red mud as an additive results in saving of Rs 250–300 per tonne of clinker produced. However, this saving will completely vary depending on the geographical location of the cement plant and the raw material quality and raw mix design of the plant.

Benefits of using red mud in cement production

- Used as substitute of iron additive in clinker production reducing dependence on natural minerals like laterite, bauxite and iron ore;
- Act as an alumina additive in clinker production; and
- Regulates the alkali to sulphur ratio in the kiln for plants using petcoke, thus reducing the cost of adding alkali.

Future scenario

By 2030, aluminium production is expected to be about 12 million tonnes.[78] For producing this amount of aluminium, approximately 24 million tonnes of alumina will be required, which will result in generating almost 36 million tonnes of red mud. As per CSE's estimate, by 2030, the production of cement is expected to be around 660 million tonnes with product mix of OPC (10 per cent), PPC (70 per cent), PSC (10 per cent) and CC (10 per cent). Considering that the share of clinker in composition of each category of cement is different, thus, for producing 660 million tonnes of cement, the clinker production will be around 482 million tonnes (clinker to cement ratio of 0.73). Considering 0.05 tonne (5 per cent) of iron additive is required for 1 tonne of clinker, the total additive requirement is estimated to be about 24 million tonnes. The use of red mud in the cement industry will save almost 20.4 million tonnes (in the case of industries using petcoke) and 8.4 million tonnes (in the case of coal) of laterite and other natural resources.

Recommendations

1. **More researches on creating avenues for red mud utilization:** The Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC) along with relevant research organizations should work on developing potential applications of red mud utilization. At present the most promising application of red mud is in cement making. Apart from that, the feasibility of usage of red mud in road making and other construction activities can also be looked in as a prospect.

   Even CPCB, in its May 2023 publication *Guidelines for Handling and Management of Red Mud Generated from Alumina Plants* highlighted that research shall be carried out expeditiously to explore additional options for utilization of red mud and that SPCB/PCC in association with concerned stakeholders shall explore options for utilization and organize awareness programmes for effective implementation of these guidelines.

2. **Standardization of red mud properties as per the application it is used for:** Based on the validation of R&D work on red mud applications, BIS should prepare the standards of red mud properties based on the usage. This will upscale the utilization of red mud and will lead to less disposal in red mud ponds.

3. **Alternative to commercial catalysts:** As red mud is largely a combination of inorganic oxides of Fe, Al, Ti and a few amounts of Si, Na and Ca, it is this a potential alternative catalyst at the commercial scale.

The simultaneous presence of various metal oxides in the RM composition makes it less susceptible to catalyst poisons like sulphur, and hence it is able to retain its catalytic activity over a relatively long period of time.

4. Potential avenues need to be upscaled

   a. X-ray shielding tiles from red mud
   CSIR- Advanced Materials and Processes Research Institute (AMPRI) has converted red mud into X-ray shielding tiles in a green and economically viable manner through a ceramic route by adding a certain weight percentage of high Z material and binder with it. These tiles can be used to build radiation shielding structures in diagnostic X-rays, CT scanner rooms, Cath labs, bone mineral density, dental X-rays, etc., instead of the toxic lead sheet to protect the public from radiation hazards[79].

   CSIR-AMPRI and M/s Prism Johnson Ltd., together have upscaled this technology from the lab to the industry level and developed a joint-free X-ray shielding tiles (30x30x1.2 cm3) on a pilot scale in 2022. The developed tiles are tested and approved by the Atomic Energy Regulatory Board (AERB) of India. The product is commercialized and the first instalment has been initiated at INS Kattabomman, Tamilnadu.

   b. Extraction of rare earth elements from red mud
   The Jawaharlal Nehru Aluminium Research Development Design Centre (JNARDDC), under Atmanirbhar Bharat Mission, has innovated a distinct technology to extract rare earth elements (REE) from aluminium waste (Red Mud).[80] This is an attempt to reduce India's import dependence for REE. The project has been undertaken under the MoU with CSIR-Institute of Minerals and Materials Technology (CSIR-IMMT), Bhubaneswar; CSIR-National Metallurgical Laboratory (CSIR-NML), Jamshedpur; National Aluminium Company Ltd. (NALCO), Hindalco Industries Ltd., and Vedanta Ltd. Under this project, JNARDDC has extracted scandium (40–50 mg) from 1 kg of red mud at a lab scale.[81] Scandium is one of the strategic elements in the group of REEs and is utilized in space and defence technologies in large amounts. JNARDDC has proposed an experimental flow-sheet for future process development and production. It claims that India produces 10 million tonnes of red mud per annum from which about 4,000 tonnes of scandium per annum can be extracted.

7. Sugar and distillery: Integrated model of circularity

Use of press mud in compressed biogas production is amalgamation of the circularity of waste and use of renewable energy in the country

India emerged as the largest sugar producer and consumer across the globe, with a record 357.4 million tonnes sugarcane crushed in 2022 to produce 39.4 million tonnes of sugar at about 11 per cent recovery rate.[82] Sugarcane is crushed in mills and the juice is boiled for further processing. This juice is then treated with milk of lime, sulphur dioxide and finally crystallized in vacuum pans. The process generates several by-products, such as molasses, bagasse and press mud, at different stages of sugar processing and presents enormous bio-economic potential.

Bagasse, which is a fibrous residue of cane stalk that is obtained after crushing and extraction of sugarcane juice, consists of high quantity of water, fibre and relatively small quantities of soluble solids. About 0.25–0.30 tonnes bagasse is produced per tonne of sugarcane. As an estimate, about 90 million tonnes of bagasse is generated from sugar industries in India. It has a calorific value of 8,021 kJ/kg.[83] The composition of bagasse varies based on the variety of sugarcane, maturity of cane, method of harvesting and the efficiency of the sugar mill. Bagasse is usually used as combustible fuel in boilers for steam generation, in co-generation power plants for power, or as raw material for paper industry and in feedstock for cattle. Considering the economic value of bagasse, several sugar mills have lately installed a 'steam economy device' to regulate its steam consumption which ultimately results in lower fuel combustion. Some sugar industries have also set up co-generation power plants in their premises, which are primarily based on combustion of bagasse. This helps the units to not only generate their own power to run the sugar mill but also build revenue by producing ample electricity for supplying to the main grid. Excess bagasse from sugar mills is in some places also supplied to the linked distilleries to be used in its boilers for energy requirement. The green energy can substitute fossil fuels in power generation hence reduce consumption of natural gas, coal, and diesel while at the same time improving the sugar industry competitiveness and sustainability. Since bagasse is a local resource, its use improves energy security and reduces the environmental impact of power generation.[84]

Another by-product of the sugar industry is **press mud**, also known as oliver cake or press cake. Press mud is the residual output after the filtration of the juice. Usually, 3–4 per cent of press mud is generated from per tonne of sugarcane crushed. Accordingly, about 14.3 million tonnes of press mud is estimated to be generated from the sugar industries. Press mud is usually mixed with spent wash from the distillery and is used to produce high quality bio-manure. Press mud typically contains 71 per cent moisture, 9 per cent ash and 20 per cent volatile solids, with 74–75 per cent organic matter on solids.[85] Recently, press mud has also found application in production of biogas through anaerobic biomethanation of press mud in anaerobic digester. Estimates suggest that only 25 tonnes of press mud is required for generation of 1 tonnes of CBG.[86] The cost of press mud is Rs 0.4–0.6 per kilogramme whereas it is much higher in case of feedstocks like agricultural residue (Rs 1.5–2/kg) and cattle dung (Rs 1–2/kg).[87] India has a potential to produce 10 MMTPA of CBG from press mud alone.[88] Furthermore, the sludge from digester is further used as fertiliser.

The third byproduct of sugar manufacturing is **molasses**. Molasses is a viscous liquid obtained from repeated crystallization during sugar preparation. It is used for manufacturing of alcohol and yeast and as cattle feed. Approximately 4.5–5 per cent of molasses is generated from crushing 1 tonne of sugarcane. Owing to economic advantage, several distilleries have been set up in and around sugar industries. Molasses from the sugar mills is diverted to these distilleries for production of alcohol, resulting in a waste stream called spent wash. Alcohol in turn is used to produce ethanol, rectified spirit, potable liquor and downstream value-added chemicals such as acetone, acetic acid, butanol, acetic anhydride, etc.

The distilleries generate approximately 10–12 litres of **spent wash** per litre generation of alcohol. Spent wash is a highly problematic effluent as it has low pH, high chemical oxygen demand and biological oxygen demand, and has high concentration of heavy metals such as high concentration of heavy metals such as Copper (Cu), Cadmium (Cd), Zinc (Zn), Iron (Fe), Nickel (Ni), Manganese (Mn) and Lead (Pb).[89]

Due to its toxic nature, spent wash cannot be released directly into open drains without treatment. In order to achieve the legal mandate of zero-liquid discharge, it is first passed through a multi-effect evaporator (MEE) where it is further concentrated and converted into semi-solid spent slops and an effluent called spent-lees. Where spent-lees is further treated in the secondary effluent treatment plant, spent slops are used as fuel in the incineration boiler. The industry generates approximately 40 billion litres of spent wash per annum from 285 distilleries across the country.[90]

Waste valorization from both sugar and distilleries fall within the broader framework of circular economy as the waste from these industries are put back into the economy through options of reuse, refurbishing, recycling or remanufacturing. In the following section, we discuss some of the case studies recorded for the purpose of documenting the practices adopted by different sugar and distillery units to deal with its wastes.

CASE STUDY 1: Use of press mud as feedstock to manufacture compressed biogas by India Potash Limited

Name of industry: **Indian Potash Limited**
Location: **Rohanna, Muzaffarnagar**

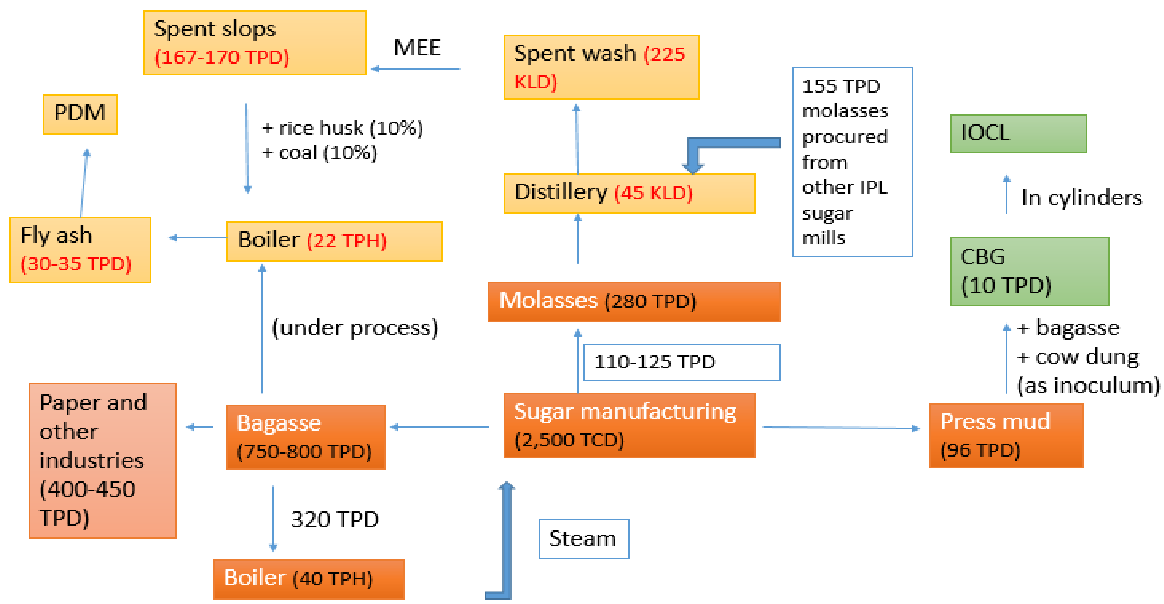
Indian Potash Limited (IPL) has a sugar and distillery plant in the same complex in Rohanna district of Muzzafarnagar, Uttar Pradesh. The sugar mill has a capacity to crush 2,500 tonnes of sugarcane per day (TCD) and distillery can generate 65.3 kilolitres alcohol per day (KLD).

All the three byproducts from the sugar unit—molasses, bagasse and press mud—are redirected for different purposes. While molasses is used in the distillery, bagasse and press mud are used in boiler and in-house compressed bio-gas CBG) plant respectively. Similarly, spent wash from the distillery also is used as fuel for the incinerator boiler (see *Figure 11: Resource circularity in sugar and distillery as practiced in IPL*).

Bagasse production is about 30–32 per cent of the total cane crushed per day. Press mud production is about 4 per cent of cane crushed while molasses generation is about 4.5–5 per cent of the total cane crushed (see *Table 14: Break-up of byproducts generated from the sugar industry*).

The sugar mill in Rohanna generates 110–125 tonnes per day of molasses, which is then used in the distillery unit for manufacturing of ethanol, industrial alcohol such as ethyl acetate, and extra neutral alcohol. The distillery came into operation in 2020 and has a total requirement of 270–280 TPD of molasses. To meet this requirement, molasses is also procured from the other two sugar mills of the IPL—

Figure 11: Resource circularity in sugar and distillery as practised in IPL



Source: CSE survey

Table 14: Break-up of byproducts generated from IPL

Byproduct	Percentage generation of sugarcane crushed	Generation in tonnes per day
Molasses	4–4.5	110–125
Press mud	4	96
Bagasse	32	750–800

Source: CSE survey

Sakoti Tanda and Titavi Sugar Mill. Approximately, 80,000 tonnes of molasses is required annually to meet the requirement. Molasses from different industries is brought to the distillery complex and stored in fermentation tanks. The distillery generates 225 KLPD or 7–8 litres of spent wash per litre of alcohol production. It is processed in the multi-effect evaporator (MEE) which further concentrates the spent wash into spent slops and spent lees that is recycled in the process. Usually 167–170 tonnes per day of spent slops are generated and burnt in the boiler for steam generation. Eighty percent of spent slops along with 10 per cent of rice husk and 10 per cent of coal is used as fuel in the incinerator boiler for steam and power generation.

Distillation unit of IPL, Rohanna

Source: CSE survey

The use of spent slops in boilers generate about 30–35 tonnes per day of fly ash which is rich in potash. The fly ash is used as a manure in the form of PDM (potash derived from molasses) and serve as another source of revenue generation for the plant. Fly ash is sold at a rate of Rs 500–1,000 per tonne.

Bagasse generation is approximately 750–800 TPD on the sugarcane crushed by the unit. Sugar complex has a bagasse fired boiler of 40 tonnes per hour (TPH) capacity which utilizes 45–50 per cent of the bagasse generated by the plant. In 2021 the unit installed a 'steam economy device', which brought down its use of steam to 30–32 per cent (900 TPD) from more than 50 per cent earlier on sugarcane crushed. The unit plans to do further modifications in the device and bring down the steam requirement to 25 per cent of sugarcane crushed. The remaining 400-450 tonnes of bagasse is sold at Rs 3,000–3,500 per tonnes to nearby paper mills to be used as raw material or to industries to be used as fuel. The CSE team was informed that the plant was able to recover its capital cost of Rs 19 crore on the steam economy device within a year of its installation.

Source: CSE survey

Bagasse storage in the industrial complex

Press mud generated from sugar manufacturing is approximately 4 per cent of the sugarcane crushed. Earlier, press mud was sold to the farmers as manure. Looking into the potential and the focus of the government on the development of renewable energy sources, IPL set-up an in-house 10 TPD of compressed biogas (CBG) plant based on press mud in year 2021. The plant has an agreement to supply the biogas produced to Indian Oil Corporation Limited (IOCL). Press mud from the sugar factory is stored in a storage yard and through hopper is fed into an anaerobic digester for decomposition and production of biogas. The digester has a hot water system and biogas-recirculation system, and a gas holder to regulate its pressure and temperature. Pressure inside the digester is automated through a 'plug flow technology'. Biogas produced is transferred into an intermediate balloon from where the gas is taken to the purification unit wherein, using HV compressors (250 bar pressure), the gas is filled into cascades and transported to IOCL. The plant owns 13 cascades comprising 60 cylinders. Each cylinder can store 12.5 kg of gas. The production cost of CBG is Rs 50–55 per kg of gas. Selling price of gas to IOCL is about Rs 62 per kg. The industry is hopeful that there will

Compressed biogas plant in IPL

Press mud collected in the trolleys to be sent to storage yard

Source: CSE survey

be higher revenue generation from its CBG plant as gas pipelines are laid in the region.

Officials informed the CSE team that the plant is in the process of making modifications in its boilers to replace the use of rice husk with bagasse. As bagasse is a byproduct of the sugar unit set up by the plant, this will reduce the energy cost for the plant.

CASE STUDY 2: Use of spent wash along with bagasse as boiler fuel in distillery complex
Name of industry: **Upper Doab Sugar mills and distillery**
Location: **Shamli, Muzzafarnagar**

M/s Shri Shadi Lal Enterprise established a sugar mill in 1933 in Shamli, Muzaffarnagar in Uttar Pradesh. The plant currently has a current cane crushing capacity of 6,250 tonnes per day. Molasses generated by the sugar mill is used as raw material by the adjacent distillery in the same industrial complex (see *Table 15: Break-up of byproducts generated from the sugar industry*).

Table 15: Break-up of byproducts generated from the Upper Doab Sugar mills

Byproduct	Percentage generation of sugarcane crushed	Generation in tonnes per day
Molasses	4.5–5	250–300
Press mud	4	250–300
Bagasse	30–32	2,000–2,400

Source: CSE survey

The molasses-based distillery was established in the year 1945, with an installed capacity of 12 KLPD. Subsequently, the capacity was increased to 100 KLPD in several stages. The plant produces rectified spirit, denatured Spirit, special denatured spirit, and anhydrous alcohol and extra neutral alcohol. The distillation process generates 10–12 litre of spent wash on per litre of alcohol generated. After processing in MEE, 10–12 TPD of spent slops (57–58 per cent of spent wash) are recovered which are sent to the plant boiler for steam and power generation for the plant. The plant has a 36 TPH boiler and one back pressure turbine of 3.5 megawatt capacity. Concentrated spent wash or spent slop and bagasse in the ratio of 70:30 is used in the boiler. Approximately fly ash generated from the boiler is 16–17 per cent of fuel burnt and is used as fertilizer as it is potash rich. The fly ash from distillery boiler is sold at Rs 700–1,400 per tonne.

Bagasse storage in loose form to be used in boiler as fuel

Bales of bagasse to be stored for off-season consumption in distillery

Spent wash stored in lagoon

Source: CSE survey

Bagasse is used in the five boilers for sugar unit (4 no. x 25 TPH and 1 no. x 38 TPH) for steam generation. Steam consumption of the plant is in the range of 2,500–2,700 tonne per day and accordingly bagasse consumption in the boiler is same as the generation of bagasse. The plant also has a baling unit which creates bales of the bagasse storage to be used during off-season by the distillery. Apart from molasses and bagasse, the sugar mill produces 4 per cent of press mud of the sugarcane crushed. The press mud is sold at Rs 3.5–4 per tonne to contractors who resell it for manufacturing of manure or for production of compressed biogas. Fly ash from the sugar mill boilers is given for landfilling, highway construction for free of cost on need basis.

CASE STUDY 3: Use of bagasse to generate electricity apart from steam in co-generation plant, with surplus energy sold to state grid

Name of industry: Tikaula Distillery
Location: Muzaffarnagar

M/s Tikaula Distillery Limited has a sugar mill of 12,000 TPD capacity and a 75 KLD distillery in the same complex. The sugar unit has four boilers—two of 35 TPH each and other two of 75 and 60 TPH respectively. Almost 28 per cent of bagasse is generated on per tonne of sugarcane crushed by the mill. Of this almost 2,200–2,300 TPD is used for generation of steam in boilers and generation of power in the 27 MW co-generation power plant. Almost 17–17.5 MW of electricity generated by the co-generation plant is utilized to power the sugar mill and balance is sold to the state grid at around Rs 3.67 per unit as per the power purchase agreement with the Uttar Pradesh Rajya Vidyut Utpadan Nigam (UPRVUNL).

The 540 tonnes of molasses generated by the sugar mill is utilized in its own distillery. The process steam generated by the boiler in distillery uses both bagasse and spent slops. For its 30 TPH boiler, 170 tonnes of bagasse is also used in the distillery as fuel. Bagasse in the distillery boiler is used along with 150–200 tonnes of spent slops. The distillery generates 600 tonnes of spent wash or 7–8 litres per litre of alcohol generated. Spent wash is processed through MEE and converted into 200 tonnes of spent slops and 400 tonnes of spent lees.

The sugar mill also generates 4–4.5 per cent of press mud on sugarcane crushed in the mill. The press mud is sold to farmers as manure for Rs 0.5 per tonne. The unit has not explored the option of using press mud for generation of compressed biogas by itself or to other such vendors.

Bagasse storage yard

Fly ash from boiler of sugar mill

Source: CSE survey

Future scenario

As per estimates, sugarcane requirement by 2030 is expected to be about 520 million tonnes to meet the demand of sugar and sugar products which is likely to be about 50-52 million tonnes.[91] Processing of 520 million tonnes of sugarcane will produce about 130 million tonnes of Bagasse, press mud generation will be about 15.6 million tonnes.

As is the practice in the sugar industry, generally around 37 per cent of steam is required to process one tonne of sugarcane, thus bagasse requirement to generate required steam is about 93.6 million tonnes which is eventually saving upon coal consumption of about 46.8 million tonnes of coal, preventing about 5.6 million tonnes of CO_2 emissions.

Regarding press mud usage in production of CBG, if all of the press mud production is used in the CBG production total 624,000 tonnes of CBG is expected to be produced.

Recommendations

1. **Development of pipeline infrastructure to tap the potential of CBG:** Press mud, another byproduct of sugar industry, is largely used as fertilizer. Recently, it has also proven to be a fine resource for generation of compressed biogas (CBG). Based on our survey, currently there are two operational models in practice for the manufacturing of CBG. The first model is the in-

house production of CBG by the sugar factory, which requires heavy capital investment. The second model is the collection of press mud from different sugar units and supply to a centralized CBG plant in the region.

Though both these models need further strengthening to realize the full potential of usage of press mud and at the same time further widens the spectrum of resources for renewable energy generation. An in-house CBG plant reduces the cost of transportation of press mud to its end user, there is no need to store press mud for long duration as it can be continuously utilised for generation of biogas, and thereby, prevents any decomposition that may reduce its energy generation potential. For sugar industries to engage in investing manufacturing of CBG, the government needs to ensure that these industries have long-term agreements with the gas companies to ensure a return on its investment. A pipeline infrastructure from industry to the gas vendors such as IOCL, GAIL, may further enhance the supply chain network.

The second model can be looked into in areas where the sugar industries are either scattered or do not have technological and infrastructure capabilities to generate compressed biogas in its own premises. In such cases, an intermediary collection point may be established where press mud from different units can be collected and sent further to a CBG plant. In this case, however, it needs to be ensured that the quality of press mud supplied to the CBG plant is not compromised.

With the right policy push, enhancement in technological capabilities, right financial incentives, and robust supply chain, CBG generation from press mud can become an economically viable and environmentally sound choice for industries.

2. **Promote usage of surplus bagasse in industrial co-firing:** Economic value in waste can be commercialized only by successfully addressing existing economic and technological bottlenecks. Wastes from both sugar and distillery have several applications as fuel and raw material. While use of molasses generated from sugar industry is fully utilized in the production of alcohol in distillery, spent wash from distillery is further processed to generate spent slops to be used as fuel for distillery boilers. Bagasse from sugar generation too finds use both as raw material in the paper industry and as fuel for boilers in industries. A good example of the increased use of biomass in industries is in Delhi-NCR, where the majority of industries have shifted away from coal to combat air pollution from burning of coal or lignite, after the intervention of

Commission for Air Quality Management (CAQM). The Centre for Science and Environment (CSE), in its survey conducted in 2022, found out that several of these industries have made changes in their burners to shift to biomass and found it to be much cheaper.[92] This policy push by the government resulted in increased demand in the market for agricultural biomass, including bagasse from the sugar industry.

8. Utilization in cement and tile making are major avenues for circularity of stone slurry and marble slurry

With 90 per cent stone-processing units clustered in Rajasthan, and 77 million tonnes annual cement production, the state has potential to upscale stone slurry usage

India is rich in stone resources and ranks third globally in natural stone production, holding an 11 per cent share of the global market. With a vast abundance of natural stone resources, India is a major player in global stone production, exporting various types of stone products worldwide. However, the rapid expansion of the stone-cutting industry has come with environmental repercussions. Extensive stone-processing operations like stone-cutting industries generate substantial amounts of stone slurry waste, leading to water and soil pollution, air quality degradation and habitat destruction. Despite regulatory efforts to mitigate these impacts, challenges persist in ensuring sustainable practices across the industry. In India, Rajasthan holds the largest share in the Indian stone industry.

Rajasthan faces significant challenges related to stone slurry generation and its environmental impact. With its abundant natural stone resources, especially marble, Kota stone and granite, Rajasthan hosts numerous stone-cutting and processing units, contributing substantially to the state's economy. However, the intensive stone-processing activities in Rajasthan generate significant quantities of stone slurry waste, primarily composed of fine particles of crushed stone, sand and other materials. It is estimated that Rajasthan produces a significant portion of India's total stone slurry waste as 90 per cent of stone-cutting industries are situated in Rajasthan. More than about 2,000 processing units all over Rajasthan are generating around 5–6 million tonnes of slurry every year.[93]

Process of waste (stone slurry) generation

Stone slurry is a semi-liquid mixture comprising particles resulting from the cutting and polishing process, along with water utilized for cooling and lubricating sawing and polishing machinery. It is generated during various stages of stone processing such as block cutting, slab cutting, and slab and tile polishing. These processes produce fine stone particles suspended in water. This slurry is generally disposed of in nearby areas. However, when stone slurry is deposited in landfills, its water content diminishes significantly, leading to the formation of stone dust. This dust poses several environmental concerns, particularly during dry seasons when it becomes airborne, disperses, and settles on vegetation and crops.

Environmental impacts associated with stone slurry dumping

There are environmental consequences linked with the dumping of stone slurry. Numerous studies have been undertaken to comprehend the environmental repercussions of stone slurry dumping. These studies have revealed that improper disposal of marble slurry leads to adverse impacts on ecology, human health, and the quality of water and air.

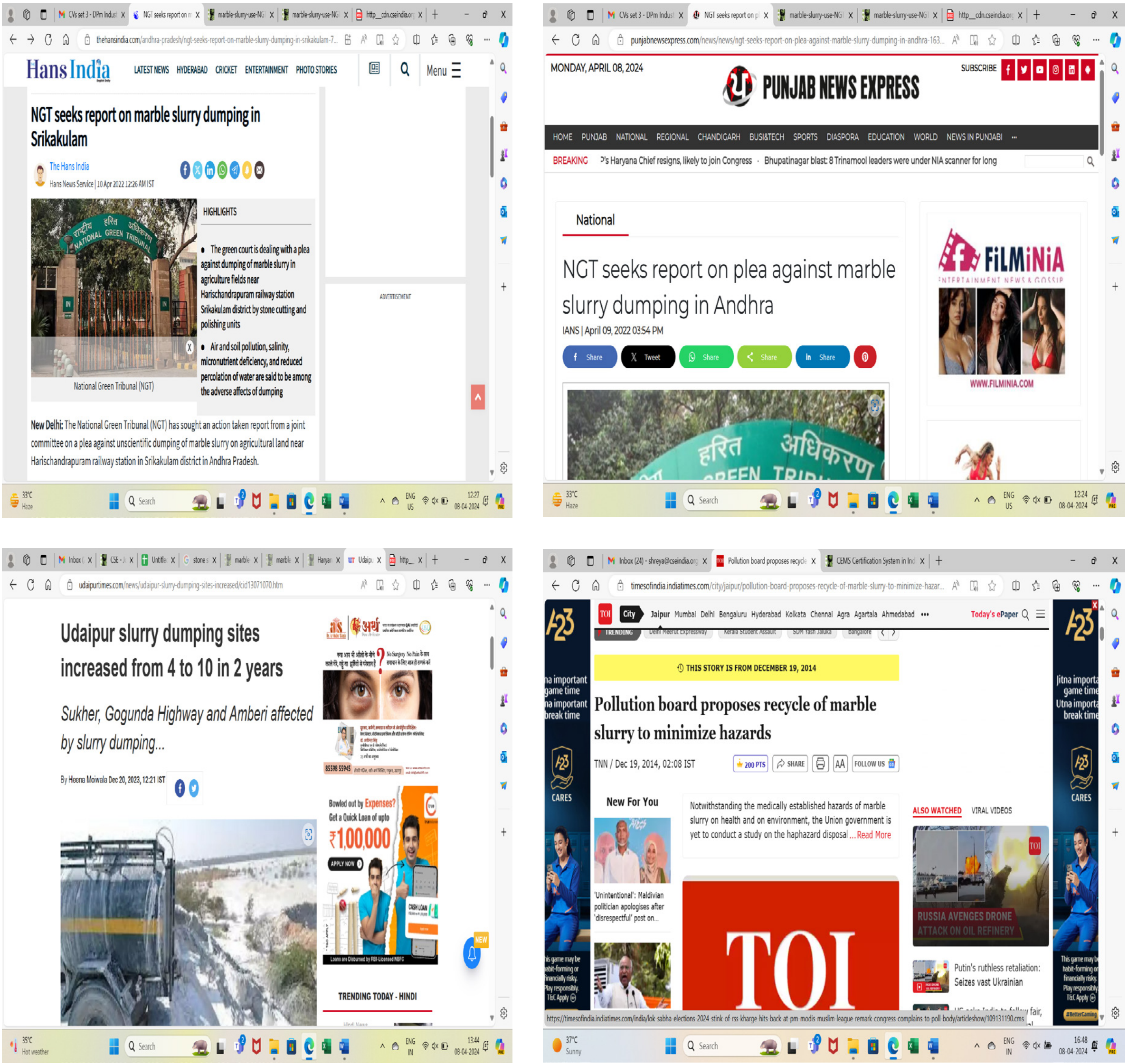
- **Impact on human health:** Exposure to marble dust can result in severe respiratory ailments such as bronchitis and asthma as well as cause dermal and eye irritation among workers and the local population.

- **Impact on soil quality:** Dumping slurry on open lands is detrimental to land productivity by reducing the porosity and permeability of the topsoil. It also diminishes soil fertility and hampers the percolation rate of rainwater, leading to a decline in groundwater recharge. Fine slurry particles, upon drying, are carried by the wind and settle on the surface of crops and plants, blocking stomata responsible for plant respiration.

- **Impact on water sources:** Disposing the slurry waste near to water bodies, road side areas can deteriorate the surface and groundwater quality by increasing turbidity, suspended solids, calcium and magnesium hardness.

What makes it essential to manage stone slurry disposal?

The state of Rajasthan has 90 per cent of India’s stone processing industries, and its stone slurry generation is also higher as compared to other states. The major challenge with the sector is handling and safe disposal of marble slurry. These stone-cutting units in Rajasthan have been in the public eye because of the various cases filed against them in the National Green Tribunal (NGT) for unscientific disposal and causing air pollution. The NGT has intervened in numerous cases related to stone slurry dumping to address environmental concerns and ensure compliance with environmental regulations.



Media reports on unscientific disposal of stone slurry

CASE STUDY 1: Utilization of Kota stone slurry in cement plant as a raw material

Name of industry: Mangalam Cement Limited

Location: Village Morak, Ramganj Mandi, district Kota

Kota stone is abundant in Rajasthan, especially in Kota and Jhalawar districts. Hundreds of mines are located in or near the town of Ramganj Mandi and in Kota district. Kota stone contains 68–70 per cent calcium carbonate and 24–25 per cent silica. Reserves in Kota and Jhalawar districts of Rajasthan alone account for roughly 100 million tonnes of Kota stone. Additionally, deposits of Kota stone are found in Ajmer, Sawai-Madhopur, Rajsamand, Udaipur and Banswara.

Kota stone slurry generation: Every year, approximately 0.25–0.3 million tonnes of stone slurry is discharged into local areas, causing significant environmental and ecological issues.[94] The slurry generated from Sukhet, Chechat and Ramganj Mandi industrial areas in Kota is being deposited at a dumpsite in Ramganj Mandi.

Utilization of stone slurry in Mangalam Cement

The Mangalam Cement plant, located in Kota district, effectively utilizes Kota stone slurry in its production processes. Specifically, the plant incorporates stone slurry

Dumping of Kota stone slurry in Ramganj Mandi

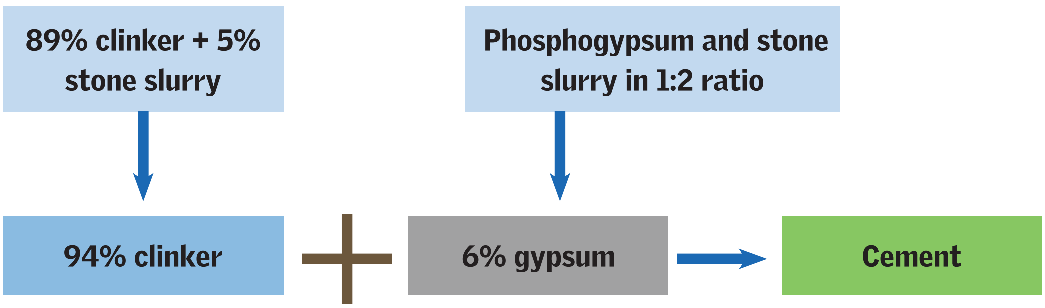
Source: CSE survey

in the production of gypsum, which is a crucial component in the manufacture of cement. The extent of stone slurry utilization in cement production varies depending on the type of cement being manufactured. The Mangalam Cement plant manufactures the following two types of cement:

I. Ordinary Portland Cement (OPC)
II. Portland Pozzolana Cement (PPC)

OPC Cement manufacturing

For OPC, a blend of 6 per cent gypsum and 94 per cent clinker is mixed and ground together. The stone slurry powder is utilized in gypsum-making process by mixing it with phosphogypsum (a byproduct of the fertilizer industry manufacturing phosphoric acid) at a ratio of 1:2 (phosphogypsum to stone slurry). Additionally, the stone slurry powder finds usage in clinker production, where 5 per cent stone slurry is mixed with 89 per cent clinker (94 per cent clinker). Stone slurry is used in clinker only in the case of OPC cement—the overall utilization of stone slurry



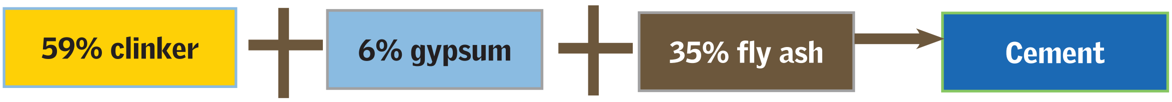
Industrial waste—Phosphogypsum and stone slurry used as a raw material for making gypsum

Source: CSE survey

powder in OPC cement production amounts to approximately 9 per cent (5 per cent in clinker and 4 per cent in gypsum making).

PPC cement manufacturing

In the case of PPC cement, the production process involves blending and grinding of 35 per cent fly ash, 6 per cent gypsum, and 59 per cent clinker altogether. The stone slurry utilization in PPC cement is 4 per cent (gypsum making). Fly ash, an essential component in PPC production, is obtained as waste from the Kota thermal power plant.



While stone slurry utilized in gypsum production is sourced from the Ramganj Mandi dumping site, phosphogypsum is supplied from the Hindalco fertilizer plant in Dahej.

What is phosphogypsum?

Phosphogypsum is an industrial waste/byproduct produced by the phosphorus fertilizer industry. It is generated from filtration process in phosphoric acid plants. During this process sulphuric acid dissolves phosphate rock creating a solid/liquid mixture (slurry) of phosphoric acid and calcium sulphate (phosphogypsum). The desired phosphoric acid component is separated from the mixture by filtration, leaving phosphogypsum as the waste product.

Quantity of stone slurry utilization in Mangalam Cement plant

The total cement production by the plant for the fiscal year 2023–24 amounted to 2.88 million tonnes/annum. According to available data, the stone slurry powder utilization in OPC cement production stands at approximately 9 per cent (comprising 4 per cent in gypsum and 5 per cent in clinker) while in PPC cement production, it is around 4 per cent. On average, stone slurry utilization amounts to approximately 6.5 per cent of the total production, equivalent to roughly 0.19 million tonnes/annum. Analysis of stone slurry utilization data provided by the Mangalam Cement plant during January–March 2024 indicates an increasing trend from 10,368 tonnes in January 2024 to 19,823 tonnes in March 2024.

Environmental and economic benefits

1. **Addressing the issue of waste disposal while mitigating environmental harm:** The utilization of stone slurry into industrial processes not only resolves

PHOSPHOGYPSUM WASTE GENERATION AND ITS UTILIZATION IN INDIA

Phosphogypsum generation in the country is about 6.5 million tonnes per annum (based on the assumption that 4.5–5 tonnes [dry form] of phosphogypsum is generated per tonne of phosphoric acid production, depending on the source of rock phosphate). Legacy stock of phosphogypsum in the country is estimated to be about 70 million tonnes at east coast.[95]

Environmental impacts associated with phosphogypsum dumping yards

Phosphogypsum contains a high level of impurities such as phosphates, fluorides and sulphates, naturally occurring radionuclides, heavy metals, and other trace elements. It is acidic in nature due to the residual phosphoric acid, sulphuric acid and hydrofluoric acid within the porous structure. Phosphogypsum waste is dumped in landfills, river and lakes.

Environmental concerns associated with phosphogypsum includes fluoride uptake and surface- and groundwater pollution. The main routes for their transport into the environment are wind and water erosion, infiltration, leaching into surface- and groundwater and airborne emissions of gaseous and radioactive elements. Water erosion of phosphogypsum stacks can lead to the formation of solution cavities and instability in constructed berms and dikes, resulting in the surface runoff of phosphogypsum, erosion around piping systems and gully erosion. Slopes of phosphogypsum stacks may become more vulnerable to failure and erosion during heavy rainfall.

The runoff from phosphogypsum may result in acidic conditions in receiving water ponds and may cause fish mortality. Additionally, dumping of phosphogypsum contributes to elevated fluoride levels in surrounding areas, affecting soil and vegetation.

Utilization of phosphogypsum—existing practices

Currently, most of the phosphoric acid plants dispose of phosphogypsum within the plant premises. Depending on demand, phosphogypsum is sent for different applications, including (i) for use as soil conditioning (for alkaline soil) or as fertilizer in agriculture (ii) in cement manufacturing to control the setting time of cement (as a retardant) and (iii) a small quantity is used in the production of plaster, plaster boards, gypsum fibre boards and gypsum blocks.

In India, phosphogypsum is mainly used in cement plants. For example, UltraTech Cement has transported a shipment of 57,000 tonnes of phosphogypsum by coastal and inland waterways to its Gujarat plant at Kovaya in Amreli district. UltraTech has sourced the phosphogypsum from Indian Farmers Fertiliser Cooperative (IFFCO) and Paradeep Phosphates.

Challenges associated with utilization of phosphogypsum

The utilization of phosphogypsum requires handling and transportation by means of railways or by road. Transportation of such huge quantity of phosphogypsum is a challenge in its utilization. Other than this, the utilization of phosphogypsum depends on the degree of impurities such as fluoride, phosphoric acid and radioactivity, which depends on type of raw material used, process adopted or pre-treatment given to phosphogypsum.

the issues of unsafe waste disposal but also minimizes its adverse impact on environmental, which often arises from the unscientific and improper dumping practices of stone slurry.

2. **Economically viable for industries:** Transporting mineral gypsum from Aligarh incurs a cost of approximately Rs 2,200 per tonne (inclusive of materials and transportation), whereas transportation of mineral gypsum from Morak costs around Rs 1,800 per ton (inclusive of materials and transportation). The Managalam Cement plant makes gypsum by blending stone slurry and phosphogypsum. The transportation cost for stone slurry is Rs 150 per tonne, with no additional charges as it is being dumped near the plant in Ramganj Mandi. Transporting phosphogypsum from Hindalco Dahej, Gujarat costs Rs 600 per tonne, with no additional fees as it is a byproduct of the Hindalco fertilizer plant. Consequently, the total cost of producing gypsum is about Rs 750 per tonne (combining phosphogypsum and stone slurry in a 1:2 ratio) which is cheaper than procuring mineral gypsum from Aligarh and Morak.

   The gypsum consumption at Mangalam Cement plant for 2023–24 is around 0.19 million tonnes/annum. If the plant procures natural mineral gypsum from Aligarh, it costs around Rs 41 million, while sourcing it from Morak costs approximately Rs 33 million. However, acquiring phosphogypsum and stone slurry for gypsum production incurs a cost of around Rs 14 million.

3. **Prevent the mining of natural mineral resources:** India is the second-largest producer of cement in the world with the annual production 334.37 million tonnes 2019–20 and 299.94 million tonnes in 2020–21. A large volume of mineral gypsum (generally 5–6 per cent in cement) is used by the cement industry as a set retarder for production of Ordinary Portland Cement (OPC) or Portland Pozzolona Cement (PPC) or Portland slag Cement (PSC). Gypsum is added to the clinker at the grinding stage of cement. By employing industrial waste or alternative materials such as stone slurry and phosphogypsum (a byproduct of fertilizer plants), India can obviate the need for mining millions of tonnes of mineral gypsum. For instance, at the Mangalam Cement plant, the utilization of stone slurry and phosphogypsum industrial waste saves an annual quantity of 0.19 million tonnes of mineral gypsum (utilizing 6 per cent gypsum in cement production).

CASE STUDY 2: Utilization of marble slurry in tile making

Rajasthan is the richest state in the country with regard to marble deposits (1,100 million tonnes). Rajasthan state has more than 95 per cent of marble processors. The important regions of marble deposits are Makrana, Kishangarh, Rajsamand, Alwar, Udaipur, Nathdwara and Abu Road, where over 1,200 marble-processing (gangsaws) units and 400 automatic tiling plants (block cutters) are spread all over the districts. Marble slurry powder is rich in calcium carbonate ($CaCO_3$) because of which it is used in tile making and other ceramic products.

Process of slurry generation: Slurry is a suspension of marble fines in water, generated during processing, cutting and polishing of marble. During processing of marble block continuous water sprinkling is done to reduce the heat generation because of the friction between stone and saws. The slurry generated during marble processing is diverted to sedimentation tanks to settle the marble dust by gravity on time span. The supernatant water is pumped back to sprinkle over the processing block. The settled semi-solid slurry is pumped in tankers and transported for disposal. Every year nearly 5–6 million tonnes marble slurry waste generated through established processing units.

In India, Morbi is the hub for tile production, hosting around 750 tile manufacturing units. Among these, a significant portion, roughly 40–50 per cent units utilize marble slurry in their production. It is estimated that marble slurry consumption in Morbi is between 5,000–6,000 tonnes/day. The extent of marble slurry utilization by tile manufacturing units depends upon the type of tiles they produce like vitrified (floor) tiles, wall and porcelain tiles. In Morbi, mainly three types of tiles are manufactured (see *Table 16: Types of tiles manufactured in Morbi*).

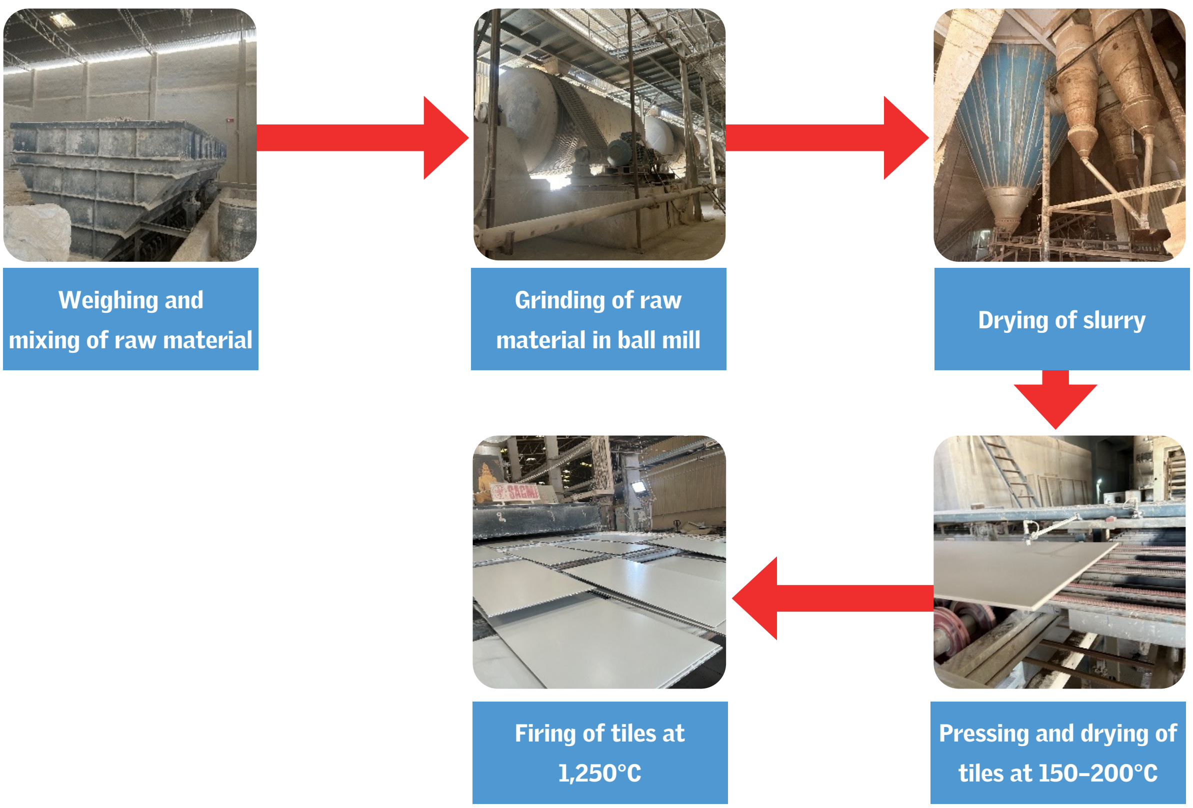
Dumping of marble slurry in Kishangarh, Rajasthan

Source: CSE survey

Table 16: Types of tiles manufactured in Morbi

Type of tiles	Water absorption	Temperature required for firing
Vitrified (floor)	0.05–0.1 %	1,200–1,250
Wall	1–5 %	1,150–1,160
Porcelain	More than 5 %	1,050

Figure 12: Tile manufacturing process



A. Name of industry: Claystone Granito Private Limited
Product: Vitrified tiles (floor tiles)
Location: Morbi, Jetpar Road

The Claystone Granito Pvt. Ltd. is a vitrified (floor tile) tile manufacturing plant located in Morbi, Gujarat. The essential raw materials for tile production include ball clay, natural feldspar and marble slurry.

Ball clay 60% + Feldspar 33% + Marble slurry 7% = Mixture for tiles

This plant integrates marble slurry into its manufacturing process, thereby reducing feldspar contribution. Feldspar, a natural mineral resource, is typically used in tiles to lower the melting point of raw materials. It improves the strength, toughness and durability of ceramic bodies by decreasing tile porosity.

The marble slurry utilized by the plant is sourced from Jalore, Rajasthan. The utilization of marble slurry in the process is 7 per cent. The tiles manufactured with this 7 per cent marble slurry exhibit a modulus of rupture (MOR) of 450 kg/cm^2 pressure, surpassing the international standard MOR 350 kg/cm^2.

Claystone Granito's tile production is 550 tonnes per day. Its marble slurry utilization is 7 per cent of the production, equivalent to approximately 40 tonnes/day, i.e. 14,400 tonnes/annually. However, the utilization of slurry in the manufacturing process cannot increase beyond 7 per cent due to higher silica content in slurry.

B. Name of industry: Astana Minerals LLP

Utilization of stone slurry in tile manufacturing unit

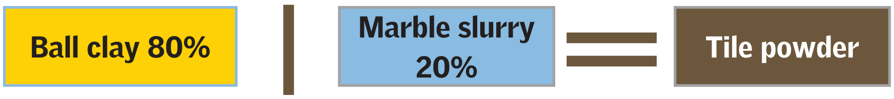
Mixing of raw material in ball mill

Source: CSE Survey

Product: Wall tile powder
Location: Morbi, Jetpar Road

Astana Minerals LLP is a wall tile powder manufacturing plant located in Morbi, Gujarat. The raw materials required for manufacturing tiles are ball clay and marble slurry.

This plant utilizes marble slurry in its production process, replacing feldspar



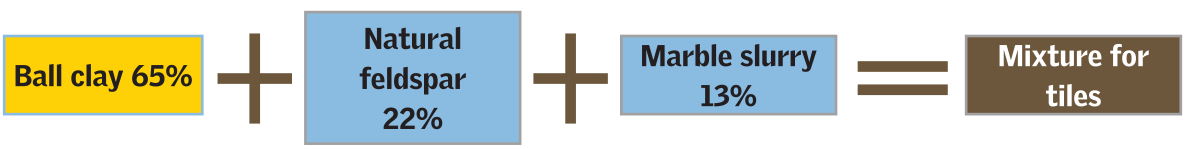
(C-grade) which is a natural mineral. The marble slurry utilized by the plant is sourced from Jalore and Kishangarh, Rajasthan. The utilization of marble slurry in the production of wall tiles powder amounts to 20 per cent.

Production of tile powder in Astana Minerals is 600 tonnes/day. Marble slurry utilization is 20 per cent of the production, which is around 120 tonnes/days and 43,200 tonnes/year. The reason for substituting C-grade feldspar with marble slurry is primarily feldspar’s impurities, which necessitate lengthier grinding times, resulting in power and production losses.

C. Name of industry: Astica Tiles LLP
Product: Porcelain tiles
Location: Khokhra Hanuman Road, Morbi

Astica Tiles LLP is a porcelain tile manufacturing plant located in Morbi, Gujarat. The raw materials required for manufacturing tiles are ball clay, C-grade feldspar and marble slurry.

This plant utilizes marble slurry in its production process, which serves as a



replacement for C-grade feldspar (which is a natural mineral). The marble slurry utilized by the plant is transported from Jalore, Rajasmand and Kishangarh, Rajasthan. The utilization of marble slurry in the process is 13 per cent. Tiles manufactured with 13 per cent marble slurry exhibit a Modulus of Rupture (MOR) of 280 kg/cm^2, surpassing the international standard for MOR 250 kg/cm^2. Production of porcelain tiles in Astica Minerals is 800 tonnes/day. The utilization of marble slurry in production is 13 per cent of the total production, which is around 105 tonnes/day, i.e. 37,800 tonnes/ annually. The reason for replacing C-grade feldspar with marble slurry is feldspar has impurities that take longer to grind, resulting in power consumption and production losses.

Environmental and economic benefits

1. Economic benefit for industries

I. Vitrified floor tiles: In the production of vitrified (floor) tiles, ball clay (60 per cent), feldspar (33 per cent) and marble slurry (7 per cent) are utilized. Feldspar plays a crucial role as it enhances strength and reduces porosity in the final product, with its proportion typically maintained at 40 per cent.

Consequently, to uphold 40 per cent feldspar content in the tile mixture, 33 per cent feldspar is mixed with 7 per cent marble slurry; 7 per cent slurry utilization reduces the consumption of feldspar by the same percentage. For example, in Claystone Granito Pvt. Ltd, this results in an approximate annual saving of 14,400 tonnes of feldspar. A-grade feldspar, which is used, typically costs around Rs 3,000–3,500 per tonne. So, by utilizing marble slurry, the plant achieves an annual saving of Rs 27.3 million (calculated as Rs 43.2 million, the cost of 14,400 tonne of feldspar—Rs 15.8 million, landed cost of 14,400 tonnes of marble slurry at Rs 1,100/tonne).

II. Wall tiles: In the production of wall tiles, a composition ball clay (80 per cent) and marble slurry (20 per cent) are used. As A-grade feldspar has a higher cost, C-grade feldspar can be used as an alternative in this process. C-grade feldspar, a byproduct of A-grade feldspar, contains impurities such as iron, mica and titanium. Due to these impurities, C-grade feldspar is considered unsuitable for production, making the utilization of marble slurry a more economical option. For example, in Astana wall tiles, this results in an approximate annual saving of 43,200 tonnes of C-grade feldspar, which costs around Rs 1,200/tonne. So, by utilizing marble slurry in the process, the plant achieves an annual saving Rs 4.3 million (Rs 51.8 million, cost of 43,200 tonnes of C-grade feldspar—Rs 47.5 million, cost of 43,200 tonnes of marble slurry). Furthermore, marble slurry necessitates shorter grinding times compared to C-grade feldspar, resulting in reduced power consumption and increased production output.

III. **Porcelain tiles:** In the production of porcelain tiles, a blend of ball clay (65 per cent), feldspar (22 per cent) and marble slurry (13 per cent) are used. Feldspar is an important raw material contributing to strength and reduced porosity in the final product, with its quantity typically maintained at 35 per cent. Therefore, to uphold this 35 per cent feldspar content in the tile mixture, 22 per cent feldspar is combined with 13 per cent marble slurry. If marble slurry is omitted from production, the consumption of feldspar would need to increase accordingly; 13 per cent marble slurry utilization reduces the consumption of feldspar by the same amount. For example, in Astica Tiles LLP, this results in an approximate annual saving of 37,800 tonnes of feldspar. The C-grade feldspar utilized in this process typically costs around Rs 1,200 per tonne. Consequently, by utilizing marble slurry, the plant achieves an annual saving Rs 3.8 million (Rs 45.3 million, cost of 37,800 tonnes feldspar—Rs 41.5 million, landed cost of 14,400 tonnes marble slurry is Rs 1,100/tone).

2. Preserve the mining of natural mineral resources

Tile manufacturing involves use of natural mineral resources such as feldspar. By utilizing industrial waste or alternative materials such as marble slurry, India can obviate the need for mining millions of tonnes of feldspar. For example, Morbi has around 90 per cent of tiles manufacturing units in India. There are approximately 750 tile manufacturing units in Morbi with a collective daily production of 120,000 tonnes of tiles. Currently, approximately 40 per cent tile making industries in Morbi are utilizing marble slurry into their process. Out of the daily tile production of 120,000 tonnes, marble slurry is currently being utilized in the production of 50,000–tonnes of tiles /day. On an average, utilization of stone slurry is about 10–13 per cent of the total production, which is 5,000–6,500 tonnes/day, i.e. 1.8–2.35 million tonnes annually. Consequently, approximately 1.65–1.8 million tonnes of feldspar mineral is conserved every year.

Future prospects for stone slurry utilization

Rajasthan generates huge quantity of stone slurry from stone processing units. To effectively manage such huge quantity of stone slurry, the Rajasthan State Pollution Control Board (RSPCB) issued a directive in January 2023. This directive's aims to encourage the utilization of stone slurry in diverse applications such as tiles and paver blocks production and cement manufacturing. Furthermore, RSPCB also recommends utilization of stone slurry in cement manufacturing and tile/brick production, among other potential uses. Through the recent surveys conducted by CSE, it was found that the stone slurry has a significant potential for utilization in tile manufacturing and cement plants.

Kota stone slurry

Kota stone is abundant in Rajasthan, particularly in Kota and Jhalawar districts. As per the information available, approximately 600–700 tonnes/day of Kota slurry is generated, amounting to 0.22–0.25 million tonnes annually. Out of such huge generation of Kota stone slurry, approximately 0.19 million tonnes are currently utilized by the Mangalam Cement plant in Morak annually. Moreover, considering the upward trend in the utilization of stone slurry, as indicated by data from the Mangalam Cement plant for the months of January, February and March 2024, it can be inferred that its utilization will continue to increase. The unused quantity of stone slurry can be utilized by other cement plants in Rajasthan by transporting the stone slurry. The state of Rajasthan has a significant number of cement plant, with total production around 77 MMTPA. By developing a transport system, the remaining quantity of stone slurry can be easily utilised by nearby cement plants in the Rajasthan.

Marble slurry

There are around 1,100 marble processing units all over Rajasthan and generating around 5–6 million tonnes of marble slurry every year.[96] The marble slurry generated in Rajasthan is transported to Morbi for tile manufacturing.

India ranks as the world's second largest producer of ceramic tiles and India's ceramic tiles industry is expected to double in size by 2027. Around 90 per cent of tiles in India are manufactured in Morbi, Gujarat. There are approximately 750 tile manufacturing units in Morbi and manufactures 120,000 tonnes of tiles per day.

Currently, approximately 40 per cent tile making industries in Morbi utilize marble slurry in their process. Out of the daily tile production of 120,000 tonnes, marble slurry is currently utilized in the production of 50,000–tonnes of tiles/ day. On an average, utilization of stone slurry is about 10–13 per cent of the total production, which is 5,000–6,500 tonnes/day and 1.8–2.35 million tonnes annually. The marble slurry used by tile units in Morbi is transported from Jalore and Kishangarh, Rajasthan.

Out of 5–6 million tonnes of marble slurry generation in Rajasthan, approximately 1.8–2.35 million tonnes of marble slurry is utilized by 40 per cent tile manufacturing plants in Morbi, Gujarat. The remaining 3.2–3.6 million tonnes can be utilized by the rest of the 60 per cent tile manufacturing plants in Morbi. The tile manufacturing units located in Morbi, with a remaining production capacity of 70,000 tonnes of tiles per day, possess the potential to utilize an additional 2.5

million tonnes of marble slurry annually. Apart from Morbi, this surplus marble slurry can also be utilized in tile manufacturing industries in neighbouring states. The tile manufacturing sector in India is set for significant expansion in the coming years, offering ample opportunities for utilizing marble slurry.

Limitation and challenges associated with utilization of stone slurry

Considering the quantum of stone slurry generation in Kota, a plant was set up by Pashan Welfare Foundation, Kota, for utilization of stone slurry in a 12,500 sq. m of land allotted by RIICO at no cost. The technology for this plant, aimed at utilizing Kota stone slurry waste, was developed by the Central Building Research Institute (CBRI), Roorkee, and supplied by the Rajasthan State Pollution Control Board (RSPCB). Furthermore, RSPCB granted a subsidy of Rs 1.36 million to the Pashan Welfare Foundation under its Special Start-Up Policy for setting up this facility.

The CBRI technology suggested the replacement of crusher sand or river bajri by Kota stone in a very low proportion; typically 15–20 per cent of Kota slurry was suggested to be used in making tiles or paver blocks. The quantity suggested for utilization is relatively small compared with total amount of slurry generated (hundreds of tonnes) every day. Thus, the process adopted by Pashan Foundation could make a little impact on the waste utilization of Kota stone in building materials.

The tiles manufactured using Kota stone slurry has low strength due to the high lime content (also called soft stone). The replacement of such less quantity of sand with Kota sand in tile making has little impact on the selling price. The price difference between tiles made with Kota stone slurry and those without it is minimal, and the reduced strength of these tiles contributes to their lower market value.

The tiles manufactured by the plants utilize a combination of cement, concrete and sand in a ratio of 1:3:3 (with 700 kg tiles comprising 100 kg cement, 300 kg concrete, 270 kg sand, and 30 kg Kota stone slurry). Kota stone slurry only replaces 10 per cent of the total sand used in production.

Due to the limited utilization of Kota stone slurry in tile making, RIICO withdrew the land provided for production after five years. Subsequently, the Pashan Welfare Association submitted another proposal, in which Kota stone slurry is treated with water along with hydrochloric acids to dissolve the calcium part of the slurry which is separated by filtration to provide a powder rich in silica, leaving lime in filtrate. However, this separation process involves the use of hydrochloric acid, necessitating a change in land use planning. The original plant was categorized as green under an SPV (Special Purpose Vehicle), but with the introduction of acid in the process, it would need to be classified as a red category industry. RIICO declined the request for a change in land use planning, resulting in the inability to obtain consent from RSPCB.

The separated silica from Kota stone slurry is found to possess the properties of high-quality sand since it contains 94 per cent silica, which is good for making paver blocks, and separated lime can be utilized in making cement. The water-soluble filtrate (lime) obtained from the filtration process is a very good quality of cement admixture/accelerator.

Recommendations

1. **Upscaling of stone slurry utilization and explore alternative applications:** Apart from the stone slurry application in cement and tile making, stone slurry can be used in wall putty, pesticides, lime production, production of calcium carbonate ($CaCO_3$) and bricks etc.

2. **Regional waste-management facilities:** Establish regional waste management facilities for effective collection and transportation of waste to a facility where it can be utilized. Since the majority of stone processing units are located in Rajasthan, Rajasthan State Pollution Control Board (RSPCB) along with Special Purpose Vehicles (SPVs) can develop infrastructure and framework to enable collection and transportation of waste to be used at different locations in the state.

3. **Viability in cost economics of transportation:** Currently, only the Mangalam Cement plant utilizes Kota stone slurry, primarily due to transportation challenges, preventing its use in other cement plants. Recognizing its potential value in the cement industry, there is a need for a transportation system to enable its utilization in cement plants located beyond the Kota district.

9. Use of biomass as fuel: A pathway to decarbonize industries and coal-fired thermal power plants

Developing a robust supply chain is essential to co-fire 230 million tonnes of unutilized biomass or agricultural residue in industries and power plants

India is on the precipice of energy transition amidst growing concerns of climate change and energy crisis. Several of the current government policies favour transition from a fossil fuel-based economy to a renewable energy-based economy. In this push for decarbonisation, increased use of biomass, especially agricultural residue, for energy generation has recently gained momentum.

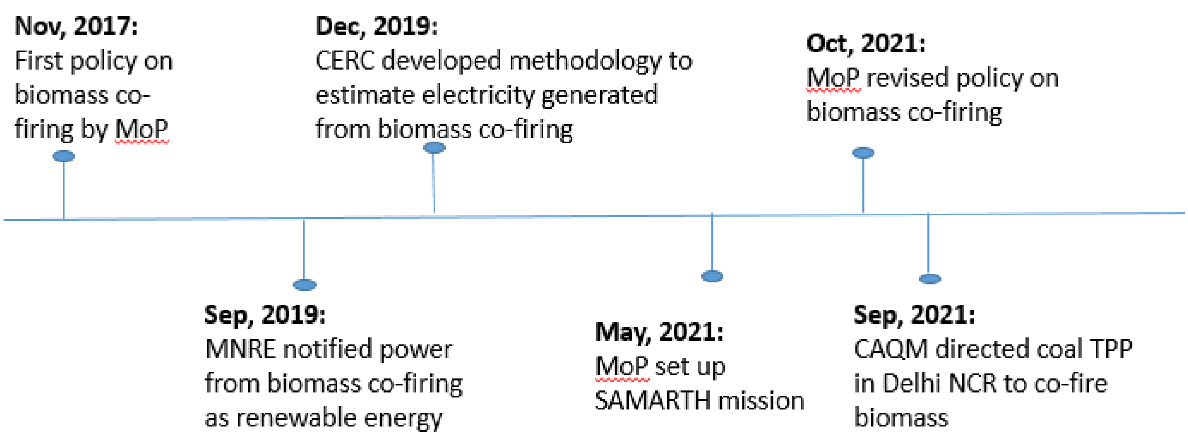
Two of the government initiatives in the past couple of years have especially been at the forefront of promoting agricultural residue as fuel for combustion. First is the mandatory use of biomass co-firing in coal-fired thermal power plants and the other is the use of biomass as an alternate fuel in boilers of industries in the National Capital Region (NCR).

Policy measures by the government

In November 2017, the Ministry of Power (MoP) introduced a policy which mandated replacement of 5–10 per cent of coal with biomass or agricultural residue for generation of electricity by coal-fired thermal power plants. This policy was further revised in October 2021, which eliminated the limitation of its implementation based on the kind of coal mill present in a plant. As per the revised policy, coal power plants with either ball-mill or ball-and-race mill or ball-and-tube mill were now covered under the scope of biomass co-firing.

The policy further gained strength as the Ministry of New and Renewable Energy (MNRE) notified that the number of units generated from biomass co-firing would be considered as renewable energy and will be eligible for non-solar renewable purchase obligation of the electricity distribution companies. According to the Indian Electricity Act (2003), the Renewable Purchase Obligation, or RPO,

Figure 13: Timeline for policy scenario of biomass co-firing in thermal power plants



Source: CSE (2023)

mandates that all electricity distribution licensees (DISCOMS) should purchase or produce a minimum specified quantity of their requirements from Renewable Energy.

However, only after the mention of biomass co-firing by Finance Minister Nirmala Sitharaman, in her budget speech of 2022, the sector witnessed some inflow of grants by the Central Pollution Control Board (CPCB) for strengthening of the supply chain of biomass to the power plants. In February 2023, the Ministry of Environment, Forest and Climate Change (MoEFCC) also notified rules that mandate the use of biomass co-firing in TPPs under the jurisdiction of the Commission on Air Quality Management with 2024–25 as the compliance year. The rules also specify environmental compensations to be levied on plants in case of non-compliance with the rules.

In another such policy measure, the Commission on Air Quality Management (CAQM) for Delhi NCR and adjoining areas in August 2021 directed all industries in the Delhi NCR region to 'stop' the use of coal and switch to cleaner fuels in its boilers. In March 2022, CAQM set the standard for emissions in industrial processes in NCR using biomass-based fuels. Later in May 2022, it permitted the use of biomass-based fuels as an alternative option in addition to PNG and other cleaner fuels even in new/under commissioning industries in the NCR beyond the jurisdiction of the NCT of Delhi. Then, finally, in late June 2022, CAQM stated that all industries operating in NCR have to shift to a list of approved fuels which included cleaner fuels like biomass and PNG, and omitted polluting fuels like coal. The order set an initial deadline of September 2022 for industries to shift to PNG (wherever PNG supply is available) or biomass-based fuels. The Commission set a further final deadline for all industries in NCR (where PNG supply is not available) to shift to one of the fuels on the approved fuel list by December 2022.

The primary purpose of the CAQM's direction is to address the twin challenge of local and regional air pollution from stubble burning in the Indo-Gangetic belt and the alarming levels of pollution from industries using coal, especially during winters when the Air Quality Index (AQI) reached the severe range of 401–500. This means air pollutants like particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO) and ozone (O_3) exceed the National Ambient Air Quality Standards (NAAQS).

Biomass availability and its use as fuel

Biomass or agricultural residue is used as fuel in raw form, or as briquettes or pellets, depending on the technical specification of the boilers. The Ministry of New and Renewable Energy (MNRE), Government of India (GoI), estimates that there is 750 million tonnes of biomass or agricultural residue available annually in the country. After substantial biomass usage as fodder or domestic usage, the surplus availability is about biomass is about 230 million tonnes.[97] More than half of the unused biomass (84–140 MT) is set on fire annually to clear the fields, primarily in the Indo- Gangetic plains.[98]

The north-western part of India accounts for 41 per cent of India's total rice production. A huge amount of crop residue is generated because of mechanized rice harvesting. It is estimated that about 85–90 per cent of paddy straw is being burnt on fields in Punjab. This is a major contributing factor in tipping the air pollution levels of Delhi to severe levels in the months of October and November.

So, agro-residue being diverted in larger quantities to industries and thermal power plants for burning in controlled environments is expected to reduce the particulate emissions, particularly in Delhi-NCR. To promote the use of paddy stubble in use of biomass for co-firing, the plants have inbuilt the condition of use 50 per cent of the agricultural residue for manufacturing of pellets for the coal power plants.

Co-firing of biomass (which is otherwise a waste) in the industries and thermal power plants is a good example of waste circularity and how it is resulting in the conservation of fossil fuels. CSE based on its past studies has come up with the case studies of using biomass as fuel in industries as well as coal-based thermal power and how usage of biomass is contributing to the reduced carbon emissions into the environment and saving upon the fossil fuels consumption in the industries.

EMISSION SAVINGS FROM BIOMASS CO-FIRING

As per the Ministry of Power, about 61 coal base power plant units are doing biomass co-firing. Cumulatively about 0.8 million tonnes of biomass have been used in the power plants till today, which is equivalent to CO_2 emission saving of about 1 million tonnes.

Table 17 depicts the scenario of total CO_2 emissions from power plants if 5 per cent biomass co-firing is done in 100 per cent, 50 per cent and 25 per cent installed capacity and respective reduction of CO_2 emissions, compared to 100 percent coal usage scenario. The estimation has been done considering 70 percent of plant load factor (see Table 17: *CO_2 emissions saving in different scenarios of biomass co-firing in coal based thermal power plants*)

Table 17: CO_2 emissions saving in different scenarios of biomass co-firing in coal-based thermal power plants

S. no.	Biomass co-firing @5 per cent at 70 per cent PLF	Formulas used	100% capacity	If 50 per cent capacity co-fires biomass at 5 per cent	If 25 per cent capacity co-fires biomass at 5 per cent	Unit
A	Total coal thermal power capacity[99]	Source: CEA	208,410			MW
B	Specific emissions (CO_2)	Source: CEA	1.017*			tonnes CO_2/ MWh
C	Total electricity generation per annum at 70 per cent PLF	70%*(A*365*24)	1,277,970,120	638,985,060	319,492,530	MWh
D	Total annual CO_2 emissions	B*C	1,299,695,612	649,847,806	324,923,903	tonnes CO_2
E	Total annual CO_2 emissions in case of biomass co-firing in all plants at 5 per cent	5%*D	1,234,710,832	617,355,416	308,677,708	tonnes CO_2
F	CO_2 emission savings	D-E	64,984,780	32,492,390	16,246,195	tonnes CO_2

* based on data analysis of thermal power plants with PLF>50 per cent.
Source: CSE analysis

CASE STUDY 1: Biomass co-firing in coal-fired thermal power plants

Biomass is mostly co-fired directly with coal in the power plant boilers. For this reason, the biomass is first converted to densified biomass pellets which are further pulverized for combustion. The pellets are almost of the same energy content as coal it is burnt along with in the boilers. They majorly comprise sugarcane leaves, mustard straw, groundnut shell and paddy straw as these residues are available in abundance and not used as fodder.

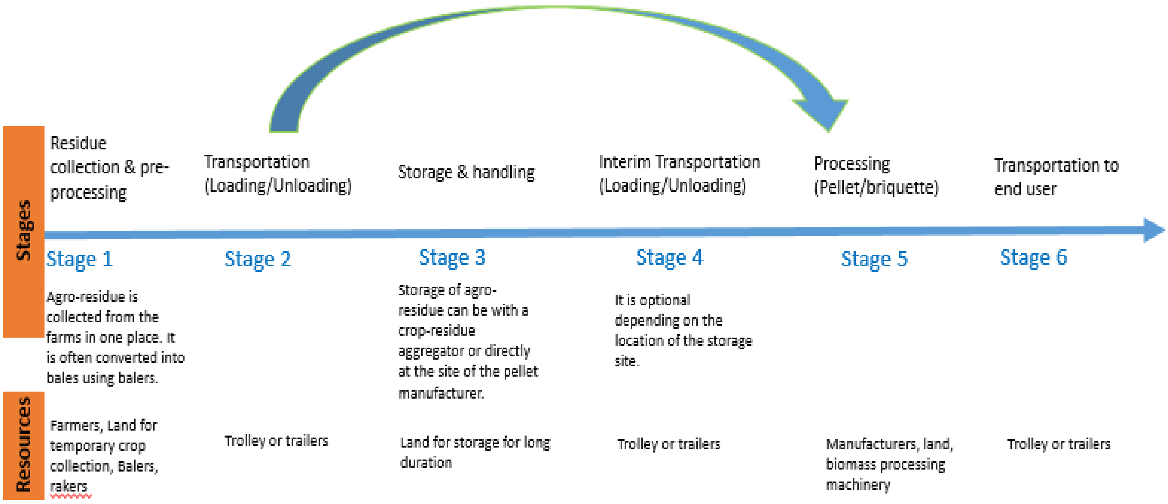
The Central Electricity Authority (CEA), the technical arm of the Ministry of Power, has issued guideline specifying the quality of biomass pellets to be manufactured and burnt in coal power plants. There are two types of biomass pellets—torrefied pellets and non-torrefied pellets. Biomass is processed at 250–350°C in the absence of oxygen, which leads to the decomposition of the biomass while preserving its energy content. This results in higher energy output from the pellets than in other solid biomass forms.

There are multiple stakeholders that are involved at each successive stage of the supply-chain management of biomass pellets, starting from the collection of agro-residue at farms to the transportation of processed biomass to the end user. The supply-chain of biomass pellets requires a dense network of agro-residue aggregators, pellet manufacturers and extensive storage facilities supported by farm equipment customisation service providers. A Centre for Science and Environment (CSE) survey conducted in August 2022 showed that typically the procurement of agro-residue by the pellet manufacturers happens within a radius of 30–50 km. However, pellets were found to be supplied to the power plants over a wide range of distance from 200–600 km in the Delhi NCR region (see *Figure 14: Supply-chain management scheme for biomass co-firing in coal-fired thermal power plants*).

The survey also established that biomass co-firing in coal power plants is done only intermittently. According to records of the National Mission on the Use of Biomass in Coal Thermal Power Plants, cumulatively, by December 31, 2022, 24,426 tonnes of biomass pellets had been co-fired in the 11 coal power plants in the Delhi NCR region. This means that less than 1 per cent of coal was replaced through biomass co-firing in the NCR till end of December 2022.

Records collected by the CSE for January 2024 show that though no significant progress has been made by the plants since the last one year. The three plants

Figure 14: Supply-chain management scheme for biomass co-firing in coal-fired thermal power plants



Source: CSE (2023)

Jhajjar Power Limited (private ownership), Harduaganj Thermal Power Station (state ownership) and Indira Gandhi Super Thermal Power Plant (joint venture of the Central and Haryana state government) have made significant progress in terms of biomass co-firing percentage reaching to about 1.5–2 per cent (see *Table 18: Change in status of co-firing in coal-fired thermal power plants in the NCR since December 2022*).

On enquiry, the remaining plants reported that the delay in implementation of biomass co-firing has been due to the inadequate supply of biomass pellets by the manufacturers or due to the non-fulfilment of tenders for supply of biomass pellets.

Though some of the issues highlighted from CSE's report, such as lack of price benchmarking of biomass pellets and the need for strengthening of the supply-chain and delays in regulations concerning biomass co-firing on electricity regulatory commissions' (ERC) end are being addressed by the government, pellet manufacturers interviewed informed CSE that other issues such as lack of long-term storage facility for biomass pellets in power plant premises and tedious tendering process for biomass pellet supply have not been addressed successfully.

Table 18: Change in status of co-firing in coal-fired thermal power plants in the NCR since December 2022

S. no.	Plant	Biomass used till December 2022 (tonnes)	Percentage cumulative biomass co-fired in comparison to coal consumed per annum (in tonne)*	Biomass used till January 2024 (tonnes)	Percentage cumulative biomass co-fired in comparison to coal consumed per annum (in tonne)*
1	Jhajjar Power Limited (JPL)	71	0.001	65,903	1.27
2	Harduaganj TPS	760	0.074	19,198	1.87
3	Aravali TPS (Indira Gandhi STPP), Jhajjar	4,286	0.091	66,947	1.42

Note: (*) these are approximate values calculated on the basis of coal consumed on an average by each of the power plants
Source: Data sourced from the Ministry of Power, 2024


Biomass feeding point at Jhajjar Power Limited

Our review of the tenders issued for biomass pellets showed that Indira Gandhi Thermal Power Plant is probably the only plant in the National Capital Region (NCR) which has deliberated on establishing a biomass pellet manufacturing unit on its land. Remaining plants interviewed informed that they have not yet considered it an option as yet.

CASE STUDY 2: Biomass use in industries in Bhiwadi and Matsya Industrial Area

CSE's 2020 report *Assessment of Industrial Air Pollution in Delhi-NCR* stated that the total consumption of coal by industries in seven major industrial districts of NCR has been estimated to be around 1.41 million tonnes per year. The report concluded that coal was the still the king of fuels in the region and is predominantly used by industries in NCR, highlighting the slow pace of adoption of cleaner fuels.

As the CAQM order in 2021 banned coal/coke across Delhi-NCR and mandates all industries to shift to approved fuels like PNG and biomass, CSE conducted an onsite survey to understand the situation of the fuel shift on the ground. The CSE surveyed a total of 30 industries in the two industrial areas of Alwar- Bhiwadi and Matsya industrial area. The industries were selected to gather the sense of fuel shift in different sectors such as chemicals, food processing, metals and ceramics in this ground survey. Especially interesting to note was the developments in Matsya Industrial Area (MIA) as it has not yet received a PNG infrastructure and most industries as per the official records assessed through Rajasthan Pollution Control Board (RSPCB) have been able to successfully shift to biomass.

Matsya Industrial Area in Alwar district has 61 industries, covering various sectors such as chemicals, food processing, lead battery recycling, metals, refineries, etc. MIA is still awaiting PNG pipeline infrastructure, so industries are shifting to biomass with no or minor modifications to their combustion equipment.

Biomass in general is being used as a fuel in various forms such as loose form, briquettes and pellets. Industries in Alwar and Bhiwadi prefer it in loose form and briquettes. CSE's survey found that the most commonly used agro-residues are mustard husk, paddy husk and oat husk in the raw loose form; and paddy straw and ground nut shell in the briquette form.

Biomass transportation involves heavy manpower right from piling up in the farm on the first hand, transporting to aggregators or briquette manufacturers and finally to industries. CSE survey showed that there were three models deployed for the procurement of biomass by industries- through tenders, directly from vendors, and directly from farmers.

According to RSPCB data, industries in MIA have significantly moved towards biomass, leaving polluting fuels like coal and fuel oil. Only one metal industry was found using coal. Other CAQM approved fuels used in a few industries of MIA are biodiesel, propane gas and LSHS. Among 62 fuel consuming industries in MIA, 40 are using biomass.

Conversion of boilers from solid to biomass fired

Solid fuel firing boilers can be converted to biomass firing with no or few modifications to the boilers. Industries in MIA mostly use grate boilers (stationary or travelling grate) and fluidized bed combustion (FBC) boilers. During the survey, CSE found that grate boilers are usually designed for combusting multiple types of fuel. So, they enable shifting from one fuel to another without any actual modifications to the existing system, i.e., from coal or pet coke to biomass. For fluidized combustion boilers, feeder line pitch and nozzle sizes had been changed for the fuel shift based on the size of the loose biomass.

Selection of APCDs for attaining emission norms with biomass firing

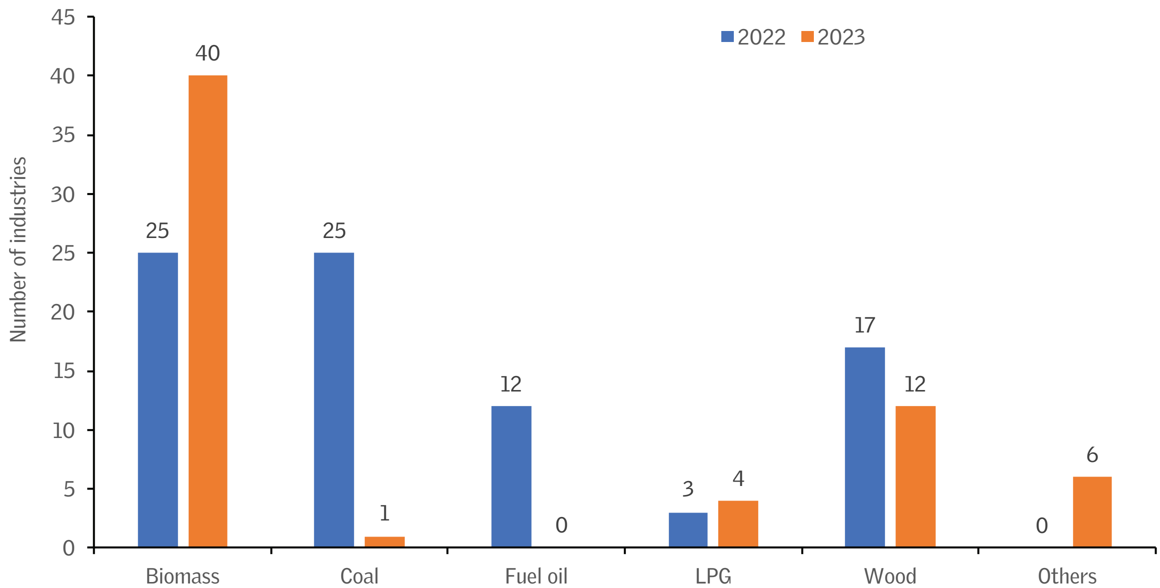
The survey showed that good progress has been made on ground in shifting to cleaner fuels. Burning biomass in controlled conditions is believed to reduce the PM emissions significantly. CAQM already directed industries to reduce PM emissions for the biomass fuelled boilers to below 80 mg/Nm^3. In direction no. 64 dated June 2, 2022, it further asked them to aim to bring it below 50 mg/Nm^3. To achieve this, industries will have to install proper air pollution control devices (APCDs) in their premises.

According to CSE's discussion with experts, it is clear that only bag filters and electrostatic precipitators (ESP) can bring down PM emissions below 50 mg/Nm3. All the other APCDs such as cyclone separators, wet scrubbers or dust collectors are incapable of reducing the PM emissions below 50 mg/Nm3.

Experts claim that even the most effective wet scrubber can only achieve particulate emissions up to 150 mg/Nm^3. This should be further investigated and clarified by respective authorities, so that the right kind of APCDs can be recommended for biomass usage.

There is also lack of information dissemination at ground level, the survey showed. Only one industry showed us the emission report with PM emission as 74 mg/Nm^3. Many industries were not aware of the CAQM direction asking industries to aim to bring down emissions below 50 mg/Nm^3.

Figure 15: Fuel shift observed in industries of MIA between 2022 and 2023



Source: RSPCB 2022 and 2023 data

Future scenario

As per the Ministry of Coal, by the end of 2029–30, the installed electric power capacity is estimated to be 777 GW, comprising coal (252 GW). The report *Coal Vision 2030* estimated that total coal demand in India would be in the range of 1,500–1,900 MTPA by 2030. Overall, thermal coal demand in 2030 is expected to be between 1,150 and 1,750 million tonnes per annum. The required coal- and lignite-based installed capacity would be 252 GW.[100] Considering two scenarios wherein, 100 per cent and 50 per cent of total capacity is doing biomass co-firing of about 5 per cent, the estimated reduction in CO_2 emissions will be in the range of 39–78 million tonnes. As per CSE estimates, the biomass required to meet 5 per cent co-firing in coal-based power plants will be about 58–88 million tonnes, which is expected to be sufficiently available in India.

Table 19: Future scenario of biomass co-firing and resultant CO_2 emissions in coal based power plants by 2030

S. no.	Biomass co-firing @5 per cent at 70 per cent PLF	Formulas used	100 per cent capacity	50 per cent capacity	Unit
A	Total coal thermal power capacity by 2030	Source: CEA	252,000		MW
B	Specific emissions (CO_2)	Source: CSE	1.017		tonnes CO_2/MWh
C	Total electricity generation per annum at 70 per cent PLF	70%* (A*365*24)	1,545,264,000	772,632,000	MWh
D	Total annual CO_2 emissions	B*C	1,571,533,488	785,766,744	tonnes CO_2
E	Total annual CO_2 emissions in case of biomass co-firing in all plants at 5 per cent	5%*D	1,492,956,814	746,478,407	tonnes CO_2
F	CO_2 emission savings	D-E	78,576,674	39,288,337	tonnes CO_2

Recommendations

Biomass or agricultural residue is a potential resource to fully or partially replace fossil fuel combustion for energy generation in industries as well as in coal-fired thermal power plants. Its easy availability makes it a convenient fuel to use. The CSE survey found, however, that conditions are far more favourable when it comes to the use of biomass use in industries as compared to its use for co-firing in coal-fired thermal power plants. Where industries have found it economically profitable and logistically more feasible to use biomass instead of coal, coal power plants are struggling with the adequate and continuous supply of biomass to their plants.

1. **Developing national inventory of biomass generation and availability:** It is observed that the data regarding the biomass availability is either not available or non-uniform across the country. Also, there is data unavailability at the state level, which is important in realizing the region-wise potential of biomass co-firing in the thermal power plants and industries.

2. **Develop a supply chain for biomass:** The thermal power plants claimed that there are not enough biomass pellet suppliers that meet their technical requirement for pellets. As per CSE's survey, suppliers have often fallen short on adequate and continuous supply of biomass to coal-fired thermal power plants (CFTPPs). The government needs to invest strategically and financially in building a robust supply-chain for biomass if these policies have to be realised to its full potential.

In comparison, biomass use in industries in the NCR is much more successful. Once the supply chain is stabilized, ensuring availability of the biomass throughout the year and costing mechanism of biomass is streamlined as suggested by CPCB, the utilization of biomass will increase gradually within industries.

3. **Ensuring demand-supply balance for biomass:** According to the Ministry of Power's (MoP) policy on biomass utilization, nearly 0.25–0.3 million tonnes (MT) of biomass pellets are required for every gigawatt capacity at seven per cent co-firing. There is an intense gap in demand and supply as there are a limited number of pellet manufacturers in the country. Currently, pellet manufacturing capacity for the entire country is 7,000 tonnes per day while the requirement is for approximately 100,000 tonnes per day, according to the inventory maintained by the National Mission on Use of Biomass in Thermal Power Plants.

   As per CSE's 2023 study *Status of Biomass Co-firing in Coal Thermal Power Plants in Delhi NCR Region*), the website of National Mission on the Use of Biomass (as accessed in August, 2022) lists only 23 pellet manufacturers in and near the Delhi-NCR region with a cumulative capacity of approximately 2,500 tonnes per day while the pellet demand in Delhi-NCR is for approximately 5,000 tonnes per day.

   To meet the rising demand, farmers should be encouraged to set up briquette/pellet manufacturing plants. As biomass is available to them, farmer producer organizations (FPOs)/co-operatives can bring scale to the manufacturing and accordingly the economics of operating such plants can work out. For establishing biomass pellet units, government should provide incentives as has been done by the government of Haryana where land use norms have been waived off for CBG plants.

10. Circularity of industrial hazardous waste has potential to replace natural resource, reducing contamination of land

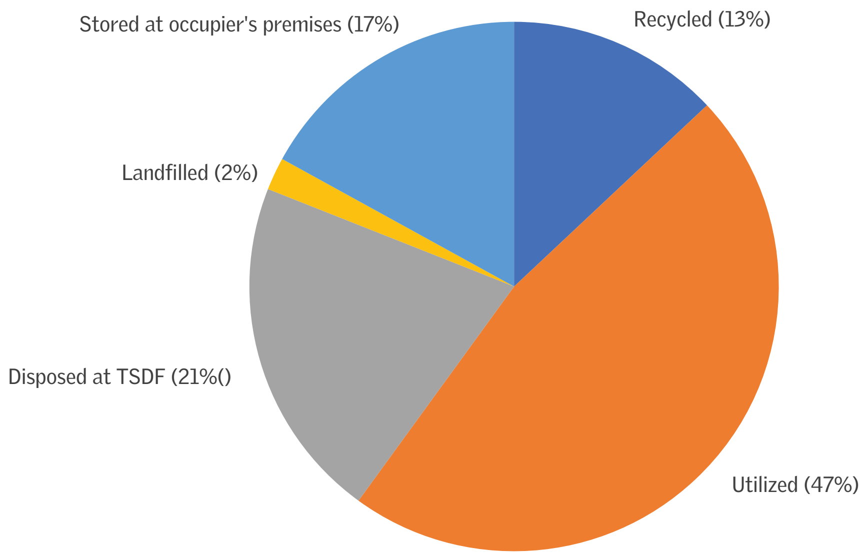
About 5 million tonnes of hazardous waste disposed of at secured landfills or stocked within industries can be put into circularity

Industrial hazardous waste has always been a concern. As industrialization increases, so does the quantum and composition of the waste.

Management of the hazardous industrial waste is an important aspect as the country is shifting its focus from a linear to a circular economy. There has been a number of different types of industrial hazardous waste that is getting generated in the country each day. Since this comes under the Hazardous Waste Management Rules in the country, there has been some obligations in the country on the management, handling and disposal of hazardous waste. With industrial waste circularity in focus, CSE examines the current scenario of hazardous waste circularity and applications where it is used, and documented the good practices on industrial hazardous waste.

According to CPCB's February 2023 report *Inventorization*, for 2021–22, about 12.35 million tonnes of hazardous waste was generated (i.e. 26 per cent) against the authorized capacity of about 46.89 million tonnes. Also, about 0.3 million tonnes of hazardous waste is imported in the country. The state of Gujarat tops the list of HW generator, contributing 34 per cent of the total HW generation while the other states' generation remains below 10 per cent. This generation includes waste generated within the state, imported from other states and the existing waste at the start of the year. Out of this total hazardous waste generated in the country, about 1.63 million tonnes is recycled, 5.97 million tonnes is utilized, 2.6 million tonnes is disposed of at secured landfills and 0.2 million tonnes has been incinerated while remaining 2.2 million tonnes of waste is at occupiers' premises (see *Figure 16: Status of management of hazardous waste [2021–22]*).

Figure 16: Status of management of hazardous waste (2021–22)



Source: CSE analysis, National Inventory on Generation and Management of Hazardous and Other Wastes (2021-22), CPCB

It is to be noted that much of the hazardous waste contains useful metals that can be recovered or have compounds that make it suitable for use as raw material, fuel or even as stabilizing agent. Thus, dumping of this waste or incinerating it is actually losing the resources and then buying those resources at an additional cost. Utilization of hazardous waste is beneficial both environmentally and economically for the country. Recycling and utilization as resource or energy recovery of hazardous and other wastes are preferential option over their disposal since it conserves resources and leads to reduction of carbon footprint.

Out of all states, Himachal Pradesh leads in disposing of the highest amount of waste—55 per cent of its generation—to secured landfills while Andhra Pradesh and Odisha reported to be the largest utilizers, with 70 per cent of the generated waste being utilized (see *Table 20: Status of state-wise utilization of waste*).

Table 20: Status of state-wise utilization of waste

State	Total waste generation (tonnes)	Recycled (%)	Utilized (%)	Disposed at SLF (%)	Incinerated (%)
Andhra Pradesh	1,288,460	12	70	15	1
Odisha	1,296,013	1	69	4	0
Rajasthan	1,297,493	12	64	13	0
Chhattisgarh	276,996	2	62	1	0
Telangana	350,667	23	55	32	1
Karnataka	553,795	21	49	13	7
West Bengal	255,093	33	41	13	4
Gujarat	4,864,739	5	40	26	2
Uttar Pradesh	481,614	36	37	15	11
Tamil Nadu	1,064,125	5	23	12	1
Haryana	225,863	89	22	10	0
Bihar	21,105	20	15	0	0
Himachal Pradesh	47,842	43	14	55	0
Madhya Pradesh	257,516	20	13	18	2
Maharashtra	1,210,764	8	10	29	5
Punjab	169,066	47	9	17	1

Source: CSE analysis

The waste utilized in Table 20 includes the following three categories as given by CPCB:

1. **Captive utilization**: Utilization of generated waste within the same industry.

2. **Non-captive utilization** (utilization under Rule 9): Waste from one industry is utilized by another industry as a raw material or fuel. Regarding the non-captive utilization of hazardous waste, CPCB is regularly developing Standard operating Procedures (SOPs) for utilization of different categories of hazardous waste and till now has prepared 100 SOPs for the same.

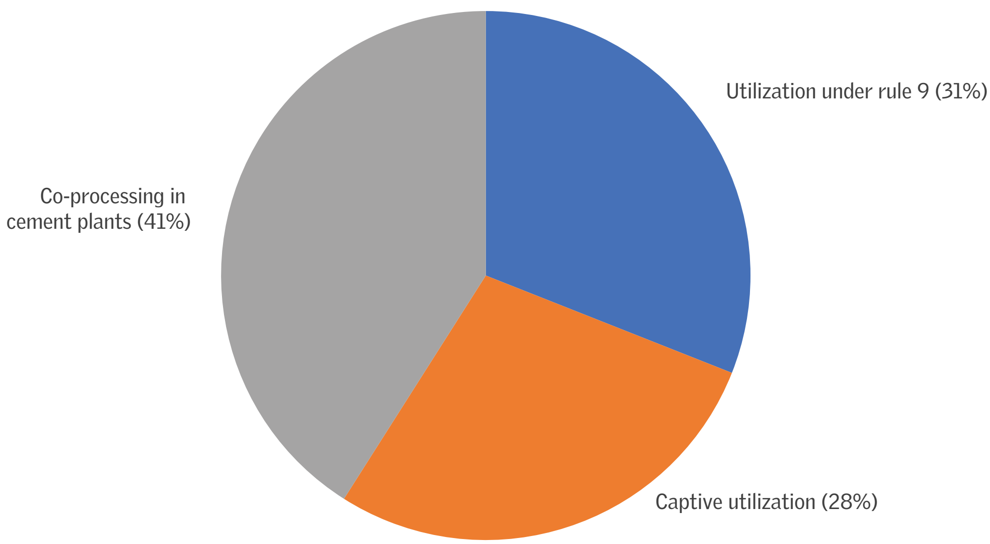
   The Rule 9 of Hazardous and Other Wastes (Management and Transboundary movement) Rules, 2016 has the provision for utilization of hazardous waste which states, '*The utilization of hazardous and other wastes as a resource or after pre-processing either for co-processing or for any other use, including within the premises of the generator (if it is not part of process), shall be carried out only after obtaining authorization from the State Pollution Control Board in respect of waste on the basis of standard operating procedures or guidelines provided by the Central Pollution Control Board*'.

3. **Co-processing in cement plants**: Waste from industry is utilized by cement industry as a resource. Central Pollution Control Board has already released a guideline in July 2017 on utilization of waste by cement plants detailing the requirements and procedure for utilization of hazardous waste as alternative fuel in cement plants.

Thus, on bifurcating the total utilized waste into these three categories, it is observed that for 2021–22, the maximum percentage of waste—41 per cent—is utilized for co-processing in cement plants (see *Figure 17: Categories of utilization of hazardous waste*).

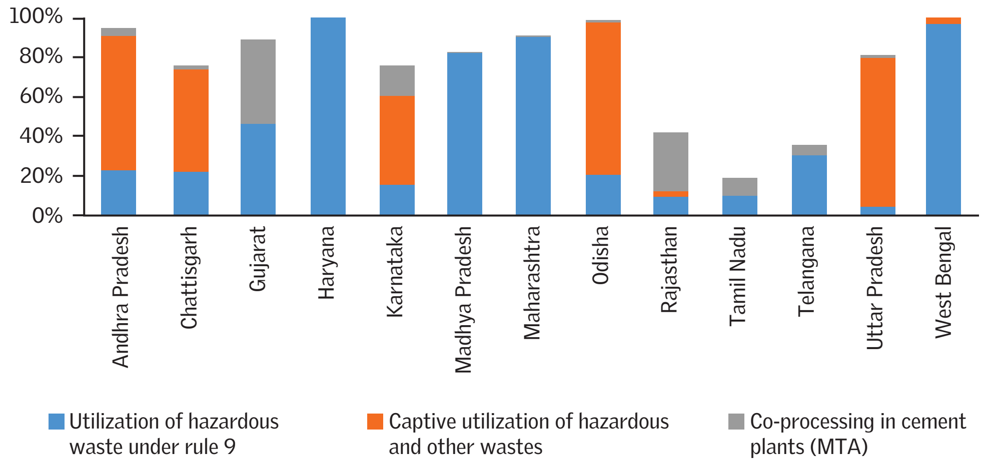
For better understanding of these waste utilization categories at the state level, the waste utilization value in Table 20 is further bifurcated in these three categories as shown in figure. The states of Andhra Pradesh and Odisha are shown as the biggest utilizers due to the fact that the majority of waste—69 per cent and 77 per cent respectively in both the states—is consumed under captive utilization. The states of Haryana (100 per cent), Madhya Pradesh (81 per cent), Maharashtra (90 per cent) and West Bengal (97 per cent) channelizes majority of utilized waste in their state under non-captive utilization.

Figure 17: Categories of utilization of hazardous waste



Source: CSE analysis

Figure 18: State-wise waste utilization in different applications

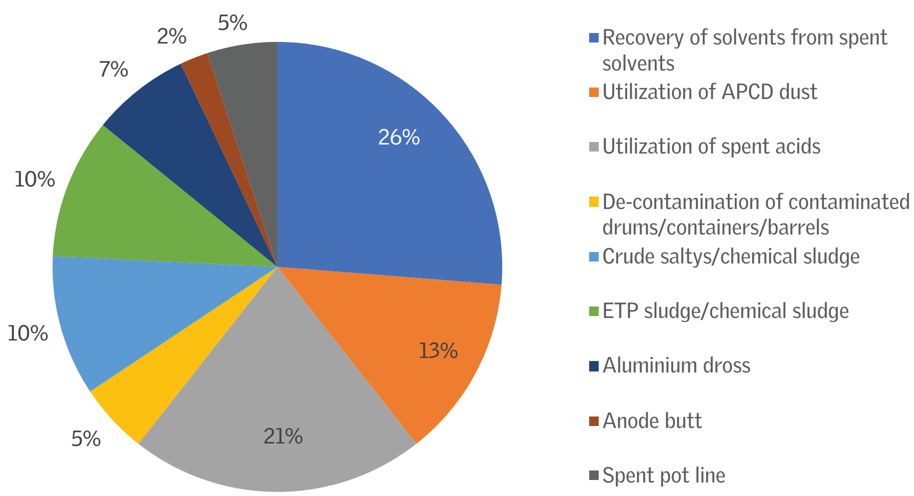


Source: CSE analysis

Non-captive utilization (utilization under Rule 9)

Currently, there are 790 utilizers under this category across the country, with a total authorized capacity of 5.03 million tonnes. For 2021–22, however, only 1.83 million tonnes of hazardous waste is being utilized. The waste that is mainly being utilized is recovery of solvents from spent solvents (26 per cent) and utilization of spent acids (21 per cent) (see *Figure 19: Major waste utilized under Rule 9 [non-captive utilization]*). These wastes are being utilized as neutralizing and stabilizing agents by other industries.

Figure 19: Major waste utilized under Rule 9 (non-captive utilization)



Source: CSE analysis

Captive utilization

As per CPCB, under this category, there are 714 utilizers in the country and for the year 2021–22 and 1.68 million tonnes of hazardous waste has been utilized. Used oil is the most prominent waste utilized under this category.

Co-processing in cement plants

According to CPCB data, for 2021–22, 104 cement plants have been authorized in the country for co-processing of hazardous waste in their plants with a total capacity of 29.34 million tonnes. For the said year, approximately 2.45 million tonnes hazardous waste has been co-processed in these plants, with Gujarat holding the top place in the ranking with 43 per cent of waste being co-processed, followed by Rajasthan with 30 per cent share.

Co-processing is defined as the use of waste as raw material or as a source of energy, or both to replace natural resources and fossil fuels such as coal, petroleum and gas in industrial processes, mainly in energy intensive industries (EII) like cement production.[101]

CASE STUDY 1: Pre-processing of hazardous waste for further utilization in cement industry
Name of industry: Re Sustainability
Location: Hyderabad, Telangana

Re Sustainability, earlier known as Ramky Enviro, has an integrated treatment, storage, and disposal facility facility (TSDF) in Hyderabad along with a facility for pre-processing of hazardous waste. The facility handles hazardous waste mainly from pharmaceutical industries (72 per cent), CETP (11 per cent), chemicals and chemical products (3 per cent) and paper and packaging (3 per cent). For 2023–24, the facility has received a total of 120,000 tonnes of hazardous waste out of which only 15 per cent (18,000 tonnes) got processed (see *Table 21: Different type of waste and its quantity received by the facility*).

Table 21: Different type of waste and its quantity received by the facility

Type of waste	Quantity received (tonnes)
ATFD salts	15,282
Evaporation salts	13,384
Fe salts	12,532
Inorganic salts	12,195

Source: As shared by organization

Overall, at the organization level, total hazardous waste received by Re Sustainability during 2023–24 was about 1.12 million tonnes till January 2024. Out of this, about 90 per cent (1 million tonne) is landfilled, 7 per cent incinerated (78,400 tonnes) while about 3 per cent (33,600 tonnes) is processed and sent to cement plants.

The facility follows the protocol as provided in Central Pollution Control Board's *Guidelines for Pre-Processing and Co-Processing of Hazardous and Other Wastes in Cement Plant as per H&OW (M & TBM) Rules, 2016*. The hazardous waste sample from an industry first undergoes pre-screening to identify the characteristics of the waste. On receipt of waste at the facility, the waste is being weighed at the entry, followed by sample collection for finger print analysis. After the lab results, the waste is stored under covered sheds until it is processed.

Addition of additives to attain the quality required

According to the characteristics of the waste, processing includes shredding, and adding additives like sawdust to reduce moisture content and spent carbon for increasing calorific value or stabilizing agents as per the requirement. Thereafter, compatible waste is being mixed mechanically in a pit to prepare a homogenized mixture. The prepared homogenized mixture is stored under a shed on a paved floor before being dispatched to the cement plants.

The facility charges Rs 5,200 per tonne for pre-processing the waste from the waste-generating industry. The pre-processed waste is currently sent to the cement plant at zero cost by the facility. The cost of transporting waste to cement plant is borne by the pre-processor (see *Table 22: Details of waste processing at Re Sustainability*).

There is another scenario where industries send their hazardous waste directly to cement plants as this is cheaper for the industries—at Rs 1,000–3,000 per tonne—

Table 22: Details of waste processing at Re Sustainability

Description	Details	Unit
Quantity of hazardous waste processed	13,131	Tonnes
Cost of processing the waste	5,200	Rs per tonne
End users of the processed waste	Cement industry	
Quantity of waste dispatched	9,344	Tonnes
Cost of sending the processed waste	Rs 6 per tonne/KM	Rs per tonne per km
Logistics cost is borne by	ReSL	

Source: As shared by organization

than sending hazardous waste to pre-processing facilities. These cement plants either have their own pre-processing facility or accept waste that does not require pre-processing and can directly be co-processed.

As per CSE estimates, utilization of 33,600 tonnes of processed hazardous waste (with GCV 3500 kcal/kg, emission factor = 0.9) in the cement industry results in replacement of 27, 540 tonnes of coal[102] (emission factor 1.52 and GCV of 4500 kcal/kg), thus preventing 11,620 tonnes of CO_2 emissions (27,640 x 1.52-33,600 x 0.9)=11,620 tCO2e. The abated emissions will vary depending upon the calorific value of the hazardous waste as well as coal used in the facility and accordingly it is to be highlighted that there can be instances where utilizing hazardous waste and replacing coal may end up in emitting more CO_2 into the environment.

Stabilization unit

Preparation of AFR by mechanical mixing

Storage of processed alternative fuels and raw materials (AFR) under a shed

Source: CSE survey

CASE STUDY 2: **Use of hazardous waste to replace coal in cement industry**
Name of industry: **Cement sector unit**
Location: **Chittorgarh, Rajasthan**

The plant utilized a total alternative fuels and raw materials (AFR) of 60,000 MT for the FY 2023–24 out of which hazardous waste utilization was approximately 40 per cent, which included both liquid and solid hazardous waste. Currently the plant is accepting liquid hazardous waste from the pre-processors as the plant do not have facility for storing and processing the liquid waste. The solid hazardous waste is accepted directly from industries and some from pre-processors.

On receipt of hazardous waste, the plant follows the same process as pre-processors, including weighing of waste at entry and sample collection for fingerprint analysis. On approval from the laboratory, the liquid hazardous waste is pumped into a calciner directly from trucks transporting the waste. The solid hazardous waste, on the other hand is stored, processed (if required) and either mixed with RDF or fed directly into the calciner. The plant currently has a shredder for the pre-processing and is in the process to install other equipments.

The cement plant charges particular amount from pre-processor and industry for accepting the waste for co-processing. The charges depend primarily on the net calorific value (NCV) of the waste as the required NCV by the cement plant is >2,500 kcal/kg. The liquid hazardous waste of low calorific value (upto 1,200 kcal/kg) is accepted by the cement plant at the cost of Rs 2500–3000/KL since it will have more moisture content and require additional coal to burn it while the waste with NCV >2,500 kcal/kg is accepted at zero cost as it can be co-processed as it is. Similarly, for the solid hazardous waste the charged cost is in the range of Rs 1,000-4,500/tonne depending on the characteristics of the waste.

The replacement of fuel quantity with hazardous waste or AFR depends on the calorific value of the type of coal used in the plant. In 2023–24, the plant utilized almost 24,000 tonnes of hazardous waste by which the plant was able to reduce their pet coke consumption by approximately 5,000–5,500 tonnes, considering some additional fuel was required to burn the AFR. Assuming the average cost of pet coke is Rs 15,000 per tonne, the use of hazardous waste for co-processing has allowed the plant to save approximately Rs 7–8 crore in a year on fuel use. In addition, the cost charged for accepting the hazardous waste is an added monetary benefit for the plant.

Future scenario

Co-processing of hazardous waste in cement plants is a complete win-win situation. On the one hand, while hazardous waste which will otherwise be disposed of at the treatment, storage and disposal facility (TSDF) or incinerated is utilized, on the other hand it results in reducing the usage of coal as a fuel. By 2030, the total cement production capacity of the country will be about 660 million tonnes.[103] This will result in increased coal requirement from existing 9 million tonnes.[104] The quantity authorized for co-processing is 29.34 million tonnes and about 2.45 million tonnes of hazardous waste has been co-processed during 2021–22.[105] Utilizing about 50 per cent of capacity for co-processing will result in availability of about 14.7 million tonne of hazardous waste, which is expected to reduce coal consumption by about 12 million tonnes of coal.

Recommendations

- **Common hazardous waste management facility in industrial clusters:** The cement plants which do not have dedicated pre-processing and waste storage facilities generally do not accept waste from industries that are low waste generators. These industries then have to send their waste to pre-processors, which is more expensive for them and thus, considering the economics, they sometimes refrain in doing so.

- **Regulate the costing of disposal and co-processing to encourage circularity of waste:** It is important to regulate the costing of disposal and co-processing for generating industries to enable them to opt for sending their waste for co-processing rather than disposing to TSDF. The cost of pre-processing is approximately Rs 6,000/tonne while the cost of disposing the waste at the TSDF is around Rs 4,000/tonne. Thus, industries producing less quantum of hazardous waste prefer to opt for disposal of waste at the TSDF considering the cost economics.

11. Pulp and paper sector: Wastepaper circularity in industries is 57 per cent but needs improvement

Integration of formal and informal sector involved in the supply chain is a way out to improve circularity of wastepaper

The Indian paper and pulp (P&P) sector has grown from production of 1.7 million tonnes per annum in 1980 to production of about 21.68 million tonnes per annum in 2020.[106] Going by the raw material used, major production is wastepaper-based (about 16.29 million tonnes), followed by 3.91 million tonnes of wood-based and about 1.16 million tonnes agro-based production.[107] The collection rate of wastepaper in India (54 per cent) is close to the world average of 58 per cent, which means that India is doing good work but there is room for improvement.

Wastepaper availability in India

Wastepaper-based industries rely on the supply chain of wastepaper for fulfilling their requirement of raw material. However, the overall availability of wastepaper in the country is not sufficient to attend to the demand of the industries. This is due to the wastepaper lost as mixed waste, diversions of collected wastepaper from within the supply chain and specific requirements of fibre strength to produce certain quality of paper.

Secondary applications of wastepaper

Wastepaper recycling is a big market wherein 95 per cent of the material is handled by the informal or unorganized sector. CSE enumerated secondary applications of wastepaper with inputs from experts, on-ground surveys and discussions with sector representatives. Significant wastepaper is used by hawkers, by roadside eateries, in packaging of fruits, as egg/apple trays and in similar moulded items. Other applications include handmade paper units, record keeping, envelope making, as filling in leather bags, etc. (see *Table 23: Estimated wastepaper consumption in secondary applications*).

Table 23: Estimated wastepaper consumption in secondary applications

Details	Consumption (million tonnes)	Consumption %
Total domestic consumption of paper (average 2018–22)	21.13	
Packaging of fruits and vegetables	2.0	9.5 %
Roadside eateries/hawkers/pharmacy/general stores	1.6	7.6 %
Moulded products (eggs trays, apple trays)	1.9	9 %
Mixed waste	2.2	10.4 %
Handmade paper units	0.062	0.3 %
Record keeping	1.3	6.2 %

Source: CSE analysis

As per Table 23, about 9 million tonnes of wastepaper is used in secondary applications. That is about 43 per cent of the total domestic consumption of paper.

Circularity of wastepaper

There is no data available in any government report on the quantity of wastepaper diverted into secondary applications. CSE conducted an extensive survey of each level of the supply chain. This included wastepaper application points (fruit markets, handmade paper units, etc.); formal and informal recyclers in the market; NGOs working in the waste management sector; and different experts working in the wastepaper management domain. CSE estimated that about 57 per cent (12.04 million tonnes) of the total consumption (21.13 million tonnes) of the wastepaper is consumed in paper industries as raw material while about 43 per cent (9 million

Table 24: Quantity of wastepaper utilized in different applications (based on average data for 2018–2022)

Details	Quantity (million tonnes)	% of total domestic consumption
Total production	20.90	
Total domestic consumption	21.13	
Packaging of fruits and vegetables	2.0	10 %
Roadside eateries/hawkers/pharmacy/general stores	1.6	8 %
Moulded products (eggs trays, apple trays)	1.9	9 %
Mixed waste	2.2	11 %
Handmade paper units	0.062	0.3 %
Record keeping	1.3	6 %
Imported RCF (2018–22)	6.5	
Total wastepaper as raw material	18.5	
Recovery of wastepaper to industries	18.5 – 6.5 = 12.0	57 %

Source: CSE analysis

tonnes) of wastepaper is diverted to the mentioned secondary applications. Out of the total wastepaper used in the manufacturing of paper, about 35–40 per cent is imported from outside the country (about 6.5 million tonnes).

CSE identified that the informal sector needs to be integrated with the formal agencies working as wastepaper collectors and suppliers for the industries. CSE's team visited some pulp and paper industries and wastepaper collection facilities. We have come across some good practices which are a working model on wastepaper supply chain. There is a need to replicate such models in India. This will also help in increasing circularity of wastepaper within the country.

CASE STUDY 1: Wellbeing out of waste (WoW) programme of ITC—an example of public-private partnership (PPP)
Name of organization: ITC-WoW
Location: Delhi

ITC's Well-being Out of Waste (WOW) initiative promotes awareness about the importance of source segregation and recycling, and establishes systems to ensure effective practice. It collaborates with local municipalities to train waste workers and ragpickers in these concepts and to provide an efficient collection system that covers virtually all segments, i.e. households, offices, schools, hospitals, commercial establishments, etc.

Proper segregation reduces the amount of waste going to landfills while the dry waste collected provides competitive raw material to several industries, e.g. glass, paper and plastic. Ragpickers and waste workers also earn higher and more regular incomes.

ITC started its wastepaper collection scheme under the WoW programme, a CSR initiative to sensitize the common people about recycling paper and bringing wastepaper back into the system. The objective of the drive is that paper should go for recycling rather than to dumpsites. The programme is currently operative in Chennai, Hyderabad, Bengaluru, Coimbatore and Delhi.

According to the WoW coordinator, the average monthly collection of wastepaper is 1,000 tonnes from all the cities. Under this sensitization drive, some quantity of collected wastepaper is used for consumption within the industries. The surplus paper is sold to outside suppliers for further recycling to industries.

Table 25: Details of the WoW initiative and quantity collected per year

City	No. of collection facilities	Quantity of wastepaper (RCF) collected per year (in tonnes)
Delhi	Collection from 300-plus wards across the five cities	10–12,000 tonnes
Bengaluru		
Hyderabad		
Coimbatore		
Chennai		

Source: CSE survey

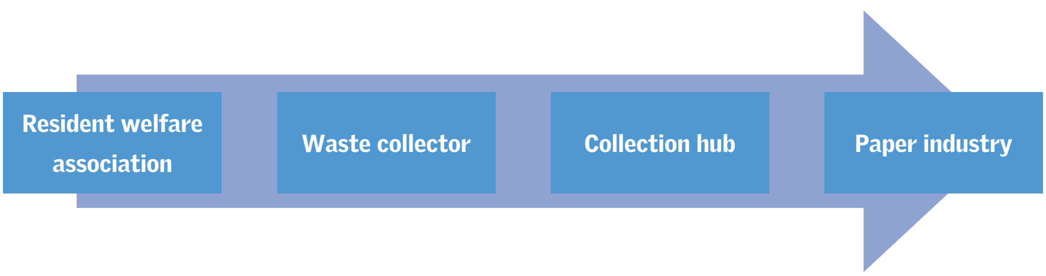
The model of the programme is such that private sector is extensively involved in providing services, while the municipal authority is acting more as a service facilitator rather than the regulator.

CSE's team visited a collection hub of South Delhi Municipal Corporation at Raghubeer Nagar, West Delhi. The collection hub has been operational since February 2021. It has an agreement with about 25 resident welfare associations, hotels and hospitals in and around West Delhi. Waste collectors or kabadiwallahs collect waste from different sources. The collected waste includes paper as well as other materials like plastic, glass, etc. The material received at the collection hub is sorted and bailed. The average collection of paper is about 13–14 tonnes per week. The major incoming grade of paper is newsprint and virgin paper. About 85 per cent of the wastepaper, including newspapers and virgin paper, is sent directly to Khatema Fibres in Uttarakhand.

Mixed paper waste and craft paper, along with other types of paper, are collected in small quantities and sent to local wholesale agencies. About 8–10 small local wholesalers are attached with the collection hub for taking small quantities of waste (up to 500 kg per week).

Supply chain of collection hub

The cost of purchase of books and newspapers for the hub is in the range of Rs 15–16/kg. The hub sells it to industries for Rs 20–25/kg, which includes the cost



Photograph: Collection hub

Photograph: Waste collected at hub before sorting

Source: CSE survey

of transportation, rejects, etc. The cost for industries changes as per the demand and supply scenario in the market. It is understood that the hub comes under the wholesaler category as it acts as a source of wastepaper for the industry.

The collection, sorting and transportation mechanism of the hub can be replicated in other cities and regions also. The quantity collected is low due to the zonal boundary limits and can be increased by including a larger area under the scope of the collection hub.

CASE STUDY 2: Recovery of paper to industries by formal agencies
Name: Greenobin
Location: Gurugram

There are many formal agencies working on the recycling of wastepaper. Greenobin is one such agency located in Gurugram. Set up in 2010, it supplies wastepaper to industries and helps reduce the volume of wastepaper going to landfill. It is working on two models—retail and bulk.

The retail model involves minimum collection quantity of 500 kg. Recycling bins are placed at the client's place—corporate offices, hospitals, etc. The wastepaper collected from recycling bins is brought to the warehouse where it is sorted and stored separately for supplying to industries. Confidential papers are shredded as per the requirement of the client.

The bulk model includes clients with minimum waste generation of 5–10 tonnes and mainly includes printing presses, publication houses, etc. The wastepaper collected from such clients is directly transported to paper mills for recycling. On an average, Greenobin recovers 500 tonnes of wastepaper per month to industries from retail and bulk recycling. The collected wastepaper is sent to paper mills located in Punjab and Uttar Pradesh.

In the supply chain, Greenobin sometimes acts as an aggregator and at times as the recovery agent, based on the channelization of wastepaper. More formal agencies should replicate this model to increase recovery to the industries with less diversions of wastepaper. The primary source of revenue for Greenobin is the sale and purchase of wastepaper collected. As per the requirement of clients, either it supplies free of cost recycled paper products or pays money in lieu of wastepaper collected. The cost of wastepaper collected varies anywhere between Rs 2–20/kg and it is sold to industries at the rate of Rs 5–30/kg. It is worth mentioning here that these prices are totally market driven and keep fluctuating. Mentioned values are average figures only.

Collected waste

Sorted waste

Trimmed wastepaper

Loading for supply to industry

Waste collection bin installed at an office
Source: CSE survey/as provided by the organization

Recommendations

1. **CSE proposes an integrated system for wastepaper recycling, including both the formal and informal sectors.** It is understood that the existing mechanism is weak and leads to considerable leakages. There is a need to integrate the informal sector with the mechanism of segregation, collection and recycling to improve the circularity of wastepaper. The inclusion of formal agencies should be made mandatory in wastepaper management. In CSE's experience, the PPP model is a good initiative, provided that the financial model of the engagement is implemented properly.

2. **Extended producer responsibility (EPR) guidelines should be developed for wastepaper management.** Currently, the EPR framework is limited to only plastic and electronic waste and yet to be fully effective. Lack of EPR framework for other dry waste streams such as paper, textile, tyres/rubber, metal and glass, etc. leads to unscientific disposal of these waste streams while also losing valuable resources. Without EPR no circularity can be obtained.[108]

   The Government of India may formulate the regulations on EPR for paper waste. These rules should include guidelines for manufacturers, consumers, CPCB/PCCs/ SPCBs and recyclers, with clear distribution of responsibilities for all stakeholders.

3. **Quality standards should be introduced for the raw material to optimize percentage of virgin paper used with recycled paper to get a particular quality of paper.** Currently, raw material is just judged by physical appearance during procurement. There is no actual analysis of the raw material regarding characteristics like tensile strength, fibre quality and other parameters which are important for the industry and play a significant role in raw material to product conversion. There is also no guideline on the optimum percentage of virgin paper which should be used with recycled paper to get a particular quality of paper (fibre strength).

It is recommended that a competent research organization like Central Pulp and Paper Research Institute should undertake R&D on how to do a quality check of the raw material, which will give an understanding as to how much conversion rate (raw material to product percentage) can be expected out of the processed raw materials. Also, it will help in optimal use of virgin and recycled wastepaper to obtain a certain quality of paper.

4. **Restrict the usage of imported finished paper by increasing the customs duty from the current rate of 10 per cent to 30 per cent:** It has been noted that about 13 per cent of the finished paper consumed domestically is imported from outside the country. As the demand gets met by the imported finished paper, thus the requirement of domestic raw material is not felt and the recovery rate cannot be increased to its highest potential. In order to increase the recovery rate of wastepaper in the country. Restricting the import of finished paper can escalate demand of paper domestically and thus increased wastepaper collection and recovery to industries.

5. It is recommended to use alternative materials for secondary applications of wastepaper.

   Agro straw for packaging of fruits: At present newspaper is majorly used in the packaging of fruits. It is recommended to utilize either agro straw or expanded polyethylene (EPE) foam sheets, which is currently in use by the fruit merchants, but to a lesser extent as compared to wastepaper. Use of agro straw in fruit packaging will prevent it from getting burnt in the open and polluting the ambient air. Agro straw packaging is a very good replacement for newspapers. It even prevents the adverse health effects of using newspaper as food packaging material.

Bamboo-based utensils: Bamboo-based utensils are 100 per cent natural and non-toxic in nature. They can be reused and are biodegradable in nature. The shift can be a bit expensive but it totally sustainable and environment- friendly in the long-run.

Use of steel utensils and pattals for roadside eateries: Instead of using newspapers, magazines or books for serving food, eateries can switch to using the pattal (broad leaved plant-based products) or steel utensils as used earlier. The shift from paper-based products will lead to more availability of wastepaper in the market and thus increased recovery rate.

References

1. Circle Economy (2023). The circularity gap report 2023 (pp. 1–64, Rep.), https://www.circularity-gap.world/2023

2. Anon 2023. *Circular economy: definition, importance and benefits*, News European Parliament. https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits

3. EAC-PM Working Paper Series EAC-PM/WP/17/2023 https://static.investindia.gov.in/s3fs-public/2023-08/eacp.pdf#:~:text=1.1%20Within%20roughly%20half%20a%20century%2C%20from%201970,populous%20country%20and%20its%20per%20capita%20consumption%20surges.(as viewed on July 31, 2024)

4. ibid.

5. https://pib.gov.in/PressReleasePage.aspx?PRID=1705772 as viewed on 26.6.2023

6. Economic Survey 2022–23; https://www.indiabudget.gov.in/budget2023-24/economicsurvey/doc/eschapter/echap09.pdf

7. EAC-PM Working Paper Series EAC-PM/WP/17/2023 https://static.investindia.gov.in/s3fs-public/2023-08/eacp.pdf#:~:text=1.1%20Within%20roughly%20half%20a%20century%2C%20from%201970,populous%20country%20and%20its%20per%20capita%20consumption%20surges.(as viewed on Juky 31, 2024)

8. Report by MPCB in OA No. 165 of 2020 (Earlier OA No. 122 Of 2015 Wz) Titled as Amita Rajender Patil vs Jindal Steel Works Ltd & Ors_0.pdf (greentribunal.gov.in)

9. https://www.downtoearth.org.in/environment/thermal-power-plants-are-still-not-disposing-of-fly-ash-properly-ngt-cases-show-93479#:~:text=The%20NGT%20ordered%20the%20Haryana,obligation%20to%20manage%20fly%20ash. (as viewed on August 1, 2024)

10. Judgement of the National Green Tribunal regarding pollution caused by Madras Aluminium Company Limited (MALCO),Salem, Tamil Nadu, 24/09/2015, India Environment Portal | News, reports, documents, blogs, data, analysis on environment & development | India, South Asia (as viewed on August 9, 24)

11. https://www.dailypioneer.com/2019/state-editions/mud-pond-wall-collapses-at-hindalco-site-in-muri.html (as viewed on August 1, 2024)

12. Order of the National Green Tribunal regarding disposal of industrial waste by a sugar unit in village Khatauli, district Muzaffar Nagar, Uttar Pradesh, 22/03/2024 - India Environment Portal | News, reports, documents, blogs, data, analysis on environment & development | India, South Asia (as viewed on August 9, 2024)

13. https://timesofindia.indiatimes.com/city/amritsar/molasses-leakage-kills-thousands-of-fishes/articleshow/64209879.cms (as viewed on August 1, 2024)

14. Order of the National Green Tribunal regarding air pollution due to crop burning, West Bengal, March 3, 2021, India Environment Portal | News, reports, documents, blogs, data, analysis on environment & development | India, South Asia (as viewed on August 2, 2024)

15. Order of the National Green Tribunal regarding waste dumped at Bhalswa, Ghazipur and Okhla dumpsites in Delhi, January 29, 2021, India Environment Portal | News, reports, documents, blogs, data, analysis on environment & development | India, South Asia (as viewed on August 1, 2024)

16. http://admin.indiaenvironmentportal.org.in/content/marble-slurry-should-be-reused-ngt (as viewed on August 1, 2024)

17. Indian Minerals Yearbook 2019 (Part- II :Metals and Alloys) https://ibm.gov.in/writereaddata/files/10082021115122IronSteel_Scrap%20and%20Slag_2019.pdf, p. 21

18. Niti Aayog, https://iced.niti.gov.in, 2024

19. Annual Report 2020-21, 47447/2022/UPC-II-HO, https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2020-21.pdf

20. Fly ash generation and utilisation report 2021–22, https://cea.nic.in/wp-content/uploads/tcd/2022/08/Fly_ash_Generation_and_utilisation_Report_2021_22-1.pdf, p. 45

21. Anon. 2023, Guidelines for Handling and Management of Flue Gas Desulphurization (FGD) Gypsum, Central Pollution Control Board.

22. Shobhit Srivastava 2024. Improving Wastepaper circularity for The Pulp and Paper Sector, Centre for Science and Environment, New Delhi. https://www.cseindia.org/improving-wastepaper-circularity-for-the-pulp-and-paper-sector-12004

23. Indian Minerals Yearbook 2022 (Part- II: Metals and Alloys) ALUMINIUM AND ALUMINA, https://ibm.gov.in/writereaddata/files/170989607765eaf18dc09eaAluminium_Alumina_2022.pdf, Page 1–2

24. Guidelines for Handling and Management of Red Mud Generated from Alumina Plants, Central Pollution Control Board, MoEFCC, May 2023, https://cpcb.nic.in/uploads/hwmd/Guidelines_HW_6.pdf, Page 20

25. https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=1865320 (as viewed on July 31, 24)

26. Sowmiya Kannappan and Parth Kumar 2023. Refuelling Delhi-NCR: A study on challenges faced by industries in transitioning to cleaner fuels in Alwar District, Centre for Science and Environment, New Delhi

27. Aggarwal Anubha 2023, Status of biomass co-firing in coal thermal power plants in Delhi NCR region, Centre for Science and Environment, New Delhi

28. https://iced.niti.gov.in

29. Ellen MacArthur Foundation, Circular Economy in India: Rethinking growth for long-term prosperity, 2016, http://www.ellenmacarthurfoundation.org/publications/.

30. https://pib.gov.in/PressReleasePage.aspx?PRID=1945155 (as viewed on 24.9.24)

31. https://indianexpress.com/article/business/critical-mineral-recycling-govt-plans-pli-scheme-to-boost-circular-economy-9429216/ (as viewed on 5.8.24)

32. JPC India Steel, Ministry of Steel, World Steel Association, https://www.ibef.org/download/1716536740_Steel-March-2024.pdf

33. *Indian Minerals Yearbook 2019* (Part II: Metals and Alloys), 58th Edition, Iron, Steel & Scrap and Slag

34. *Indian Minerals Yearbook 2019* (Part II: Metals and Alloys) https://ibm.gov.in/writereaddata/files/10082021115122IronSteel_Scrap%20and%20Slag_2019.pdf, p. 21

35. National Steel Policy, 2017

36. Parth Kumar 2023. Decarbonizing India: Cement Sector, Centre for Science and Environment, New Delhi

37. www.kviconline.gov.in (as viewed on June 28, 2024)

38. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1993425 (as viewed on February 21, 2024)

39. Central Road Research Institute

40. Pramod Kumar et al., International Journal of Innovative Research in Technology, Case study of India's first steel slag road construction at Hazira Industrial Area in Gujrat's Surat, April 2022

41. Indian Minerals Yearbook 2022 (Part III: MINERAL REVIEWS) 61st Edition Cement (Advance Release) Government of India Ministry of Mines Indian Bureau of Mines, September 2023

42. Indian Minerals Yearbook 2020 (Part III: Mineral Reviews), 59th Edition, Cement, (Advance Release) Government of India Ministry of Mines Indian Bureau of Mines, December 2021.

43. Parth Kumar, 2023. Decarbonizing India: Cement Sector, Centre for Science and Environment, New Delhi

44. Emission Reduction Approaches for the Cement Industry, February 4, 2021 https://aeee.in/emission-reduction-approaches-for-the-cement-industry/#:~:text=This%20rising%20demand%20for%20cement,fuel%20(coal%2C%20gas%20etc. as viewed on September 9, 2023

45. Blended Cement Green, Durable & Sustainable, The Global Cement and Concrete Association, 2022 https://gccassociation.org/wp-content/uploads/2022/04/Report_Blended-Cement-Green-Duratable-Sustainable_13Apr2022.pdf (as viewed on September 23, 2024)

46. OECD/IEA and The World Business Council for Sustainable Development, 2009, https://iea.blob.core.windows.net/assets/e3d8a122-455c-49f1-9347-635f46529826/Cement_Roadmap_Foldout_WEB.pdf (as viewed on September 23, 2024).

47. Nitturu, Kartheek et.al, 2023 Evaluating Net-zero for the Indian Cement Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

48. Niti Aayog, https://iced.niti.gov.in, 2024.

49. Cement Manufacturers Association, Vol XXII-I, January–June 2023.

50. Case study manual on utilisation of wastes as AFRs in Indian cement Industry, Confederation of Indian Industry, CII-Sohrabji Green Business Centre, 2011.

51. European Committee for Standardization [ECS], 2002.

52. https://beeindia.gov.in/sites/default/files/publications/files/BEE_Final%20Report_Website%20version.pdf, Page 29 (as viewed on July 3, 2024).

53. The Cement Sustainability Initiative, Cement Industry Energy and CO2 Performance, World Business Council for Sustainable Development (WBSCD), 2009 http://docs.wbcsd.org/2009/06/CementIndustryEnergyAndCO2Performance.pdf (as viewed on August 8, 2024).

54. Dr Dharmendra C. Kothari and Prof. Prashant V. Thorat, d-RDF (Refused Derived Fuel) for SMART-CITIES of INDIA, 2014 https://www.nswai.org/docs/d-RDF_Refused_Derived_Fuel_for_SMART-CITIES_of_INDIA.pdf (as viewed on August 8, 2024)

55. https://powermin.gov.in/sites/default/files/uploads/power_sector_at_glance_Feb_2024.pdf

56. https://www.coal.nic.in/sites/default/files/2024-05/srn-march-2024.pdf

57. https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/09/2023090112560713349.pdf

58. https://coal.gov.in/sites/default/files/2021-01/Generation-of-Thermal-Power-from-Raw-Coal-and-Coal-Consumption-during-last-ten-years.pdf

59. Sugandha Arora (2020): *'n Ashen Legacy*, Centre for Science and Environment, New Delhi.

60. https://cpcb.nic.in/uploads/flyash/MoEFCC_order_09032022.pdf

61. MoEF&CC notification on fly ash and amendments to it in 1999, 2003, 2009, 2016, 2019 and 2021

62. Anon. (2022): Report on fly ash generation from coal/lignite based thermal power stations and its utilization in the country for the year 2021-22, Central Electricity Authority, New Delhi.

63. Blended cement: Green, Durable and Sustainable, GCCA India, 2022.

64. Parth Kumar, 2023. Decarbonizing India: Cement Sector, Centre for Science and Environment, New Delhi

65. https://cea.nic.in/ (as viewed on February 22, 2024).

66. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1983658#:~:text=The%20Union%20Minister%20for%20Power,FGD)%20units%20have%20been%20installed. (as viewed on February 22, 2024).

67. Guidelines for Handling and Management of Flue Gas Desulphurization (FGD) Gypsum, Central Pollution Control Board (CPCB), February 2023.

68. Indian Minerals Yearbook 2022 (Part III : Mineral Reviews) 61st Edition Minor Minerals Gypsum (Minor) and Selenite (Major) (Advance Release) Government of India Ministry of Mines Indian Bureau of Mines, https://ibm.gov.in/writereaddata/files/1712755928661694d8d8774Gypsum.pdf (as viewed on July 10, 2024).

69. Annual Report 2022–23, Ministry of Mines https://mines.gov.in/admin/storage/app/uploads/6433da09a9f741681119753.pdf (as viewed on July 10, 2024).

70. Sunita Narain and Vinay Trivedi 2020, Flue Gas Desulphurization: Limestone Availability and Gypsum Use, Centre for Science and Environment, New Delhi.

71. Circular Economy in Metal Sector, Ministry of Steel

72. Guidelines for Handling and Management of Red Mud Generated from Alumina Plants, Central Pollution Control Board, MoEFCC, May 2023

73. Ministry of Mines, https://mines.gov.in/webportal/content/Aluminium (as viewed on July 16, 2024).

74. ibid.

75. Guidelines for Handling and Management of Red Mud Generated from Alumina Plants, Central Pollution Control Board, MoEFCC, May 2023.

76. Guidelines for handling and management of Red Mud generated from Alumina Plants, CPCB, 2023.

77. Vedanta sustainability report, 2022–23.

78. Indian Minerals Yearbook 2020 (Part II: Metals and Alloys) 59th Edition Aluminium and Alumina (Advance Release) Government of India Ministry of Mines Indian Bureau of Mines.

79. https://pib.gov.in/PressReleseDetail.aspx?PRID=1871866 (as viewed on July 16, 2024).

80. https://www.alcircle.com/news/jnarddc-invents-a-technology-to-extract-rare-earth-elements-from-red-mud-under-atmanirbhar-bharat-mission-63931

81. JNARDCC Annual report, 2019–20

82. https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=1865320 (as viewed on July 25, 2024).

83. https://www.sciencedirect.com/science/article/abs/pii/S0301479711002362

84. https://www.hindawi.com/journals/jen/2023/5749122/

85. https://www.hindawi.com/journals/jen/2023/5749122/

86. https://www.downtoearth.org.in/news/renewable-energy/sugarcane-byproduct-pressmud-can-be-a-sweet-spot-for-india-s-compressed-biogas-sector-93022

87. https://www.downtoearth.org.in/news/renewable-energy/sugarcane-byproduct-pressmud-can-be-a-sweet-spot-for-india-s-compressed-biogas-sector-93022

88. K. Yadav and A. Sircar 2022. 'Fundamentals and developments of compressed biogas in city gas distribution network in India: A review', *Petroleum Research* Vol. 7 Issue 3. Accessed at https://doi.org/10.1016/j.ptlrs.2021.12.003 on April 3, 2023.

89. https://www.mdpi.com/2073-4395/11/1/183

90. https://www.sciencedirect.com/science/article/abs/pii/S2214714420302324

91. Vision 2030 Indian Institute of Sugarcane Research Lucknow, krishi.icar.gov.in

92. Sowimya Kanappan and Parth Kumar (2022), *Refuelling Delhi NCR*, Centre for Science and Environment.

93. 12102018131237Marble 2017.pdf (ibm.gov.in)

94. https://dst.gov.in/ 21Development.pdf (dst.gov.in)

95. https://www.ultratechcement.com/corporate/media/stories/ultratech-pioneers-coastal-waterway-transport-to-address-environmental-challenges-of-phosphogypsum-stockpile#:~:text=Legacy%20stock%20of%20phosphogypsum%20in,16%20MMT%20of%20phosphogypsum%20annually (as viewed on August 1, 2024).

96. https://cpcb.nic.in/openpdffilephp?id=UmVwb3J0RmlsZXMvMjg3XzE0NzEzMzkwNzVfRGlzcG9zYWwgT3B0aW9ucyBvZiBNYXJibGUgU2x1cnJ5IGluIFJhamFzd Ghhbi5wZGY=

97. Ministry of New and Renewable Energy Bio-Energy and Waste to Energy – Recovery of Energy from Urban, Industrial and Agricultural Wastes/Residues and Role of Urban Local Bodies in Energy Management Forty-First Report, Lok Sabha Secretariat, December 2023.

98. Aggarwal Anubha 2023, Status of biomass co-firing in coal thermal power plants in Delhi NCR region, Centre for Science and Environment, New Delhi.

99. Quarterly Review Report Renovation & Modernisation of Thermal Power Stations Quarter: Oct–Dec. 2023. https://cea.nic.in/wp-content/uploads/thermal_

renovatn/2024/03/Dec_Quarterly_Review_Report_updated2_1.pdf (as viewed on July 30, 2024).

100. Energy Cell Annual Report 2023–24, Ministry of Coal; https://coal.gov.in/sites/default/files/2024-03/10-07-2024a-energy.pdf (as viewed on July 30, 2024)

101. *Guidelines for Pre-Processing and Co-Processing of Hazardous and Other Wastes in Cement Plant as per H&OW (M & TBM) Rules, 2016*, July 2017, CPCB

102. Case study manual on utilisation of wastes as AFRs in Indian cement Industry, Confederation of Indian Industry, CII-Sohrabji Green Business Centre, 2011.

103. Parth Kumar 2023. Decarbonizing India: Cement Sector, Centre for Science and Environment, New Delhi.

104. Niti Aayog, https://iced.niti.gov.in, 2024.

105. National Inventory on Generation and Management of Hazardous and Other Wastes, Central Pollution Control Board (2021–22), February 2023; https://cpcb.nic.in/uploads/hwmd/Annual_Inventory2021-22.pdf (as viewed on August 9, 2024).

106. Indian Pulp and Paper Technical Association, Central Pulp and Paper Research Institute (CPPRI), 2020–21.

107. Annual report 2020–21, CPPRI.

108. Anon. 2021. Circular Economy in Municipal Solid and Liquid Waste, Ministry of Housing and Urban Affairs. Accessed at https://mohua.gov.in/pdf/627b8318adf18Circular-Economy-in-waste-management-FINAL.pdf

Various types of industrial wastes are generated in significant quantities in the country. Mismanagement and mishandling of such wastes in several cases has led to environmental accidents and impacted inhabitants, flora and fauna of regions. The wastes can be utilized to replace natural resources, which are available in finite quantities in the environment.

The Centre for Science and Environment (CSE) found that several initiatives have been taken by different industries or sectors in the country towards industrial waste circularity on which, notably, some industries are doing appreciable work. Industrial waste circularity has three major advantages—pollution control, improved waste management and conservation of natural resources. Currently, however, these initiatives are either not upscaled to their maximum potential or, if done, the circularity of different wastes is relatively low.

This report documents case studies on 10 different wastes generated from diverse sectors and utilized in various applications either as raw material or fuel, thus reducing consumption of natural resources and fossil fuels. It frames future scenarios—the expected quantity generated and utilized for each waste, the quantity of natural resources replaced by using the industrial waste along with cost economics and possible carbon dioxide emissions prevented under each initiative in different applications by 2030.

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