INCREASING THE USE OF ALTERNATIVE FUELS AT CEMENT PLANTS: INTERNATIONAL BEST PRACTICE

Associação Brasileira de Cimento Portland

SNIC
SINDICATO NACIONAL DA INDÚSTRIA DO CIMENTO

IFC International Finance Corporation
WORLD BANK GROUP
Creating Markets, Creating Opportunities

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Cover Image: Sofies AS

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ABBREVIATIONS

CAPEX	Capital Expenditure
CDM	Clean Development Mechanism
COD	Chemical Oxygen Demand
CSI	Cement Sustainability Initiative
GTP	Gross Technical Potential
IFC	International Finance Corporation
Kt	Kiloton
LCV	Lower Calorific Value
MBT	Mechanical Biological Treatment
MJ	Mega Joule
MSS	Municipal Sewage Sludge
MSW	Municipal Solid Waste
MW	Megawatt
MWh	Megawatt hour
NHIS	National Health Information Survey
OPEX	Operational Expenditure
PCB	Polychlorinated Biphenyl
RDF	Refuse-derived Fuel (typical calorific value of 8–15 MJ per kilogram, moisture of 25–40% and particle size of 0–400mm)
SRF	Solid Refuse Fuel (also known as Solid Recovered Fuel, (typical calorific value of over 15 MJ per kilogram, moisture of less than 15% and particle size of 0–35mm)

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ABSTRACT

This report, and an accompanying report on thermal and electric energy efficiency, provide a summary of international best practice experience in the cement sector and focus on specific technical measures that could be implemented by cement plants to reduce their operating costs and improve their carbon footprints. The reports provide a plethora of practical information from implemented projects and include detailed technical descriptions, estimates of capital and operating costs, as well as case studies and references from locations where the measures have been implemented. A combination of general and in-depth information will make these reports a helpful read to both management and technical and operating personnel of cement plants as well as to a larger range of stakeholders.

FOREWORD

Cement is paramount for economic development and poverty reduction in emerging markets. Along with aggregates and water, cement is the key ingredient in the production of concrete, and, as such, is an essential construction material that enables large infrastructure projects in energy, water, and transport, as well as, importantly, the construction of modern buildings and urban infrastructure. Given the rapid urbanization rates in developing countries, cement is crucial for delivering on the climate-smart cities agenda. Emerging markets have been rapidly increasing their cement use and now account for over 90 percent of cement consumption worldwide (4.1 billion tons in 2016).

Cement accounts for at least 5 percent of anthropogenic emissions of greenhouse gases, and, according to some estimates, this share may be even higher. At the same time, energy-related expenses in the cement sector, mostly on fossil fuels and electricity, account for 30 to 40 percent of the industry's cash costs. While current energy prices are still recovering from the global financial and economic crises, there is no doubt that they will continue to increase in the long run. In recent years, the cement industry has been successful in reducing its operating costs and improving its carbon footprint (emissions per unit of output) by improving energy efficiency, increasing the use of alternative fuels, and deploying renewable energy sources.

With a cumulative investment portfolio in cement of over $4.2 billion, IFC has accumulated a vast experience in the industry, including in sustainable energy projects. To share its knowledge with external stakeholders and to promote sustainable practices in the sector, IFC commissioned two studies on international best practice, covering alternative fuels, and thermal and electric energy efficiency. These studies were developed as part of the Brazil Low Carbon Technology Roadmap led by the National Cement Industry Association of Brazil (SNIC), the Brazilian Association of Portland Cement (ABCP), the International Energy Agency (IEA), the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD), and IFC.

This report, and an accompanying report on thermal and electric energy efficiency, provide a summary of international best practice experience in the cement sector and focus on specific technical measures that could be implemented by cement plants to reduce their operating costs and improve their carbon footprints. The reports provide a plethora of practical information from implemented projects and include detailed technical descriptions, estimates of capital and operating costs, as well as case studies and references from locations where the measures have been implemented. A combination of general and in-depth information will make these reports a helpful read to both management and technical and operating personnel of cement plants as well as to a larger range of stakeholders.

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OVERVIEW OF THE USE OF ALTERNATIVE FUELS IN THE CEMENT INDUSTRY

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This chapter provides an overview of the worldwide use of alternative fuels in the cement industry, followed by a review of the different categories of alternative fuels and of pretreatment technologies.

1.1 WORLDWIDE USE OF ALTERNATIVE FUELS IN THE CEMENT INDUSTRY

The first major use of alternative fuels in the cement manufacturing industry emerged during the mid-1980s. The primary goal in substituting fossil fuels was to enable the industry to remain economically competitive, as fuel consumption accounts for almost one-third of the cost of producing clinker. Any positive impact on the environment was considered an added benefit.

Since then, there has been increasing sensitivity to the environmental impact of human and industrial activities. Beyond the cost-cutting benefits of alternative fuels, use of these fuels can contribute greatly to the environmentally sound disposal of waste and to the mitigation of greenhouse-gas emissions (GHG). Therefore, key cement players started to consider alternative fuels as a lever to improve their contribution to sustainable development and as a key component of corporate social responsibility. Alternative fuels are at the heart of the Cement Sustainability Initiative (CSI), in which the largest worldwide cement companies are actively involved under the umbrella of the World Business Council for Sustainable Development.

The growth in alternative fuel use in cement kilns has been fostered by the 17 members of the CSI, all of whom are large cement companies operating worldwide. In December 2005, the CSI issued guidelines for the selection and use of alternative fuels and alternative raw materials in the cement manufacturing process. The document also contained details on alternative fuel use in different countries.

Table 1 summarizes the alternative fuel substitution rate in the cement sectors of selected countries during the period 2010–2012. Poland, in particular, has seen rapid evolution in its substitution rate, with the share of alternative fuels in the country's cement sector now at 45 percent, far exceeding the CSI guidelines. Factors behind this remarkable growth are elaborated in Box 1.

Table 1: Alternative Fuel Substitution Rates in Selected Countries and Regions[a]

Country	Substitution Rate (%)	
	CSI Guidelines	2010–12
Germany	42	65
Belgium	30	60
Switzerland	47.8	52.8
Poland	1	45
Sweden	29	45
France	28	30
Spain	1.3	22.4
United Kingdom	6	19.4
Japan	10	15.5
Brazil (2014)	no data	8.1

Source: Sofies AS.

a. Azad Rahman et al., "Recent Development on the Uses of Alternative Fuels in Cement Manufacturing Process," *Fuel* 145 (April 2015): 84–99, doi:10.1016/j.fuel.2014.12.029.

Box 1: Use of Alternative Fuels in Cement Production: The Case of Poland

Over the past decade, the cement sector in Poland has experienced rapid growth in its use of alternative fuel sources for industrial processing. As shown in Table 1, the alternative fuel substitution rate in Poland reached 45 percent in 2011. It has continued to increase in recent years and is now above 60 percent, with some cement plants using up to 85 percent alternative fuel.

The expansion of co-processing in Poland was made possible as a result of:

- Strong commitment of the cement sector, including through: grasping the alternative fuel market opportunities as they were emerging; establishing mid-term and/or long-term contracts with the waste management sector; smart and continuous investments in the handling (and in some cases preparation) of alternative fuels; and the development of skills in kiln operation to accept low-quality alternative fuels.
- Ongoing enforcement of waste regulations, particularly those related to landfilling.
- A favorable economic context comprising smart national and international investments, taxation on landfilling, and some alternative fuel opportunities supported by European subsidies.

A more detailed overview of the experience with alternative fuels in Poland can be found in Appendix 2.

1.2 REVIEW OF ALTERNATIVE FUELS, MARKETS, AND ACTORS

Although a variety of technical constraints limit the use of alternative fuels in cement plants, the range of wastes that potentially can be used in the cement sector is very broad. In addition to any processing limitations, the cement sector has developed international guidelines listing waste that is prohibited for use as alternative fuel, including radioactive waste, infectious waste, and explosives.

The waste used by cement plants as alternative fuel can be classified into five broad categories, which generally are associated with specific regulations and/or implementation constraints related to the materials:

- Municipal waste
- Biomass
- Non-hazardous industrial and commercial waste
- Other unclassified alternative fuels.

Both research and international experience suggest that no single alternative fuel can, by itself, meet the entire thermal demand of cement manufacturing. However, a mix of different alternative fuels can achieve that goal.

Figure 1 shows the breakdown of the alternative fuel supply in the European Union. Alternative fuels are dominated by plastics which account for 31.6 percent of the total fuel supply in the region, followed by tires and mixed industrial waste.

Table 2 summarizes the shares of different types of waste that are being used as alternative fuels by five leading international cement producer groups.[1]

Below is an overview of the various types of alternative fuels used in the cement industry, followed by a review of diverse pretreatment techniques.

1.2.1 HAZARDOUS WASTE

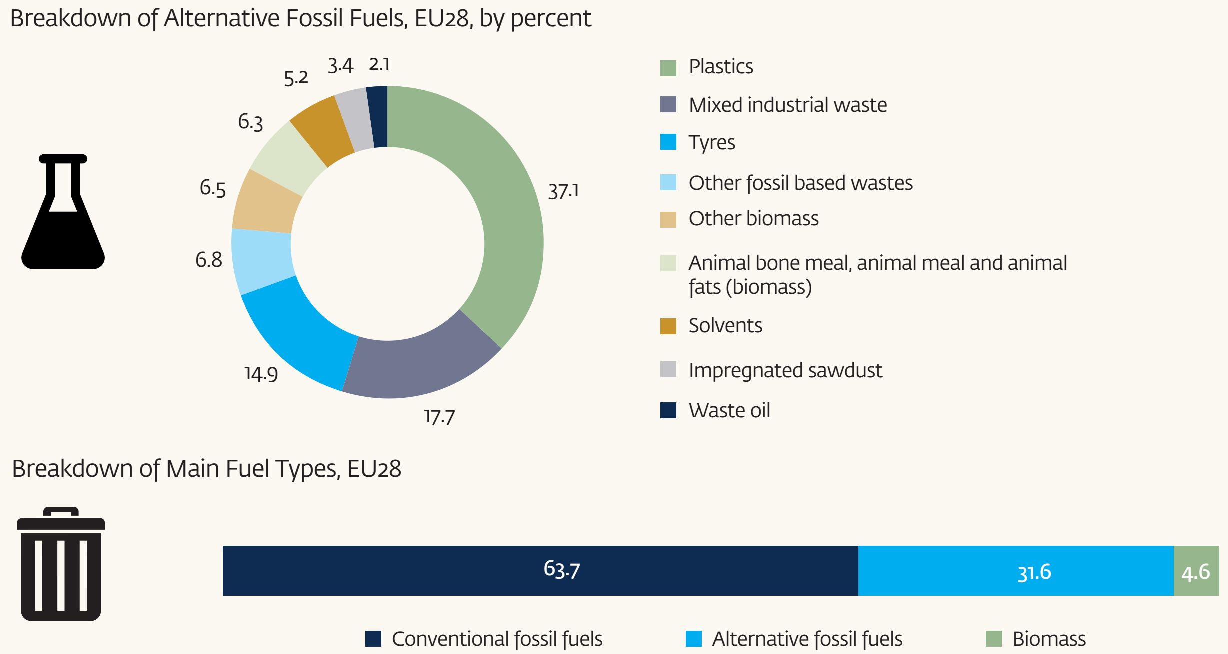
Cement plants in the United States and Europe began their use of alternative fuels with hazardous waste, which offers specifications that are close to those of the fuel oil and coal that traditionally are used in cement manufacturing.

SPENT SOLVENTS

Spent solvents were the first category of waste to be targeted as alternative fuel by cement companies. Largely available on the market in the late 1970s, spent solvents combine three main advantages: high calorific value, a liquid phase facilitating their injection into the heating hood, and the ability for the cement to receive a disposal (gate) fee as a result of regulatory pressures on hazardous waste management. There are a number of important factors to be considered including but not limited to: the chlorine content, compatibility mixtures (concern about setting off reactions),

1 Azad Rahman, M. G. Rasul, M. M. K. Khan, and S. Sharma, "Impact of Alternative Fuels on the Cement Manufacturing Plant Performance: An Overview," *Procedia Engineering* 56 (2013): 393–400, doi:10.1016/j.proeng.2013.03.138.

Figure 1: Breakdown of Alternative Fuels and Main Fuel Types in the EU-28



Source: Cembureau, March 2015.

and security constraints related to the handling of products with a low flash point.

The main sources of spent solvents are the chemical and pharmaceutical industries and the manufacture and use of paints, glues, and varnishes (including in the automotive industry). Available quantities of spent solvents have declined considerably over the years as a result of producers' efforts to reduce solvent use at the source, to develop regeneration, and to alter manufacturing processes (particularly for powdered and water-based paints). Spent solvents are still a significant alternative fuel in some cement

Table 2: Shares of Different Types of Waste Used as Alternative Fuels by Large International Cement Groups

Waste Type Used as Alternative Fuel	Holcim	Cemex	Heidelberg	Italcementi	Lafarge
Waste oil	5		3.7	8.5	22.1
Solvent and liquid waste	11		4.7	21.9	
Tires	10	16	11.6	14.9	19.7
Impregnated sawdust	6				
Plastic	9		26.4	4.7	33.1
Industrial and household waste (solid)		65		13.8	
Industrial waste and other fossil-based fuel	30				
Meat and bone meal	2	4	6.1	15.7	
Agricultural waste	9	10	4.2	11.1	
Wood chip and other biomass	15	5	24.5		25.1
Sewage sludge	2		4.1	1.7	
Other alternative fuel			14.6		

Source: Sofies AS.

plants in the United States and Europe (see Figure 2). Even with low substitution rates, they have the advantage of making it easier to use low-calorific fuels in the mix nozzle.

Finally, spent solvents are used to dilute pasty wastes (paint sludge, resins, glues, distillation bottoms, and distillation columns) in pretreatment facilities and to facilitate the handling of a liquid mixture injection at the nozzle (see Section 2.3).

The market for spent solvents is competitive, with cement plants vying with hazardous waste incineration facilities for the resource. The solvents are useful to incinerators because they can supply the energy required to operate the incineration kilns, avoiding the need for additional fossil fuels. When the average calorific value of their waste mix is low, incineration companies have no problem moving into the spent solvents market segment at very competitive prices compared to those of cement plants.

Cement plants complement solvent recycling activities, as the spent solvents can be distributed to one use or the other depending on the quality of the solvent. Moreover, the solvent recycling process generates distillation residues that can be used as alternative fuel by the cement industry.

The market for used solvents has stabilized in Western Europe and North America. It still represents some 100,000 to 200,000 tons per year in the Benelux countries, France, and the United Kingdom. This alternative fuel source also allows at least two cement plants in the United States to operate at nearly 100 percent substitution.

USED OIL

Because of its high calorific value and ease of handling and burning, used oil is a very attractive and valuable alternative fuel. The ability of cement plants to access this waste segment at competitive prices depends entirely on the regulatory environment.

The illegal disposal of used oil, facilitated by a multitude of small users (such as garages and repair shops), contributed greatly to the eutrophication (excessive nutrient loading leading to oxygen depletion) of surface waters in Europe. The use of oil-burning stoves to heat factories also was a source of pollution because of incomplete combustion and the emission of heavy metals.

In the mid-1980s, to prevent the unsafe disposal of used oil, France set up a clear regulatory scheme with an efficient financial incentive tool and tracking system, helping to

Figure 2: Solvent Storage in Austria (left) and Storage and Recirculation Pumps in the United States (right)

Source: Sofies AS.

greatly reduce illegal disposal. Because of the country's low recycling capacity, the cement industry has quickly seized this waste segment, with annual consumption of used oil peaking at 150,000 tons. The French government has encouraged energy recovery in cement kilns, as a lifecycle assessment showed that the cement route had preferable outcomes to acid regeneration in all categories of environmental impact.

The European Union nevertheless has taken a dogmatic approach in favoring material recovery over energy recovery. This has greatly reduced the amount of waste oil recovered in the cement industry. Outside of Europe, the used oil market segment has been accessible only sporadically to the cement industry (for example, in Chile). Pollution arising from the illegal and unsafe disposal of used oil could bring change, but this would need to pass by a regulatory lever.

INDUSTRIAL SLUDGE

The industrial sludge market segment has grown rapidly in parallel with the decrease in the use of spent solvents, in part because of the source reduction efforts undertaken by waste producers (the byproduct of concentrating industrial waste is industrial sludge, for example). The use of concrete pumps for injection has allowed for the direct use of sludge in cement kilns; however, direct injection is limited by the need to maintain good combustion. Industrial sludge therefore typically is either pretreated by diluting the liquid or dispersed using a powdery carrier.

Industrial sludge and spent solvents have similar origins (for example, chemical, parachemical, petrochemical, mechanical, paints, varnishes, resins, distillation residues). In developed countries where regulation prohibits the landfilling of hazardous organic waste, specialized hazardous waste incinerators compete directly with cement producers for the sludge resource. The production costs of the two sectors are similar, making this competition relatively balanced.

In developing countries, low regulatory pressure fosters the landfilling or onsite storage of industrial sludge. In this market segment, manmade lagoons of aging oil sludge are often found. Oil sludge is used in well drilling and is present in oil-refining countries, particularly in the Middle East. Significant amounts of this sludge are recoverable in dedicated lagoons (for example, 100,000 tons per year have been recovered for use in cement plants in Romania in the last five years). Deposits estimated at 12 million cubic meters in the Gulf countries and 5 million cubic meters in Nigeria could be valorized (see Figure 3).

POLLUTED (WOOD AND PLASTIC) PACKAGING

This category includes, for example, chemical packaging, oil packaging from garages, and fertilizer packaging. The market segment is relatively new and is growing both in developed countries with advanced regulation as well as in countries with emerging regulation, where it represents one of the first segments of solid waste that is banned from landfilling. Polluted packaging waste is generated by industries of various sizes, as well as by the general population. Selective collection and strict enforcement of regulation are the two key factors necessary to create this waste stream. For example, France alone produces an estimated 1 million tons per year of polluted packaging waste. This is an affordable segment for the cement industry, with prior shredding occurring given the potential

Figure 3: Oil Lagoons in the United Arab Emirates

Source: Sofies AS.

chemical hazards. As with many other wastes, the main competition is from specialized incinerators. In Brazil, the polluted packaging waste segment already exists, and several pretreatment platforms are focused on it.

AQUEOUS WASTE

Although aqueous waste is not classifiable under the category of alternative fuel, the cement process can provide an effective service for removing this type of waste. Moreover, the injection of water at the mixing nozzle lowers the amount of thermal nitrogen oxides produced.

There are many types of aqueous waste, including cutting oils; wastewater from chemical reactions and reactor cleaning in the chemical, pharmaceutical, and para-chemical industries; and de-icing water from airports and roads. Generally speaking, any type of wastewater that has a high chemical oxygen demand (COD), which is difficult to dispose of in a wastewater treatment plant, is of interest for the cement disposal route.

This market segment exists only in countries where regulations on water pollution are strong and restrictive. France is probably the country where incineration, evapo-incineration, and co-incineration of aqueous waste in cement plants have been most developed. The amount used by the French cement industry reaches several hundred thousand tons per year.

POLLUTED SOIL

Geographical sites and polluted soil constitute a specific waste market segment. Their remediation stems from regulatory requirements and is generally practiced in countries that have strict soil pollution regulation. However, remediation also can be practiced in the case of rehabilitation of polluted sites, for example in connection with real estate development in or near big cities.

The mineral composition of polluted soil is mostly compatible with the raw material for cement kilns. The sector therefore is well suited to the treatment of soils polluted with hydrocarbons. The injection is done at the foot of the preheating tower so as to ensure destruction of the organic matter while combining the minerals with the feedstock.

SUMMARY

Overall, hazardous waste is an easily accessible market segment for the cement industry. The cement process offers specific environmental advantages, enabling it to be a competitive solution compared to traditional hazardous waste disposal routes. In some countries, such as India, hazardous waste represents one of the only economically accessible segments because of the high concentration of polluting industries in certain states (for example, chemical industries in Gujarat).

However, the amount of hazardous waste generated is lower than that of non-hazardous waste (discussed later); thus, it generally does not ensure a very high level of fossil fuel substitution for the cement industry. Except in special cases, such as with some plants in the United States and Europe, the average level of fuel substitution with hazardous waste rarely exceeds 10 to 15 percent.

An important note regarding the market for hazardous waste is that the evolution of its characteristics makes pretreatment increasingly unavoidable. In the past, most of the material flow occurred via direct delivery to the cement kiln. Today, more than 80 percent of the flow pass is pretreated. This trend can be seen in all geographical areas, including developing countries.

Because of gate fees, hazardous waste can be transported over long distances without questioning the economic feasibility of co-processing in cement factories. In the United States, waste transfers occur between states as far apart as Ohio and Kansas. In India, cement plants can receive waste from 1,000 kilometers away.

Finally, one must keep in mind that using hazardous waste in cement plants often requires going through long and complex administrative authorization procedures, sometimes with a low success rate.

1.2.2 NON-HAZARDOUS INDUSTRIAL AND COMMERCIAL WASTES

Initially, non-hazardous industrial and commercial wastes did not receive particular attention from the cement industry, as the sector was more focused on hazardous waste. At that time, the costs of landfilling were low and landfill capacities were significant. In addition, mechanical pretreatment technologies were still embryonic.

The shift came from two converging effects:

- Regulatory changes resulting in significant increases in waste disposal costs, mainly in Europe as a result of the ban on the landfilling of recyclable and organic waste; and
- Willingness of the cement plants to reach a high substitution rate even with limited and decreasing amounts of hazardous waste.

Demand for non-hazardous industrial and commercial wastes first emerged in Germany and Austria, thanks to strict implementation by countries affected by the European directive limiting landfilling. Following implementation of the Landfill Directive, Germany faced a lack of waste disposal solutions, given its limited incineration capacity. Consequently, the manufacturing of shredded solid fuel developed naturally, spurring advances in sorting and pretreatment techniques.

Cement manufacturers themselves have made advances in their ability to use shredded solid waste. Use of this waste has developed steadily in Europe (Austria, the Benelux countries, the Czech Republic, France, Italy, Poland, Spain, and the United Kingdom) and is now progressing worldwide (see Figure 4). In the German cement industry, the rate of substitution of fossil fuels has grown rapidly to more than 60 percent on average, with some plants exceeding 80 percent.

Note that quantities are potentially important, given the large capacities of cement kilns. The market is broad. The level of interest depends on the cost of alternative solutions, but the evolution of pretreatment techniques has made the cement industry competitive, including in the United States (where landfill capacity is an important concern), where running costs are as low as $20 to $25 per ton outside the Northeast.

Unlike for hazardous waste, where cement manufacturers often are able to approach producers directly, the structure of the industrial and commercial solid waste market is based primarily on a collection service. Cement manufacturers have to deal with waste collection companies to guarantee their supplies in a context of balance or imbalance in supply and demand, which affects the relative power of the economic partners. To consolidate their positions, the major cement companies often integrate pretreatment in their offer. This vertical integration sometimes is achieved through partnerships between a collector and a cement producer.

1.2.3 MUNICIPAL WASTE

Municipal waste covers two major types of waste: municipal solid waste and municipal sewage sludge.

MUNICIPAL SOLID WASTE

Because of its heterogeneity, physical state, odor, and low calorific value, municipal solid waste is not, as such,

Figure 4: Storage and Injection Facility for Solid Wastes in Mexico

Source: Sofies AS.

ready for direct delivery to cement plants. It also can be prohibited from use for co-processing under certain guidelines. However, for the same reasons as for industrial waste (landfill space limitations combined with difficulties in opening incinerators), the opportunity to produce an alternative fuel derived from municipal solid waste has emerged in recent years.

The production of RDF (refuse-derived fuel) from municipal solid waste involves two main aspects: sorting and shredding. The main producers of shredders developed dedicated machines mainly in Central Europe. Mechanical sorting has been established in parallel based on the density and/or size of the material. Sorting by material type has been much more complex, but efficient solutions now exist for the removal of chlorine, iron, and non-iron metals. A particular attention should be paid to moisture management. Various drying technologies are used in the industry: thermal or biological. Integrated solutions are being proposed under the name mechanical biological treatment (MBT) that include the technologies described above.

RDF production is well developed in Central Europe and Italy as well as in the United Kingdom, but with some differences in recovery routes. In Germany and Austria, the produced RDF is used locally in cement plants and power plants; in Italy and Great Britain, the output is primarily exported because of a lack of usage capacity.

Cement plants can enter into a contract either directly with local authorities or with private companies that own and operate pretreatment facilities. As is the case for industrial waste, cement plants may have the opportunity to vertically integrate by taking part in the RDF preparation step.

Technically, municipal solid waste markets can be accessed by cement plants for RDF worldwide. However, in an emerging market context, considering the waste characteristics, low or no gate fee and limited regulations and enforcement, simpler technologies or more selective or labor intensive processes must be considered to produce RDF that is both technically and economically acceptable for use by cement kilns, while taking into consideration the low calorific value of the waste.

MUNICIPAL SEWAGE SLUDGE

Production of municipal sewage sludge has increased greatly with the development of communal sanitation. The land area for spreading this sludge is becoming more and more restrictive, and some disposal channels are increasingly regulated (such as ocean dumping and landfilling). The use of sewage sludge as fuel, however, offers great interest.

Sewage sludge can be injected directly into the back of the cement kiln, after a single pass on a filter press. However, its calorific value is too low to make it a substitute fuel. In this case, cement plants function instead as a disposal service.

The sludge also can be dried, giving it the characteristics of a mid-calorific value alternative fuel, especially if it has not undergone digestion. This market, however, is totally dependent on the local context. The co-processing of sewage sludge competes with use of the sludge in incineration and with its burning in power plants.

Use of municipal sewage sludge in cement plants already exists in several countries, such as China, France, Japan, Spain, and the United Kingdom. There are a few cases of drying in cement plants using waste heat from the cement kilns.

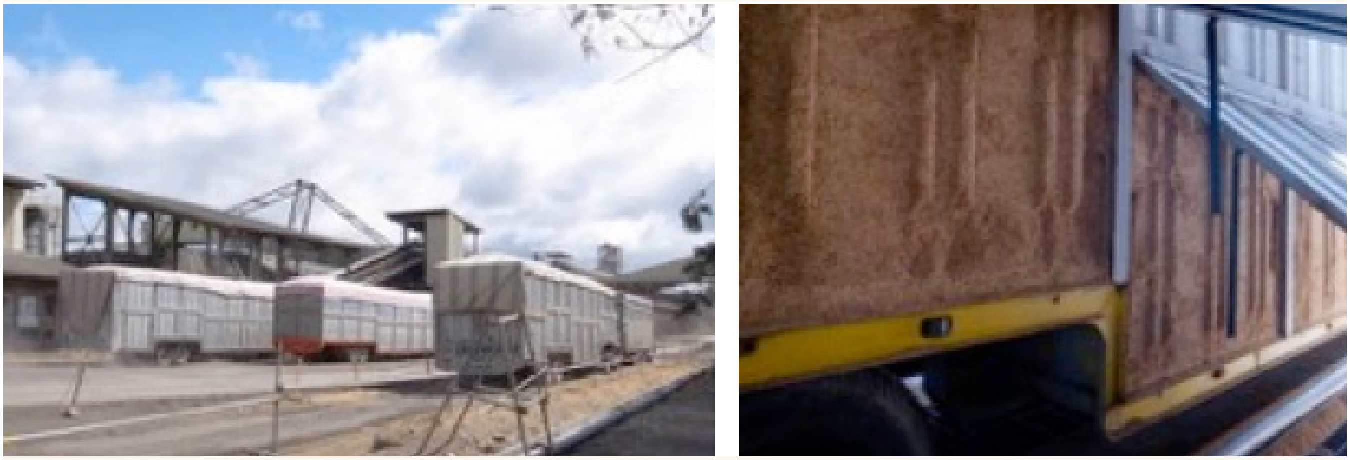
1.2.4 BIOMASS

AGRICULTURAL AND AGRO-INDUSTRIAL WASTES

The best-known agricultural and agro-industrial waste for use in the cement industry is rice husk. In addition to its high calorific value, it contains a significant proportion of highly reactive silica, which combines very easily with some raw mix. The use of rice husk in cement production has been developed in most rice-producing countries. The involvement of some cement manufacturers in professionalization of the supply logistics enabled them to capture significant market share. In the Philippines, for example, Lafarge has achieved substitution rates of more than 30 percent using only rice husk (see Figure 5).

Other forms of agricultural biomass waste include coffee husk, oil palm husk, cashew nut husk, and sunflower husk. Because the markets for these feedstocks are seasonal, their use often follows the rhythm of the seasons; however, it also

Figure 5: Jumbo Trucks Used in the Cement Industry in the Philippines



Source: Sofies AS.

can be spread throughout the year if stocks are substantial (see Figure 6).

These wastes have received attention from international organizations. As part of its Resource Efficiency and Cleaner Production program, the United Nations Industrial Development Organization (UNIDO) has launched a major study on the development of biomass waste from the production of rice and coffee in Asia and South America. The program especially addresses energy recovery of waste in cement plants.[2]

In the agricultural and agro-industrial waste market segment, cement producers usually compete with diffuse valorizations of this material. In India, for example, the government supports the use of husks for electricity generation in coal power plants.

Cement plants can use other agricultural and agro-industrial wastes as well. For example, significant amounts of waste from the cotton ginning and rice straw industries are often left in the fields, either to decompose or be burned. This burning leads to air pollution, producing the high concentrations of smog found in places such as Cairo, Egypt. Although the quantities of these feedstocks are significant, their use in cement plants is limited because of their high phosphorus content.

Cement producers have positioned themselves in niche markets for this waste segment. For example, some have used decommissioned seeds that have been treated with pesticides, a source that cannot be overlooked (see Figure 7).

2 United Nations Environment Programme, "UNEP-UNIDO joint RECP Programme," http://www.unep.org/resourceefficiency/Business/CleanerSaferProduction/ResourceEfficientCleanerProduction/UNEP-UNIDOjointRECPProgramme/tabid/78757/Default.aspx.

Figure 6: Storage of Rice Husks for Off-season Use

Source: Sofies AS.

Figure 7: Decommissioned Seeds

Source: Sofies AS.

Additionally, genetically modified corn cobs have been offered to cement producers in Chile. Such residues represent tens of thousands of tons per year of byproducts with a high calorific value. The list of agricultural waste from the food industry is long, and it depends on the local context. In general, however, this waste is more accessible for the cement sector in developing countries.

Finally, biomass fuel can be found in many agro-industries—for example, chicken litter from poultry farming or dried sludge from the production of beer.

GREEN WASTES

Cement manufacturers have launched projects to exploit the byproducts of forest management. This includes, for example, wood from the management and replacement of rubber trees in Africa (see Figure 8). Large tree plantations represent a significant source of untapped fuel. In such cases, the cement manufacturer traditionally has contracted directly with the owner of the plantation and outsourced operations.

Freshly cut wood has a low heating value. To be properly valorized, it must be subjected to natural drying or forced drying after being ground up. The economic feasibility of

Figure 8: Wood from Rubber Trees in Africa

Source: Sofies AS.

the latter option could be improved by using the waste heat from cement kilns for drying operations.

The market for wood chips and pellets also is significant. For example, several million tons of this feedstock is produced in Canada and the United States each year. The decline in production of wood pulp in these countries has led manufacturers to switch their activities to wood energy, much of which is exported to Europe. Generally, these fuels are marketed at rates that remain unattractive for cement plants.

1.2.5 OTHER UNCLASSIFIED ALTERNATIVE FUELS

ANIMAL MEAL

Because of concerns about mad cow disease, markets in many countries have stopped using meal from livestock quartering in animal feed. The need to find a rapid solution for disposing of these flours pushed cement producers to respond by developing equipment for receiving and storing this material and injecting it into their kilns (see Figure 9). In France, the quantities of animal meal processed peaked at 350,000 tons per year. Many European countries, as well as Japan, also were concerned about mad cow disease. Thus, public incentives have contributed to accelerated development of this sector. Although the quantities of animal meal have decreased sharply in recent years, the facilities in cement plants continue to operate using other waste, including powdery waste such as sawdust and coal dust.

PLASTIC AND WOOD WASTE FROM THE CONSTRUCTION AND DEMOLITION SECTORS

In some countries, particularly in North America, large quantities of wood materials are used in construction, resulting in significant construction and demolition waste. Projects aimed at recovering this waste and turning it into a fuel for cement plants have been developed in Richmond (Vancouver) and St-Constant (Montreal) in Canada, as well in Singapore (see Figure 10).

Because of its large volume, construction and demolition waste is receiving growing attention. Extraction of its fuel fraction may have to grow in industrialized countries. The Netherlands has been a pioneer in this area. In Japan, the

Figure 9: Reception and Storage of Animal Meal in France (left) and Japan (right)

Source: Sofies AS.

Figure 10: Wood Waste Sorting Table in New England (left) and Grinding Unit in Singapore (right)

Source: Sofies AS.

lack of landfill capacity also has led to the recovery of such waste in the country.

USED TIRES AND RUBBER WASTE

Used tires are often cited as the best example of an alternative fuel for use in the cement industry. This waste is by definition homogeneous, although the calorific value is impacted by the level of wear, and iron from the tire frames enters easily into the chemical composition of the raw mix. Kiln temperatures ensure complete combustion. Whole tires from light vehicles and small vans can be introduced via a double-flap system, requiring only a low level of investment.

Although the cement process is highly suitable for energy recovery from used tires, the market realities differ by country. In industrialized countries, uncontrolled disposal of tires is less accepted by the general population (because of the visible impact on the landscape). Furthermore, accidental fires at used tire storage facilities have attracted attention because of the difficulties of controlling the blazes (for example, at St. Amable tire depot in Canada). Finally, water that stagnates in the envelopes of tires promotes the breeding of mosquitoes, bringing associated risks of dengue fever and malaria.

Today, around 50 percent of the available used tire resource worldwide is recovered. This material recovery can take very different forms, from the production of granules to the stabilization of road banks. The production of granules is a source of secondary waste, such as steel tire cords or granules without economical value.

Attempts to convert tires into a more convenient fuel source, for example by using pyrolysis, have not yielded expected results.

In Europe, introduction of the principle of extended producer responsibility has facilitated the development of this market. In France, for example, Aliapur, owned by the country's major tire manufacturers, manages the bulk of used tire disposals. In general, the supply chains of used tires for cement plants are based on direct agreements with manufacturers.

However, used tires often find a second or third life in many emerging countries, with parallel material recovery routes. The production of shoe soles is probably the most well-known valorization of used tires, but it is not the only one (see Figure 11).

These parallel recovery routes enable valorization of used tires that makes them inaccessible to cement producers, as is the case in India and China.

1.3 REVIEW OF PRETREATMENT TECHNOLOGIES

Various pretreatment technologies are available to the cement industry today. Their purpose is to homogenize a range of alternative fuels into a form that can be introduced

Figure 11: Examples of Manufactured Items Based on Used Tires

Source: Sofies AS.

more easily into the kiln, while removing undesirable components and/or increasing the calorific value of the fuel.

1.3.1 MIXING IN LIQUID PHASE

MIXING WITH SOLVENTS

Historically, mixing with solvents was the first pretreatment technique developed for alternative fuels. This approach was applied to solvents in the mid-1980s. Originally, the high availability of spent solvents with negligible impurities meant that only simple pretreatment techniques were necessary. In some cases, this involved merely mixing the solvent via recirculation in the storage tanks on-site at the cement plant (see Figure 12).

More recently, the decline in the amounts of spent solvents available, along with the advent of high-viscosity muddy and/or pasty wastes, including the frequent conditioning of pasty waste in barrels, has led to increased sophistication in liquid-phase mixing techniques. These techniques generally are based on a pre-mixture of pasty waste with a small amount of solvents by means of a stirrer at greater or lesser speed. The result of this pre-mixture is then diluted via recirculation and agitation in large storage tanks (see Figure 13).

Figure 12: Solvent Mixing in Storage Tanks in France

Source: Sofies AS.

Figure 13: Pretreatment in Liquid Phase in the United States

Source: Sofies AS.

The most advanced variant includes first a milling process for treating full barrels, with separation of the metal component prior to the mixing phase (see Figure 14).

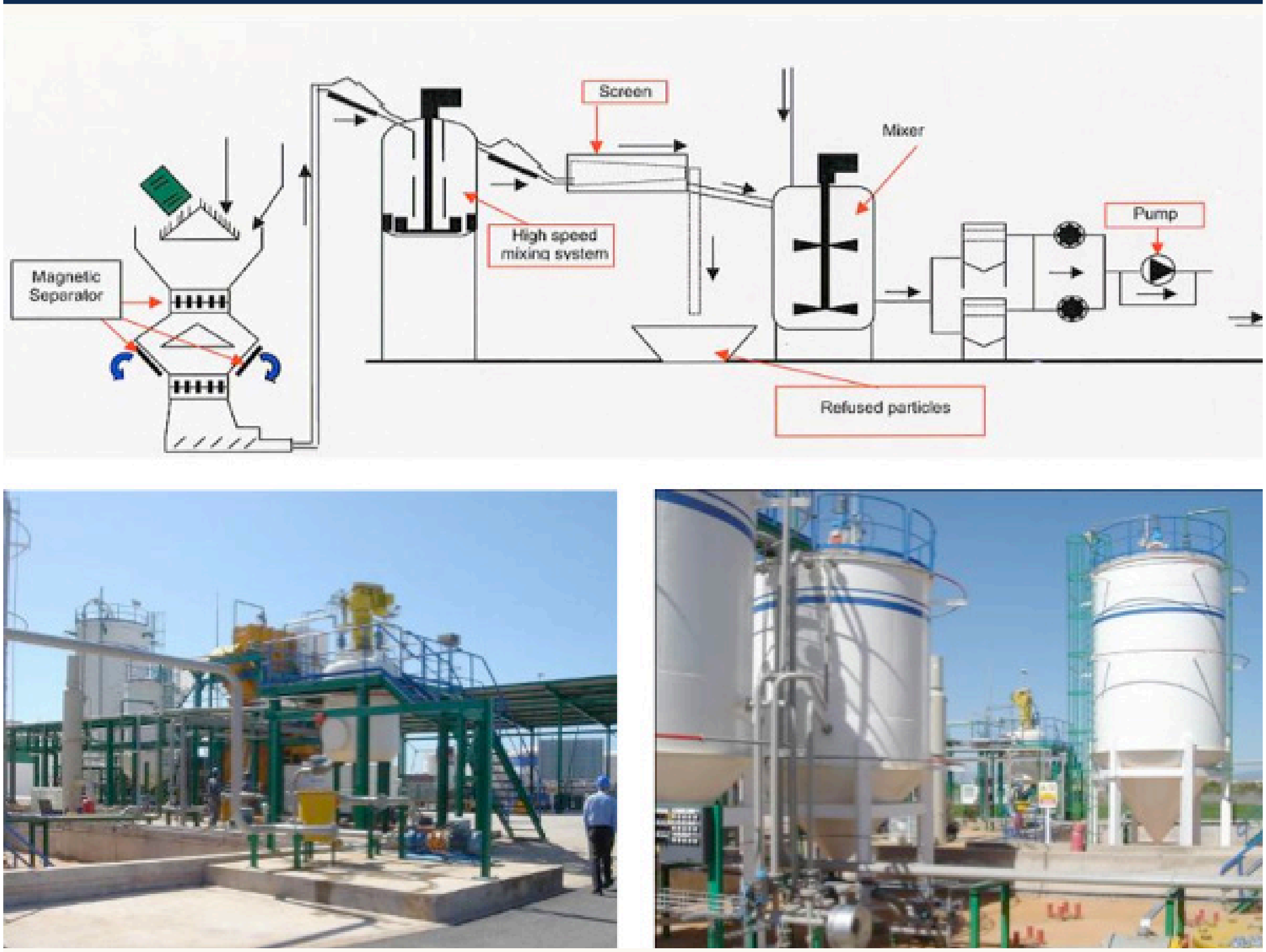
Techniques that use fast mixers allow for the injection of fuels that have pasty-solid contents of up to 70 percent through injection nozzles. These approaches are well suited to the scarcity of liquid waste.

EMULSIONS

A more suitable pretreatment technique exists for hydrocarbons that have high flash points. This technique, which is akin to the emulsification of "oil in water," was developed in France from the know-how and technology acquired from the rheology of cement pastes in wet kilns. In brief, the solids and hydrocarbons are diluted in water in the presence of surfactant adjuvants. The respective percentages of water, solids, and oil are identical. The resulting fuel does not have a high calorific value, but its homogeneity, stability, and ease of use make it attractive.

However, it is unlikely that use of this technology will develop further given the limited market, as the process control today is concentrated on a single operator.

Figure 14: Pretreatment Line in Spain, with Milling at the Top of the Process



Source: Sofies AS.

PHASE SEPARATION

Early pretreatment technologies were based on the principle of manufacturing homogeneous mixtures from liquid, solid, and pasty wastes. Phase separation, however, involves the opposite approach, whereby the unwanted waste components of more or less liquid heterogeneous waste are extracted, leaving only the most useful fuel phase.

This approach applies primarily to waste oil that contains water and sediment (for example, oil waste, cleaning waste bins, emulsion cutting fluids).

Phase separation is carried out using physical-chemical treatment techniques (see Figure 15). The raw waste is subject to filtration and a first separation of the static phase, and reagents are added to facilitate the final step of separation by simple or forced sedimentation (centrifugation).

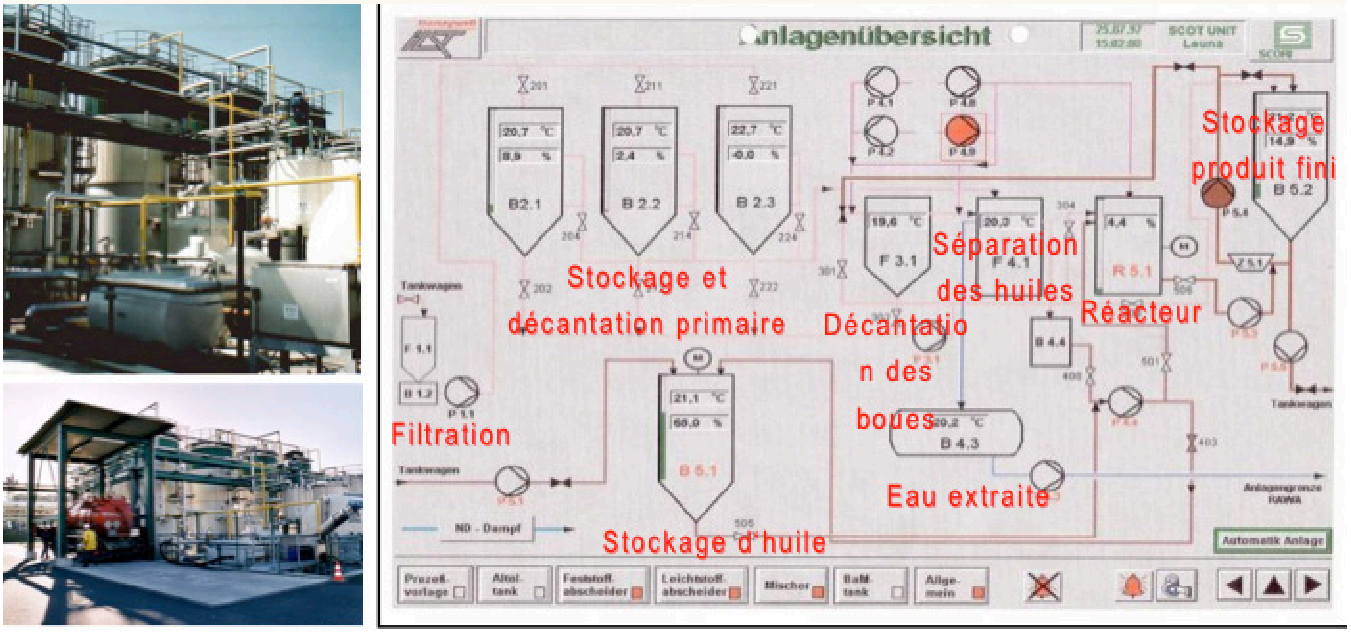
These technologies produce a high-quality fuel that can substitute the heating or ignition fuel. Their disadvantage is that they generate solid waste for disposal and waste to be treated.

DISPERSION ON A POWDERY CARRIER

The reduction in the quantity of liquid waste that was available and usable for producing alternative fuel that could be pumped and injected through injection nozzles led to the development of technologies based on the dispersion of pasty waste on a powdery carrier (generally made of sawdust).

The process was first used in Belgium from pre-impregnated waste in Germany. At the time, the control of waste

Figure 15: Physical-chemical Pretreatment Unit Scori at the Leuna Refinery in Germany



Source: Sofies AS.

flows was not very strict, and the industry could be seen, probably rightly, as a means of circumventing regulations on hazardous waste.

The first installations of this type were very rustic and used simple wheel loaders for the blending. Few precautions were taken to control the dust and volatile organic compounds produced during preparation of the fuel. However, these questionable practices do not undermine the real attraction of pasty waste dispersion on a powdery carrier. Far from being marginalized or rejected, this technology was further developed by serious operators who have tackled and resolved the associated health and environmental issues.

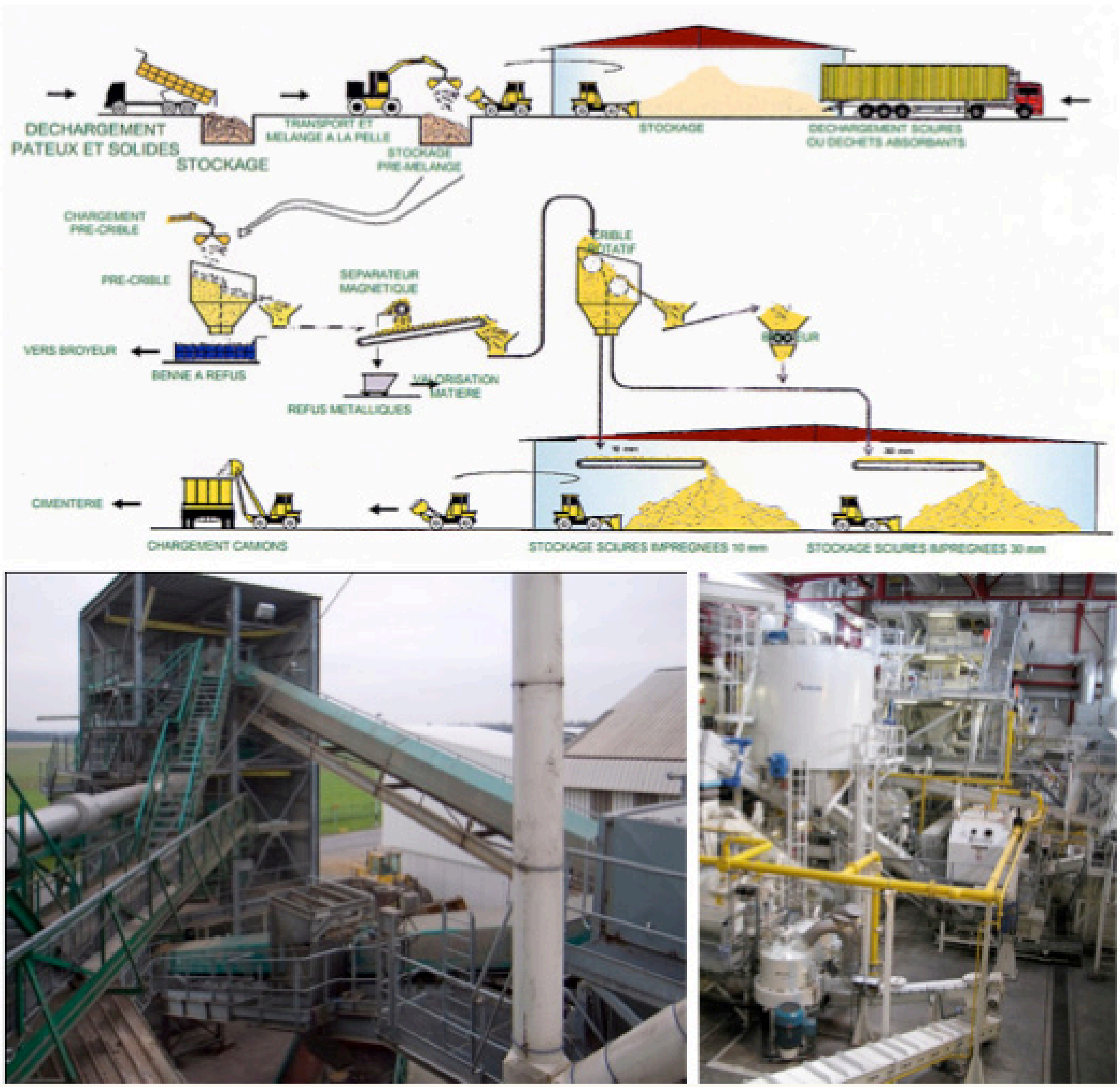
Today, the technology is well controlled and is recognized as a good practice in the Best Available Techniques Reference Document (BREF) for waste treatment published in 2006 by INERIS under the European Industrial Emissions Directive.

The process is based on a sequence of mixing and screening phases. Most of the more advanced facilities have a head crusher for primary treatment of solids or barrels (as in the case of liquid mixtures discussed previously) and a secondary crusher for refining the finished product. Volatile organic compounds are collected and processed, as well as dust.

Some facilities are operated in a completely closed circuit (see Figure 16).

Now, the main challenge is linked to the choice of adsorbent. In many countries, sawdust, which was the first and main adsorbent, is becoming too expensive because of the development of biomass incineration. Many other adsorbents have been tested, with only a few providing the same efficiency as sawdust (for example, some foams sourced from plastic wastes or some variety of cellulose). This new economic burden is linked to a decline in the number and scope of applications of this technology.

Figure 16: Schematic of the Fabrication Process (top), Mixing Tower in Belgium (bottom left), and Closed-circuit Production Unit in Norway (bottom right)



Source: Sofies AS.

1.3.2 MECHANICAL TREATMENT

The pretreatment methods presented so far have focused on the preparation of alternative fuels from hazardous waste. Mechanical treatment methods are most commonly applied to municipal, commercial, non-hazardous industrial waste streams to make an RDF.

The first of these mechanical treatment RDF platforms is for the organic fraction of non-biodegradable solid waste. This includes industrial waste (packaging and manufacturing waste), construction and demolition waste, commercial waste, and the dry fraction of municipal waste after collection and sorting and from landfills (see Figure 17).

Figure 17: Example of Typical Solid Waste Before Pretreatment, in Austria

Source: Sofies AS.

The aim of mechanical treatment is to transform the waste into RDF, reducing it to a particle size that enables its introduction in a cement kiln and to remove unwanted components that may be subject to higher-value materials recovery.

Injecting the RDF into the top kiln requires a relatively fine particle size, whereas introducing it to the rear oven may necessitate only a primary crushing. The sophistication of the applied technology therefore depends on the specifications of the finished product.

Shredding technology has progressed steadily during the last 15 years. How each particular type of waste responds to shredding depends on the nature of the material. The complexity of the operation is increased by the heterogeneity of the waste materials and the specifications of the RDF required by the cement kiln. Shredder maintenance (and the sequencing of the maintenance) is also key to reaching high-level efficiency. The protection of shredders using prescreening improves the efficiency of the shredding line and reduces maintenance costs by removing large pieces and metallic parts that are present in the waste streams and cannot be shredded.

A typical pretreatment line comprises:

- Coarse sorting using an industrial excavator in the receiving and storage area for the raw waste
- Primary grinding in a slow grinding mill (see Figure 18)

Figure 18: Examples of a Primary Mill and Cutting Table

Source: Sofies AS.

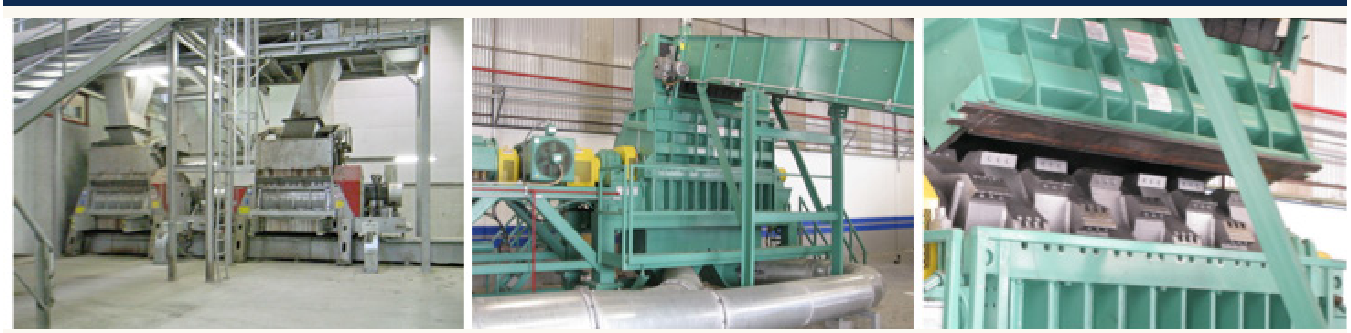
- First removal of ferrous metals using an over-band magnet conveyer
- Sorting of fractions from primary crushing, either manually or in a fully mechanized fashion (vibrating or star, trammel, ballistic, or ventilation sorting) (see Figure 19)
- Second removal of ferrous metals to protect the secondary crusher, and eventual extraction of nonferrous metals by eddy current
- Lastly, high-speed secondary shredding to adjust the desired final particle size (see Figure 20).

Mechanical pretreatment chains are increasingly well mastered, and this industry is well organized and has broad experience. Most machine suppliers are proposing adapted shredders or integrated lines. However, an integrated line proposed by one supplier might not always be the most efficient solution for a given waste stream.

Figure 19: Manual Sorting Table, Trammel, and Air Separator

Source: Sofies AS.

Figure 20: Secondary Shredding Mill in Austria (left) and Mexico (center and right)



Source: Sofies AS.

1.3.3 BIO-MECHANICAL TREATMENT

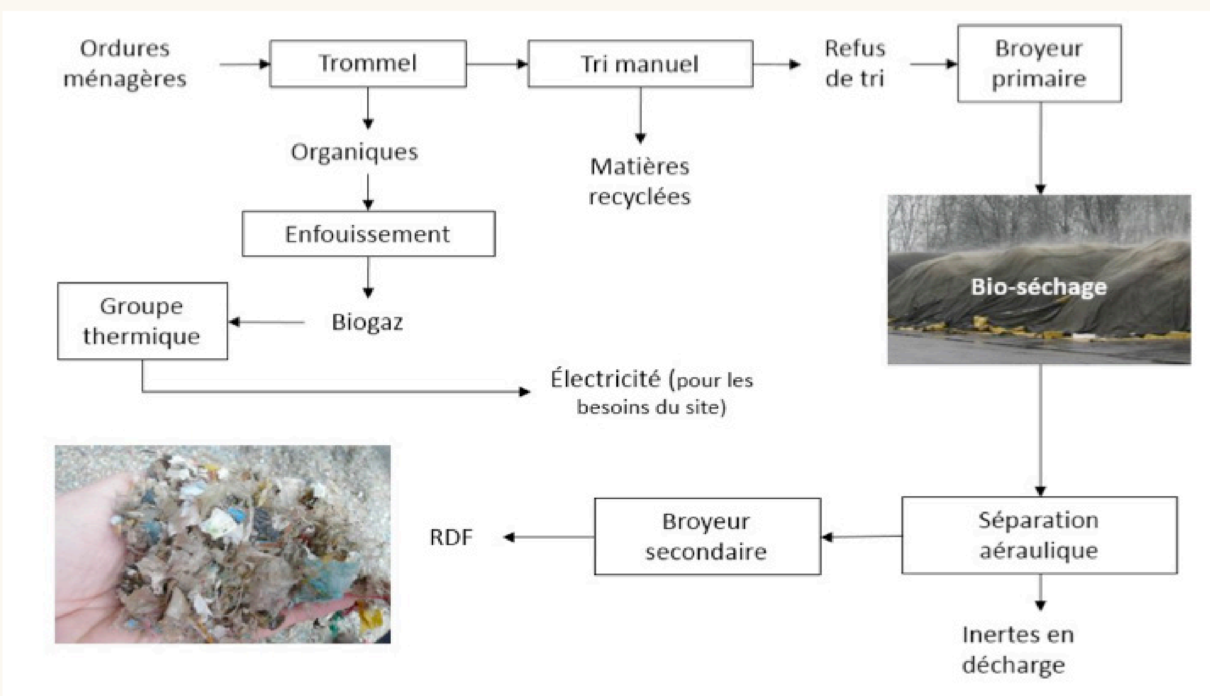
Purely mechanical treatment may not be most appropriate for waste streams that contains a biodegradable fraction, as is found in municipal solid waste (unless biodegradable fraction is removed first). For this type of waste, mechanical treatment could be accompanied by biological treatment that uses bacteria to degrade the organic matter and dry the alternative fuel.

With the addition of biological technology to the mechanical treatment RDF platform described in the previous section, the MSW, including the biodegradable fraction, are treated so that they are suitable as RDF. these technologies, the production of This biological technology, generally is based on an aerobic degradation process that does not produce methane. The heat generated during the degradation process reduces the moisture content of the waste, and increases the calorific value. However, there are technologies that combine anaerobic degradation to recover methane, followed by a bio-drying step. These are not widespread, and they do not yet benefit from an extensive list of industrial references. Nevertheless, one can cite a simplified variant of this approach to achieve accelerated anaerobic digestion in small-scale digesters on landfill sites, to later extract the solid fuel fraction (known as the Ikos Environment process).

Bio-mechanical treatment units can be implemented independently, although they also can be coupled with a landfill to benefit from synergies, as shown in Figure 21.

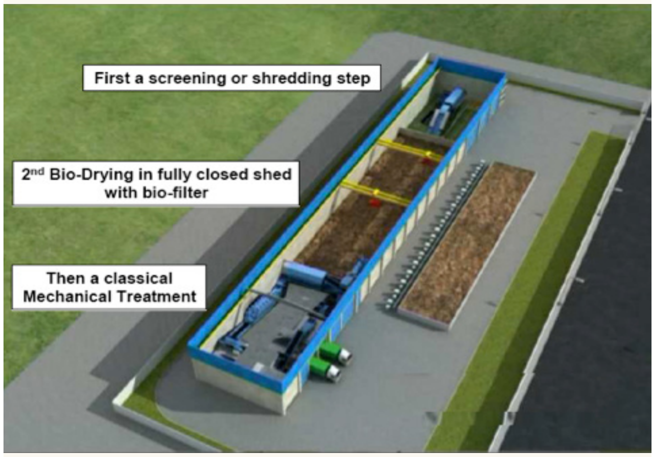
Bio-mechanical treatment is a popular option with surrounding communities due mainly to the combined effect of regulatory pressure to close landfills and to the reluctance of populations to embrace incinerators. Accelerated growth of the bio-mechanical option is observed in some European countries (for example, the United Kingdom). However, these technologies are still expensive, requiring a significant civil engineering effort and the effective treatment of odors (see Figure 22). Investments of €15 million to €20 million are typically necessary for an installation of 100,000 tons per year and a price of €26 per ton.

Figure 21: Schematic Showing the Bio-mechanical Treatment Process on a Landfill Site



Source: Sofies AS.

Figure 22: Classical Bio-mechanical Treatment Unit



Source: Sofies AS.

Bio-drying techniques derived from composting practices offer an interesting alternative. Investment costs are minimal, but this approach may require long periods of biodegradation and high land use. An intermediate solution developed by the German company Convaero[3]—accelerated drying in a breathable textile membrane—appears to be an interesting compromise.

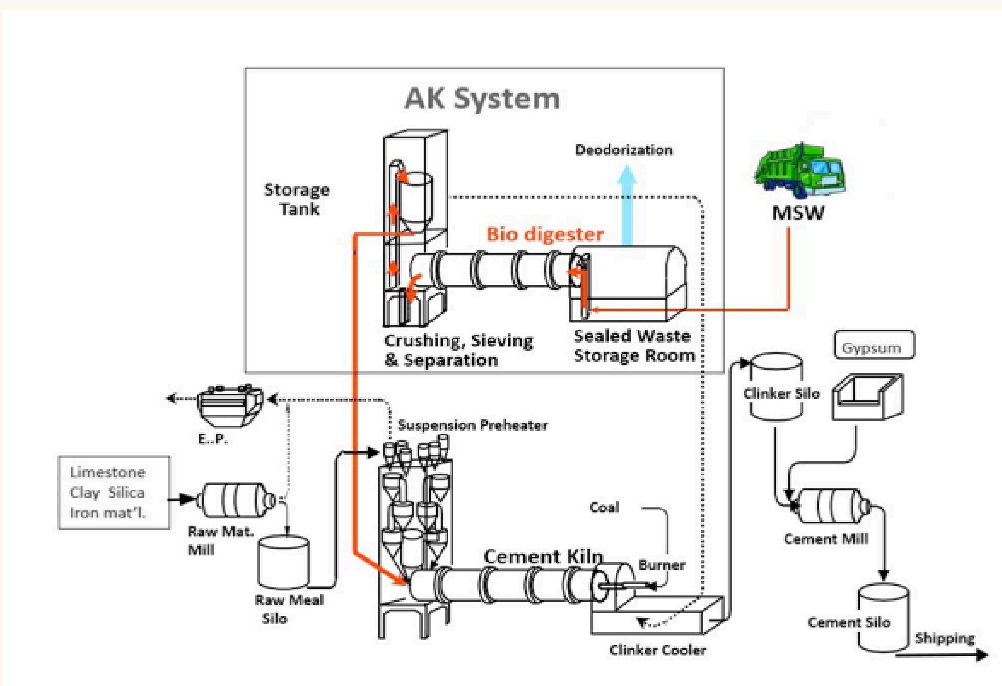
In another example, the Japanese cement company Taiheiyo has transformed one of its kilns into a bio-digester to prepare an alternative fuel for kiln operation (known as the AK System process; see Figure 23), as part of a contract with the community of Hidaka. The project focuses on a relatively small quantity of 15,000 tons per year; however, it generated some €3.3 million in economic gain for the cement plant, although this also included the high royalties (€300 per ton) paid by the municipality.

1.3.4 OTHER PRETREATMENT TECHNIQUES

The pretreatment technologies presented up to now are relatively widespread. They are fairly flexible and cover a wide scope of applications. This section describes a

3 Purchased by Eggersmann.

Figure 23: Schematic of the AK System Process



Source: Taihiyo.

variety of other technologies that are adapted for specific applications and thus are less commonly applied.

TORREFACTION

Although less common, this technique is gaining in popularity worldwide. Torrefaction of biomass (for example, wood or grain) is a mild form of pyrolysis at temperatures typically between 200 and 320 degrees Celsius. Torrefaction changes biomass properties to provide a much better fuel quality for combustion and gasification applications. Thus, this pretreatment increases the calorific value and ease of grinding for an injection nozzle. An interesting example of implementation for the cement industry is that of the group Solvay, which has launched production at the industrial level in the United States as part of a joint venture with the U.S. company New Biomass Energy.

PYROLYSIS

Pyrolysis does not in itself present a strong option for the cement industry, which normally is capable of using the energy content of waste without having to go through any treatment for gasification and/or production of heavy oil. In addition, pyrolysis, which is a traditional and proven method, presents multiple implementation challenges related primarily to control of the load and quality of secondary products generated by the reaction.

With that said, at least one successful implementation has been conducted in a cement plant for the pretreatment of waste for raw biomass with excessively high hydrocarbon content. The application of pyrolysis for the cement industry should remain very anecdotal. Even then, pyrolysis likely will remain a low-value option for the industry.

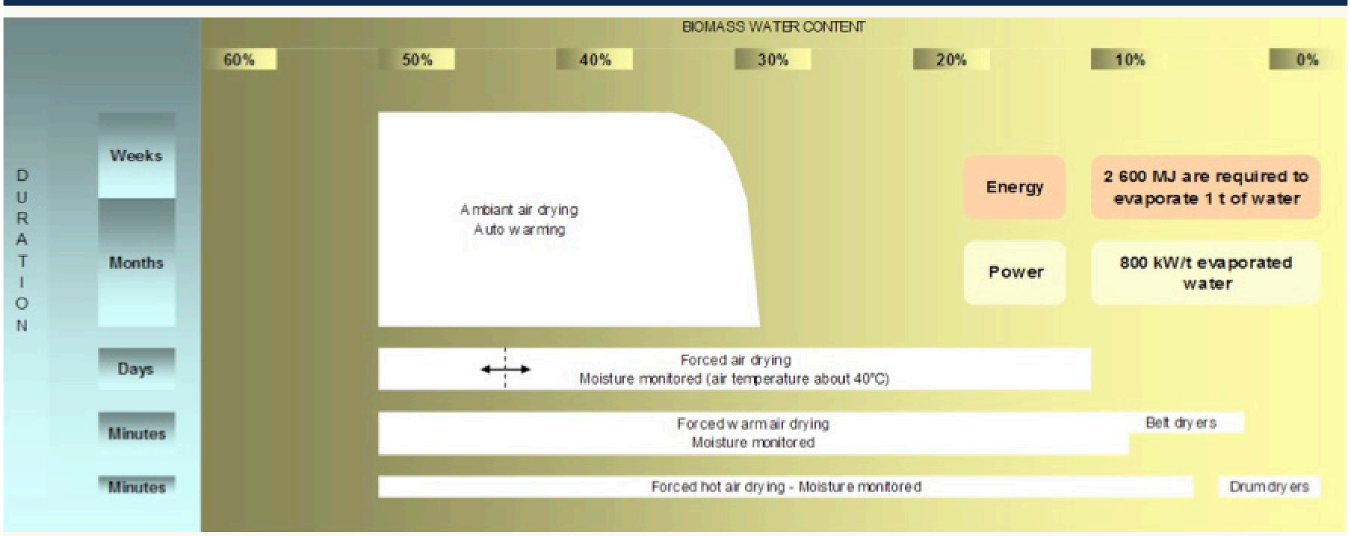
DRYING

Some wastes, such as sewage sludge biomass, and the biodegradable fraction of developing nations' MSW, have a moisture content that is high enough to negatively affect their calorific value. Drying techniques such as thermal, waste heat, and solar therefore greatly increases their potential use as alternative fuels.

Drying can be natural or forced with different temperature levels. Figure 24 shows the drying time and the residual moisture content for biomass based on the techniques used.

The possibility of recycling free energy in the form of the hot exhaust gas that leaves cement kilns is not new. Already, this method is used extensively to produce electricity to run the process, especially in cement plants in China. Belt dryers are well suited to the relatively low temperatures of the exhaust gases (see Figure 25). In the last three years, this technology has been implemented in cement plants to dry RDF produced from municipal solid waste, for example. The moderate investment coupled with low operating costs and

Figure 24: Schematic of the Biomass Drying Process and Moisture Content



Source: Sofies AS.

Figure 25: Belt Dryer Using the Excess Exhaust Gases from Kilns

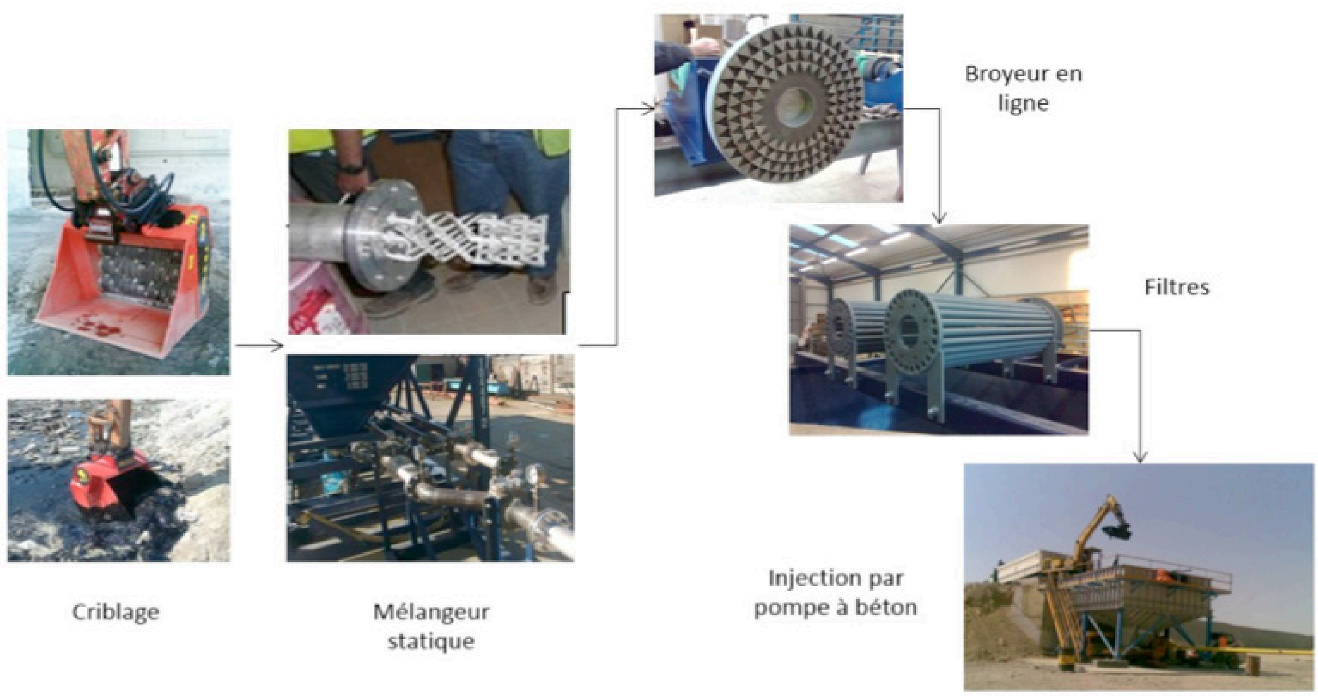
Source: Sofies AS.

the straightforward adjustment of moisture levels for specific punctual needs are strong advantages. Producers of dryers for agricultural products are now diversifying their machines for use in waste treatment (for example, Stela of Germany).

INLINE MIXING

Lastly, it is worth mentioning the inline mixing technique, which relies on the use of static mixers and inline mills. This approach is particularly suited to the homogenization of pasty waste. For example, the technique has been developed in the United Arab Emirates for the pretreatment of waste oil contaminated with sand (see Figure 26).

Figure 26: Sequence of Pretreatment of Oil Sludge



Source: Sofies AS.

2 COMPREHENSIVE INFORMATION BY ALTERNATIVE FUEL TYPE

2.1 HAZARDOUS SPENT SOLVENTS

- The spent solvents segment is of interest for the clinkerization process, given that the physico-chemical characteristics of these solvents are close to those of liquid fossil fuel. However, the available quantities must be significant to compensate for the investment costs required to manage the health and safety risks. Because handling of the solvents requires special competencies that frequently are not available in a traditional cement plant, a dedicated skilled team is often called upon.
- A cement plant can achieve 100 percent substitution with spent solvents.
- For a kiln producing 500,000 tons per year of cement, a 20 percent thermal substitution rate means between 5,000 and 15,000 tons of spent solvents per year, with a calorific value of about 20 gigajoules per ton.
- The availability of spent solvents is decreasing as the industry has started to successfully replace solvents with water.
- The gate fee/cost of spent solvents is directly linked to the fuel cost. In the case of a high fuel cost, the spent solvents must be bought by the cement plant and recycling becomes a more profitable alternative, reducing available quantities. With a low fuel cost, a gate fee could be expected.

Hazardous Spent Solvents
Origin
• Chemical and pharmaceutical industries • Painting and production of building materials • Cleaning activities in metals workshops or garages • Recycling activities
Composition
• Chlorine: 0% to 2%, average 0.6% to 1% • Moisture: 0% to 25% • Metal: 1,000 to 5,000 parts per million (ppm) • LCV: 20 to 28 gigajoules per ton
Traditional Disposal/Usage Practices
• Thermal recovery in specialized incinerators or in cement plants (major) • Recycling in an internal workshop or in specialized activities
Supply Chains
• Collection and transport in adapted tanks (specialized companies) or in drums for small and medium-sized production • Nature of solvent and risk information clearly mentioned
Preprocessing and Utilization Technologies
• Transfer from drums • Blending • Phase separation • Homogenization **Main risks:** chemical reaction, creation of a solid phase, mixing of chlorinated with non-chlorinated solvents
Risk Identification: Environmental Implications and Operational Health and Safety Considerations
• Compliance with environmental regulation • Appropriate and safe storage: steel that is compatible with solvent specifications, fire protection system • Handling within confined equipment or workshops with collection of volatile organic compounds • Use of personal protective equipment

Typical Technical, Policy, and Financial Barriers
Technical barriers:
• Chlorine quantity due to traditional chlorinated solvents
• Wide range of flash points possible
• Risk of phase separation in storage with huge calorific value variation
Other barriers:
• Availability of large quantities of spent solvents
• Complex permit procedure for hazardous wastes with possible opposition from the population
• Priority given to recycling
• Competition with specific incinerators
Recommended Policy Actions
• Ban on disposal in the natural environment
• Financial support (tax exemption, subsidies to investment, etc.)
CAPEX and OPEX
• Unloading zone for trucks on concrete with collection of spillage
• Stirred tanks in retention basins
• Pumping system for unloading, stirring, and injection
• Filtration by auto-cleaning system or a static system in the unloading line
• Electrical devices must be designed with consideration of the flash point of the solvents (ATEX rules)
CAPEX: €5 to €10 million
OPEX: €10 to €20 per ton
Carbon Dioxide Mitigation Potential
Biomass concentration = 0%
Full replacement of fossil fuels

2.2 WASTE OIL AND INDUSTRIAL OIL

- The used oil segment is of interest for the clinkerization process, given that the physico-chemical characteristics of the oil are close to those of liquid fossil fuel. Provided that the investment needs for storage and handling are low, use could be profitable even for small quantities.
- A cement plant can achieve 100 percent substitution with used oil. For a kiln producing 500,000 tons per year, a 15 percent thermal substitution rate means between 5,000 and 15,000 tons of waste oil per year, with a calorific value of about 25 gigajoules per ton.
- Mobilization of the resource is a key issue given the geographical dispersion of sources. The cost of collection also is a key factor and could be subsidized via an eco-tax on new oil.
- Recycling of used oil is developing and can absorb the entire production of a country in a limited number of facilities.
- The potential of development for cement plants is decreasing rapidly as recycling offers sufficient capacity.

Waste Oil and Industrial Oil
Origin
• Any engine requiring lubrication (truck, car, power generator, etc.)
• Industrial processes (steel production, tire manufacturing, food oil production, etc.)
Composition
• Chlorine: 0% to 1% (due to potential presence of cleaning solvents)
• Moisture: 0% to 20% (linked to storage conditions)
• Metal: < 1,000 ppm
• Pollution risks: PCB and solvents with low flash point
• LCV: 25 to 35 gigajoules per ton
Traditional Disposal/Usage Practices
• Recycling: limited by the cost of recycling (profitability threshold: oil waste production > 100,000 tons per year)
• Incineration with energy recovery (mainly in cement plants)
Supply Chains
• Collection from garages: need for frequent collection because of limited tank storage
• Transit via central platforms before being sent to final destinations
Preprocessing and Utilization Technologies
Occurring at transit platforms:
• Emptying of drums
• Blending of different oil wastes
• Extraction of water via decantation (natural or accelerated by surfactant chemicals)
• Control of PCB pollution (small tanks to avoid pollution diffusion)
Risk Identification: Environmental Implications and Operational Health and Safety Considerations
• Equipment and regulations have to be compliant with regulation related to hydrocarbon management
• Leakage prevention: tanks located in retention basins, pumping system locations that facilitate leakage collection (usually retention bin or concrete soil with drainage)
• Fire protection: adapted to hydrocarbon storage
• Protections adapted to solvents with low flash points

Typical Technical, Policy, and Financial Barriers
Technical barriers: • Chlorine and PCBs because of oil coming from electrical equipment (transformers or condensers) • Homogeneity: risk of water separation in storage Financial barriers: • Cost of collection: need for a free and reliable collection system Policy barriers: • Distortion of competition: recycling (artificial market competition) and energy recovery (not the same environmental rules) • Complex permit procedure for hazardous wastes with possible opposition from the population
Recommended Policy Actions
Implementation of a regulation that: • Bans the discharge of used oil in sewers (1 liter of oil contaminates 1 milliliter of water) • Bans illegal burning of used oil Homogenization of regulations for different energy recovery processes
CAPEX and OPEX
• Unloading zone for trucks on concrete with collection of spillage • Tanks in retention basin (former tanks for fuel oil in cement plant can be reused) • Pumping system for unloading, stirring, and injection • Filtration by auto-cleaning system or a static system on the unloading line • Electrical devices CAPEX: €1 million to €3 million OPEX: €5 to €10 per ton
Carbon Dioxide Mitigation Potential
Biomass concentration = 0% Full replacement of fossil fuels

2.3 WASTEWATER

- The wastewater segment is of interest for cement plants, but in limited quantities and as a local service for industries.
- An injection rate of about 1 to 2 tons per hour is achievable with a small capital expenditure, but quality control must be established.
- The technical benefit is limited to a decrease in nitrogen oxide emissions. This means that the cement plant is offering a service that must be compensated at the right price.

Wastewater
Origin
Liquid wastes from economic activities such as: • Chemical and pharmaceutical processes • Metals workshops • Airport (de-icing) and road activities • Industrial cleaning activities
Composition
• Chlorine: < 0.5% • Moisture: > 80% • Metal: 1,000 to 2,000 ppm • Pollution risks: chemicals, surfactants, solvents, or oil. • LCV: 0 gigajoules per ton
Traditional Disposal/Usage Practices
• Sewage plants (biological treatment) • Physico-chemical treatment • Incineration
Supply Chains
Wastewater that is registered as hazardous waste (flammable or containing hazardous components) requires transport by specialized companies
Preprocessing and Utilization Technologies
• Blending • Phase separation • Homogenization Main risks: chemical reaction, solidification, mixing of chlorinated solvents with non-chlorinated ones
Risk Identification: Environmental Implications and Operational Health and Safety Considerations
Equipment and regulations have to be compliant with regulation related to solvent management. Delivery: • Handling of drums: volatile organic compound treatment system for buildings and personal protective equipment adapted for workers Storage: • Steel storage tanks adapted for alkaline or acidic components • Fire protection systems • Pumping system locations that facilitate leakage collection

Typical Technical, Policy, and Financial Barriers
Technical barriers:
• Chlorine: potential presence of salts
• Flash point: potential presence of solvent traces
• Homogeneity of the calorific value of waste: potential phase separation of solvents
• Risk of exceeding the capacity of the steam removal fan
Solution: introduce the wastewater in the clinker cooler
Policy barriers:
• Complex permit procedure for hazardous wastes with possible opposition from the population
Recommended Policy Actions
Regulation that bans and controls the discharge of wastewater in rivers.
CAPEX and OPEX
• Unloading zone for trucks on concrete with collection of spillage
• Tanks in retention basin or double-envelope tanks
• Pumping system for unloading, stirring, and injection
• Filtration by auto-cleaning system or static system on the unloading line
• Electrical devices: must be designed with consideration of the flash point of the solvents (ATEX rules)
CAPEX: €1 million to €3 million depending on the flash point and size
OPEX: €5 to €10 per ton
Carbon Dioxide Mitigation Potential
Biomass concentration = 0%
Decrease nitrogen oxide production
Full replacement of fossil fuels

2.4 USED TIRES AND RUBBER WASTE

- Cement plants offer a perfect service for the recycling/recovery of used tires. Used tires are of interest for the cement process because of their high and constant calorific value, the possibility to recycle the steel as iron oxide in the clinkerization process, and the opportunity to reduce nitrogen oxide emissions at the stack.
- The critical step is collection, given that the resource is scattered across large areas.
- A cement plant can burn whole tires as well as shredded tires.
- The solution could be put into operation quickly; thus, co-processing is the rational first reponse to the problem of tire disposal in a country, offering significant capacity.
- As other solutions develop, the cost of used tires is increasing, making shredded tires more expensive compared to other waste segments.
- A 20 percent thermal substitution rate is achievable in cement plants with precalciners or preheaters. For a cement kiln producing 500,000 tons per year of clinker, this means 12,000 tons per year of whole tires.

Used Tires and Rubber Waste
Origin
• Used tires: tire production and replacement
• Rubber waste from the recycling process (tire cords)
• Other rubber waste: from conveyor bands, shoe production, etc.
Composition
• Chlorine: < 0.1%
• Sulfur: around 1.5%
• Moisture: 0% (but possible accumulation of water inside the tire during storage)
• Metal: iron: 10% to 15%, zinc: 1% to 2%, other: 1,000 to 4,000 ppm
• LCV: 26 to 28 gigajoules per ton (23 to 26 gigajoules per ton for truck tires)
Traditional Disposal/Usage Practices
• Retreading: 10% in developed countries, close to 0% in developing countries
• Material recovery: use in civil works or rubber recycling
• Energy recovery: mainly in cement plants
Supply Chains
Collection is the critical issue due to small quantities stored in garages, at tire retailers, or in companies managing vehicle fleets.
One solution is the creation of a specific network of collectors, which could be:
• The new tire distribution network
• The cement distribution network
If extended producer responsibility systems exist, responsibility for collection and treatment is given to producers.
Many countries have large stockpiles of used tires without official owners.
Preprocessing and Utilization Technologies
Shredding operation only
For large-size tires: extraction of the metallic structure or pre-cutting in large pieces

Risk Identification: Environmental Implications and Operational Health and Safety Considerations
Equipment and operations have to be compliant with environmental regulation related to used tires. The main risks are related to storage: • **Health risks:** mosquito presence (tropical countries) because of water accumulation • **Fire risks:** create several small heaps rather than one large one, use sand (or any high-density mineral) to block fire • **Other risks:** Health risks from handling large tires
Typical Technical, Policy, and Financial Barriers
Technical barriers: • Sulfur: limited impact • Management of whole tires: injection and impact on the process Financial barriers: • Competition with other energy recovery processes Policy barriers: • Application for a permit to use waste could be complex and could raise opposition from the population
Recommended Policy Actions
Collection facilitation: Implementing an extended producer responsibility system Ban on tire landfilling: use of tires in civil works would approximate landfilling and should be strictly controlled Favor material recovery
CAPEX and OPEX
Shredding line: • **CAPEX:** €1 million • **OPEX:** €15 to €40 per ton In the cement plant: Injection of entire tires (precalciner, back end) or injection of shredded tires • **CAPEX:** €1 million to €3 million • **OPEX:** €5 to €10 per ton
Carbon Dioxide Mitigation Potential
Biomass concentration = 25% to 30% Full replacement of fossil fuels

2.5 INDUSTRIAL SLUDGE

- Generally speaking, industrial sludge is a complex problem for waste producers. Because access of sludge to landfills and land spreading is limited, waste producers often use temporary lagoons as a solution.
- Co-processing offers a flexible solution by combining both energy and material recovery. It also is flexible from a physical point of view because of the capability of receiving liquid, pasty, or solid sludge. The technical evolution of pumping is bringing new flexibility to this solution, enabling it to now accept a wide range of viscosity.
- Considering the quality of the service and the low calorific value, the service must be paid for at the right price.
- This market segment is promising in many countries for a wide range of industries, such as refineries and chemical plants.

Industrial Sludge
Origin
Industrial sludge comes from the treatment of industrial effluent. There are two kinds of sludge: biological and physico-chemical. It also comes from tank, pipe, or canal cleaning operations (for example, sewers). The remediation of old lagoons or storage is also a source of sludge.
Composition
Composition can vary widely depending on the treatment process. Example of oil sludge (from refineries or drilling): • Chlorine: 0% to 0.5% • Moisture: 1,000 to 3,000 ppm • Metal: <1,000 ppm • Ash: 10% to 50% • LCV: 5 to 15 gigajoules per ton
Traditional Disposal/Usage Practices
A wide range of destinations given the potential variety of qualities. Typical destinations are: • Land spreading for inorganic sludge, respecting regulation on pollutant concentration • Landfilling for sludge with low moisture • Incineration • Onsite treatment

Supply Chains
Conventional trucks are used; for basic trailers, the risk of spillage must be managed
Preprocessing and Utilization Technologies
Mechanical drying in the sewage plant Thermal drying in the sewage plant or in the cement plant through use of waste heat from the kiln Mixing with adsorbents to produce a solid alternative fuel: • Sawdust or some wastes (with high adsorption properties) for organic sludge • Lime or limestone for oil sludge
Risk Identification: Environmental Implications and Operational Health and Safety Considerations
Equipment and operations have to be compliant with environmental regulation related to sludge, in some cases hazardous. The main risks linked to industrial sludge are: • Smell, mainly for biological sludge • Dust pollution in the neighborhood • Any chemical hazard linked to the presence of specific chemical or hazardous wastes in the sludge Prevention: personal protective equipment adapted to potential exposures
Typical Technical, Policy, and Financial Barriers
Technical barriers: • Variability of the calorific value and/or the ash content • Variability of the viscosity Financial barriers: • Competition with land spreading: cement plants are more flexible (can accept hazardous sludge) and their activity is not seasonal • Competition with incineration: cement plants do not need to dispose of ash • The cost of the adsorbent could make preparation costly (case of sawdust) Policy barriers: • Application for a permit to use waste could be complex and could raise opposition from the population
Recommended Policy Actions
Regulation on landfilling: • A clear regulation defining landfilling must be issued with regular controls • The rules for landfilling onsite prepared wastes must be clearly defined
CAPEX and OPEX
In the cement plant, in case of injection of pasty sludge: • Unloading pits • Feeding hopper • Concrete pump • High-pressure pipe to injection line • Special burner CAPEX: €1 million to €3 million OPEX: €10 to €20 per ton In the cement plant, in case of injection of dry sludge: • Unloading zone for truck • Vertical silo with explosion protection; in some cases, inertization possible • Extraction • Pneumatic injection CAPEX: €1 million OPEX: €5 to €10 per ton
Carbon Dioxide Mitigation Potential
Biomass concentration: variable Oil sludge: biomass = 0% Full replacement of fossil fuels

2.6 NON-HAZARDOUS INDUSTRIAL WASTE

- For the cement process, the non-hazardous industrial waste segment is valuable because it could guarantee large and constant quantities as well as quality. It also offers the advantage of creating a direct industry-to-industry relationship for the waste coming from industrial processes. A preparation step is mandatory, involving at a minimum a shredding line that could conclude with a drying facility; these investments could be shared between waste producers and cement plants.
- Industrial recycling operations produce wastes that also could be included in this segment. For example, the paper industry could be a good partner for cement plants.
- Packaging waste from industry is of much higher quality (in terms of calorific value, moisture, and chlorine) than the packaging waste extracted from municipal solid waste; however, recyclers also demand this higher-quality waste, presenting competition.

- Polluted packaging is of particular interest for cement plants. This category includes, for example, chemical packaging, oil packaging from garages, and fertilizer packaging. Separate collection of this segment is becoming mandatory to avoid the spread of pollution, and recycling of this waste is not possible. Shredding of the waste requires a facility that can manage potentially low-flash-point solvents, and special fire and explosion protections are necessary. The cement plant must apply for a hazardous waste permit. The service provided to the customer is paid to the cement plant; this gate fee could, at minimum, cover the preparation costs.

Non-hazardous Industrial Waste

Origin

This category covers various sources:

- Packaging wastes
- Process wastes such as pulper wastes in paper recycling industry
- Off-spec products and product falls
- Special category for packaging polluted with chemicals; same approach but including the chemical risks

Composition

Main industrial wastes:

- Chlorine: 0% to 2%
- Moisture: 10% to 20%
- Metal: 1,000 to 3,000 ppm
- LCV: 15 to 25 gigajoules per ton

Pulper wastes:

- Chlorine: 0.5%
- Moisture: 40% to 60%
- LCV: 6 to 12 gigajoules per ton (20 to 25 gigajoules per ton after drying)

Traditional Disposal/Usage Practices

- Recycling: a leading destination of these wastes when the wastes are made of mono-product
- Incineration: with or without energy recovery could be carried out internally and/or in a collective facility
- Landfilling: in waste producers' facilities or external facilities

Supply Chains

Different options for collection:

- Selective collection: source separation of the recyclable fraction, plus waste sorting
- Universal collection with transfer stations (especially for small and medium enterprises)

Preprocessing and Utilization Technologies

Preparation of SRF/RDF in dedicated facilities respecting regulations related to waste management:

- Sorting operation
- Drying of the waste

Risk Identification: Environmental Implications and Operational Health and Safety Considerations

Equipment and operations have to be compliant with environmental regulation related to municipal waste.

The main risks linked to industrial SRF/RDF are:

- Fire caused by fermentation: fire detection equipment
- Dust explosion: cleaning procedures

Typical Technical, Policy, and Financial Barriers

Technical barriers:

- Moisture and calorific value
- Chlorine
- Particle size
- Homogeneity

Financial barriers:

- Competition with landfilling due to low landfill gate fee
- Competition with incineration: incinerator fixed costs are expensive, so it must be operated at full capacity to be profitable. However, compared to existing cement plants, building an incinerator represents a higher investment.

Policy barriers:

- Application for a permit to use waste could be complex and could raise opposition from the population
- Regulation that bans any thermal usage: co-processing and recycling should be complementary (the former using the wastes of the latter)

Recommended Policy Actions

Competition with landfilling: the regulation must limit access to landfilling by technical restriction or taxation

Competition with incineration:

- Design of the incineration capacity must be strictly adapted to the needs of residual waste to be incinerated
- Priority should be given to existing equipment to increase the efficiency of waste management
- For polluted packaging, ban on mixing polluted (considered as hazardous) and non-polluted

CAPEX and OPEX
Shredding operations: • One-step shredding line (granulometry = 50 to 80 mm): CAPEX: €0.5 million to €1 million + civil works and utilities OPEX: €15 to €25 per ton • Two-step shredding line (granulometry = 20 to 35 mm): CAPEX: €1 million to €2 million + civil works and utilities OPEX: €20 to €40 per ton, plus cost of chemical management for polluted packaging **Cement facilities:** • For small capacity (1 to 5 tons per hour): CAPEX: €1 million to €2 million OPEX: €5 to €10 per ton • For bigger capacities (more than 5 tons per hour): CAPEX: €5 million to €15 million OPEX: €5 to €20 per ton
Carbon Dioxide Mitigation Potential
Biomass concentration = 25% to 50% Full replacement of fossil fuels

2.7 MUNICIPAL SOLID WASTE

- Municipal solid waste is produced everywhere in large quantities, and landfilling is becoming less of an option for municipalities because of increasing regulation and enforcement, existing landfills are at end of their capacity, and/or limited land availability.
- Municipal solid waste must be pretreated to produce a suitable alternative fuel (or RDF). The quality produced is suitable for precalciner injection. Because of the high cost of treating the waste for use in the main burner, this alternative fuel could become too expensive to be of interest for the main burner. Drying the material using waste heat from the cement process is an option to generate the quality required for use in the main burner.
- To offer waste treatment and disposal service to municipalities, different options are possible. One of the options is to locate the RDF platform in an existing landfill or transfer station and then to send the sorted burnable waste to the cement plant for final shredding. Full preparation of the RDF could be done in a dedicated location close to the municipal collection system.
- Creating a network of cement plants is critical to offer year-round service to the municipality and to properly manage the annual maintenance stoppage requirements of cement kilns.
- The use of RDF from municipal solid waste is a factor of integration of the cement plant into the local community.
- This segment is very promising for the development of co-processing.

Municipal Solid Waste
Origin
Municipal wastes are the wastes produced by citizen activities at home, in their offices, or in commercial areas. The scope of the wording "municipal wastes" could be different including (or not) commercial wastes, non-hazardous wastes produced by the industries, green wastes, cleaning wastes from the streets.
Composition

Composition varies widely depending on the distribution (vertical/horizontal housing, density of population), the districts of the city, the seasons, the organization of collection (selective or not, scavengers or not), the food standards of the city, etc.
Standard composition:
• Chlorine: 0.5% to 1.5%
• Moisture: 30% to 45%
• Metal: 2,000 to 5,000 ppm
• LCV: 8 to 10 gigajoules per ton
SRF/RDF:
• Quality for main burner
  • LCV: 20 to 25 gigajoules per ton
  • Moisture: < 15%,
  • Granulometry: 20 to 30 mm
• Quality for pre-calciner
  • LCV: 13 to 15 gigajoules per ton
  • Moisture: 15% to 25%
  • Granulometry: 50 to 80 mm
• Quality for pre-combustion chamber
  • LCV: 10 to 13 gigajoules per ton
  • Moisture: 20% to 40%
  • Granulometry: 100 to 200 mm

Traditional Disposal/Usage Practices
• Landfilling is the main destination • Incineration (with or without energy recovery) • Recycling is developing everywhere under the pressure of regulation and targets related to the circular economy

Supply Chains
• Selective collection: source separation of the recyclable fraction and sorting center • Universal collection with several transfer stations in big cities Collection and treatment responsibility: Municipalities or directly by citizens. Private sector may be involved.
Preprocessing and Utilization Technologies
Preprocessing in dedicated facilities and respecting regulations related to waste management: • Sorting lines associated with shredding: extraction of recyclables and organic/inert fraction and shredding of the combustible fraction • Mechanical biological treatment: production of SRF/RDF associated with compost production or methanization • Drying (biological or thermal): key point to produce alternative fuel acceptable in cement plant
Risk Identification: Environmental Implications and Operational Health and Safety Considerations
Equipment and operations have to be compliant with environmental regulation related to municipal waste. The main risks linked to SRF/RDF are: • Fire caused by fermentation: fire prevention systems • Dust explosion: frequent cleaning procedures
Typical Technical, Policy, and Financial Barriers
Technical barriers: • Low LCV and high moisture (in cement plant, only used in calciner) • Chlorine: sources are PVC and salt from food. Financial barriers: • Competition with landfilling due to low landfill gate fees • Competition with incineration: incinerator fixed costs are expensive, so it must be operated at full capacity to be profitable. However, compared to the use of existing cement plants, building an incinerator represents a higher investment. Policy barriers: • Application for a permit to use waste could be complex and could raise opposition from the population • Regulation that bans any thermal usage: co-processing and recycling should be complementary (the former using the wastes of the latter)
Recommended Policy Actions
Competition with landfilling: • The regulation must limit access to landfilling by technical restriction or taxation. • Policies to encourage proper waste disposal in sanitary landfill, enforce illegal dumping/burning, encourage diversion through recycling composting should also be considered. Competition with incineration: • Design of the incineration capacity must be strictly adapted to the needs of residual waste to be incinerated • Priority should be given to existing equipment to increase the efficiency of waste management Mixing of hazardous wastes, including household hazardous wastes, must be prohibited.
CAPEX and OPEX
Sorting line with a capacity of 250,000 tons per year: • CAPEX: €1 million to €2 million + €7 million to €8 million for biodrying • OPEX: €5 to €15 per ton depending on the fraction of recyclables and the market price Shredding line and cement facilities: same as for "Non-hazardous industrial waste"
Carbon Dioxide Mitigation Potential
After pretreatment, biomass concentration = 35% to 45% Full replacement of fossil fuels

2.8 MUNICIPAL SEWAGE SLUDGE

- The market for dried sewage sludge is of interest to cement plants.
- In terms of sourcing, the quantities produced are significant and constant.
- The co-processing of sewage sludge must be considered as a service to the community, with the gate fee accounting for the impact of water in the process and the low calorific value.
- Co-processing of sewage sludge offers an advantage by allowing for greater flexibility in the chemical composition of the material compared to land spreading.

Municipal Sewage Sludge

Origin

Sewage sludge is produced by sewage plants treating municipal or industrial wastewater.

The wastewater is cleaned by biological treatment. The pollution is concentrated in the sludge.

After biological treatment, the sludge could be dried by mechanical treatment (centrifuge or filter press) or by a thermal process.

Composition

Composition depends on the drying process:

- Chlorine: 0.5% to 1%
- Moisture: 40% to 60% raw, 5% to 20% after drying
- Metal: 1,000 to 5,000 ppm, special attention to aluminum and iron
- LCV: 2 to 3 gigajoules per ton raw, 10 to 15 gigajoules per ton after drying

Traditional Disposal/Usage Practices

Land spreading as fertilizer. Issues: pollutant concentration, seasonality, agronomic value

Incineration in different places:

- Sewage plant premises
- Municipal waste incinerator
- Power plant

Supply Chains

Conventional trucks are used (tankers for fluids or basic trailers); with basic trailers, the risk of spillage must be managed

Preprocessing and Utilization Technologies

Mechanical drying in the sewage plant

Thermal drying in the sewage plant or in the cement plant through use of waste heat from the kiln

Risk Identification: Environmental Implications and Operational Health and Safety Considerations

Equipment and operations have to be compliant with environmental regulation related to sewage sludge.

The main risks linked to industrial sludge are:

- Smell
- Dust in case of dry sewage sludge
- Any chemical or biological hazard

Prevention: personal protective equipment adapted to potential exposures

Typical Technical, Policy, and Financial Barriers

Technical barriers:

- Low LCV and high moisture

Financial barriers:

- Competition with land spreading: the cement industry activity is not as seasonal as land spreading.
- Competition with power plants or municipal solid waste incinerator: cement plants do not need to dispose of ash, other incineration processes need to be compliant with waste incineration

Policy barriers:

- Application for a permit to use waste could be complex and could raise opposition from the population
- Ban on phosphorus waste incineration (as in Germany)

Recommended Policy Actions

Regulation that limits land spreading to sewage sludge with a high potential agronomic value and a low pollutant concentration

CAPEX and OPEX

CAPEX:

- For pasty sewage sludge: same as for "Industrial sludge"
- For dried sewage sludge: same as for "Animal meal"

OPEX: €5 to €10 per ton

Carbon Dioxide Mitigation Potential

Biomass concentration: 100%

Full replacement of fossil fuels

2.9 CONSTRUCTION AND DEMOLITION WASTE

- The construction and demolition of buildings creates opportunities for waste co-processing. In most countries, the natural destination of this waste is landfills because of its heterogenous nature. Sorting is key to separating the different components of the waste to extract the burnable fraction. Although the concept of sorting is emerging in some countries, the economical equilibrium is still not stabilized in countries where the landfilling of inert wastes is inexpensive and not sufficiently controlled.
- Depending on the material used for construction, the burnable fraction of this waste can vary widely. Of greatest interest for alternative fuel are the shingles used for roofing in many countries. Windows and doors are of interest only if they are made of wood; plastic windows and doors made from PVC (polyvinyl chloride) are not compliant with cement plant specifications.

- For cement companies, which themselves are providers of materials for construction, becoming a player in this waste segment is an opportunity to implement the concept of a "circular economy." The use of sorted rubble as aggregate in concrete activity completes the concept.

Construction and Demolition Waste

Origin

Construction and demolition waste comes from:

- Building works
- Building deconstruction

Main characteristics:

- Huge heterogeneity
- Geographical dispersion of the sources

Composition

Depends strongly on local construction materials and deconstruction processes (selective or not)

- Chlorine: depends on PVC content
- Moisture: 5% to 10% for plastic wastes, 15% to 20% for paper and cardboard
- Metal: < 1,000 ppm

LCV:

- Plastic waste: 28 to 35 gigajoules per ton
- Paper and cardboard: 10 to 15 gigajoules per ton
- Mix of industrial wastes: 15 to 20 gigajoules per ton

Traditional Disposal/Usage Practices

- Landfilling: private or municipal landfills
- Backfilling in aggregates quarries or embankment (for pure rumbles)
- Material recovery: wood, concrete (aggregate), metals, etc.
- In some countries, sorting line to extract material with value on site or at a dedicated location

Supply Chains

If landfilling is restricted, collection is favored. Demolition and construction wastes are often collected in bins.

Preprocessing and Utilization Technologies

Sorting operations allow for extraction of different fractions: doors, windows, shingles, wood parts, plaster board, etc.

Shredding of the extracted fractions for alternative fuel production:

- Special attention to plastics because of PVC (risk of chlorine pollution)
- Hazardous wastes can be used in cement plants after shredding

Risk Identification: Environmental Implications and Operational Health and Safety Considerations

Equipment and operations have to be compliant with environmental regulation related to construction and demolition waste.

Special attention to:

- Chlorine
- Ash composition
- Appropriate and safe storage

Typical Technical, Policy, and Financial Barriers

Technical barriers:

- Reliable collection and sorting network: SRF/RDF production, sorting lines close to production places, etc.

Financial barriers:

- Competition with landfilling (the main destination)

Policy barriers:

- Application for a permit to use waste could be complex and could raise opposition from the population

Recommended Policy Actions

- Regulation that bans the landfilling of burnable wastes or mixed wastes
- Standard on aggregates must be revised to allow the use of the inorganic part as aggregate

CAPEX and OPEX

Same as for "Non-hazardous industrial waste"

Carbon Dioxide Mitigation Potential

- Wood fraction: biomass concentration = 100%
- Average wastes: biomass concentration = 10% to 50%
- Full replacement of fossil fuels

2.10 BIOMASS AND GREEN WASTES

- The opportunities in the biomass sector are multiple and heterogeneous but potentially highly volatile.
- Competition in this waste segment comes from many potential uses, including combined heat and power plants, methanization, livestock feed, and local heating. In some countries, the subsidization of green electricity offers an advantage to the power sector in use of biomass feedstocks.
- For agricultural or green waste, the sourcing is often local to maintain a competitive position, as transportation costs can make use of this waste uncompetitive.

- A strategic approach that includes the collection and transport of biomass and even agroforestry waste would give an advantage to the cement sector. Diversification of the biomass is a key factor to secure sufficient sourcing.

Biomass and Green Wastes

Origin

Agricultural residue categories:

- Field-based residues, coming from farming activities: stalks, straw, chicken litter, tops and leaves
- Process-based residues, coming from transformation processes: husks, bagasse, glycerin, sawdust

These wastes, especially the first category, are scattered over large territories.

Composition

Composition varies widely depending on the kind of waste. Some examples:

Coffee husk:

- Chlorine: < 0.5%
- Moisture: 10% to 20%
- Ash: presence of silica
- Grain size: < 15 mm
- LCV: 17 gigajoules per ton dry

Chicken litter:

- Chlorine: 0.4% to 0.8%
- Moisture: 15% to 30%
- Ash: 10% to 30%
- LCV: 10 to 13 gigajoules per ton

Glycerin:

- Chlorine: marginal
- Moisture: 5% to 10%
- Ash: 0%
- LCV: 25 to 35 gigajoules per ton

Traditional Disposal/Usage Practices

Burning on-site: small quantity and field-based residues.

- Ashes used as fertilizer
- Prevent the spread of diseases

Cattle feeding: directly or after transformation

Energy recovery: an important destination for these wastes, considering the calorific value

Supply Chains

For crop wastes, collection is a key point. Two parameters must be considered:

- Low density: 0.1 tons per m^3 or less
- Resource dispersion: small quantities and large areas.

Collection could be optimized by implementing transfer stations. The stations must be managed properly to avoid exposure to rain.

Preprocessing and Utilization Technologies

- Physical modification: grinding and pelletization
- Moisture reduction: solar or thermal drying (the latter is possible in the cement kiln)
- Calorific value concentration: carbonization and roasting

Risk Identification: Environmental Implications and Operational Health and Safety Considerations

Storage must be managed properly to avoid:

- Rodent infestation
- Fire caused by direct inflammation or fermentation
- Flying dust that could pollute the neighborhood

Typical Technical, Policy, and Financial Barriers

Technical barriers:

- Low LCV: mitigated by drying, torrefaction, or carbonization
- Collection: could be managed by cement plant team
- Low density: storage and handling facilities should be adapted to big quantities
- Ash concentration in biomass (20% to 50% on dry): low LCV, chlorine concentration (1% to 5% on dry), silica concentration, etc.

Financial barriers:

- Competition with energy recovery for internal uses: low yield, poor-quality emissions
- Competition with energy recovery for external uses (power stations): high financial investment, high biomass quantity needed

Advantages of cement plant: high energy efficiency, no ash, localization near production sites, low financial investment

Recommended Policy Actions

Ban biomass burning directly in the field

Promote safe usage of biomass

Develop network of information centers for the farmers

CAPEX and OPEX

Same as for "Non-hazardous industrial waste"

Carbon Dioxide Mitigation Potential

Biomass concentration = 100%

Full replacement of fossil fuels

2.11 ANIMAL MEAL

- Cement plants were the main destination for potentially tainted animal meal during the "mad cow" crisis of the 1980s and 1990s. Following reorganization of the treatment chain, animal meal is now returning to its initial destinations, and only small fractions remain in co-processing.

- The market for animal meal is a spot market, making it necessary to set up handling and storage facilities that are compatible with different waste streams, as is also the case for biomass and dried sewage sludge.

Animal Meal

Origin

Animal meal is produced in rendering plants, which are in charge of managing waste from cattle, slaughterhouses, and meat production.

Regulation defines quantity authorized to be used for energy recovery. Authorized categories depend on the risk of disease outbreaks.

Composition

- Chlorine: < 0.5% depending on the cleaning strategy in the rendering plant
- Moisture: 10% to 20%
- LCV: 15 to 17 gigajoules per ton

Special attention to fat concentration: if fat > 15%, then risk of clogging in cement plant

Traditional Disposal/Usage Practices

- Traditional destination is the feeding of different species of animal or fishes after the animal meal is certified free of disease
- Use as fertilizer, given the high agronomic value
- Energy recovery is the main destination in case of health crisis (for example, the "mad cow" crisis) or in case of ban from other uses for overproduction reasons

Supply Chains

Transportation:

- Most convenient solution is tanks (and silo storage at production sites)
- Trailers could be used, but this requires more complex facilities in the cement plant: hopper and transfer to silo

Preprocessing and Utilization Technologies

Preprocessing is performed in rendering facilities

Recommendation: no preparation step in the cement plant

Risk Identification: Environmental Implications and Operational Health and Safety Considerations

Storage must be managed properly to avoid:

- Rodent infestation
- Fire caused by direct inflammation or fermentation
- Explosion because of flying dust: silo design must be adapted
- Hopper must be located in a building to avoid contact with water and outside dissemination of smell

Typical Technical, Policy, and Financial Barriers

Technical barriers:

- Resource quantity can vary widely depending on authorizations or bans during crisis (for example, mad cow)

Policy barriers:

- Application for a permit to use waste could be complex and could raise opposition from the population

Recommended Policy Actions

Fundamental role of regulation:

- Clear definition needed of the different qualities as well as the allowed destinations
- Strong enforcement also required for the whole chain from animal wastes to the final destination.

CAPEX and OPEX

Facility required is a silo and an injection line to the main burner:

CAPEX: €0.5 million to €1 million

OPEX: €5 per ton

Carbon Dioxide Mitigation Potential

Biomass concentration = 100%

Full replacement of fossil fuels

KEY SUCCESS FACTORS FOR ALTERNATIVE FUEL PROJECTS

3

The success of an alternative fuel project depends on a combination of several key factors, which can be either powerful levers or prohibitive barriers depending on how well or poorly they are controlled. Those key factors are discussed below, followed by a special focus on municipal waste.

3.1 SUCCESS CRITERIA FOR ALTERNATIVE FUEL PROJECTS

- Probably the most important factor in the success of a co-processing project is the **commitment of management**, starting with the cement plant manager. It is fairly easy for an unmotivated management team to argue that substitution of fossil fuels is not possible or entails additional and prohibitive costs. The management team must leave its comfort zone and understand that the use of waste as fuel is primarily a service offered to waste producers. This practice is not comparable to the traditional procurement process for fossil fuels.
- The use of waste in cement plants has been, and still is, the subject of numerous attacks by specialized incinerators. Opponents of co-processing highlight unfair competition because of different levels of investment, and they engage in **lobbying** to support regulatory barriers against co-processing. The cement sector has had to organize itself to tackle these barriers. If this issue has mostly been addressed in industrialized countries, the **capacity of cement plants to respond to regulatory changes** in countries that do not yet have co-processing remains a key success factor. Downstream of the regulatory framework, **permitting the use of waste as alternative fuel** is often a long and complex process that needs to be managed.
- The establishment of **transparent dialogue and trust relationships with stakeholders**, particularly local residents, is crucial for the success of a project. Local residents have the right to understand the implications (especially for pollution, health, and safety) of waste treatment in a cement plant located close to their homes. Such an approach should be based on regular exchanges between the cement plant and the surrounding community.
- The success of a project requires a **good knowledge of the various waste sources that are available at a competitive price**. It therefore is imperative to **analyze and understand the market** in the country. The selection of wastes should not be based on the experience and technical know-how of cement manufacturers. This analysis should include an economic assessment that allows cement producers to define how to approach the market. Cement producers often have the choice to develop their own supply or to partner with one or more players already in the waste sector.
- All cement plants are not equal in their ability to replace a significant portion of their fossil fuel use. The type of process, quality of the raw material, nature of the fossil fuel used, and behavior of the kiln all have a direct influence on the feasibility of a project. **Understanding phenomena and process control** are key success factors. Some cement kilns are not able to achieve the substitution rate specified for a project. Analyzing the kiln's ability to replace its fossil fuel is a precondition of any project.
- **Control of waste pretreatment** is critical to the quality and regularity of alternative fuels. For instance, a poorly controlled liquid mixture can result in large variations in calorific value. It therefore is imperative that the **operator of a pretreatment facility** manage its production with a strong knowledge of the constraints of the cement kilns that it supplies. Similarly, the cement producer must be familiar with delivery check techniques as well as the unloading, storage, and handling of waste. The **quality of dialogue between the two actors** is key to the success of the operation.

4 FOUR CASE STUDIES OF ALTERNATIVE FUEL USE

The presented case studies were selected based on their relevance to the Brazilian cement sector as expressed by the leading cement players in the country.

4.1 MUNICIPAL SOLID WASTE

4.1.1 COMPOSITION OF MUNICIPAL SOLID WASTE

The composition of municipal solid waste depends on the following factors:

- The scope of waste collection in a given city, including waste produced by:
  - The general population
  - Shopping malls and other commercial areas (more packaging means more recyclables and higher calorific value)
  - Technical workshops that provide services to the population, such as automotive garages, maintenance and repair shops, and restaurants (with related risk of hazardous wastes)
  - Industrial zones with small and medium enterprises (more packaging means more recyclables, higher calorific value, and risk of polluted wastes).
- The waste collection logistics, for which two main approaches exist:
  - Universal collection
  - Selective collection for recycling and other uses (in the case of packaging waste, the material that remains after collection will have a lower calorific value, and in the case of green or organic wastes, the portion that remains will have less moisture content).
- The structure of the city and its suburbs (horizontal or vertical density structure).

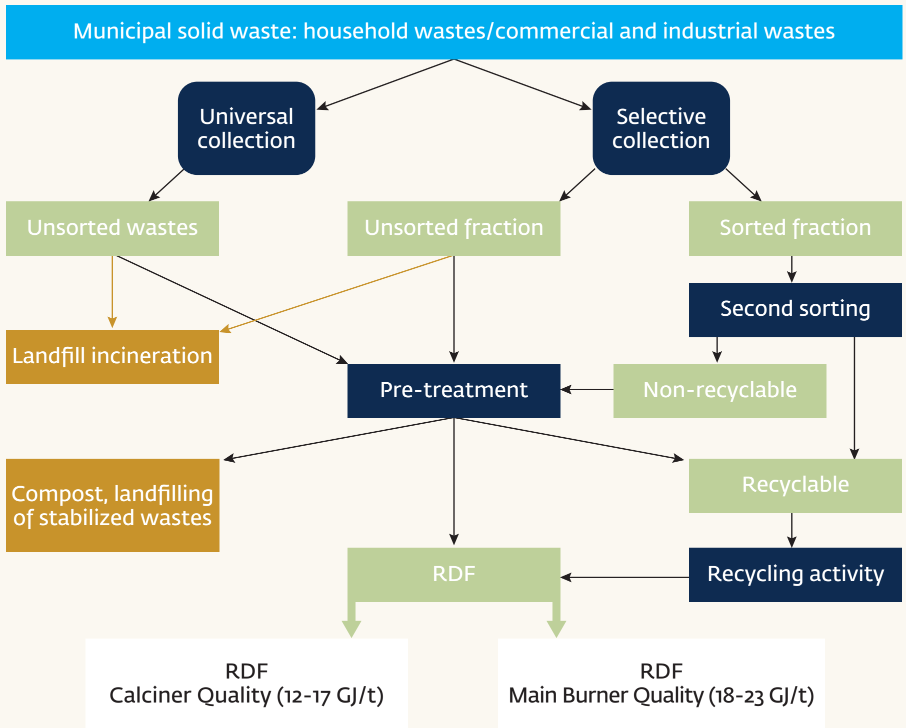
POSITIONING OF CEMENT PLANTS IN THE MUNICIPAL SOLID WASTE SEGMENT

Cement plants could offer a service for waste management through the preparation of refuse-derived fuel (RDF) (also known as solid refuse fuel (SRF) or solid shredded wastes (SSW)) or Process Engineered Fuel (PEF) out of some fraction of the municipal solid waste.

The positioning of cement plants could vary depending on how the waste is collected (see Figure 27):

- In the case of universal collection, RDF preparation will start with a sorting line to extract first the recyclables and then the combustible fraction. The extraction of the combustible fraction is performed either by a negative collection means (removing the biodegradable fraction and fine particles with a sieve, with the remainder going to RDF production) or by a positive extraction means (manually extracting the fraction for RDF production, with the rest going to landfill or incineration).
- In the case of selective collection, the extracted fraction is sent to a second sorting operation to further separate the materials (such as paper, plastics, textiles, cardboard); the remaining fraction often presents a calorific value favorable to RDF production. The remainder after selective collection is treated the same way as for universal collection, but without sorting of recyclables, only negative or positive selection to extract the burnable fraction.
- It should be noted that recycling activities also produce wastes with a high calorific value for the production of RDF. Close association with these activities is therefore of interest.

Figure 27: Schematic Definition of the Collection and Sorting Systems Leading to RDF Production



Source: Sofies AS.

4.1.2 QUALITY OF REFUSE-DERIVED FUEL

Considering the low calorific value of raw municipal solid waste, the selection of the waste used to produce RDF is a key point, and there are possibilities to create different qualities of RDF suitable for different injection points in the cement kiln.

Usually, cement companies consider two qualities defined by the calorific value and the granulometry:

- **RDF for the calciner** (calorific value: 12 to 17 gigajoules per ton; granulometry: 50 to 80 millimeters)
  This quality is the most important and could be produced after stringent selection and sieving without drying but will represent a limited fraction of the source (25 to 35 percent). In the case of drying (thermal or biological), production of this quality could reach 50 percent of the input.
- **RDF for the main burner** (calorific value: 18 to 23 gigajoules per ton; granulometry: 20 to 35 millimeters)
  This quality will be limited and will require either a significant fraction of commercial and industrial waste and/or refuse from recycling operations or a drying operation.

A new technology is emerging in the cement process that would enable the kiln to receive very low-quality RDF. This technology is based on installing a pre-combustion chamber before the calciner to burn the waste before it is introduced into the process. This pre-combustion chamber could be based on a rotary sole or step burning, as in a waste incinerator. This technology is aimed at receiving wastes with low calorific value (10 to 13 gigajoules per ton) and larger size (up to 300 millimeters), which would greatly reduce preparation costs. Several pilots are now in industrial operation.

4.1.3 PREPARATION OF MUNICIPAL SOLID WASTE

A cement plant will have several options for starting co-processing using municipal solid waste. Among these, we have selected three that could be considered as key steps of development: the pilot step, the development step, and mechanical and biological treatment. For these examples, we assume the production of 500 kilotons of RDF per year.

PILOT STEP

This step is focused on the production of RDF from municipal solid waste (see Figure 28). The quality of the fuel is obtained through strict selection of the waste in order to implement a process that is as simple as possible to produce the RDF in the context of a low gate fee for the waste. This pilot step would include a sorting line (with bag opener) to extract those recyclables that have a market value and then engage in negative or, even better, positive selection to extract the combustible fraction of the waste. The combustible fraction is sent to a shredding line comprising one or two steps of shredding with a sieving machine and an over-band magnet conveyer to extract the larger parts and metallic pieces.

With this process, the RDF will have a calorific value of about 15 gigajoules per ton and a particle size of 80 millimeters. The quantity produced will represent between 10 and 25 percent of the raw municipal solid waste.

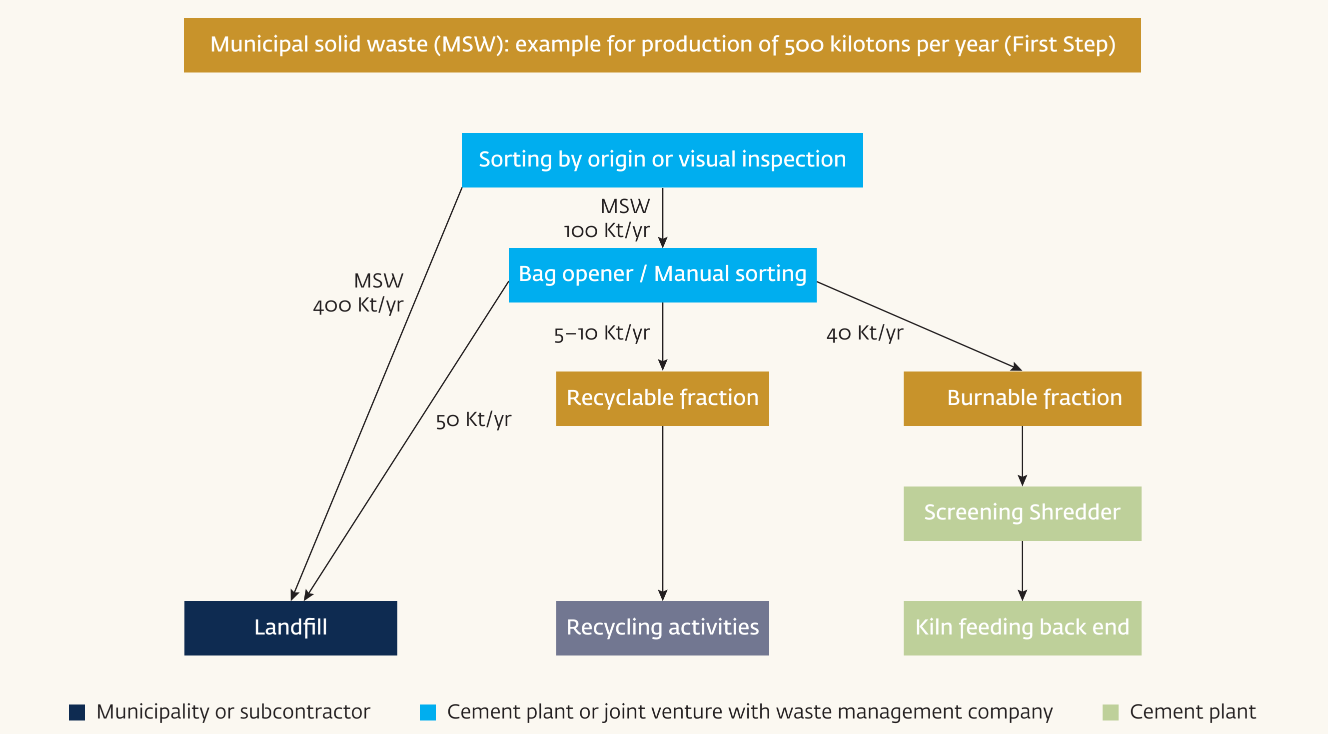
The sorting operation could be performed at the landfill that initially receives the municipal waste, to reduce transport costs. The fraction could be shredded on-site or in the cement plant.

DEVELOPMENT STEP

This option is aimed at obtaining larger quantities of RDF and preparing the two alternative fuel qualities that are usable in a cement plant (see Figure 29). This preparation is compatible with other waste management solutions, such as a waste incinerator, a composting plant, or a landfill. The preparation would start with the selection of trucks based on the different collection routes. Depending on the collection logistics, it could make sense to set up an initial separation step to extract the large pieces in instances where more potential recyclables are present. This fraction is sent to a sorting line to extract the recyclables that can generate revenue for the treatment chain.

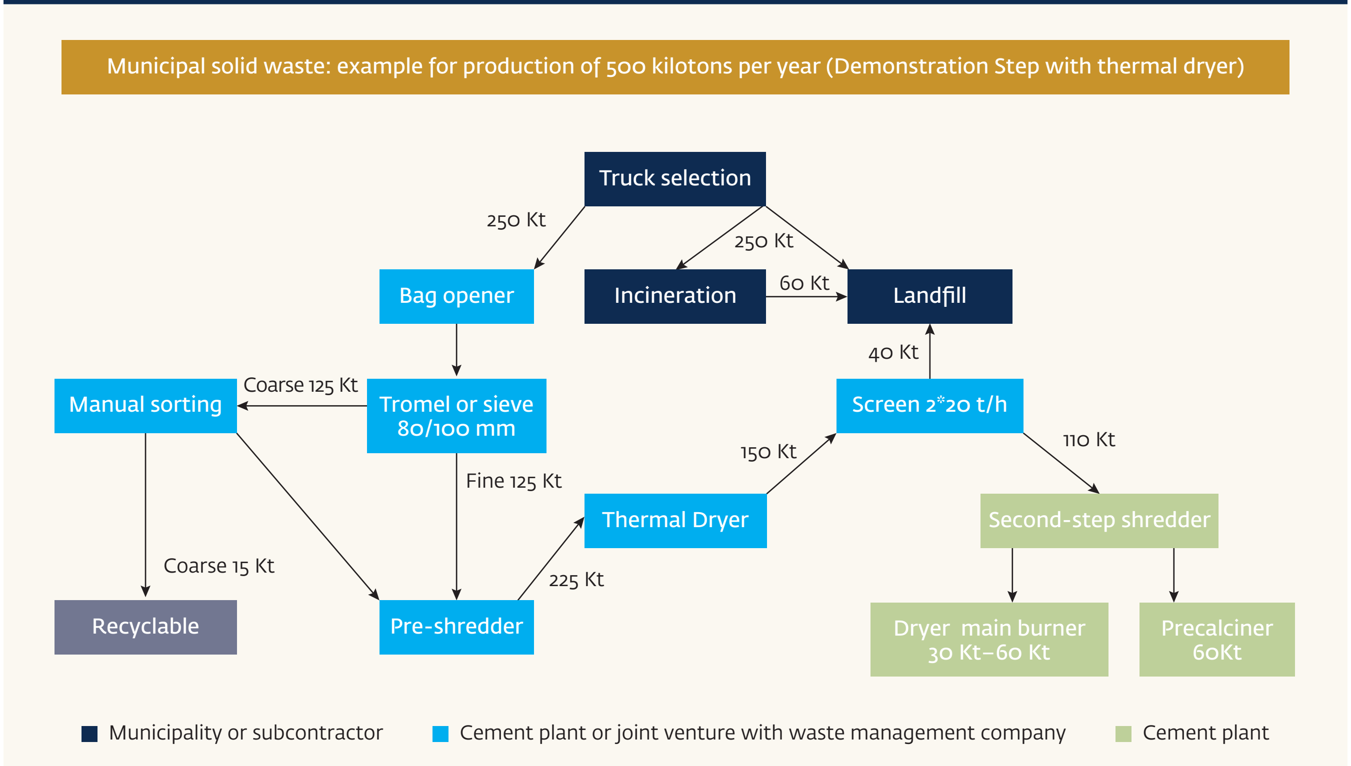
To produce the two RDF qualities important for the cement plant, and considering the moisture content of the waste, a drying operation is required. The drying operation is more efficient with shredded waste, and pre-shredding could take place before drying. The drying operation could be thermal or

Figure 28: Schematic of the Sorting System for the Preparation of Municipal Solid Waste



Source: Sofies AS.

Figure 29: Schematic Showing the Preparation of Municipal Solid Waste with Thermal Dryer



Source: Sofies AS.

biological, with the former requiring a source of energy but less volume, and the latter requiring more volume, given the time required for the bacterial activities. After drying, a sieve is helpful to extract the inert fraction to be sent to landfill.

The waste must be submitted to a second step of shredding, mainly to provide the quality of material necessary for use in the main burner. The calorific value required for the main burner will be secured, just before feeding the main burner, by a simple belt dryer using the waste heat of the kiln.

MECHANICAL AND BIOLOGICAL TREATMENT PLANTS

The mechanical and biological treatment plant (MBT) will treat the entire volume of municipal solid waste. Cement companies are not typically motivated to adopt this process, as RDF is only one of the potential outputs of the process; one potential exception is the case of a cement plant using a quarry as a landfill for stabilized wastes in the context of quarry rehabilitation.

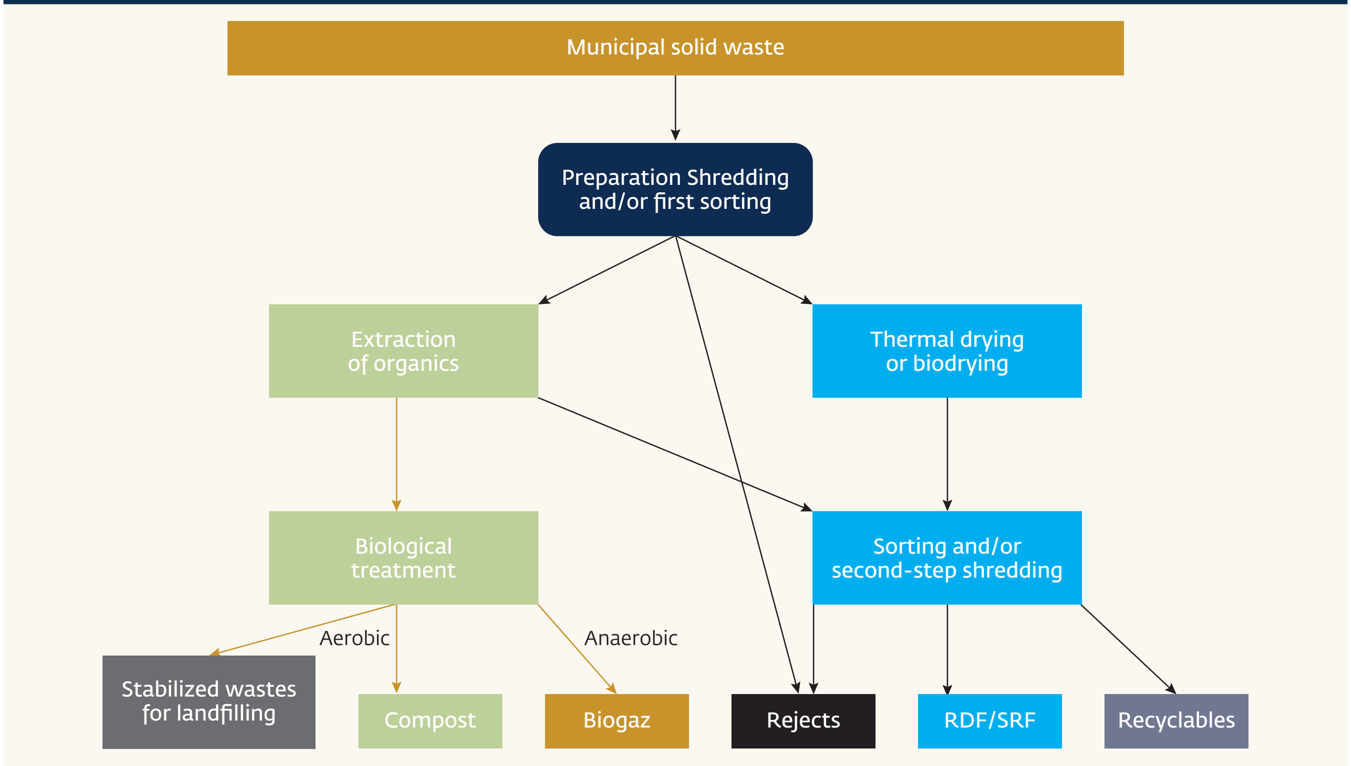
There are several concepts of MBT plants. The initial idea is to optimize the separation of the different constituents of municipal solid waste into four parts: recyclables (paper, plastics, metals, textiles), organics (food rejects, green wastes), combustibles (mixed materials or materials with high moisture content or without an attractive selling price), and inerts (ash, bricks, stones). The distribution of the fractions depends on the composition of the waste and on the availabilities of the outputs.

After the initial sorting steps, two treatment lines occur (see Figure 30):

- A mechanical line to prepare the RDF and extract the recyclables, and
- A biological line to prepare the compost through aerobic treatment or, less commonly, to prepare biogas through anaerobic treatment.

The bio-drying also could be included in the first step. Then, sorting is done to extract the organic fraction. In the case

Figure 30: Schematic of Biodrying Process for Municipal Solid Waste



Source: Sofies AS.

of no outlet for the compost, because of its low quality or its non-compliance with land spreading, the biological treatment is simplified as stabilization to make the waste compatible with landfill regulation.

4.1.4 BUSINESS MODELS

The involvement of the cement company in RDF production depends on the strategy of the cement company and on the quality of the relationship created with the operator of the preparation step and/or the municipality. The cement company will consider **the sustainability of waste sourcing** in terms of quantity and quality. In some countries, contracting provides sufficient confidence to the cement company: the contract must set the technical and economic conditions as well as guarantees on the outputs. In other countries, the cement company prefers to be involved in pretreatment to have strong control over the quality; in some cases, even the final shredding will take place at the cement plant to allow the plant to maintain the flexibility needed for different sources of RDF (where it makes sense to separately collect non-polluted industrial and commercial waste alongside municipal solid waste). The cement company's involvement could be managed by the creation of a joint venture with a waste operator, by sharing some investment, or through the delegation of a quality/production manager inside the preparation platform. Additionally, involvement of the cement company in the RDF production entity can make the deal more bankable for financing, as offtake arrangements can be stronger and longer term.

The **continuity of the service** offered by the cement plant is also a critical topic. Municipal solid waste must find a year-round destination. To manage the waste stream during annual kiln stoppages for maintenance, possible solutions including forming a network of cement plants; sharing the waste volume with another buyer, such as incineration; and landfill or storage in bales in the case of a short stoppage period.

Management of the informal sector could be critical to the success of the RDF production concept. Involving the informal waste pickers in the advanced RDF production, along with municipality or a waste management company/

RDF producer by offering formal employment in the sorting lines could be a win-win solution, which can improve the working conditions dramatically.

4.1.5 CONDITIONS FOR AN ALTERNATIVE FUEL PROJECT USING MUNICIPAL SOLID WASTE

The success of an alternative fuel project depends on a combination of criteria, including existing regulations on waste and industry, economic factors, technical knowledge, and good cooperation between different industrial sectors and public institutions.

As discussed previously, for municipal solid waste, one of the most promising waste segments, the following criteria will contribute to a successful project associating a municipality and a cement plant.

CRITERIA FROM THE MUNICIPALITY SIDE

- The existing waste disposal site is a landfill that has a significant[4] gate fee (including transfer and/or transport costs).
- Municipality is creditworthy and/or has a history of on time payment to the private sector for waste or other infrastructure services.
- The municipality is facing difficulties in or the impossibility of opening new landfills or increasing the capacity in existing ones.
- The municipality is in charge of waste collection and disposal, even if the execution of these tasks is subcontracted.
- The contract with the landfill operator presents no incentive (direct or indirect) to increase the quantity of waste landfilled and/or is open to possibilities for renegotiation.
- A piece of land is available for the creation of a sorting line somewhere either at the landfill or at a transfer station.
- There is a strong willingness to develop recycling in cooperation with the existing organization responsible for recycling (waste pickers or at the landfill).
- There are potential buyers for recyclables at attractive prices.

CRITERIA FROM THE CEMENT PLANT SIDE

- The cement plant is not sold out for clinker production.
- The cement plant offers a capacity to absorb extra quantities of chlorine (and sulfur).
- The cost of the fossil fuel is high enough to motivate the use of alternative fuels, or the alternative fuels are cheaper than traditional fossil fuels.
- The cement plant management shows a strong willingness for technical development of alternative fuels.
- There is no existing conflict with stakeholders of the cement plant.
- The cement company is willing to pay a reasonable price and price adjustments for the RDF at the specification level, with sufficient contract term.

The proximity of the city and the cement plant also helps to create the conditions for a viable project. These criteria may include, for example:

- A city with between a half million and 1 million inhabitants;
- A cement plant with a kiln capacity of at least 1 million tons per year;
- Distance between the city and the cement plant of less than 100 kilometers.

4 In many emerging markets, a "significant" gate fee may not be available. However, that does not mean that an RDF production facility cannot be considered. Simpler, lower CAPEX approaches may be required, or a plan needs to be in place to increase the tipping fee.

4.2 SEWAGE SLUDGE

4.2.1 DESCRIPTION OF MUNICIPAL SEWAGE SLUDGE

Sewage sludge is produced by water treatment facilities that collect the wastewater from a city's sewers, including from local industries and in some cases from small and medium enterprises. The wastewater is treated through physical and biological methods, and the organic content is concentrated in sludge that is submitted to biological treatment to enable degradation of any pollutants.

Historically, treatment ended at this stage, and the most common destination for the sludge was land spreading, which is still widely used in small cities that have nearby fields and where farmers are available to accept the sludge. However, these conditions are becoming more difficult to find in many countries, and sewage plant operators are now forced to seek alternative solutions by decreasing the volume of municipal sewage sludge and extracting more value from it.

The sludge could be treated using varying solutions:

- Anaerobic Digestion (AD)[5] to produce methane that is used to generate power and also used directly in thermal engines
- Composting mixed with organic wastes to increase its possible use as fertilizer
- Drying to reduce the volume and to concentrate the calorific value
- Incineration to reduce the volume and to produce heat.

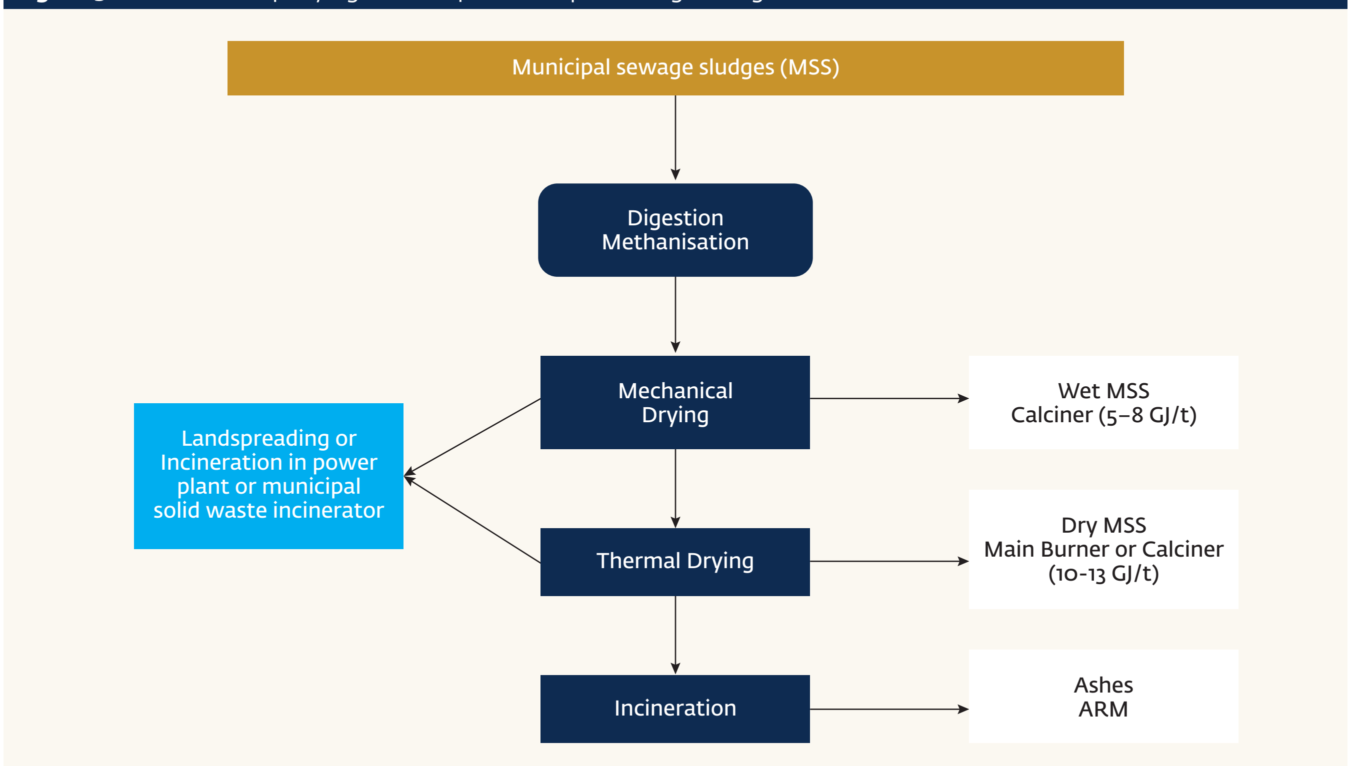
4.2.2 POSITIONING OF CEMENT PLANTS IN THE MUNICIPAL SEWAGE SLUDGE SEGMENT

Cement plants could offer a service for sewage sludge management at different stages of its production, with varying interests and uses in the cement process as follows (see Figure 31):

- **The sludge produced after mechanical drying via a filter, screw, or centrifugal press:** Because the moisture content is still high, the calorific value is low. As a consequence,

5 Bio-methanization usually refers to the process of producing methane through AD and cleaning it up to natural gas specification levels.

Figure 31: Schematic of Drying Process for Municipal Sewage Sludge



Source: Sofies AS.

the quantity is limited (1 to 5 tons per hour), and the cement plant must be paid for providing this service.

- **The sludge produced after thermal drying** (in some countries, it could be solar drying): The lower moisture content of the dried sludge has a lower negative impact on the kiln process. The quantity could be increased to 10 tons per hour, provided that the impact of the ash is managed. The cement plant can be used as a key destination for a municipality. The transport cost also would be substantially lower.
- **The ash from a sewage sludge incinerator:** The potential use of this ash in cement plants is limited to its use as an alternative raw material, provided that the composition is compatible with the raw mix composition of the cement kiln.

Generally speaking, cement plants are not interested in raw sludge that has not undergone mechanical drying (via filter press). The quantity that is usable in a cement plant is marginal compared to the quantity produced; a community cannot be interested in this service except in the case of a small village where the cement plant is located. In addition to a gate fee, which is expensive given the high moisture content of the waste, the transport cost is becoming too high for transporting what is considered to be mainly water.

4.2.3 QUALITY OF MUNICIPAL SEWAGE SLUDGE

The quality of municipal sewage sludge is linked to the process used in the sewage plant (see Table 3).

Digestion could reduce **the calorific value** of the sludge. Methanization introduces a decline in the calorific value, making the sludge less appealing for cement plants.

The concentration of **heavy metals** must be controlled. The sewage plant potentially could receive wastewater with a high concentration of metals from local industries involved in metal finishing or leather treatment.

Management of **the smell** must be taken into consideration during the design of the facility within the cement plant. The risk of smell is much higher in the case of wet municipal sewage sludge.

A new concern is emerging about **the phosphorus** concentration of municipal sewage sludge. Germany plans to ban the incineration of sewage sludge that has not undergone phosphorus extraction.

Dried municipal sewage sludge could be produced as a powder or pelletized. Pelletization is making transport easier (in traditional trailers versus tanks for powder), but a grinding step (via hammer mill) often is mandatory to guarantee good burning conditions as the material is injected into the main burner.

4.2.4 PREPARATION OF MUNICIPAL SEWAGE SLUDGE

Internationally, a few cases exist of cement plants installing dryers that use the waste heat from the kiln. This concept has been implemented in Germany, where the gate fee for wet municipal sewage sludge is expensive and where several

Table 3: Type of Municipal Sewage Plant Affects Quality

Type of Sludge	Calorific Value (gigajoules per ton)	Water Content (percent)	Other Characteristics
Wet	0–5	30–50	Ash: 5% to 10% Phosphorous: <1% Chlorine: <0.2%
Dried	10–13	5–10	Ash: 20% to 25% Phosphorus: <1% Chlorine: <0.2%
Ash	0	0	Inorganic composition: silicon dioxide; aluminum oxide; iron oxide; trace elements such as zinc and copper

Source: Sofies AS.

medium-size cities are looking for an alternative to land spreading.

Technical solutions in the cement plant have been developed for wet and dry municipal sewage sludge, and for ash, as follows:

WET SLUDGE

The wet sludge (mechanically dried) can be injected at the back end of the kiln. Considering the viscosity of the sludge, pumping must be undertaken using a concrete pump that is adapted to sludge. The pipe must be designed to manage high pressure. Storage could be in a rectangular silo with an extracting screw at the bottom feeding a piston pump (see Figure 32).

DRY SLUDGE

The facility for dry municipal sewage sludge comprises:

- A reception hopper, screw conveyor, or bucket elevator
- A weigh belt
- A silo for management of dust and explosion risk
- Pneumatic transport to the calciner or main burner (for pellets, a grinder is recommended).

This kind of facility has the flexibility to receive different types of waste in pellet or powder form, provided that the silo design takes into consideration dust management and explosion risk. It is usable for sawdust, animal meal, black carbon, and rubber dust/granules.

ASH

The ash can be mixed directly into the raw mix.

4.2.5 BUSINESS MODELS

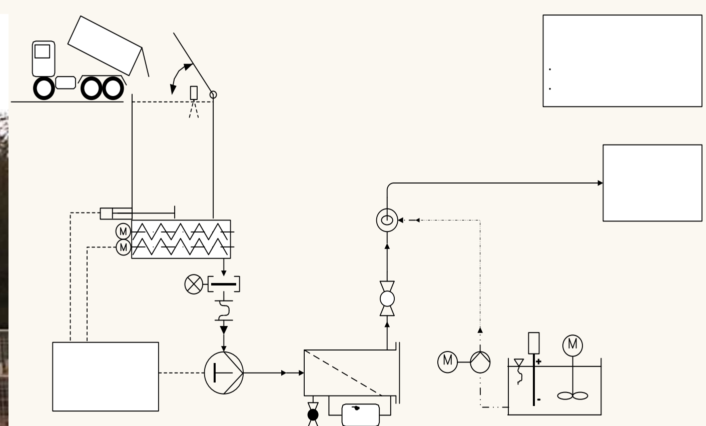
The decision-making process in the municipal sewage sludge segment is often complex and lengthy, and municipalities often ask for **long-term commitments**. This represents an advantage for cement plants in terms of sustainability of sourcing and amortization of the requested investment in the plant; however, pricing must take into consideration the potential evolution of the waste market, with smart revision systems.

The **continuity of the service** offered by the cement plant is also a critical topic. Municipal sewage sludge must find a destination year-round; to manage the waste stream during annual kiln stoppages for maintenance, options including creating a network of cement plants and sharing the sludge resource with another solution, such as incineration or landfills.

4.2.6 EXTENSION TO INDUSTRIAL SLUDGE

All industries must manage their wastewater and could operate wastewater treatment plants. If biological treatment is performed, which is common in the chemical, pharmaceutical, and agro-industries, the industrial sludge produced could

Figure 32: Picture and Schematic of Sewage Sludge Processing Unit



Source: Document Putzmeister/Lafarge.

be used in a cement plant in the same facility that uses wet municipal sewage sludge. Refineries and steel industries produce oil sludge that also is compatible with such facilities. Industries often pay a lower gate fee than municipalities because alternatives such as land spreading frequently are not allowed for industrial sludge, but the contracts are often of shorter duration than for municipal sewage sludge.

A mixture of these two different sources would provide cement plants with greater comfort in the sustainability of their sourcing.

4.3 BIOMASS

4.3.1 DESCRIPTION OF BIOMASS WASTE

Many different potential sources of biomass waste exist, such as sugarcane straw, coffee husks, and food oil waste. These can be divided among the three categories of waste discussed earlier: field-based sources, process-based sources, and waste sources (see Section 5.2). Because biomass waste is made of 100 percent renewable organic matter, it has high potential for mitigating carbon dioxide emissions from the cement industry.

However, some challenges remain:

- **Heterogeneity**: For each residue, the quantity and quality can vary widely because of different characteristics such as crop or animal variety, weather, and farming region.
- **Geographical dispersion**: Biomass waste sources often are dispersed over large territories, making collection expensive.
- **Seasonality**: Because most agricultural residues are produced only during harvesting periods, this could be an issue for a cement plant that needs a year-round energy supply.
- **Existing competitive uses**: Most of the time, biomass wastes already are used locally for energy purposes, for livestock feed, or as fertilizer. Even if using them in the cement industry may be more efficient, other competitive uses exist.
- **Profitability**: The profitability of a biomass-based project depends strongly both on the carbon price and on the fossil fuel price. Given the current low prices of both carbon and fossil fuels, biomass projects could be impacted.

Despite these barriers, biomass waste remains of interest for supplying energy in the cement industry. As seen in Section 2.2.4, biomass alternative fuels are used widely in cement plants, substituting completely for costly fossil fuels that release carbon dioxide to the atmosphere. Experience has proved the real feasibility of using biomass as an alternative fuel in cement production.

This section will describe some of the critical points for implementing pilot projects using agricultural residues in the cement industry.

4.3.2 POSITIONING OF CEMENT PLANTS IN BIOMASS SOURCE COLLECTION

First, it is important to identify the production areas for this resource, as biomass waste or residue production tends to be concentrated in specific regions.

Secondly, it is important to quantify and evaluate the local waste sources. Because local biomass sources already may be used for local purposes, these competitive uses and the owners of the production sites need to be clearly identified.

- Coffee production:
  - In Brazil, there is one harvesting season, which covers May to August for Robusta and Arabica. It should represent about four or five months of coffee husk supply for a cement plant.
  - Weather, especially rainfall, can greatly affect coffee production and thus the stability of the resource. A severe drought in 2015 sharply reduced Brazilian coffee production.
- Sugarcane production:
  - In Brazil, sugar cane (and the associated residue) is produced nine months a year. Cement industry activity stops one month a year for maintenance. With storage infrastructure adapted for two months, cement plants could be supplied with sugarcane residues year-round.
  - Although bagasse is used as a fuel for steam generation (see Table 4), this energy potential

remains under-exploited. Moreover, some sugar producers do not consume all of the bagasse they produce, selling the surplus to other users.

- The sugarcane tops and leaves (sugarcane straw) appears to be relatively unused, with most of it disposed of in the field. Assessments suggest that, at most, only 50 percent of the straw is required to maintain the soil's agronomic value.

Finally, a collection network can be implemented. Collection is the most critical step and needs to be studied carefully to tackle the main challenge: potentially high collection costs. Collection expenses can be high because of scattered resources and low biomass density. The two means of collection are local collection and centralized collection.

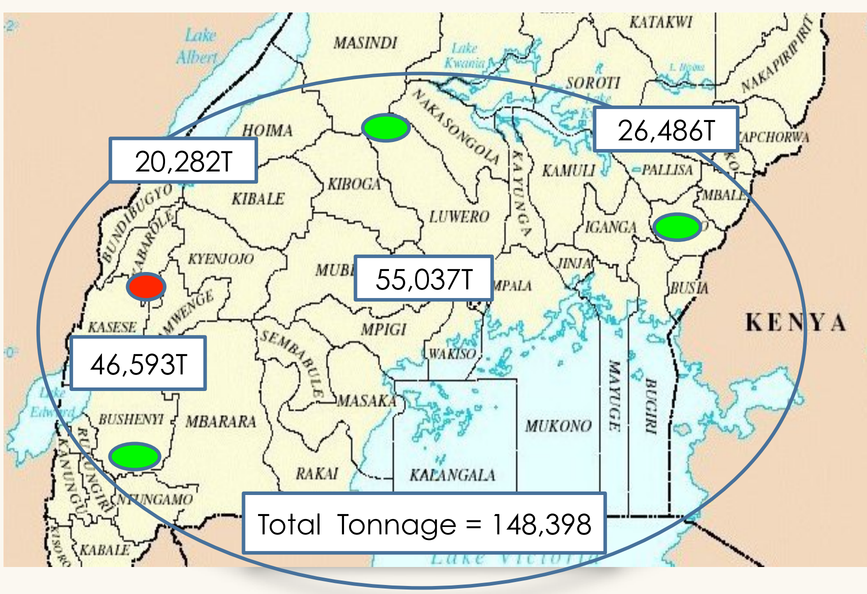
- In Uganda, Lafarge has implemented a special collection system for coffee husk recovery, using the existing cement distribution network to reduce the collection cost. First, husks are collected locally and consolidated in the cement intermediary storage areas (the green circles on Figure 33). Next, trucks that return empty from cement deliveries transport the husks from the intermediary areas to the cement plant (the red circle in the figure).
- Despite the collection cost, the use of agricultural residues could be profitable. Lafarge assessed that cement plants would save €4 per ton of clinker by replacing fossil fuels with sugarcane straw.
- It could be laborious to sign an agreement with each small producer. In Brazil, supply agreements with producers could be easier for sugarcane straw collection because the same large companies often own both the production and processing infrastructure.

4.3.3 QUALITY OF BIOMASS ALTERNATIVE FUELS

The composition varies widely among the different biomass alternative fuels.

With regard to our selected biomass resources, the approximate quality characteristics are shown in Table 4.

Figure 33: Map of the Coffee Husk Collection Network in Uganda



Source: Sofies AS.

Table 4: Quality Characteristics of Selected Biomass

Type of Biomass	Calorific Value (gigajoules per ton)	Moisture Content (percent)	Ash (percent)	Other Characteristics
Bagasse	7.8	50	3.2–5.5	Phosphorous: 0.73% to 0.97% Chlorine: 0.05% to 0.2% Sulfur: 0.10% to 0.15%
Sugarcane stalk	15	20	7.7	Chlorine: 0.3% to 0.5%
Coffee husks	17.5 (dry)	10–20	2.5; presence of silica	Chlorine: <0.5% Sulfur: 0.2% Grain size: <12 millimeters

Source: Sofies AS.

4.3.4 PREPARATION OF BIOMASS ALTERNATIVE FUELS

Generally speaking, preprocessing is fairly simple.

- The storage capacity should be adapted to low biomass density and seasonality.
- Depending on the biomass residue, drying or shredding steps could be implemented.
- Some of the alternative fuels are roasted or carbonized to concentrate the calorific value. Even if it is an added cost, roasting is of interest for two main reasons:
  - It increases the calorific value
  - Roasted biomass can be co-injected in the kiln directly with coal, obviating the need for other preparation infrastructure such as a supplementary shredder or multi-fuel injection system.

4.3.5 TECHNICAL CONSIDERATIONS FOR BIOMASS INTEGRATION IN THE CEMENT PROCESS

Direct feeding for low-density material (0.1 to 0.3 tons per cubic meter): it is possible to introduce the alternative fuels directly without additional processing.

- This includes coffee husks, rice husks, bagasse, sugarcane straw, and sunflower shells.
- The material should be introduced via a large burner placed on the top or in the center of the burner pipe (not on the bottom).
- For precalciner kilns, the injection could be realized to the riser duct at the same level, but on the opposite side, of the existing coal feed points.

4.3.6 MAIN STEPS TO IMPLEMENT A PILOT PROJECT BASED ON BIOMASS SOURCES

The critical points are the supply chain and collection, for the reasons explained above.

It also is important to tackle social and environmental issues:

- Indirect changes in land use may have an impact on greenhouse-gas emissions.
- In Brazil, sugar cane is used in large quantities for biofuel generation. This can create competition with food production and increase food prices. Cement plants should keep in mind these elements before implementing an alternative fuel project.
- In poor countries where child labor remains significant, cement plants should make sure that no children would be exploited in the fields.

4.4 INDUSTRIAL WASTE

Typical hazardous solid wastes include oily sludge and the spent catalysts and solids from air pollution control systems. Oily sludge has a liquid and pasty consistency and complex chemical composition, including asphaltenes, resins, and polycyclic aromatic hydrocarbons. The water in the sludge contains heavy metals and other chemical elements such as sodium, calcium, magnesium, and potassium. Spent catalysts are granular solids with a chemical composition that includes a matrix of silica or alumina impregnated with nickel, cobalt, platinum, molybdenum, or other heavy metals. Solids generated in pollution control systems contain organic material, such as hydrocarbons, ash, and other particulate matter.

Recycling and reuse are the most common solutions for the disposal of solid waste in this sector. The oil and gas exploration and production segment recycled about 70 percent of the hazardous waste it generated in 2010. Incineration and biotechnological methods also are employed. Waste disposal in landfills has been avoided over the years.

4.4.1 NON-HAZARDOUS INDUSTRIAL WASTE

MARKET FOR NON-HAZARDOUS INDUSTRIAL WASTE

There are two main types of non-hazardous industrial waste:

- Production waste, such as the raw material remainder and off-spec products
- Packaging waste from the containers and wrappings of raw material and equipment (for example, from factories and administrative buildings).

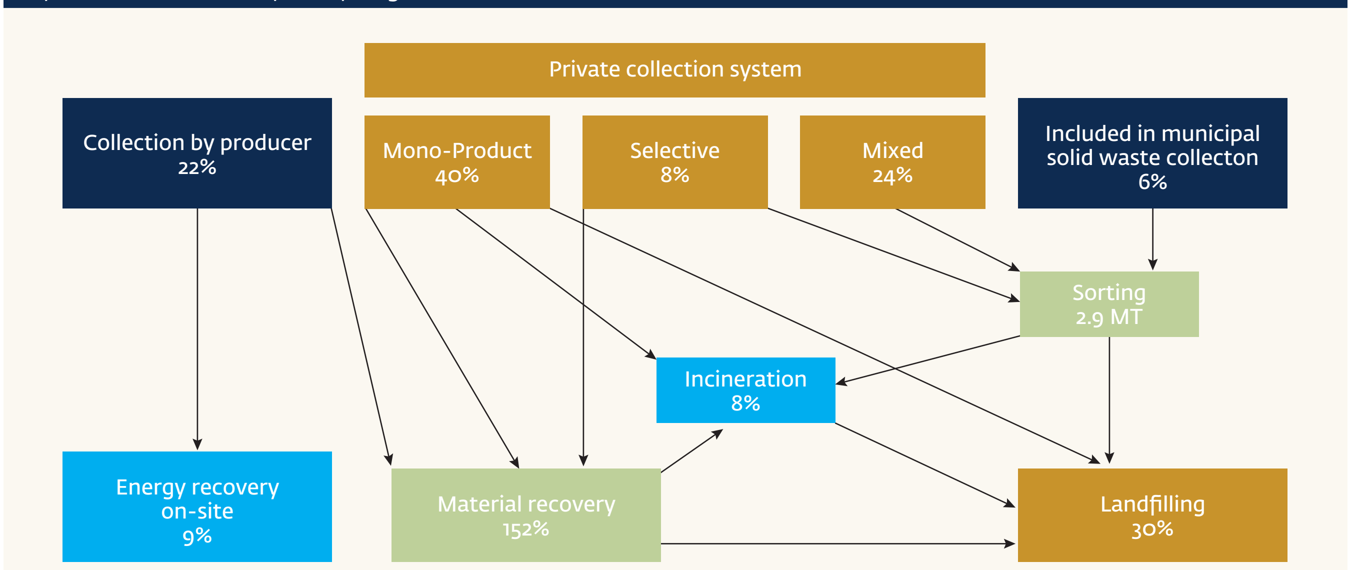
European statistics show that the main industries producing non-hazardous industrial waste are:

- Wood, including the production of furniture
- Paper and cardboard
- Metallic equipment
- Automotive
- Food
- Rubber and plastic
- Electrical and electronics equipment
- Shoe and textile industries.

Management of this waste stream could be handled directly by the producer—including waste collection but also operations such as sorting, recycling, and on-site recovery (including the production of steam or, less frequently, power) (see Figure 34).

The production of waste made of a mono-product often is managed directly between the producer and the collector-recycler, mainly in the case of large production. The collection is managed by a collecting company with highly skilled professionals in waste/raw material sorting to deliver the qualities compliant with the specifications of the recycling industry (for example, paper, cardboard, plastics). The company then finely sorts and delivers the waste in

Figure 34: Schematic of the Distribution in the Collection and Treatment Modes in France in 2008 Before the Reduction of Landfilling



Source: Sofies AS.

compressed bales, which are often exported. China has been the main destination of this waste, but the development of domestic recycling industries in many countries is reintroducing this waste source in the country for both recycling and co-processing.

For smaller amounts of waste, collection often is done via a rented bin that is used for receiving the non-hazardous industrial waste produced by a factory, for example. In the case of several factories, several bins are located at the plant. The quality of the waste collected in a bin could be very poor, as no sorting is done and the bins might be exposed to the elements. A sorting operation is always required to extract the burnable fraction.

In the case of small and medium enterprises, the collection of non-hazardous industrial waste often is included in the municipal waste collection service.

POSITIONING OF CEMENT PLANTS IN THE NON-HAZARDOUS INDUSTRIAL WASTE MARKET

There are several options for positioning cement plant co-processing in this market:

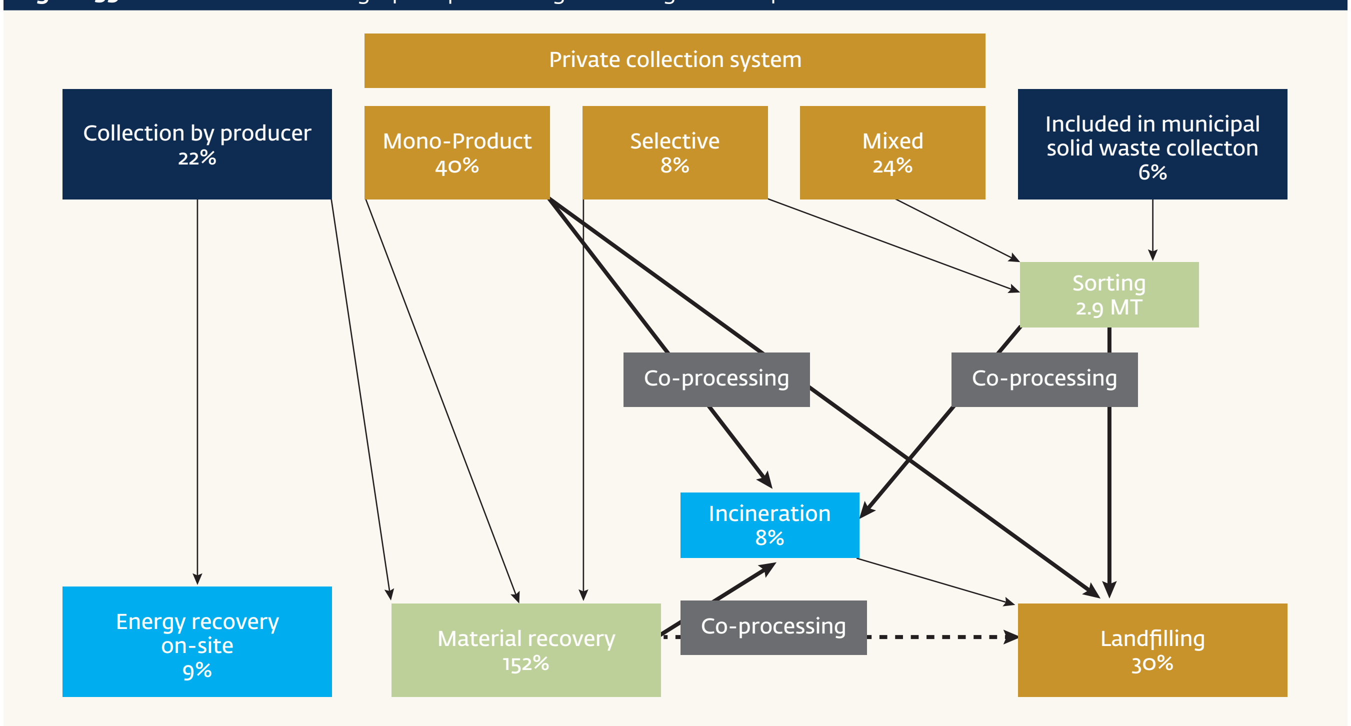
- **As a unique provider of service:** In the case of large-scale waste production, the cement plant can contract directly with the waste producer, creating a direct link industry to industry.
- **After a sorting operation:** This scheme is comparable to that used in the case of municipal solid waste.
- **As a service to the recycling industry:** The recycling industry is receiving used product that contains pollutants (such as from the paper industry), and the process requires extracting those pollutants that could be of sufficient quality for co-processing (see Figure 35).

PREPARING ALTERNATIVE FUELS FROM NON-HAZARDOUS INDUSTRIAL WASTE: THE CASE OF PAPER

Preparing RDF from non-hazardous industrial waste is similar to the process of preparing RDF from municipal solid waste. One useful example is the cooperation of the cement industry with another industrial sector: the paper industry.

Producing recycled paper creates waste at the initial stage of the paper recycling process—when the paper fiber is extracted from the used paper. The bales of used paper are

Figure 35: Potential Positioning of Co-processing in Management of the Non-hazardous Industrial Waste Stream



Source: Sofies AS.

mixed with water in a pulper. Any "impurities" mixed in with the paper in the bales (for example, plastics, textiles, inerts) are extracted by flotation or settling/sedimentation and become waste.

These impurities can represent 5 to 10 percent of the input when saturated with water (40 percent). As produced, the calorific value is relatively low (8 to 10 gigajoules per ton), but it can reach 25 gigajoules per ton after drying and extraction of the inert fraction.

A shredding line with an air separator and overband conveyer will produce the RDF with the adapted particle size. A thermal dryer fed with waste heat from the kiln will produce the quality required for the main burner.

The waste from the paper industry also could be mixed with waste from plastics recycling to guarantee a high calorific value (see Figure 36).

RDF QUALITY

The process used to produce RDF out of non-hazardous industrial waste is comparable to that described for municipal solid waste, with two main differences:

- The quality of packaging waste from industry is much better (in terms of calorific value, moisture, chlorine) than the packaging extracted from municipal waste, and
- The process used to produce the RDF, even the quality for the main burner, is often simpler and produces less waste compared to RDF produced from municipal solid waste.

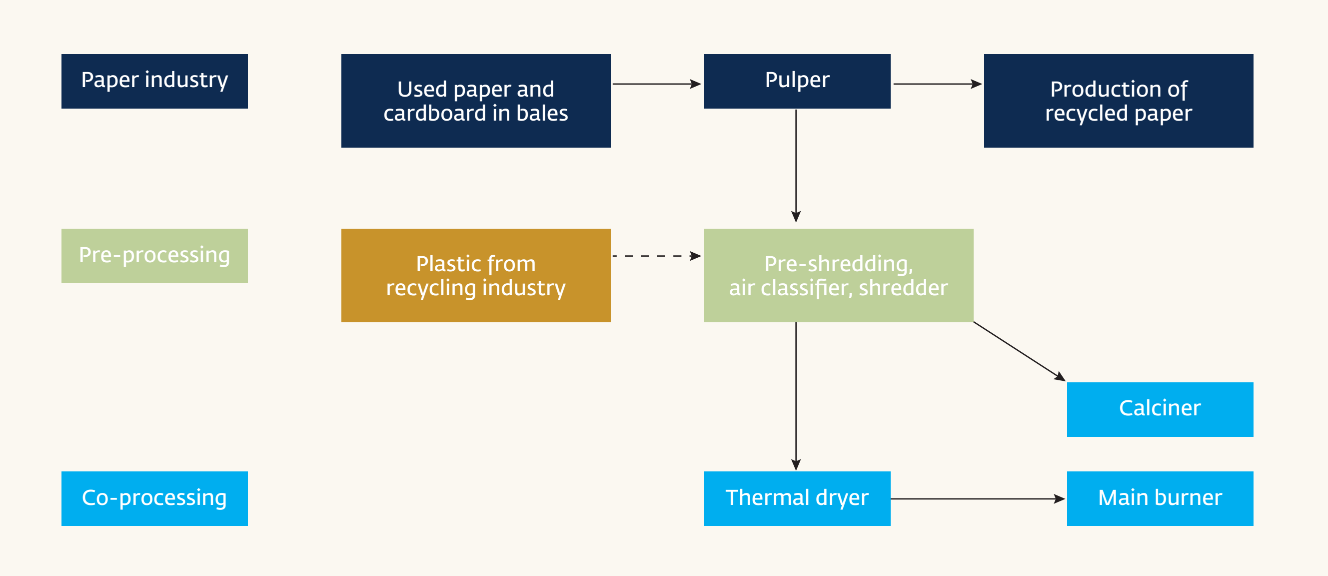
In countries where RDF for cement plants is produced from non-hazardous industrial waste, it is possible to achieve a calorific value above 20 gigajoules per ton, and in some cases 23 to 25 gigajoules per ton, a quality that is directly usable for the main burner.

Considering the homogeneity of non-hazardous industrial waste, the quality will be much more constant than for municipal solid waste because the RDF is produced out of mono-product waste.

This waste segment should be considered a priority, given the high potential of use in co-processing and the small quantities available in the market.

The industry will be more sensitive to the reduction of landfilling, and, in a country where the incineration capacity is very limited, co-processing is an operational option for the entire industrial sector.

Figure 36: Schematic of RDF Production from Paper Waste to Cement Plant



Source: Sofies AS.

Cooperation with recycling activities is important to reduce the potential perception of co-processing being a competitor. Co-processing the waste from recycling activities supports this activity and increases the recovery ratio of a country.

4.4.2 BLENDING OF HAZARDOUS INDUSTRIAL WASTE

HAZARDOUS INDUSTRIAL WASTE FOR THE BLENDING MARKET

In most countries, hazardous industrial waste was the first waste stream available for waste treatment. In light of its heterogeneity and the small batch quantities made available by some producers, the concept of pretreatment was introduced to produce an alternative fuel acceptable for burning in cement kilns.

The first pretreatment processes were very simple and were oriented along two main directions:

- Production of a **liquid** alternative fuel
- Production of a **solid** alternative fuel.

The pretreatment facility has to take into consideration the chemical, physical (liquid, sludge, or solid), and conditioning (bulk and drums) heterogeneities.

Hazardous industrial waste is generated by all industries that process, produce, or use chemicals or oils. The main producers are the following industries or activities:

- Chemical, pharmaceutical, and cosmetology
- Oil (both extraction and refining)
- Paint
- Automotive
- Steel and metallurgic
- Industrial cleaning.

POSITIONING OF CEMENT PLANTS IN THE BLENDING MARKET

Based on the nature of the waste (heterogeneity and variability of the composition), a preparation step is mandatory. Given the chemical specificities of the waste, however, this step resembles more closely a chemical activity, requiring highly skilled technicians to manage processes, chemical risks, and health risks.

In some countries, preparation is carried out by waste management companies dedicated to hazardous waste, with whom the cement companies sign mid- to long-term contracts. However, relations between these companies can turn to conflict when the waste management company operates its own treatment solutions using incinerators, with co-processing being considered as a buffer (or secondhand solution) to guarantee full use of its equipment.

In some countries, cement companies have opted to create joint ventures with waste management companies or subsidiaries dedicated to the management of hazardous industrial waste in order to have greater control over sourcing and the market.

Given the specificities of the waste, some cement companies also have opted to subcontract operations inside the cement plant, giving control over waste receiving and handling to these dedicated companies.

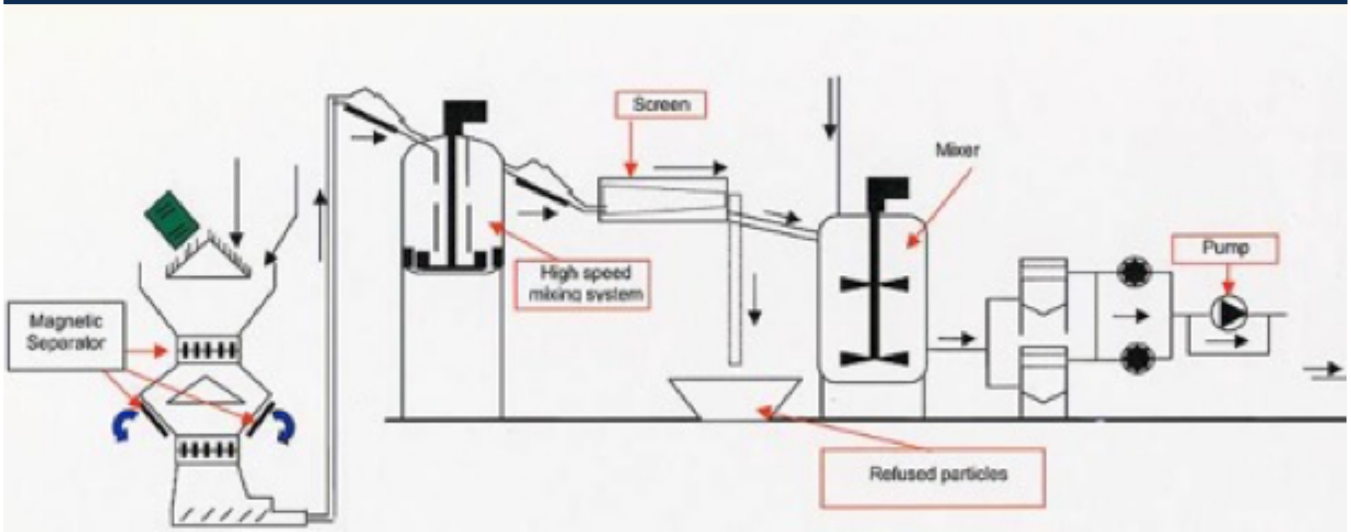
PREPARATION OF ALTERNATIVE FUEL THROUGH A BLENDING OPERATION

There are two blending options for the hazardous waste: one producing a liquid alternative fuel (with high viscosity) and the other producing a solid alternative fuel.

Preparation of Liquid Alternative Fuel, or Fluidification

This concept is based on a dilution of the pasty and small portion of solid waste with liquid wastes (spent solvents or oily wastes), with the blending occurring in a high-speed mixer (see Figure 37). The blend is screened to extract the remaining solid fraction. Some facilities also are including a shredder for drums to avoid the need for emptying them; the shredded metal is extracted using a magnetic separator before introduction in the high-speed mixer. The blend must be stored in a vertical silo with continuous stirring. The maximum quantity of solid (pasty) waste that could be introduced is below 50 percent, with an average of 30 percent. The remaining waste from the process must be disposed of in a specific incinerator at a high cost.

Figure 37: Example of Flowsheet for Liquid Alternative Fuel Preparation



Source: Sofies AS.

Preparation of Solid Alternative Fuel

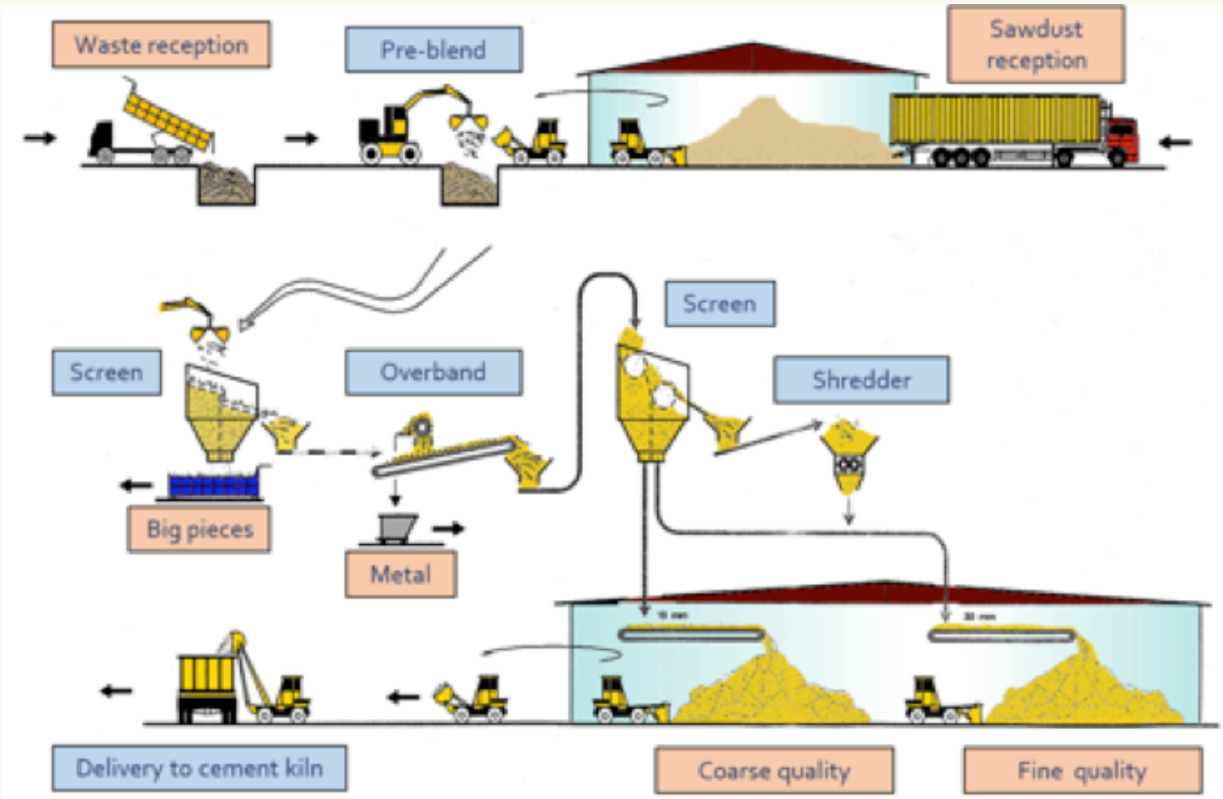
The basic concept is the mixing of solid and pasty wastes with an adsorbent to produce a solid alternative fuel (see Figure 39). The mixing is realized in several steps: coarse blending in a pit and one or two steps of mixing within screens, extracting the foreign bodies. To achieve a quality that is compliant with the main burner specifications, a shredder is mandatory. The most popular adsorbent is sawdust, but with the increase in the cost of sawdust, operators have been looking for alternatives; some plastics in foam form have been identified, but they have lower efficiency compared to sawdust. The ratio of sawdust is often about 40 percent, making this process relatively costly.

The facility must be located in a closed building to avoid the dispersion of volatile organic compounds. The collected air must be treated; bio-filtering and catalytic burning have shown good efficiencies.

Figure 38: Example of Facilities for Liquid Alternative Fuel Preparation

Source: Sofies AS.

Figure 39: Example of Flowsheet for Solid Alternative Fuel Preparation



Source: Sofies AS.

ALTERNATIVE FUEL QUALITY

The alternative fuel specifications are set in the contract between the preparation step and the cement plant.

For the liquid alternative fuel, the calorific value depends mainly on the quality of the solvents; it is often above 15 gigajoules per ton, with 20 gigajoules per ton being possible in the best cases.

For the solid alternative fuel, the calorific value depends on the moisture content of the sawdust (furniture sawdust is one of the driest) and the moisture of the wastes. A calorific value between 12 and 15 gigajoules per ton is achievable.

APPENDIX 1 DETAILED INFORMATION BY ALTERNATIVE FUEL TYPE

1. Hazardous Spent Solvents

Origin	Composition
The hazardous solvents available in the waste market originate from: • Chemical and pharmaceutical processes • Manufacturing of paint and other building materials, as well as the use of paint in the automotive industry, furniture production, and elsewhere. • Cleaning activities in metals workshops or garages • Recycling activities. The production of spent solvents in the painting sector is decreasing as solvents are replaced by water. At the same time, stricter regulation of volatile organic compounds in most factories could increase slightly the quantity of spent solvents. However, this increase is mitigated by the replacement of solvents with water to avoid complex management of volatile organic compounds.	A wide variety of hazardous solvents are available in the waste market, ranging from the most expensive to the most common. They include hydrocarbon- and alcohol-based solvents as well as solvents that are mixed with water or that are polluted with chlorine and heavy metals to varying degrees. These solvents could exist in a liquid or a pasty phase, with the latter being generated mainly from internal or external recycling activities. The standard composition of the waste solvents that are available for energy recovery is: • LCV: 20 to 28 gigajoules per ton (alcoholic solvents are below these values) • Chlorine: 0% 2%; average 0.6% to 1% • Moisture content: 0% to 25% • Metals: 1,000 to 5,000 parts per million
Traditional Destination	**Supply Chains**

Provided that strict regulations are implemented for managing volatile organic compounds and preventing water discharge, the typical destinations for spent solvents are:
• Recycling
  • This could occur within factories in the case of large-scale production or expensive solvents, or in specialized facilities.
  • Recycling activities produce distillation residues with high concentrations of chlorine, metals, and sediments.
• Thermal recovery
  • This could occur in specialized incinerators or in cement plants operating with a hazardous materials permit.
  • Given the high calorific value of spent solvents, they are used in incinerators as a valuable energy source for burning other waste material.
	Because spent solvents are classified as hazardous waste and can be highly flammable, transport must be managed by specialized companies using specially adapted tanker trucks. The transport company must be notified about the specific risks linked to each component of the waste mixture.
	Small-to-medium volumes of spent solvents also could be stored in drums, with the nature of the stored solvents and the risk information written clearly on the drum casing. Collecting this waste could be done using trailers or by direct transfer in tanker trucks equipped with vacuum pumps. With the latter option, the risk of reaction between two different qualities must be managed as the solvent is pumped, meaning that this operation must be handled by workers who are trained in responding to potential risks (for example, heating, boiling, explosion, production of solid phases).

Preprocessing

The preprocessing operations for spent solvents could be:

- Transfer of wastes from drums to tanks
- Blending
- Phase separation.

The main risks associated with the two first operations are:

- Chemical reaction producing heat, gas, or explosion
- Solidification or creation of a solid phase (for example, by mixing paint with alcohol)
- Mixing of chlorinated solvents with non-chlorinated ones, producing a chlorinated product that is not compatible with recovery in cement kilns.

These operations must be handled in a dedicated facility that has a permit for hazardous waste. The workers must be trained in the risks. A lab to manage the quality and risk associated with blending must be controlled by a chemist.

Whatever the operation performed, the wastes maintain their "hazardous" classification following preprocessing, even in the case of blending hazardous with non-hazardous wastes.

Environmental Implications

The equipment and operations must be compliant with environmental regulations related to solvent management.

Spent solvents must be stored in steel tanks that are compatible with solvent specifications. The tanks must be located in a retention basin to prevent spillage to the soil or water. The pumping system must be located in a place that facilitates the collection of leakage.

The storage zone must be equipped with a fire protection system that is adapted to the stored solvents.

The solvents must be handled as much as possible in a confined unit or factory to avoid the release of volatile organic compounds to the atmosphere and the exposure of the workers and stakeholders to these compounds. Depending on their specifications, the spent solvents could be managed in tanks with a nitrogen atmosphere or capping of the gas. The potential dispersion of vapors must be taken into consideration during the loading and unloading of trucks.

For drums, it is recommended that handling be managed in a closed building with capping and treatment of the volatile organic compounds. Workers must wear personal protective equipment that is adapted to potential exposure.

Carbon Dioxide Mitigation

Spent solvents originate from hydrocarbons and have no impact on carbon dioxide reduction.

CAPEX and OPEX

Facility requirements include:

- Unloading zone for trucks on concrete, with collection of spillage
- Tanks in a retention basin
  - Preference for vertical tanks with conical bottoms
  - Small tanks (10 to 25 cubic meters) in preprocessing facilities
  - Large tanks (100 to 500 cubic meters) in cement plants
- Two stirring technologies: one vertical mechanic and one recirculation loop
- Separate pumping systems for unloading, stirring, and injection
- Filtration by auto-cleaning system, or static filtration in the unloading line
- Electrical devices designed with consideration of solvent flash points (ATEX rules)
- CAPEX: €5 million to €10 million
- OPEX: €10 to €20 per ton

Barriers

- Quantity of spent solvents with characteristics compatible with the cement process
  - National regulations must ban discharge into the natural environment (for example, via sewers, sewage plants, rivers)
  - Mixing of chlorinated with non-chlorinated solvents must be avoided
- Cement plants must apply for a hazardous waste permit, a procedure that could be complex and could raise strong opposition from stakeholders
- Competition with incinerators, which could buy high-quality spent solvents and drive up the price to levels that are non-competitive with traditional fossil fuels in a cement plant.
- Prioritization of recycling
  - However, recycling activities still need a recipient for the distillation residues, which could lead to natural cooperation between recycling and co-processing.
- Technical barriers
  - Chlorine: traditional chlorinated solvents are not acceptable
  - Flash point: a wide range of flash points is possible, with costly consequences for capital expenditures (CAPEX)
  - Homogeneity: risk of phase separation in storage, with huge variation in calorific value at the burner

2. Waste Oil and Industrial Oil

Origin

Waste oil originates from any engine that requires lubrication (for example, car, truck, bus, mining machine/ truck, diesel locomotive, power generator, lawn maintenance equipment). Some industrial processes also generate used oil, such as steel plants (liquid), tire manufacturing, food oil production, and others.

Composition

The standard composition of the waste oil available for energy recovery is:

- LCV: 25 to 35 gigajoules per ton
- Chlorine: 0% to 1% (related to the potential presence of cleaning solvents)
- Moisture content: 0% to 20% (linked to storage conditions)
- Metals: <1,000 parts per million

Special attention should be given to potential PCB (polychlorinated biphenyl) pollution and to solvents with a low flash point.

The composition of industrial oil could vary significantly. Blending of industrial oil with used engine oil must be checked in a lab prior to occurring in the cement plant.

Traditional Destination

The top two typical destinations for waste oil are:

- Recycling: producing recycled oil out of used oil
  - Recycling could be limited if the cost of producing recycled oil exceeds the cost of new oil. Some older recycling processes, such as the sulfuric process, produce waste (sulfuric tar) that is very difficult to dispose of.
  - Recycling is becoming more profitable in facilities with significant capacity (>100,000 tons per year)
- Energy recovery: cement plants are the top destination when the used oil is classified as waste.

Supply Chains

Collection of waste oil is a key issue. Garages typically store their used oil in small tanks and therefore need responsive and frequent collection. Often, the collection is performed by small trucks (5 to 7 cubic meter volume) that ship the waste to a transit platform before it is delivered to its final destination.

Preprocessing

Waste preparation occurs at the transit platform, including:

- Blending of different collection sources
- Separation of water via decantation, either naturally or accelerated by surfactants
- Emptying of drums

Because garages generally do not have the means to control waste quality, this control must take place at the transit platform. For example, PCBs could be detected at this stage. The storage capacity of these facilities comprises small tanks (10 to 25 cubic meters) to avoid the diffusion of pollution within bigger waste volumes and to perform the appropriate blending.

Environmental Implications

The equipment and operations must be compliant with environmental regulations related to hydrocarbon management.

The tanks must be located in a retention basin to prevent spillage to the soil or water. The pumping system must be located in a place that facilitates the collection of leakage (usually in the retention bin or on concrete soil with drainage).

The storage zone must be equipped with a fire protection system adapted to hydrocarbons and must consider the potential presence of solvents with low flash points.

Carbon Dioxide Mitigation

Used oil is composed of hydrocarbons and has 0 percent biomass.

CAPEX and OPEX

Facility requirements for waste oil include:

- Unloading zone for trucks on concrete with collection of spillage
- Tanks in a retention basin
  - Preference for vertical tanks with conical bottoms
  - Small tanks (10 to 25 cubic meters) in preprocessing facilities
  - Large tanks (100 to 500 cubic meters) in cement plants
  - Tanks that formerly were used for fuel oil in cement plants can be reused
- Stirring by a recirculation loop
  - In case of vertical possibility, extract the water
- Pumping system for unloading, stirring, and injection
- Filtration by auto-cleaning system, or static filtration on the unloading line
- Electrical devices
- CAPEX: €1 million to €3 million (could be reduced in cases of reuse of old tanks)
- OPEX: €5 to €10 per ton

Barriers

- Mobilizing the market at a reasonable price
  - A good waste collection system with efficient quality control is required to mobilize this resource. Garages will give their used oil to a formal collection service if it is free.
- Clear regulation
  - The illegal burning of used oil in garages as a heating source or mixed with other hydrocarbons to produce fuel for engines is the largest competitive use when regulation is not clear and does not classify used oil as waste.
  - Regulation also must control the discharge of used oil into sewers, which often occurs when people change the oil in their vehicles themselves. One liter of oil can contaminate more than 1 million liters of water!
- Fair competition with recycling, based on market rules and not artificial competition
- Fair competition with other energy recovery process (such as waste burning), meaning that the other processes must be subjected to the same environmental rules
- Cement plants must apply for a waste permit (since used oil is considered waste), a procedure that could be complex and could raise strong opposition from stakeholders.
- Technical barriers
  - Chlorine and PCBs, since the engine oil could be mixed with used oil from electrical equipment (for example, transformers, condensers)
  - Homogeneity: risk of water separation in storage.

3. Wastewater

Origin

The wastewater available in the waste market originates from:

- Chemical and pharmaceutical processes
- Metals workshops
- Airport and road de-icing activities
- Cleaning activities in industries.

Composition

Wastewater is mainly water that is polluted with chemicals, surfactants, solvents, or oil.

The standard composition available for energy recovery is:

- LCV: 0 gigajoules per ton
- Chlorine: <0.5%
- Moisture content: >80%
- Metals: 1,000 to 2,000 parts per million

Traditional Destination

The typical destinations for wastewater are:

- Sewage plants (when the water is compatible with biological treatment)
- Physico-chemical treatment (to separate water and pollutants such as oil and solvents)
- Incineration (direct, or following a concentrating process).

Supply Chains

Because wastewater is classified as hazardous waste and can be highly flammable, transport must be managed by specialized companies with specially adapted tanker tanks. The transport company must be notified about the specific risks linked to each component of the mixture, even if the concentration of pollutants is low.

Preprocessing

The preprocessing operations for wastewater could be:

- Blending
- Phase separation.

The main risks associated with these operations are:

- Chemical reaction producing heat, gas, or explosion
- Solidification or creation of a solid phase (for example, by mixing paint solvents with alcohol)
- Mixing of chlorinated solvents with non-chlorinated solvents, producing a chlorinated solvent that is not compatible with recovery in a cement kiln.

These operations must be handled in a dedicated facility that has a permit for hazardous waste. The workers must be trained in the risks. A lab that manages the quality and risks associated with blending must be controlled by a chemist.

Whatever the operation performed, the preprocessed waste is still classified as "hazardous" following preprocessing, even when hazardous wastes are blended with non-hazardous wastes.

Environmental Implications

The equipment and operations must be compliant with environmental regulations related to solvent management.

The wastewater must be stored in steel tanks that are compatible with its potentially alkaline or acidic characteristics. The tanks must be located in a retention basin to prevent spillage to the soil or water. The pumping system must be located in a place that facilitates the collection of leakage.

In case of the potential presence of solvents, the storage zone must be equipped with a fire protection system.

For drums, it is recommended that their handling occur in a closed building with capping and treatment of the volatile organic compounds. Workers must wear personal protective equipment adapted to a potential exposure.

Carbon Dioxide Mitigation

Wastewater has no impact on carbon dioxide, but it decreases the production of nitrogen oxide.

CAPEX and OPEX

Facility requirements include:

- Unloading zone for trucks on concrete, with collection of spillage
- Tanks in retention basin or double-envelope tanks
  - Preference for vertical tanks with conical bottoms
  - Small tanks (10 to 25 cubic meters) in preprocessing facilities
  - Large tanks (100 to 500 cubic meters) in cement plants
- Stirring by ic stirrer and a recirculation loop
- Separate pumping systems for unloading, stirring, and injection
- Filtration by auto-cleaning system, or static filtration on the unloading line
- Electrical devices designed with consideration of solvent flash points (ATEX rules)
- CAPEX: €1 million to €3 million, depending on the flash point and installation capacity
- OPEX: €5 to €10 per ton.

Barriers

- Regulations must set strict rules for the discharge of wastewater in rivers.
- A leading impact results from the introduction of water, which produces high-temperature steam inside the cement kiln. The extracting fan is designed to handle a certain quantity of steam at the kiln's maximal load; however, this capacity could be reached with new injection of water. To mitigate this impact, it is possible to inject the water into the clinker cooler, a stage at which the temperature is compliant with regulations.
- Cement plants must apply for a permit for hazardous waste, a procedure that could be complex and could raise strong opposition from stakeholders.
- Technical barriers
  - Chlorine: potential presence of salts
  - Flash point: potential presence of solvent traces
  - Homogeneity of the calorific value of waste: potential phase separation of solvents

4. Used Tires and Rubber Wastes

Origin	Composition
Used tires originate from the production of tires and the replacement of tires from vehicles such as cars, trucks, and buses. Other rubber waste originates from conveyor belts, shoe production, and many other sources. Used tires are stored at garages, tire retailers, and large fleet depots for cars, trucks, and buses. In many countries, historical disposal has created large stockpiles of used tires, without formal ownership. In countries where extended producer responsibility is implemented, tire manufacturers are in charge of the collection and treatment of used tires. Often, these manufacturers create an entity to which they subcontract the collection and disposal management of used tires.	The standard composition of used tires available for energy recovery is: • LCV: 26 to 28 gigajoules per ton (for truck tires, 23 to 26 gigajoules per ton) • Chlorine: <0.1% • Sulfur: around 1.5% • Moisture content: 0%, but possible accumulation of water inside the tire during storage • Metals: iron: 15% to 20%, zinc: 1% to 2%, others: 1,000 to 4,000 parts per million
Traditional Destination	**Supply Chains**

The typical destinations for used tires and rubber wastes are:
• Retreading
  • In most developed countries, the national retreading ratio is close to 10 percent
  • In developing countries, the ratio is very low, in part because the tires are used until the very end of their lives, making retreading almost impossible
• Material recovery, which could take different forms:
  • Use in civil works in the form of bales, or direct use to reinforce road banks or dams
  • Production of granules used to produce rubber equipment, athletic field surfaces, and other items.
  • The production of granules generates waste such as tire cords and steel. Tire cords are an interesting alternative fuel for cement plants, with high calorific value.
• Energy recovery
• Cement plants are a natural destination of used tires (shredded or not), as they provide an advantage from the recycling of the steel structure combined with energy recovery
• Some trials have been done in steel plants, but with limited quantities because the process is very sensitive to the presence of the metallic structure of the tires as well as some metal traces.
	Tire collection is the main management issue. Used tires are dispersed widely in small quantities and are stored in factories with limited storage capacity, meaning that used tires need to be moved out frequently.
	Solutions for organizing collection include:
	• A specific network of collectors that could be registered by tire manufacturers.
	• The distribution network for new tires also could be used for used tire collection.
	• The distribution network for cement could be used, with the same trailers that transport bagged cement being used for tire transport.

Preprocessing

The preprocessing of used tires is limited to shredding operations. Dedicated shredders must be used to manage the combined shredding of steel with rubber.

The shredding of large tires is more complex and occurs in several steps, including first extracting the metallic structure or precutting the tire into large pieces using a specialized machine (for example, a crocodile cutter).

Environmental Implications

The main environmental risk is related to storage of used tires, with two aspects:

- The accumulation of water in tire envelopes provides a breeding ground for mosquitoes
- Handling procedures for tires (mainly truck tires) must address ergonomic aspects to prevent back pain.

The equipment and operations must be compliant with environmental regulations related to used tires.

Fire management in tire storage depots is a unique issue and requires a specific approach:

- Creation of several smaller piles rather than one big pile to limit the risk of a large fire, since fire extinction could be a long process.
- Storage of sand or another high-density mineral close to the tire piles to block fire and as part of the prevention plan
- Taking enough time to fully extinguish a fire.

Carbon Dioxide Mitigation

Because the rubber typically used in tires comes partially from natural sources, the biomass content is between 25 and 35 percent.

CAPEX and OPEX

For shredding operations:

- Shredding line, depending on the size required after shredding
- CAPEX: €1 million (30,000 to 50,000 tons) plus potential infrastructure costs (for example, civil works, roads, power supply)
- OPEX: €15 to €40 per ton (from 25 to 100 millimeters)

In the cement plant, facility requirements include:

- For injection in the pre-calciner or backend:
  - Storage zone for used tires, with fire management system
  - Transporting the tire to the injection point by lift, hock elevator, conveyor belt
  - Dosing system
  - Double- or triple-flap airlock to feed the tire in
- For injection of shredded material:
  - Hall for receiving shredded tires
  - Tank for storage
  - Conveyor
  - Injection system
- CAPEX: €1 million to €3 million
- OPEX: €5 to €10 per ton

Barriers

- Cement plants must apply for a permit for waste (since used tires are considered waste), a procedure that could be complex and could raise strong opposition from stakeholders.
- Organizing tire collection is key and could be expensive.
  - Strict bans on the landfilling of used tires drive the need to find an organized solution.
  - In several countries, extended producer responsibility has proven its efficiency in creating an efficient collection operation, making tire producers responsible for addressing waste management, with the cost passed on to purchasers of new tires through a small eco-tax.
- Competition with material recovery
  - Use of the tires for land stabilization is very close to landfilling and, in some cases, becomes a means to bypass the landfill ban.
  - Use of the tires in civil works must bring a real advantage and must be framed and classified to avoid the uncontrolled dispersion of tires in the environment.
  - The production of granules is economically more attractive than co-processing because of the good market price for granules. In Europe, investment in large granulating capacities over the last two years created a production overcapacity that led to a direct decline in the granule price, leading some companies to deliver the granules to cement plants.
- Competition with other energy recovery processes
  - The use of tires in steel plants is limited.
  - Some power plants are using used tires, but facility investments are required for feeding, burning, and emission depollution.
- Technical barriers
  - Management of whole tires: injection and impact on the process
  - Sulfur: limited impact

5. Industrial Sludge

Origin

Industrial sludge originates from the treatment of all of the effluent of a plant, including process rejects, rainwater collection, and other effluent.

In the production plant, different options for preparation can be implemented:

- Reception in tanks or lagoons to blend the different sources and manage the quality control before discharging into a sewer, a combined sewage plant, or a river.
  - The tank or lagoon must be cleaned on a regular basis (monthly, annual), producing sludge that needs to be disposed of.
- Simple decantation with or without oil separator
  - Sludge produced in small quantities is usually pumped by a vacuum cleaning truck.
- Biological or physico-chemical sewage plant
  - Different natures of sludge are produced: physico-chemical or biological
  - After biological treatment, the sludge could be dried by mechanical treatment (centrifuge or filter press) or a thermal process.

These operations can be performed in an external collection facility that will produce the sludge.

The cleaning of tanks also produces sludge.

The remediation of old lagoons or storage, either orphaned or with an identified owner, is also a source of sludge.

In a similar category, dredge sludge originates from the cleaning of canals or sewers.

This analysis focuses specifically on the oil sludge produced in refineries or during oil extraction. Huge quantities are produced worldwide, and cement plants are one of the main destinations for this sludge.

Composition

The composition of sewage sludge depends on the source and the preparation process.

For oil sludge, the composition is as follows:

- LCV: 5 to 15 gigajoules per ton
- Chlorine: 0% to 0.5%
- Moisture content: 1,000 to 3,000 parts per million
- Metals: <1,000 parts per million
- Ash: 10% to 50%

Traditional Destination

A wide range of destinations exist, considering the potential variations in quality. Typical destinations are:

- Land spreading
  - This solution could be used for inorganic sludge, presenting real agronomic value coming from inorganic chemistry.
  - The presence of pollutants, even in small concentrations, is a limiting factor on this use.
- Landfilling
  - Landfilling of sludge is applicable for sludge with low moisture content.
  - Water present in the sludge could easily leach or give thixotropic properties to the sludge, disrupting landfill operations (production of leachate and destabilization of the waste layers).
- Incineration
  - Within an incinerator located on the sewage plant premises (for large-scale production)
  - Within a external incinerator managed by a waste management company
- In the case of remediation of old lagoons, the pretreated sludge could be landfilled on-site after preparation (mixing with lime or sawdust).

Supply Chains

Traditional trucks are used to transport the sludge. In the case of simple trailers, the risk of spillage must be managed.

Preprocessing

For producing alternative fuel for cement plants, there are several preprocessing options:

- Mechanical drying in the sewage plant
- Thermal drying (in the sewage plant or in the cement plant using waste heat from the kiln)
- Mixing with adsorbents to produce a solid alternative fuel
  - For organic sludge, the adsorbent could be sawdust or other waste with high adsorption properties.
  - The adsorbent could be lime or limestone, used widely for oil sludge.
  - The cost of the adsorbent could make preparation expensive (as in the case of sawdust) compared to the benefit of handling solid wastes.

Environmental Implications

The equipment and operations must be compliant with environmental regulations related to sludge, in some cases hazardous sludge.

The main risks associated with industrial sludge are:

- Smell (mainly in the case of biological sludge)
- Dust (in the case of very dry sludge)
- Chemical hazard linked to the presence of chemical or hazardous wastes in the sludge
- Biological hazard, which can be limited if workers wear personal protective equipment adapted to a potential exposure.

Carbon Dioxide Mitigation

The biomass content could be very variable. For oil sludge, it is 0%.

CAPEX and OPEX

In the cement plant, for the injection of pasty sludge, the facility requirements include:

- Unloading pits
  - Several pits to enable blending
  - One pit with mechanical extraction at the bottom to feed the pump below this storage
- Feeding hopper
  - Transfer from pit to hopper by crane
- Concrete pump
  - Traditional concrete pump with some adaptation to oil handling
- High-pressure pipe leading to the injection line
- Special burner (atomization)
- CAPEX: €1 million to €3 million
- OPEX: €10 to €20 per ton, depending upon the use of a crane

In the cement plant, for the injection of dry sludge, the facility requirements include:

- Unloading zone for truck
  - Pneumatic delivery, or
  - Delivery in an hopper at the bottom of the silo and feeding by mechanical conveyor
- Vertical silo with explosion protection; in some cases the silo is equipped with an inertization system (N_2 or other gas)
- Extraction
- Pneumatic injection
- CAPEX: €1 million
- OPEX: €5 to €10 per ton

Barriers

- Cement plants must apply for a permit for waste (hazardous, in some cases), a procedure that could be complex and could raise strong opposition from stakeholders.
- Competition with land spreading
  - Clear regulation regarding landfilling must be issued, with regular controls.
  - Cement plants offer a service nearly year-round, compared to land spreading that has high seasonality.
  - Cement plants are more flexible than land spreading because they can receive hazardous and non-hazardous sludge whatever the physical nature.
- Competition with incineration. Some waste producers operate incineration capacity, but they need to find a solution for the ash.
  - The environmental regulation applied to these incinerators must be compliant with regulation on waste incineration.
- Competition with on-site treatment
  - Rules for the on-site landfilling of prepared must be clearly defined.
- Technical barriers to co-processing
  - Variability of the calorific value and/or the ash content: managing the impact on the process and on the raw mix composition
  - Variability of the viscosity.

6. Non-hazardous Industrial Waste

Origin

This waste can originate from several different sources:

- Packaging waste
- Process waste, such as pulper waste in the paper recycling industry
- Off-spec products and product losses.

Composition

The composition of industrial packaging waste is similar to that of household packaging waste. The composition of other non-hazardous waste is linked to the process generating the waste.

The standard composition of non-hazardous industrial waste available for energy recovery is:

- LCV: 15 to 25 gigajoules per ton, depending on the composition (paper vs. plastics)
- Chlorine: 0% to 2%
- Moisture content: 10% to 20%
- Metals: 1,000 to 3,000 parts per million

The standard composition for pulper waste available for energy recovery is:

- LCV: 6 to 12 gigajoules per ton (20 to 25 gigajoules per ton after drying)
- Chlorine: 0.5% wet
- Moisture content: 40% to 60%
- Metals: <1,000 parts per million

This waste segment is a source for producing solid recovered fuel (SRF)/RDF (see section on CAPEX/OPEX)

- Quality required for main burner
- Quality required for pre-calciner
- Quality require for pre-combustion chamber.

Traditional Destination

The typical destinations for non-hazardous industrial waste are:

- Recycling, a leading destination mainly when this waste is a mono-product
- Incineration (with or without energy recovery), which could be carried out internally and/or in an external collection facility including municipal waste incinerators
- Landfilling, which is an important destination in many countries and could occur on the premises of the waste producer or externally (municipal or not).

Supply Chains

There are different options for organizing the collection of non-hazardous industrial waste:

- Selective collection (more or less complex) to extract the recyclable fraction at the source. This could be followed by sorting of the materials, mainly within the recycling management company.
- Universal collection, with use of a transfer station
- For small and medium enterprises, industrial wastes are mixed in a designated bin. Recycling is more difficult in this case, and the waste is considered to be normal municipal waste and follows the standard chain of treatment..

Preprocessing

For producing alternative fuel for cement plants, there are several preprocessing options:

- Sorting operations
- Drying of the waste

These operations must be handled in a dedicated facility that has a permit for waste management. The workers must be trained in the risks. A quality management system must be implemented, with subcontracting (or not) to an external lab.

The mixing of hazardous waste, including household hazardous waste, must be prohibited.

Carbon Dioxide Mitigation

SRF/RDF produced from non-hazardous wastes contains a biomass fraction made of wood, paper, and organic wastes. Depending on the country, the biomass fraction is between 25 and 50 percent.

Environmental Implications

The equipment and operations must be compliant with environmental regulations related to municipal waste.

The main risks linked to the SRF/RDF are the same as the risks identified for SRF/RDF produced from municipal waste:

- Fire provoked by a shredding operation, by self-combustion (when organic material is stored too long), and by other means
  - Solution: fire detection equipment such as thermal cameras and adapted extinguishing equipment as well as frequent training of workers
- Dust explosion: given the fluffy aspect of the waste and the organic fraction of the dust, the accumulation of dust in factories and storage facilities could provoke an explosion
  - Solution: frequent cleaning of the halls and superstructure of buildings.

CAPEX/OPEX	Barriers

The facility requirements include:
• Preprocessing shredding line
• Shredding line: the design depends on the targeted granulometry
• A one-step shredding operation could be performed to achieve the quality required for the precalciner (50 to 80 millimeters). For a typical design, requirements include:
  • First-step shredding
  • Wind-shifter or ballistic separator
  • Recirculation of the larger pieces to the shredder
  • Magnetic separator
  • CAPEX: €0.5 million to €1 million plus civil works and utilities
  • OPEX: €15 to €25 per ton
• Two-step shredding is required to achieve the quality required for the main burner (20 to 35 millimeters)
  • First-step shredding
  • Wind-shifter
  • Second-step shredding with two shredders in parallel
  • Wind-shifter
  • Magnetic separator
  • CAPEX: €1 million to €2 million plus civil works and utilities
  • OPEX: €20 to €40 per ton
In the cement plant, the receiving facility could range from very simple to more complex:
• For small capacity (1 to 5 tons per hour):
  • A simple docking station for two to three trucks is enough, provided the logistics are adapted (for example, proximity of the shredder, possibility of delivery over the weekend, low cost for immobilization of delivery trucks).
  • Storage is in a silo with protection from dust explosion.
  • Transport to the burning location must occur by mechanical conveyor as much as possible, finished by pneumatic feeding though a rotating valve and dosing system.
  • CAPEX: €1 million to €2 million
  • OPEX: €5 to €10 per ton
• For larger capacities (more than 5 tons per hour):
  • A storage facility must be created (for example, a simple hall, such as former clinker storage), adapted with fire detection and protection.
  • Hopper filling using a front loader
  • Injection line (as above)
  • Mechanical storage such as a top loader or a pit with an automatic crane; in this case, it is recommended to have one pit for deliveries and at least one pit to feed the hopper (in some cases, two cranes could be required)
  • CAPEX: €5 million to €15 million, depending on the capacity and civil works required
  • OPEX: €5 to €20 per ton, depending on manual or automatic operation and manpower costs
	• Cement plants must apply for a permit for waste (since SRF/RDF is considered waste), a procedure that could be complex and could raise strong opposition from stakeholders
	• Competition with landfilling
	  • SRF/RDF production must be competitive compared to landfilling. In some countries, the landfill gate fee is too low to cover the cost of RDF/SRF preparation.
	  • Regulation must limit access to landfilling (through either technical restriction or taxation) and place a clear priority on recycling and recovery operations.
	• Competition with incinerators
	  • Because an incinerator as high fixed costs, it must operate at full capacity. The design must be strictly adapted to the needs of the waste to be incinerated.
	  • Regulation can give clear priority to the most efficient use of the waste (in the context of optimizing resource management), to energy efficiency, and to phasing out energy-intensive industrial equipment.
	  • Cement plants operate a high-energy process and often approach large-scale waste utilization. This investment is minimal compared to building a new incinerator.
	• Bans on thermal use of this waste
	  • Co-processing (generally speaking, any thermal use) could be seen as competing with recycling, providing an easy and cheap solution for waste generators.
	  • However, recycling activities need a destination for their own recycling wastes, which could lead to natural cooperation between recycling and co-processing.
	  • The profitability of recycling is linked to the market price of the recycled materials, and the alternative fuel also must be cheaper than the fossil fuel. Sustainable recycling must be profitable.
	• Technical barriers:
	  • Moisture and calorific value
	  • Chlorine
	  • Particle size
	  • Homogeneity.

7. Municipal Waste

Origin	Composition

Municipal waste is the waste produced by residents at home, in offices, or in commercial activities. This waste could include commercial waste, non-hazardous produced by industries, green waste, and street cleaning waste.
Responsibility for the collection and treatment of municipal waste is often in the hands of the city or regional council; however, in some cases, this responsibility falls to residents, meaning that they must self-organize or create an entity responsible for waste collection and treatment (as was the case in Poland until July 2014).
The city council could delegate (in part or total) the collection and/or treatment of the waste.
	The composition of municipal waste depends on the distribution of housing (vertical/horizontal density), the city's districts, seasonality, the organization of collection (selective or not, using waste pickers or not), the city's food standards, and other factors.
	The standard composition of municipal waste available for energy recovery is:
	• LCV: 8 to 10 gigajoules per ton
	• Chlorine: 0.5% to 1.5%
	• Moisture content: 30% to 45%
	• Metals: 2,000 to 5,000 parts per million
	The standard composition of SRF/RDF is as follows:
	• Quality required for the main burner:
	  • LCV: 20 to 25 gigajoules per ton
	  • Moisture: <15%
	  • Granulometry: 20 to 30 millimeters
	• Quality required for the precalciner:
	  • LCV: 13 to 15 gigajoules per ton
	  • Moisture: 15% to 25%
	  • Granulometry: 50 to 80 millimeters
	• Quality required for the precombustion chamber:
	  • LCV: 10 to 13 gigajoules per ton
	  • Moisture: 20% to 40%
	  • Granulometry: 100 to 200 millimeters

Traditional Destination	**Supply Chains**

The typical destinations are:
• Landfilling, which is still the main destination in many countries, although the level is decreasing because of:
  • Strict bans on landfilling of organic or recyclable waste (as in some countries in Europe) or taxes on landfilling
  • High population densities
  • Ambitious recycling targets.
• Incineration (with or without energy recovery), which is well developed in :
  • Countries with landfill limitations
  • Large cities or places where it is difficult to site a landfill.
• Recycling, which is developing everywhere in response to regulations and targets related to the circular economy.
	Options for organizing municipal waste collection include:
	• Selective collection (more or less complex) to extract the recyclable fraction at the source. The recyclable fraction is sent to a sorting center to separate out the material, and the non-recyclable fraction is sent to final treatment
	• Universal collection, with several transfer stations in large cities.

Preprocessing

For producing alternative fuel for cement plants, there are several preprocessing options:

- Creation of a sorting line to extract the recyclables and the organic/inert fraction. The combustible fraction (without recyclables) must be shredded to produce the quality expected by the cement plant.
- Creation of a mechanical biological treatment (MBT) plant with different options for production of SRF/RDF (without or without drying) that are associated with compost production or methanization
- Drying is a key issue for producing alternative fuel that is acceptable for use in cement plants. The drying could be biological or thermal. In MBT, biological drying is mainly used. To use municipal waste to create the fuel quality required by the main burner, thermal drying is mandatory.

These operations must be handled in a dedicated facility that has a permit for waste management. The workers must be trained in the risks. A quality management system must be implemented with subcontracting (or not) to external labs.

The mixing of hazardous waste, including household hazardous waste, must be prohibited.

Carbon Dioxide Mitigation

SRF/RDF produced from municipal waste contains a biomass fraction made of wood, paper, and organic wastes. Depending on the country, the biomass fraction is between 25 and 50 percent.

CAPEX and OPEX

Producing alternative fuel from municipal waste requires two steps:

- Sorting operation before or after shredding
- Full shredding.

For a sorting line with a capacity of 250,000 tons per year:

- CAPEX: €1 million to €2 million plus €7 million to €8 million for bio-drying
- OPEX: €5 to €15 per ton, depending on the fraction of recyclables and the market price.

For the shredding line and the handling/sorting and injection line in the cement plant, see Figure 41 in the section "non-hazardous industrial waste."

Environmental Implications

The equipment and operations must be compliant with environmental regulations related to municipal wastes.

The main risks associated with SRF/RDF are:

- Fire provoked by a shredding operation, by self-combustion (when organic material is stored too long), and by other means
  - Solution: Fire detection equipment such as thermal cameras and adapted extinguishing equipment as well as frequent training of the workers in fire management
- Dust explosion; considering the fluffy aspect of the waste and the organic fraction of the dust, dust accumulation in factories and storage facilities could provoke a dust explosion
  - Solution: Frequent cleaning of the halls and superstructure of buildings.

The biological hazard is limited if workers wear personal protective equipment that is adapted to a potential exposure.

Barriers

- Cement plants must apply for a permit for waste (since SRF/RDF is considered waste), a procedure that could be complex and could raise strong opposition from stakeholders.
- Competition with landfilling
- RDF/SRF production must be competitive compared to landfilling. In some countries, the landfill gate fee is too low to cover the cost of RDF/SRF preparation.
  - Regulation must limit access to landfilling (through technical restriction or taxation) and prioritize recycling and recovery operations.
- Competition with incinerators
  - Because an incinerator has high fixed costs, it must operate at full capacity. The design must be strictly adapted to the needs of the waste to be incinerated.
  - Regulation can give clear priority to the most efficient use of the waste (in the context of optimizing resource management), to energy efficiency, and to phasing out energy-intensive industrial equipment.
  - Cement plants operate a high-energy process and often approach large-scale waste utilization. This investment is limited compared to building a new incinerator.
- Bans on thermal use of this waste
  - Co-processing (generally speaking, any thermal use) could be seen as competing with recycling, providing an easy and cheap solution for waste generators.
  - However, recycling activities need a destination for their own recycling wastes, which could lead to natural cooperation between recycling and co-processing.
  - The profitability of recycling is linked to the market price of the recycled material, and the alternative fuel also must be cheaper than the fossil fuel. Sustainable recycling must be profitable.
- Technical barriers
  - Low calorific value and high moisture are the main barriers to the use of municipal waste in cement plants; as such, this waste segment is used only in the calciner.
  - Chlorine presence comes from two sources: PVC and the salt from food.

8. Sewage Sludge

Origin	Composition
Sewage sludge is produced by sewage plants that receive municipal or industrial wastewater. The wastewater is cleaned using biological treatment, and the pollution is concentrated in the sludge. After biological treatment, the sludge could be dried through mechanical treatment (centrifuge or filter press) or a thermal process.	The composition of sewage sludge depends on the drying process used in the plant. The standard composition of sewage sludge available for energy recovery is: • LCV: 2 to 3 gigajoules per ton raw (10 to 15 gigajoules per ton after drying) • Chlorine: 0.5% to 1% • Moisture content: 40% to 60% raw (5% to 20% after drying, depending on the process) • Metals: 1,000 to 5,000 parts per million, with special attention to aluminum and iron.
Traditional Destination	**Supply Chains**

The typical destinations for sewage sludge are:
• Fertilizer use in fields
  • Different countries support this solution to reduce the use of synthetic fertilizers; however, limitations include the presence of pollutants, the real agronomic value, and seasonality
• Incineration
  • This could occur at the sewage plant, in a municipal waste incinerator, or at a power plant.
	The traditional transport method is by tanker truck or trailer. In the case of simple trailers, the risk of spillage must be managed.

Preprocessing	**Environmental Implications**
For producing alternative fuel for cement plants, there are several preprocessing options: • Mechanical drying in the sewage plant • Thermal drying, in the sewage plant or in the cement plant using waste heat from the kiln.	The equipment and operations must be compliant with environmental regulations related to sewage sludge. The main risks associated with sewage sludge are: • Smell, mainly for sludge with high or medium moisture content • Dust, in the case of dry sewage sludge. Biological hazard is limited if workers wear personal protective equipment that is adapted to a potential exposure.

<table>
<tr><th></th><th></th></tr>
<tr><th>Carbon Dioxide Mitigation</th><th>Barriers</th></tr>
<tr><td>Sewage sludge is considered to be 100 percent biomass.</td><td rowspan="3">• Cement plants must apply for a permit for waste (since sewage sludge is considered waste), a procedure that could be complex and could raise strong opposition from stakeholders.
• Competition with land spreading
  • Land spreading is not available year-round and requires large areas of land.
  • Land spreading should be limited to sewage sludge with real agronomic value and no pollutants and probably to small/medium volumes of production.
• Competition with incinerators
  • Some sewage plants want to operate a full line but need to find a solution for the ash.
  • Co-incineration in power plants
  • Regulation applied to power plants must be compliant with waste incineration.
• Ban on incineration of waste containing phosphorus
  • Some countries (such as Germany) could soon implement a ban on sewage sludge incineration to address limited phosphorus resources.
  • Recycling is considered as competition to co-processing.
• Technical barrier: impact of moisture on calorific value.</td></tr>
<tr><th>CAPEX and OPEX</th></tr>
<tr><td>CAPEX:
• For pasty sewage sludge, facility requirements are similar to those for industrial sludge.
• For dried sewage sludge, pelletized or not, facility requirements are similar to those for animal meal.
OPEX: €5 to €10 per ton</td></tr>
</table>

9. Construction and Demolition Waste

<table>
<tr><th>Origin</th><th>Composition</th></tr>
<tr><td>Construction and demolition waste originates from:
• Building construction activities
• The deconstruction of buildings.
The main characteristics of this waste segment are:
• Huge heterogeneity of the materials
• Geographic dispersion of these waste sources.</td><td>The composition of construction and demolition waste depends on:
• The material used for construction:
  • In North America, wood is very important, whereas in Europe, rubble is the most important.
• The deconstruction strategy
  • Preparation of the building before demolition, such as extraction of the doors, windows, and other components
  • Selective waste collection on-site (mainly for large operations)
  • Use of dedicated bins to collect the waste (for small operations).
• Construction waste often is mixed with polluted packaging such as paint containers, glue, adhesives, and others.
The standard composition of sorted construction and demolition waste is very variable. As an example, the composition for shingles is: LCV: 25 to 30 gigajoules per ton; chlorine: 0%.</td></tr>
<tr><th>Traditional Destination</th><th>Supply Chains</th></tr>
<tr><td>The typical destinations for construction and demolition waste are:
• Landfilling
  • In most countries, demolition waste is considered to be inert and is delivered to low-grade landfills without any control
  • In some cases, the burnable fraction is extracted and burned on-site
  • Construction waste can be disposed of in municipal landfills.
• Material recovery
  • The rubble could be used as backfill in aggregate quarries or embankments
  • The packaging and production losses from construction waste are landfilled.</td><td>Construction and demolition waste is often collected in bins.
In the case of strict rules on landfilling, sorting centers have been created near cities to allow for extraction of the burnable fraction.</td></tr>
<tr><th>Preprocessing</th><th>Environmental Implications</th></tr>
<tr><td>The preprocessing operation is linked to the sorting operation. Sorting extracts different fractions such as doors, windows, shingles, wood parts, plaster board, and other components.
These fractions can be shredded to produce alternative fuel:
• Shingles made of paper with bitumen are used in cement plants in Germany and North America.
• For wood waste taken from houses (mainly in North America), dedicated facilities prepare the alternative fuel for cement plants.
• The plastic fraction cannot be used in cement plants because of the presence of PVC.
• Plasterboard has been used in the Republic of Korea, although the main problem is separating the cardboard from the gypsum. Both parts can be used separately or mixed.
• Hazardous waste such as polluted packaging can be used in cement plants after shredding.
The remaining portion of this waste could be crushed to produce aggregate. Several operations are ongoing (for example, in France) to recycle waste as aggregate in concrete production.</td><td>The equipment and operations must be compliant with environmental regulations related to construction and demolition wastes.
For the burnable portion, the environmental implications are the same as for SRF/RDF.</td></tr>
</table>

Carbon Dioxide Mitigation	Barriers

The wood fraction is 100 percent biomass.
 	
CAPEX and OPEX
 	
The CAPEX and OPEX are similar to those for non-hazardous industrial waste.
	• Organizing an efficient collection network is key to producing alternative fuel usable for co-processing.
	  • Cement plants cannot use these wastes in the form in which they are produced.
	  • The creation of sorting lines near cities is helping to separate the different fractions to produce valuable alternative fuels and raw materials.
	• Competition with landfilling (the main destination of this waste)
	  • Regulation banning the landfilling of burnable or mixed waste is a major step to make this market available for cement plants. This ban must be combined with the enforcement of quality controls in landfills.
	• The standard for aggregate must be revised to allow for use of the inorganic portion of the waste.

10. Biomass/Green Wastes

Origin

The term "green waste" includes different categories:

- Waste from crop production, for example:
  - Out-of-date seeds, which could be considered hazardous waste depending on the pesticides applied to protect them
  - Rice husk, palm kernel shell, bagasse, coffee husk, cotton stalks, and others
  - Pesticide packaging or plastic from greenhouses (see "polluted packaging")
- Green waste from urban and forestry services
- Waste from agro-industries, for example:
  - Different kinds of sludge
  - Chicken litter and other animal waste
  - Glycerin from biofuel production.

For waste from crop production and from urban and forestry services, production is scattered across large territories.

Composition

The standard composition for crop waste (for example, coffee husk) is:

- LCV: 17 gigajoules per ton (dry)
- Chlorine: <0.5%
- Moisture content: 10% to 20%
- Ash: Presence of silica causes high wear
- Granulometry: <15 millimeters

The standard composition for chicken litter is:

- LCV: 10 to 13 gigajoules per ton
- Chlorine: 0.4% to 0.8%
- Moisture content: 15% to 30%
- Ash: 10% to 30%

The standard composition for glycerin is:

- LCV: 25 to 35 gigajoules per ton
- Chlorine: Marginal
- Moisture content: 5% to 10%
- Ash: 0%

Traditional Destination

The typical destinations for biomass and green wastes are:

- Burning on site
  - Waste from crop production (rice husks, coffee husks, corn waste) is often burned directly in the field. This is typical for small-scale production, and the ash may have some fertilizing properties. However, keeping the waste in the field after harvesting is often a source of disease for the next planting.
  - Waste from forestry operations is typically burned on-site.
- Feeding cattle
  - Some sludge or crop production waste is used to feed cattle, either directly on small farms or following transformation.
- Energy recovery is an important destination for this waste, given the high calorific value.

Supply Chains

For crop waste, collection is a key issue. Two parameters must be considered:

- Low density: 0.1 tons per cubic meter or less
- Dispersion of the sources in small quantities across large areas.

Collection could be optimized through the use of transfer stations, which must be managed properly to protect the material from long-term exposure to rain and other elements.

Preprocessing

Preprocessing of biomass/green wastes is targeted at:

- Modifying the physical aspects
  - Through grinding, pelletization, and other means
- Decreasing the moisture content
  - Drying via solar or thermal means
  - Thermal drying can occur in the cement plant using waste heat from the kiln.
- Concentrating the calorific value
  - Carbonization and torrefaction are two technologies available for biomass.

Environmental Implications

Storage of biomass/green wastes must be managed properly to avoid:

- Rodents
- Fire caused by direct inflammation or fermentation
- Flying dust that could pollute communities around the plant.

Carbon Dioxide Mitigation	Barriers

This waste material is 100 percent biomass.
 	
CAPEX and OPEX
 	
The facility requirements are comparable to those for non-hazardous industrial waste.
	• Organizing waste collection is key and is often the main cost to be borne.
	  • Cement plants could be involved in the collection system, as a way to also increase the degree of control over sourcing.
	• Low calorific value
	  • The calorific value of biomass is low (compared to traditional cement fuel), at around 10 gigajoules per ton.
	  • Several technologies can be used to concentrate the calorific value, including drying (mechanical or thermal), torrefaction, and carbonization. Implementation of these technologies must bring real benefit, in terms of quality and compensation for costs.
	• Very low density
	  • Storage and handling facilities must be designed to manage large quantities (to achieve the same heat load as is produced by traditional fuel).
	• The biomass contains ash (20 to 50 percent on dry) of varying composition (silica and others) as well as some large amounts of chlorine (1 to 5 percent on dry).
	  • This must be taken into consideration in the raw mix of the cement kiln, given the low calorific value.
	• Competition with other energy recovery processes
	  • This includes competition with own-use of the waste to produce heat. Most cement transformation processes require heat, and green wastes are considered a free source of energy; however, operating with poor yield and poor-quality emissions is not always taken into consideration.
	  • In cement plants, energy efficiency is high and there is no production of ash.
	  • Power plants with up-to-date emission treatment are being developed, but they require significant quantities of biomass to be profitable, given the high investment cost.
	  • Cement plants have a cost advantage by using the biomass energy close to the source and because using it on-site requires limited investment.

11. Animal Meal

Origin

Animal meal is produced in rendering plants, which are in charge of managing the waste from cattle, from slaughterhouses, and from meat production.

Regulation defines the standards for animal feed (such as for cattle and fish) and determines the quantity available for other destinations such as energy recovery. Regulation defines different categories depending on the potential for pollution by disease.

Composition

The standard composition of animal meal available for use in energy recovery is:

- LCV: 15 to 17 gigajoules per ton
- Chlorine: <0.5%, depending on the cleaning strategy in the rendering plants
- Moisture content: 10% to 20%
- Fat concentration: if fat >15%, there is a risk of clogging in the cement plant.

Traditional Destination

The typical destinations for animal meal are:

- Use as animal feed, to feed different species of animals or fish, once the meal is certified as being free of disease
- Use as fertilizer, given the agronomic value of animal meal
- Energy recovery, which has become the main destination for animal meal in the case of a health crisis (for example, the "mad cow" crisis) or in the case of overproduction or specific qualities that are banned from previous use.

Supply Chains

The most convenient transport solution is by tanker truck, given that animal meal is stored in silos at the production site. Trailers also could be used, but they require a more complex receiving facility in the cement plant: use of a hopper and then transfer to the silo.

Preprocessing

Preprocessing is performed at rendering facilities. It is recommended that no preparation occur at cement plants.

Environmental Implications

Storage of animal meal must be managed properly to avoid:

- Rodents
- Fire caused by direct inflammation or fermentation
- Explosion risk due to dust (the silo must be designed with this consideration in mind)
- Smell (if a hopper is used for receiving the waste, it must be located in a building to avoid contact with water and the dissemination of smell outside).

Carbon Dioxide Mitigation

Animal meal is made from 100 percent biomass.

CAPEX and OPEX

The facility requirements include a silo and an injection line to the main burner.

- CAPEX: €0.5 million to €1 million
- OPEX: €5 per ton

Barriers

- Regulation of animal meal plays a fundamental role. It must clearly define the different qualities as well as the allowable destinations for this waste, and it must be enforced strongly along the complete chain from animal waste to the final destination.
- Cement plants must apply for a permit to use the waste, a procedure that could raise concern among the general population. The local community could be opposed to the use of animal meal.
- Sustainability of the resource. In Europe and other regions, cement plant capacity has been used during periods of health crisis. After the crisis, the waste streams return to their original destinations. The available quantities are limited, making the price less (or not at all) appealing to replace traditional fuel in cement plants.

USE OF ALTERNATIVE FUELS IN CEMENT PRODUCTION: THE CASE OF POLAND

APPENDIX 2

Over the past decade, the cement sector in Poland has experienced rapid growth in its use of alternative fuel sources for industrial processing. Two key factors helped initiate the adoption of co-processing (the use of waste as an energy source) in the country's cement sector:

1. The willingness of Polish cement companies to reduce their operating costs by quickly replicating the alternative fuel experience of international cement groups; and
2. The enforcement of Polish waste regulations in order to conform to relevant European Union directives, namely the Waste Framework Directive, the Waste Incineration Directive, and the Landfill Directive.

Initial adoption of co-processing in Poland was relatively slow and focused only on the use of hazardous waste, which was prohibited from being landfilled. The alternative fuel substitution rate grew to a few percent following the adoption of the first waste regulation in 1998, which included a small state tax on landfilling. Initially, this tax proved non-dissuasive and difficult to implement, largely because the producers of waste were responsible for collecting it. At that time, waste was particularly heterogeneous, which prompted a simple solution: the blending of pasty, solid, and some liquid waste with sawdust for use in co-processing.

The second waste stream developed in Poland centered on used tires. By law, tire manufacturers were responsible for the management of used tires, based on the principle of "extended producer responsibility." As a response, the country's tire manufacturers created a shared company to manage this obligation through coordinated organization and subsidization of used tire collection. This propelled Poland's alternative fuels substitution rate to the low teens.

As the pressure grew to find ways to utilize non-hazardous industrial waste, Poland used subsidies from the European Union to implement the first waste shredding line to produce refuse-derived fuel (RDF). In 2001, the state tax was further simplified and extended to municipal waste. Responsibility for waste collection was transferred to landfill operators, which were easier to control and organize than hundreds of thousands of individual waste producers.

In parallel, with competition growing both for used tires and for the small quantities of hazardous waste that were available, cement companies started investing in the development of handling facilities for RDF in their cement plants, creating significant demand that went beyond the local market. This demand inflated the RDF price, further benefiting the cost-effectiveness of RDF preparation. At that time, municipalities were not yet responsible for municipal waste management; rather, this responsibility was scattered among a small grouping of waste producers, including large commercial buildings, housing communities, and farms, which had individual contracts with private waste management companies for the disposal of smaller quantities of waste.

In 2005, Germany adopted a ban on the landfilling of recyclable and organic waste, leading to overproduction of RDF. Poland's shift toward alternative fuel development based on RDF was thus supported by importation of the fuel from Germany for five years, before Germany increased its own waste burning capacity. At that point, the alternative fuel substitution rate in Poland reached 20 percent.

In 2008, the state tax was increased sharply, climbing from €4 per ton in 2007 to about €17 per ton, with a further doubling announced within the next 10 years. The enforcement of this tax for municipal waste incited waste management companies to invest in alternative solutions. With cement plants capable of burning more than 1 million tons of municipal waste per year, and given the relatively lower financial and time investment required for building a mechanical biological treatment plant compared to an incinerator, Poland's waste management sector invested heavily in shredding lines for RDF preparation.

Waste management companies, supported by mid- to long-term contracts with the cement industry (which was guaranteeing a sustainable source of RDF produced locally), thus have developed numerous shredding lines in Poland. Some of the investment has been subsidized by European Union and local government funds, supported in part by the state tax. Some of the investments also were shared between cement plants and RDF preparation plants. The typical investor profile was a local entrepreneur with the support of international companies or investment funds. The increase in the state tax immediately drove up the share of waste going to recycling and heat recovery, which more than doubled from 8 percent in 2007 to 18 percent in 2008 and 22 percent in 2009.

At that point, shredding line operators were sourcing waste from the industrial sector (obtaining good-quality waste for a low gate fee) as well as from the municipal waste sector, with large cities being the main providers. The extension of sourcing to include municipal waste resulted in a degree of downgrading of RDF quality, but the cement sector continued the effort and pushed the substitution rate to 40 percent in 2010.

Once the capacity of RDF production lines reached an equilibrium with the alternative fuel capacity of cement plants, the cement companies were able to pressure RDF producers to further improve the fuel quality. To face this new demand, RDF producers had to innovate, improving the quality of the RDF significantly through better sorting and drying sequences (thermal or biological). In parallel, the cement plants developed new tools to improve drying, such as by installing thermal dryers that used the waste heat from the kilns. A new increase to the state tax then put more waste on the market—and at a better price—confirming the trend toward alternative fuel use.

On July 1, 2013, a new law was issued (Journal of Law of 2013, item 1399 and item 21), transferring the responsibility for municipal waste management to the municipalities as well as capping the municipal waste tax paid by each citizen at €17 per year.

The National Waste Management Plan 2014 (Official Journal Polish Monitor of 2010 N°101, item 1183) included, among others, the promotion of mechanical biological treatment for medium-sized communities, incineration for big cities (greater than 300,000 inhabitants), the reduction of landfilling (capped at 35 percent of the 1995 waste weight for 2020), as well as increasing the recycling targets to 50 percent by 2020.

The Polish waste management market is now restructuring, with an increase in incineration capacities. Several incinerators are under construction, targeting large cities. However, co-processing is now a well-established waste management stream—producing 1.5 million tons per year of alternative fuels—and will grow to a capacity of about 2 million tons of RDF, for a global production of municipal waste of between 15 and 20 million tons per year. To stay competitive, Polish cement plants are now looking for innovative solutions to decrease RDF preparation costs and increase the use of less-prepared wastes. New technologies are under investigation based on longer residence time in the calciner or the use of external pre-burners ("hot disks").

As shown in Table 1, the alternative fuel substitution rate in Poland reached 45 percent in 2011. It has continued to increase in recent years and is now above 60 percent, with some cement plants using up to 85 percent alternative fuel.

To summarize, the expansion of co-processing in Poland was made possible as a result of:

3. Strong commitment of the cement sector, including through: grasping the alternative fuel market opportunities as they were emerging; establishing mid-term and/or long-term contracts with the waste management sector; smart and continuous investments in the handling (and in some cases preparation) of alternative fuels; and the development of skills in kiln operation to accept low-quality alternative fuels. Ongoing enforcement of waste regulations, particularly those related to landfilling.
4. A favorable economic context comprising smart national and international investments, taxation on landfilling, and some alternative fuel opportunities supported by European subsidies.

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