Implementation of co-processing of waste in cement kilns for Ukraine. Waste management issues.

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IMPLEMENTATION OF CO-PROCESSING OF WASTE IN CEMENT KILNS FOR UKRAINE

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The manual discusses the theoretical and practical provisions for the assessment and implementation of co-processing of waste in cement kilns. Specific calculations of the environmental effect of the co-processing of waste are provided. Attention is paid to the legislative, best available technologies, financial and energy efficiency issues.
The material is intended for students of higher educational institutions, graduate students and engineers engaged in the development, design and audit of electromechanical systems of energy-intensive industries, specializing in 141 Electricity, electrical engineering and electromechanics, 144 Heat power engineering, 101 Ecology and others.

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1. INTRODUCTION

1.1. Waste Management in Ukraine

One of the most pressing problems for Ukraine is waste accumulation. To date, the total volume of waste generation in Ukraine is over 290 million t/a [1]. Waste recycling is known to be a desirable technology for the introduction into a waste management system. However, a waste sorting system is required to implement it. At present, such a system does not work in Ukraine, so it is necessary to look for alternatives to waste technology to reduce their level of accumulation.

Current waste management challenges in Ukraine and other countries can be described as follows [2]:

- accumulation of waste both from the industrial and domestic sectors in controlled and uncontrolled landfills having an adverse effect on the environment, human health and land space;
- improper treatment and disposal of hazardous waste from industries;
- disposal of MSW without separation of hazardous fractions (e.g. batteries, oil paints);
- open burning of recyclable waste (e.g. paper, garden waste).

According to the State Statistics Service of Ukraine [3], as of 2016, more than 6 tonnes of waste per person has generated annually in Ukraine, **Figure 1.1**.

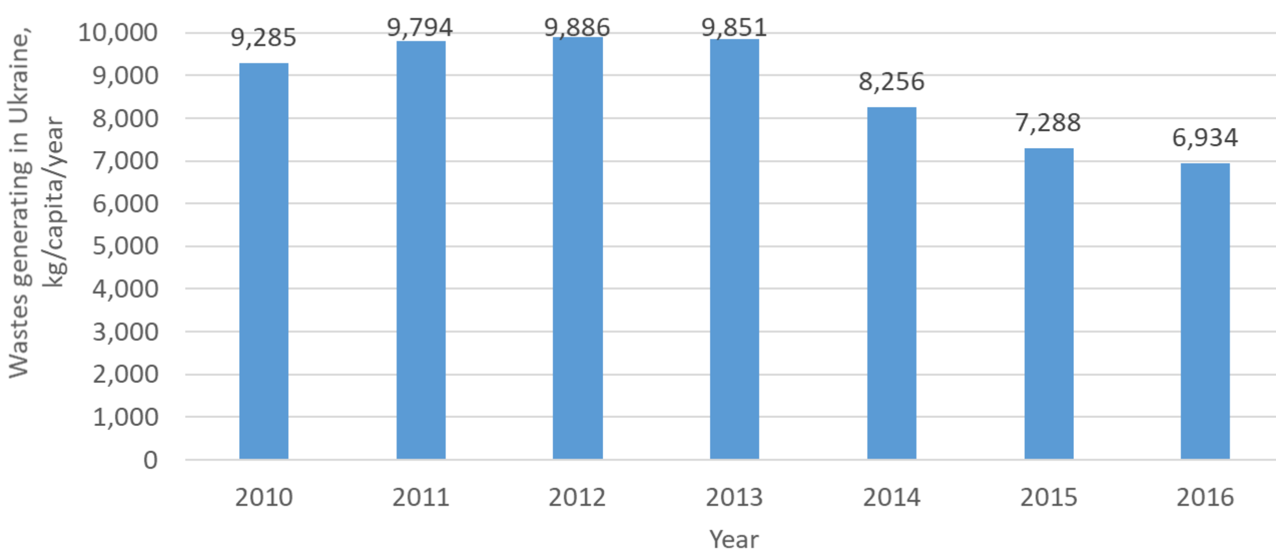

Figure 1.1 – Waste generation statistics in Ukraine

There is a declining trend of annual waste generation per person. Nevertheless, this figure is still higher than European values (4'931 kg/person/a in 2014 for EU-28 [4]).

In Ukraine, waste separation and recycling are not done systematically yet. Waste infrastructure is largely outdated with some landfills built more than 40 years ago, overflowing with waste and being unsafe. The legislation governing waste management is unclear [5] and does not encourage the private sector to invest. Waste collection rates are too low and do not cover the cost of disposal. This does not motivate investors to enter the recycling market.

For example, it is more expensive for waste collection companies to deliver waste to the only incineration plant in Ukraine ("Enerhiia"), located in Kyiv, than to dump the collected waste nearby, in uncontrolled landfills. Waste collection companies charge on average EUR 8.06 per ton for the collection of waste [6]. The gate fee of the incineration plant and legal landfills is about EUR 2.80 per ton. That means a waste collection company must spend about 30% of the income on incineration or landfilling. To avoid these treatment costs, the waste has often been dumped in illegal/semi-legal landfills for about EUR 1.6 per ton. Due to weak enforcement of the environmental legislation, this practice, unfortunately, is still widely used today.

This leads to an increase in landfill sites and an increase in the negative impact on the environment. This hinders the implementation of circular economy principles in Ukraine, such as reuse and recycling. These approaches cannot be replaced. However, in conjunction with their implementation, co-processing of waste in cement kilns will reduce the level of garbage at landfills and allow for new approaches to waste sorting. Investors in the cement industry are interested in the co-processing of waste (as an alternative fuel) in cement kilns. Therefore, the implementation of this technology is beneficial not only for the development of a waste management system in Ukraine, but also for industry.

The state investments in environmental protection, including waste management, in Ukraine, according to [7], were:

- in 1996 – UAH 77 million;
- in 2011 – UAH 1,187 million;
- in 2015 – UAH 737 million;
- in 2016 – UAH 2,209 million.

П This means that, nominally, the investments have increased more than thirtyfold since 1996. However, if for comparison we use the prices of 1996, we will see that due to inflation capital investments have increased only by 50%. The share of the investments in waste management increased from 14.8 % in 1996 only to 16.5% in 2016, with a basis UAH 77 million in 1996 in the prices of 1996.

During 2007-2017, several phases of expenditures reduction of the consolidated budget of Ukraine (expenditures of state and local budgets) for waste management were observed. In 2009, compared to 2008, the volume of budget financing decreased by UAH 186.8 million, in 2010 - by UAH 248.7 million, see **Figure 1.2**.

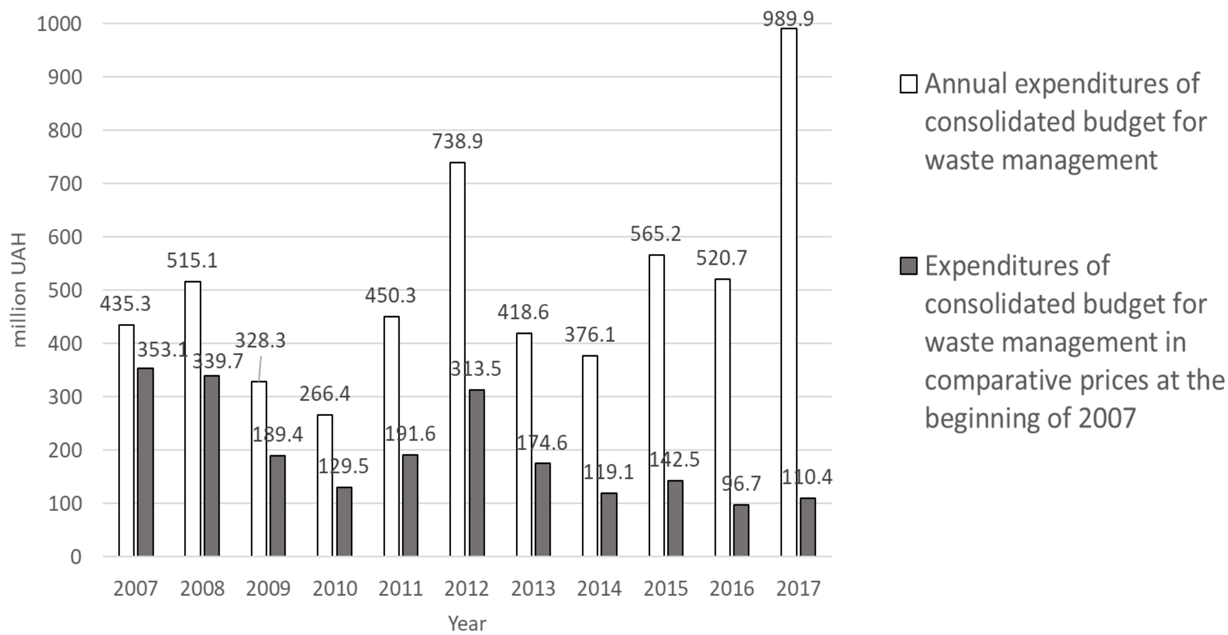

Figure 1.2 –Expenditures of the consolidated budget for waste management in Ukraine: white - annual expenditures of the consolidated budget for waste management

The threefold reduction in Ukraine's consolidated budget for the waste management system, **Figure 1.2**, is explained by inflation in Ukraine during the same period. An analysis of the expenditures of the state and local budgets on the waste management system revealed a growing trend of local budgets against the background of the declining state budget. Since 2014, local budget expenditures for waste management in comparative prices at the beginning of 2007 have increased more than twofold (from UAH 18.2 million in 2014 to UAH 37.9 million in 2017), see **Figure 1.3**.

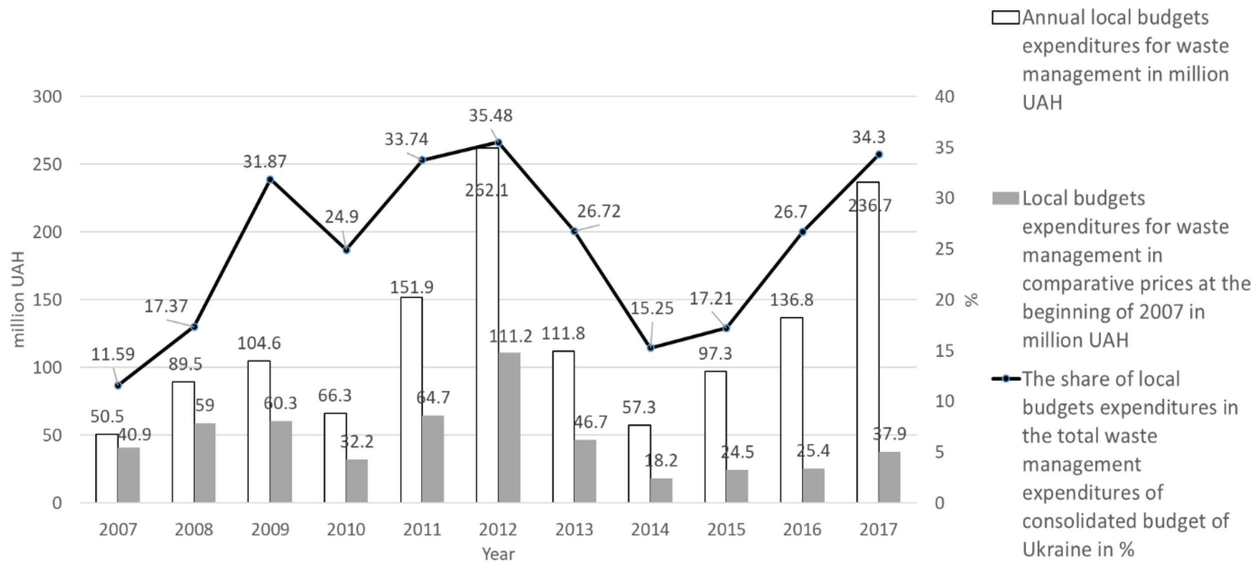

Figure 1.3 – Local budgets expenditures for waste management

As the required investments cannot be financed by the state and local budgets alone, they need to be supplemented by both domestic and foreign private investments.

Ukrainian legislation lacks the specification of possible forms of public-private partnerships to attract private investments in waste management. It does not define different models of cooperation of territorial communities with private partners (residents and/or non-residents) that have the necessary material and technical base and considerable experience in conducting entrepreneurial activity in the field of waste management.

As most of the waste is created by the industrial sector, agricultural enterprises and municipalities; it is also an important challenge for the economic sector that should be more involved based on the polluter-pays principle. The formation of industrial waste management capacities should be one of the priorities of decentralization and local self-government reform, as well as attracting investments into waste management.

The messages of this paragraph are:

- Taking into account inflation, even with the increase in expenditures from local budget since 2014, **Figure 1.3**, they are 3-4 times less than the state consolidated budget, which tends to decrease, **Figure 1.2**). Thus, the overall level of investment in the waste management system does not increase;
- Without increasing investment in the waste management system, Ukraine will need more time to develop it.

1.2. Legislation of Ukraine in the field of waste management

The Law “On Waste” [8] is one of the main documents, which regulates waste management in Ukraine. It defines not only institutional aspects, but also “legal, organizational and economic principles of activity connected with prevention or reduction of waste, its collection, transportation, storage, processing, recycling, removal, neutralization, and burial, as well as prevention of negative influence of waste on the environment and human health on the territory of Ukraine”.

The Law of Ukraine "On Waste" of 1998, No. 36-37, including amendments No. 2530-VIII (2530-19) of 06.09.2018, also guarantees state support for alternative use of waste which is relevant for co-processing and recycling of waste as follows:

- article 5, paragraph h: to aid in the disposal of waste by direct re-use or alternative use of resource-valuable waste;
- article 16, paragraph h: to obtain benefits in the prescribed manner if taking part in establishing waste management facilities;
- article 17, paragraph ye: to take organizational, scientific, technical and technological measures for the maximum recovery of waste, sale or transfer to other consumers or enterprises, institutions and organizations involved in waste collection, processing and disposal, as well as to provide environmentally friendly disposal of waste that is not suited for recycling at their own expense;
- article 17, paragraph n: to have a license for conducting operations in the field of handling hazardous waste and/or permission to transport hazardous waste abroad;
- article 18, paragraph b: to ensure development and implementation of national and intergovernmental waste management programmes, as well as the implementation of low-energy, energy-saving and resource-saving technologies;
- article 18, paragraph v: to ensure organizational and economic principles in the field of waste management, the introduction of low-waste and non-waste technologies, as well as the promotion of separate collection of waste and its recovery;
- article 20, paragraph h: to coordinate and promote entrepreneurial activity in the waste management sector;
- article 35-1. When local state administrations or bodies of self-government select a scheme of sanitary purification, the preference is given to proposals that provide for a greater degree of household waste recycling or recovery. Household waste incineration is to be carried out only with the purpose of obtaining heat and/or electric energy.

According to Art. 37 of the Law of Ukraine "On Waste" [8] ("Control and supervision in the field of waste management"), state control and supervision must be carried out by a specially authorized central body of executive authority in the field of waste management (Ministry of Ecology and Natural Resources of Ukraine) or other competent bodies of executive authority. Supervision over compliance with the regulations in the field of waste management must be carried out by the Prosecutor General of Ukraine and the offices subordinated to them in accordance with the law. Public control over waste management must be carried out by public inspectors for environmental protection in accordance with the current legislation.

The scheme of territorial management in the field of waste management [6, 9] is given in **Figure 1.4**.

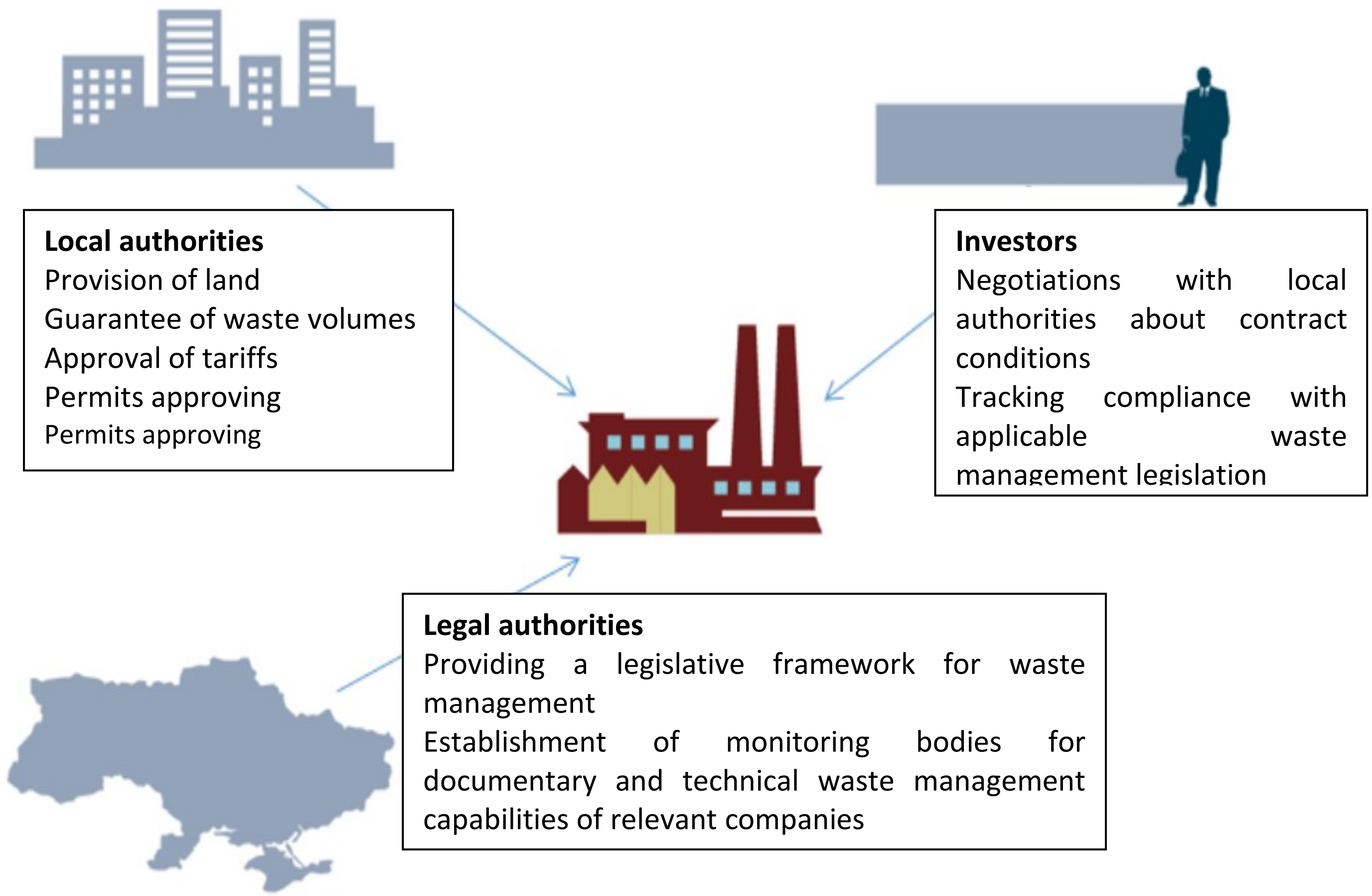

Figure 1.4 – Ukrainian territorial waste management as a part of environmental protection

Local authorities can decide which waste management operations will be implemented in their areas, which gives them the opportunity to implement the most suitable technologies for their individual conditions. In practice, this process can be delayed due to the unclear procedure for blocking it.

To determine the direction of development of waste management activities, the Government of Ukraine has approved a National Waste Management Strategy in Ukraine until 2030 [10]. The strategy is aimed at:

- implementation of modern approaches to waste management at the national and regional levels;
- reducing waste generation through active recycling and reuse.

The National Strategy defines the Government's intentions to reduce the number of landfills and to create new facilities for recycling. This should be done in three stages [11], **Table 1.1**.

Table 1.1 – Stages of implementation of the National Waste Management Strategy in Ukraine until 2030

Stage	Reducing the quantity of landfills	Establishing facilities for the processing of secondary raw materials
2017-2018	from 6000 to 5000	from 65 to 100
2019-2023	from 5000 to 1000	from 100 to 250
2024-2030	from 1000 to 300	from 250 to 800

The strategy defines the main directions of state regulation in the field of waste management for the coming decades, taking into account the European approaches to waste management. The strategy includes:

- establishing up to 800 new facilities for waste recycling and reusing, as well as biowaste composting by 2030,
- reducing the total amount of household waste disposal from 95% to 30% (with basis 100% ≙ 6,000 kt/a of MSW generation),
- minimizing the total amount of disposed waste from 50% to 35% by 2030 (with basis 100% ≙ 290,000 kt/a of total waste without specification of options),
- creating the network of 50 regional landfills that will meet the requirements of the 31st EU Directive.

In order to ensure the monitoring and control of waste management, it is planned to develop an information system that will include information on the nomenclature and the amount of waste that is generated, processed and disposed of. Businesses providing such services will also be registered. An important control tool will be the establishment of a National Register of Waste Generation Sources, Production Facilities in the Field of Recycling and Accounting Systems by Business Entities.

In general, the waste management system in Ukraine is driven by trends [12]:

- accumulation of household and industrial waste at landfills, which has a negative impact on the environment and human health;
- inadequate processing and disposal of hazardous industrial wastes;

- recycling of household waste without the separation of hazardous fractions (eg batteries, paints, solvents, etc.);
- open incineration of recyclable waste (eg paper, garden waste).

Changing these trends is crucial for the country's energy and resource independence, the conservation of natural material and energy resources, and the protection of the environment.

The strategy takes into account the European waste management approaches outlined in the following Directives:

- Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste, repealing certain Directives;
- Directive 1999/31/EC of 26 April 1999 on the landfill of waste;
- Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries, amending Directive 2004/35/EC;
- Directive 94/62/EC of the European Parliament and of the Council of 20 December 1994 on packaging and packaging waste;
- Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE);
- Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators.

The messages from this paragraph are:

- the Ukrainian Law “On Waste” defines state support for fostering the implementation of new technologies (e.g. co-processing), which will help improve the ecological situation in the country;
- Ukraine has an official National Waste Management Strategy by 2030, but not a step-by-step implementation plan. At the moment, the deadlines mentioned before do not seem realistic;
- local authoritie can decide which waste management operations will be implemented in their areas, which gives them the opportunity to implement the most suitable technologies for their individual conditions. Partly, such projects could be financed by local budgets or by the private sector;
- clearer procedures for dealing with appealing from citizens are required.

1.3. “Co-processing of waste in cement kilns” in waste legislation

As mentioned above, the state guarantees its support for the development and implementation of technologies for waste-based energy and resource recovery.

However, the process of co-processing waste in cement kilns is not mentioned explicitly. Moreover, the following paragraph could be interpreted to exclude the use of cement kilns to incinerate waste because their primary function is clinker production:

– article 35-1: waste incineration is to be carried out only by enterprises or facilities specifically designed for this purpose.

Therefore, it is proposed to amend the Law of Ukraine "On Waste" to explicitly allow co-processing waste fractions in cement kilns under certain conditions.

According to the legislation, Ukraine needs to seek ways of preventing waste generation. Comparing current waste management approaches in terms of the stated priorities, Ukraine is mainly focusing at the lowest disposal level within the waste treatment hierarchy, see **Figure 1.5**.

Figure 1.5 – General hierarchy of approaches fora comprehensive waste management [13, 14]

According to **Figure 1.5**, implementation of co-processing could help Ukraine increase the recovery level in the waste management hierarchy and would be a step towards the circular economy by transforming waste into revenue streams [15]. The aim of the circular economy implementation is to transform waste into streams of raw materials for various industries [16]. Waste could be used as an energy source (as alternative fuel for cement rotary kilns) and as raw material (as a part of clinker). However, co-processing should complement but not compete with other recycling approaches. The current waste management system in Ukraine is not yet able to cope with the rising generation of waste, which results in increasing landfill areas and environmental pollution. Co-processing could contribute to alter this trend together with the implementation of sorting and recycling infrastructure for the different waste streams. Ukraine's position in the waste management structure, **Figure 1.5**, leads to an increase in landfills and an increase in negative environmental impacts.

The approaches currently used in Ukraine do not allow the transition to a circular economy. Waste reuse or recycling (higher priority in the waste hierarchy, **Figure 1.5**) cannot be replaced by waste co-processing in cement kilns (which is the second priority approach in the hierarchy). However, the introduction of the co-processing technology will facilitate the adaptation of the waste management system in Ukraine. The co-processing of waste in cement kilns, implemented in parallel with the development of waste sorting technologies, will help in the short term to reduce the level of landfilled waste and become a basis for further implementation of more prior approaches according to the waste hierarchy.

The messages from this paragraph are:

- the current version of the Law "On Waste", including amendments N 2530-VIII (2530-19) since 06.09.2018, does not mention the technology of co-processing waste in cement kilns as a possible waste treatment approach. Moreover, the article 35-1 of the law could be interpreted to exclude the use of cement kilns for waste incineration purposes because their primary function is clinker production;
- co-processing implementation could significantly contribute to increase the recovery level in the waste management hierarchy and would be a step towards the circular economy.

1.4. Co-processing in Ukraine. Possibilities and challenges.

Cement production is an energy-intensive process in which coal is a major fuel for Ukrainian companies. The cement industry of Ukraine is at a good level of development. Cement production is stable from year to year [17], see **Figure 1.6**.

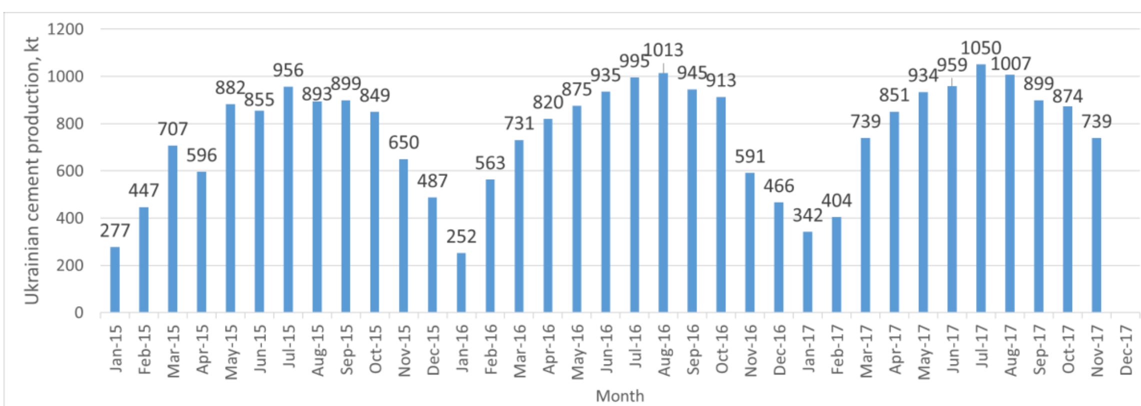

Figure 1.6 – Statistics of cement production in Ukraine

Clinker is known to be a major component of cement. For its production, the cement industry uses rotary kilns with operating temperatures in excess of 1723 K. This is sufficient to dispose of prepared industrial and household waste.

The technological scheme of the process [18] is shown in **Figure 1.7**.

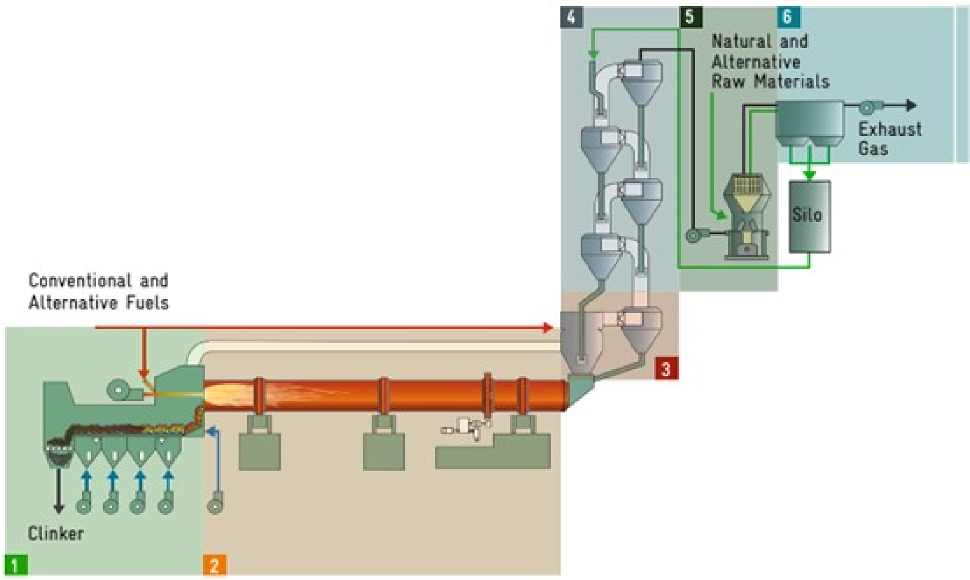

Figure 1.7 – Technological scheme of co-processing, where 1 – clinker cooler, 2 – rotary kiln, 3 – precalciner, 4 – raw meal (cyclone) preheater, 5 – raw meal, 6 – bag filter (or electrostatic separator)

According to [18], the temperature regimes during the clinker production are:

- 2273 K in the rotary kiln, where all organics from waste burns;
- 1473 K in precalciner, where SO_2 and HCl trapped due to pres-ence of CaO;
- 1153 K in raw mealpreheater and raw meal, that act as a 5-stagedry scrubber for combustion gases;
- 1123 K – 99.999% dedusting efficiency.

The Industrial Emission directive 2010/75/EU defines the conditions for co-incineration (co-processing) waste in cement kilns. The key requirement is that the combustion gases are exposed to temperatures of at least 1353 K for at least two seconds. If hazardous waste with a content of more than 1% of halogenated organic substances, expressed as chlorine, is incinerated, the temperature must be raised to 1,373 K for at least two seconds [19].

Table 1.2 provides the results of CO_{2eq} emissions calculation for anthracite coal burning process and for mixed fuel burning process (i. e. 70/30 ratio of anthracite coal /RDF).

Table 1.2 – Results of CO_{2eq} specific emissions and specific RDF consumption for clinker production estimation for anthracite coal burning process and for mixed fuel burning process

Parameter, unit	Value
Specific CO_{2eq} emission for anthracite coal, kg_{CO2eq}/kg_{fuel}	3.37 [20]
Specific thermal heat energy requirements for clinker production, MJ/t of clinker	3,788 [21]
Specific anthracite coal consumption for clinker production, kg/t of clinker (experimental data from Ukrainian cement plant)	116.91
Calorific value of anthracite coal, MJ/kg of coal	32.4 [22]
Specific CO_{2eq} emission from anthracite coal in clinker production, kgCO_{2eq}/t clinker	**394**
Estimated substitution rate of anthracite coal with RDF, % of thermal energy	30
Specific calorific value of RDF, MJ/kg	24.1 [23]
Calculated specific RDF consumption in clinker production, kg_{RDF}/t clinker (by using data from this table)	47.15
Specific fossil CO_2eqemission from RDF, kg_{CO2eq}/kg_{RDF}	1.7 [23]
Calculated specific emission for co-processing, $kg_{CO2eq}/t_{clinker}$ (by using data from this table)	**355.96**

The specific CO_{2eq} emissions could be reduced by about 15% through co-processing at an energy substitution rate of 30%, **Table 1.2**. In **Table 1.3**, there is shown ecological and resource potential, estimated for the Ukrainian cement industry in case of co-processing implementation. The following was assumed for the calculation:

- Traditional fuel used – anthracite coal;
- Alternative fuel – mixed with traditional with the ratio of 70% anthracite coal per 30% RDF from MSW;
- Co-processing with the above alternative fuel mix is implemented at all Ukrainian cement enterprises.

Table 1.3 –Calculation of the yearly CO_{2eq} and anthracite coal reduction potential by co-processing RDF in the Ukrainian cement industry

Parameter, unit	**Value**
Average annual cement production, kt/a	8,798
Share of clinker in cement, % (experimental data from Ukrainian cement plant)	85
Calculated average annual clinker production, kt/a (by using data from this table)	7,478
Specific thermal heat energy requirements for clinker production, MJ/t of clinker	3,788 [21]
Calculated total annual anthracite coal consumption for clinker production, GJ/a (by using data from **Tables 1.2** and **1.3**)	28,327,800
Calculated total annual anthracite coal consumption for clinker production, kt/a (by using data from **Tables 1.2** and **1.3**)	874.31
Calculated potential reduction of anthracite coal consumption for clinker production, kt/a (by using data from this table)	262.29
Calculated average annual CO_{2eq} emission, kg_{CO2eq}/a, (by using data from this table)	2,946.44
Calculated potential reduction for CO2eq emissions from substitution of anthracite coal, kg_{CO2eq}/a, (by using data from this table)	284.46

Using the methodology [24], specific emission of greenhouse gases emitting household waste by their morphology from Ukrainian landfills has been determined, see **Table 1.4**.

Table 1.4 – Results of the calculation of the specific emission of greenhouse gases emitting household waste by their morphology

Waste stream	**The share of waste, % [25]**	**Degradable organic carbon fraction, (Mg C in waste/Mg waste) [24]**	**Decay rate constant, yr^{-1} [24]**	**Ultimate methane yield test results, m^3CH_4/t [26]**	**GHG generation, $m^3CO_{2eq}/tMSW$**
Organics	44	0.15	0.06	419.9	12.81
Paper	13	0.4	0.04	284.9	15.30
Polimers	11	0	0	75.5	0.00
Glass	9	0	0	75.5	0.00
Metalls	2	0	0	75.5	0.00
Textile	5	0.24	0.04	230.8	7.44
Construction	5	0.08	0.03	47.5	0.38
Wood	1	0.43	0.02	213.1	6.09
Other	10	0.2	0.04	295.4	7.93
				Total	49.95

In order to calculate the potential for the reduction of landfill emissions in the case of co-incineration of RDF waste with MSW in cement kilns, the necessary amount of waste for RDF production was estimated, see **Table 1.5**.

Table 1.5 – Specific waste consumption for RDF production

Country	**Amount of the processed waste input, kt_{MSW}/a [27]**	**Amount of the produced fuel output, kt_{MSW}/a [27]**	**Waste consumption for RDF production, t_{MSW}/t_{RDF}**
Austria	340	70	4.86
Finland	220	65	3.38
Ireland	1,000	300	3.33
United Kingdom	250	90	2.78
Average	762	245	3.44

Using data from **Table 1.5**, the potential of reducing the amounts of MSW has been estimated, as well as the potential of reducing GHG emissions from landfills, in case the technology of co-processing waste in cement kilns gets implemented with the use of RDF produced from MSW, see **Table 1.6**.

Table 1.6 – Potential of reducing MSW and GHG

Parameter	**Value**
Specific RDF consumption for clinker production, kg/t	47.15
Average annual clinker production, kt/a	7,478.00
Waste consumption for RDF production, tMSW/tRDF	3.44
Potential of reducing the amount of MSW, kt/a	1,212.9
Potential of reducing GHG emissions, ktCO_2eq/a	110.5

Despite the potential the technology has, calculations were made for Ukrainian cement industry and could be hardly achieved in full. But, the resource potential of the cement industry in Ukraine (more than 262 kt/a of anthracite coal consumption) is not the only possible benefit. Large amounts of municipal and industrial waste could be incinerated by the time the waste management system is implemented and starts working in Ukraine – up to 1,212 ktMSW/a. The potential of reducing amount of municipal solid waste is more than 19% from total municipal solid waste annually generated in Ukraine (6,346.50 ktMSW/a) [1]. In 2013 recovery rate in Ukraine was 3-8%. But, in 2025 Ukrainian recovery rate must constitute about 41% [25]. The co-processing of municipal and industrial waste in cement kilns could be part of the solution to this problem. Sewage sludge, which is often landfilled or used in agriculture, can be used as an alternative fuel and raw material in the cement clinker manufacturing process.

Resulting from the information above the following key messages can be concluded:

- implementation of co-processing of waste in cement kilns technology has huge potential for cement industry: saving potential is more than 262 kt/a of anthracite coal consumption with reducing of CO_2 emissions up to 284 ktCO_2/a. It is result for specific conditions: 30% of the substitutional rate, RDF from MSW use for overall clinker production in Ukraine;
- in case of implementation of this technology will influence on reduction of ecological footprint in Ukraine, which will have potential of energy recovery from up to 1,212 ktMSW/a (which is 19% of total municipal solid waste generated annually in Ukraine) and prevention of up to 110 ktCO_{2eq}/a of GHG emissions from landfills.

1.5. Key barriers for the implementation of co-processing and measures to mitigate them

According to the International Cement Review, People's Republic of China is also facing the problem of waste accumulation. China is now actively seeking to increase its waste recovery in cement kilns, with producers such as Huaxin Wuxue and Sinoma's Liyang having taken up the challenge. They are assisted by Dahai Yan, Chinese Research Academy of Environmental Sciences, China, Kåre Helge Karstensen, Sintef, Norway, and Zheng Peng and Zuguang Wang, Ministry of Environmental Protection [28]. That is why the key barriers Ukraine is facing on its way to implementing the technology of co-processing waste in cement kilns are comparable to those of China [29]. They include:

Permitting

Cement industry prefers uniform emission standards for co-processing, and not individual cases. But, for co-processing certain hazardous types of waste, individual permits are needed to ensure safety and compliance with the environmental standards.

How to counteract. Providing standards for types of alternative fuels will help decrease time for preparing permissions for different types of waste.

Regulations and standards.

In some countries, there are no specific rules and standards for co-processing waste in cement industry. Partial implementation of the waste management system in many developing countries is also one of the main barriers.

How to counteract. In Ukraine, waste legislation is harmonized with European legislation, but executive policy needs to be optimized.

Supportive policies.

Co-processing may not be financially viable if it does not take into account its large public waste management benefits. Municipalities and governments, if they wish to implement the technology of co-processing waste, should develop programmes based on the full benefit for local communities and the environment.

How to counteract. In Ukraine, main cement producers are presented by worldwide consortiums: CRH Group, IFCEM, BUZZI, Heidelberg, EuroCement [30]. Mostly all of them have successful experience of implementing the technology of co-processing waste in cement kilns in different countries. Using their experience could help find effective options for support.

Public acceptance.

Residents and local groups often perceive the technology of co-processing waste in cement kilns as its incineration and often protest the implementation of said technology. The main problem with waste incineration is emissions, especially dioxins, and therefore there is a legitimate concern for the population.

How to counteract. Basic knowledge about co-processing waste and how it is different from incineration of waste, as well as its potential benefits, is important to be shared at national and local levels. Authorities should publicly report emission monitoring data and information from co-processing wastes to assure the community that emissions of pollutants do not exceed the permitted levels.

Costs.

The costs of RDF generation usually exceed the existing landfill charges.

How to counteract. It should be noted that most of the current landfill fees do not determine the costs of future groundwater contamination or emissions of greenhouse gases such as methane. Therefore, these external costs should be included in landfill fees or financial incentive. Additional support programmes should be designed to ensure that co-processing waste is able to meet competition of other waste management methods.

Infrastructure.

Currently, an alternative infrastructure for pre-processing and transportation of waste to cement plants is needed.

How to counteract. It will be necessary to install equipment and approve procedures for adequate separation of waste materials and generation of RDF.

Lack of qualified workforce.

Co-processing waste in cement plants requires highly skilled specialists and trained personnel to operate the equipment. This capacity is currently limited in most developing countries.

How to counteract. 90% of the cement plants operating in Ukraine have implemented the technology of co-processing waste in cement kilns in their facilities in other countries. If needed, their foreign qualified staff could share their experience with Ukrainian engineers and experts.

Resulting from the information above the following message can be concluded:

- there are barriers, which could block implementation of co-processing of waste in cement kilns technology in Ukraine, but for each of these barriers, there are counteracts for their prevention. Moreover, 90% of Ukrainian cement plants are from international cement holdings, so for them the last key barrier (lack of qualified workforce) is not a barrier, because their foreign qualified staff could share their experience with Ukrainian engineers and experts.

2. ECOLOGY LEGISLATION

2.1. Swiss ecology legislation

The federal Environment Protection Law (Umweltschutzgesetz) [31] contains general principles that apply to buildings and construction work. People, animals, plants and the environment are to be protected against harmful influences of any kind. The polluter-pays principle is stipulated amongst others.

Influences are defined as [32]:

- pollution of the air;
- pollution of water bodies;
- pollution of the ground;
- noise;
- vibration;
- radiation;
- changes to the genes of organisms;
- construction and operation of buildings and plants;
- handling of substances, organisms or waste;
- exploitation of the ground.

2.2. EU waste legislation system

Waste Framework Directive

The following information in the unit 2.2 is based on the source [29]. According to the [29], the European Union sets its basic waste policy through the Waste Framework Directive (2008/98/EC) [33]. All state members are required to align their national laws with the directive within a defined period of time. The Waste Framework Directive establishes basic concepts and definitions, including waste prevention, recovery, recycling, and management. The directive also establishes waste management principles, requiring that "waste be managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odors, and without adversely affecting the countryside or places of special interest" [29]. In addition, the Waste Framework Directive stipulates a waste management hierarchy, which prioritizes waste prevention, followed by waste materials preparing for reuse, recycling of wastes, recovery in the form of energy, and, as a last option, disposal by landfilling. Co-processing of municipal solid wastes and sewage sludge in the cement industry is regarded as energy recovery and is thus prioritized over landfilling. Waste prevention and reuse and recycling of wastes should not be seen as competing or conflicting with co-processing. All serve the overall goal of reducing negative impacts of increasing quantities of waste. Moreover, co-processing is only feasible if municipal waste is sorted, and properly pretreated. The Waste Framework Directive establishes two waste recycling and recovery targets: a re-use and recycling rate of 50 percent for household waste materials (including paper, metal, plastic, and glass) by 2020, and a reuse - recycling target of 70 percent for construction and demolition waste by 2020 [33]. The EU Waste Framework Directive also outlines general principles for waste collection and management. Based on the "polluter pays" principle, the Waste Framework Directive specifically requires that producers or holders of waste must carry out waste treatment themselves or have treatment carried out by a broker or establishment. The Waste Framework Directive also opens the waste management market through "extended producer responsibility," which shifts waste treatment responsibilities from the government to the waste-producing entities.

These principles provide strong incentives for co-processing because waste-producing facilities (such as industrial companies), and waste-handling organizations (such as municipalities) must pay the cement industry for waste treatment when waste is co-processed. The price of waste treatment varies among nations. In Japan, for example, where natural resources are heavily constrained, the price of waste treatment is usually high; therefore, co-processing plants realize high-profit margins. To ensure implementation, the Waste Framework Directive requires all EU member states to establish "one or more [waste] management plans" that should contain "the type, quantity and source of waste, existing collection systems and location criteria," and information on waste prevention programs. The purpose of the waste management plans is to analyze current waste management practices; identify measures to improve reuse, recycling, recovery and disposal of waste; and determine how to support the implementation of the Waste Framework Directive. In addition to the general Waste Framework Directive, the European Commission has also issued several specific directives on landfills, waste incineration, pollution, and industrial emissions, which are relevant to waste co-processing and are discussed below.

Landfill Directive

One of the most influential drivers of cement kiln co-processing in Europe was the establishment of the Landfill Directive (1999/31/EC) [34] in 1999. The Landfill Directive was issued in response to growing concerns about the negative effects of landfilling of wastes, including contamination of soil, water resources, and air and resulting deterioration in living conditions and human health. The ultimate goal of the directive is to implement the EU's waste hierarchy, which defines landfills as the last option for waste treatment and disposal.

The Landfill Directive introduces tight procedures for waste landfills, such as the development of landfill categories, setting up of a standard waste acceptance procedure for landfills (including detailed descriptions of waste characterization procedures, limits on waste composition, leaching behaviors, and acceptance procedures at landfill sites) [35], and requires a landfill permitting system. The directive also imposes staged landfill reduction targets for the biodegradable fraction of MSW, liquid waste, and used tires. Member states are obliged to devise national strategies to meet the landfill reduction targets. Examples of a national strategy are Sweden's 2002 ban on landfilling of separated combustible waste and 2005 ban on landfilling of organic waste.

Because the Landfill Directive limits the landfill capacity, it has pushed the market to find alternative waste treatment measures for wastes that cannot be reused or recycled. Incineration and co-processing are two of these measures. Landfills cost vary among EU countries, ranging from 30 EUR/t in Greece to 126 EUR/t in Denmark (Eunomia Research & Consulting, 2011). To comply with the Landfill Directive, countries have introduced various measures to increase the cost of landfilling. For example, the gate fee for landfilling in Finland increased by 300 percent from 1996 to 2006. Landfill taxes are also used to discourage landfilling of waste in Estonia, Finland, and Italy (European Environmental Agency, 2009).

Industrial Emissions Directive

The Industrial Emissions Directive (2010/75/EC) has been established to succeed the IPPC Directive when the IPPC Directive expires in 2013 [36]. The Industrial Emissions Directive integrates seven existing directives4 related to industrial emissions and restates the principles outlined in the Integrated Pollution Prevention and Control Directive, including an environmental permitting system based on an integrated approach, required adoption of BATs, flexibility of licensing authorities, and facilitating public participation in the permitting process as well as public access to reported data on emission/pollutants.

However, unlike the Integrated Pollution Prevention and Control Directive, the Industrial Emissions Directive requires EU member states to establish a system of environmental inspections, prepare environmental inspection plans, and conduct site visits every 1 to 3 years depending on the pollution risk posed by a site [37].

Also, in this Directive issues discussed the incineration of wastes and its impact on human health. There are some issues on minimizing the negative environmental impacts of waste incineration by establishing operational and technical requirements and emission limits for waste-burning plants.

The Industrial Emissions Directive (2010/75/EC) lays out requirements for burning wastes, delivery and reception of waste, operational conditions, air emissions limits, water discharges, residues, monitoring and surveillance, access to information and public participation, reporting, and penalties. In particular, the directive imposes stricter regulations on emissions and more stringent operational conditions and technical requirements than were previously in force.

While requiring that industrial installations meet its requirements in order to minimize pollution, the Integrated Pollution Prevention and Control Directive also gives flexibility to EU member states so that the environmental permitting authorities can take into account factors such as the technical characteristics of a facility, its geographic location, and local environmental conditions.

The Integrated Pollution Prevention and Control Directive sees public participation as vital in the decision-making process related to environmental permits and monitoring. It gives the public access to permit applications, permits, monitoring results, and the European Pollutant Release and Transfer Register (E-PRTR), a database containing emissions data reported by member states [38].

Permitting and Performance Approval

European Union

The legislation of the EU (Industrial Emissions Directive) provides for the purpose of conducting a waste management system. Permits determine the category and amount of waste that can be co-processed, the technical requirements for waste management, safety requirements and precautions, the capacity of the co-processing facilities for individual cement plant, as well as the procedure for sampling, measurement and control of pollutants. The EU directives require a high level of energy efficiency at co-processing cement plants [39]. Permissions are issued for 3 or 5 years. Implementation will require the Member States or the "competent authorities" to set specific requirements based on local conditions [40]. To avoid duplication, permits can be used for various purposes, such as to regulate air and water pollution and other environmental impacts. Permits may be canceled if procedures for compliance with human health and environmental regulations are violated.

Procedure for obtaining a permit for several stages: submission of an application, assessment, issue, follow-up and training / guidance, as shown in **Figure 2.1**.

1. Application for a permit

- **Specification of content of permit documents** (determination if permit or registration procedure is applicable, competent authority, content of documents)
- **Advisory service for applicants** (guidance for applicants, face-to-face consultation, helpdesk, etc.)
- **Preliminary check** (quick check of competencess of documents)

↓

2. Assessment by competent authority

- **Assessment of completeness and compliance of application**
- **Participation of authorities, public and experts** (consultation with/approval from other authorities, provision of information, public hearings, expert reports, certificates)
- **Consideration of objections** from other authorities and the public
- **Control of criteria and conditions** (on-site inspections)

↓

3. Issue of permit

- **Formulation of permit** (content of permit, including explanation of conditions for operation, information about monitoring and inspection, legal specification)
- **Issuing a permit**

↓

4. Follow-up

- **Information storage** (data base, central register etc.)
- **Communication of issued permits** (to other public authorities, other level authorities)
- **Using of information** for inspection planning

Figure 2.1 – Key Stages in Issuing Co-Processing Permits in Brazil [29]

Monitoring System Requirements

The best monitoring practices for co-processing wastes plants include standard measurement methods, certified tools, personnel certification and accredited laboratories. The monitoring of joint waste management has three elements: monitoring of treatment, monitoring of emissions and monitoring of the environment [41].

European Union

The EU Waste Incineration Directive requires co-processing plants for the installation of emission and combustion measurement and monitoring systems. Air and water emissions must be measured continuously and periodically [40]. The following parameters need to be monitored continuously: NOx, CO, total dust, TOC, HCl, HF, SO_2, combustion chamber temperature, oxygen concentration, pressure and temperature, and also the content of water vapor in the exhaust gas. Periodic monitoring is required for the following substances: metals, semi-metals and their compounds, general organic substances, PCDDs/PCDFs. For enterprises with a nominal capacity of over 2 tons per hour, operators provide annual reports on the operation and monitoring of the plant. Annual reports are also available to the public. Local authorities publish a list of plants with a nominal capacity of less than 2 tons per hour [40].

Facilities in the European Union have to submit key environmental data to the European Pollutant Release and Transfer Register (E-PRTR). E-PRTR replaces the previous European Pollutant Emission Register (EPER) system for environmental reporting and contains annual data reported by approximately 24,000 industrial facilities covering 65 sectors in Europe, including cement industry co-processing plants. Each facility provides information on the number of pollutants released to air, water, and land; as well as off-site transfers of waste. E-PRTR aims to increase transparency and public participation in the environmental decision-making process. In Germany, this regulation was implemented with the PRTR Act (SchadRegProtAG) [42].

EU legislation also obliged co-processing plants to submit annual reports on their functioning and monitoring, including descriptions of the plants' general process, emissions to air and water, and comparison of the plant's emissions to the applicable emissions standard. Many EU member states also require plants to submit information on the types of waste co-processed and the capacity of the installation. EU legislation requires member states to report to the European Commission every 1 or 2 years. The European Commission uses a standard questionnaire (EC, 2006a) for member states to report the status of their waste incineration and co-incineration plants, including co-processing plants.

The UK uses the Operator Pollution and Risk Appraisal scheme to assess the environmental performance of cement plants. In 2004, 11 cement plants (85 percent of the total in the country) achieved an "excellent" score for operator performance, compared to 44 percent of all of British industry. All cement plants must have a formal environmental management system in place. All have ISO 14001 certification, and 10 are registered to the EU Eco-Management and Audit Scheme. All cement plant parent companies in England and Wales produce sustainability or environmental report. In January 2008, Lafarge Cement UK was the first manufacturer to apply for permission to trail a waste-derived fuel, which was produced from paper, plastics and some domestic refuse, under a new code of practice agreed with the UK Environment Agency. The permission was granted in April 2008, and the trail was successfully trailed. CEMEX completed two trails of using solid recovered fuel and received the permit to use this fuel at all of its UK cement plants. In each trail, more than 10,000 tonnes of waste were used in cement-making. By 2008, the UK cement industry has achieved an overall of 26.5% replacement of fossil fuels by waste-derived materials [43]. To monitor environmental releases from using sewage sludge, the cement sector in Catalonia, Spain signed an agreement in 2005 with the Catalan administration, trade unions, and local councils, and piloted the monitoring of the environmental impacts of using dried sewage sludge in cement plants [44].

Enforcement of Regulations

Enforcement of regulations and standards is key for a successful, environmentally safe co-processing industry. Enforcement of regulations and standards can also ensure the financing and marketing of co-processing.

European Union

In the European Union, member states must report to the European Commission every 1 or 2 years regarding achievement of waste management system targets. Reports are sent 18 months after the end of the reporting period. The commission then must report to the European Parliament and Council on the application of the Waste Incineration Directive. Plants that violate the IPPC Directive face administrative sanctions.

Pre-processed MSW and sewage sludge have relatively high net calorific value (NCV) per dry ton. Pre-processed MSW and sewage sludge also have a much lower CO_2 emissions factor compared to coal when treated in a cement kiln.

The Basel Convention (2011) defines co-processing as "the use of waste materials in manufacturing processes for the purpose of energy and/or resource recovery and the resultant reduction in the use of conventional fuels and/or raw materials through substitution”. This is also a concept in industrial ecology, related to the potential role of industry in reducing environmental impact throughout a product`s life cycle [29]. Also, the Basel Convention defines co-processing as an operation “which may lead to resource recovery, recycling, reclamation, direct reuse or alternative uses”.

Today it is a new draft of Directive is reviewing and editing after Brussels, 23 February 2018 [45]. According to it, waste management in the Union should be improved and transformed into sustainable material management with a view to protecting, preserving and improving the quality of the environment, protecting human health, ensuring prudent, efficient and rational use of natural resources.

2.3. Swiss Regulatory Authorities

Environmental regulations in Switzerland are established by the Federal Office for the Environment, FOEN [46]. Engine emissions are regulated based on the Ordinance on Air Pollution Control, OAPC (Luftreinhalte-Verordnung, LRV) of 16 December 1985, with a number of later amendments. The OAPC mandates that “emissions are to be reduced in as much as technically, organizationally and economically justifiable...”. Since 1998, it also classifies diesel particulate emissions as carcinogenic. Occupational health regulations and exposure limits are set in Switzerland by SUVA (Schweizerische Unfallversicherungsanstalt)—Swiss National Accident Insurance.

2.4. The EU's air quality standards

The EU's air quality directives (2008/50/EC Directive on Ambient Air Quality and Cleaner Air for Europe and 2004/107/EC Directive on heavy metals and polycyclic aromatic hydrocarbons in ambient air) set pollutant concentrations thresholds that shall not be exceeded in a given period of time. In the case of exceedances, authorities must develop and implement air quality management plans. These plans should aim to bring concentrations of air pollutants to levels below the limit and target values.

Selected EU standards and the World Health Organization (WHO) guidelines are summarised in the table below.

Table 2.1 – The EU's air quality standards [47]

EU Air Quality Directive				WHO Guidelines	
Pollutant	Averaging period	Objective and legal nature concentration	Comments	Concentration	Comments
$PM_{2.5}$	Daily			25 µg/m^3	99th percentile (3 days/a)
$PM_{2.5}$	Annual	Limit value, 25 µg/m^3		10 µg/m^3	
PM_{10}	Daily	Limit value, 50 µg/m^3	Not to be exceeded on more than 35 days per year	50 µg/m^3	
PM_{10}	Annual	Limit value, 40 µg/m^3		20 µg/m^3	99th percentile (3 days/a)
O_3	Maximum daily 8-hour mean	Target value, 120 µg/m^3	Not to be exceeded on more than 25 days per year, averaged over three years	100 µg/m^3	
NO_2	Daily	Limit value, 200 µg/m^3	Not tob e exceeded more than 18 times a calendar year	200 µg/m^3	
NO_2	Annual	Limit value, 40 µg/m^3		40 µg/m^3	

These apply over differing periods of time because the observed health impacts associated with the various pollutants occur over different exposure times.

The WHO guideline values are set for the protection of health, and are generally stricter than the comparable politically agreed EU standards.

2.5. Swiss emission trading scheme (ETS) for companies

Emissions trading is a quantity control instrument applying the "cap-and-trade" principle. Based on historical data from the years 2008-2012, an absolute quantity of emission allowances is determined in the system ("cap"). For each ETS participant, benchmarks are used to calculate the quantity of emission allowances that are allocated free of charge to the ETS participant regardless of its greenhouse gas emissions. Emission allowances are freely tradable ("trade") and can be surrendered to the Confederation to cover the greenhouse gases emitted or sold to other ETS participants.

2.6. Participation in the emissions trading scheme (ETS)

Certain categories of companies referred to in Annex 6 to the CO_2 Ordinance must compulsorily participate in the Swiss emission trading scheme. Research, development and testing facilities, as well as special waste management facilities can be excluded from the ETS upon the company's request. If an ETS company's total emissions in each of the previous three years are less than 25,000 tonnes CO_2 equivalent (CO_{2eq}), the company can apply for an exemption from the ETS obligation ("opt-out"). Certain categories of companies referred to in Annex 7 of the CO_2 Ordinance can voluntarily participate in the ETS ("opt-in"). In return, all ETS participants are exempt from the CO_2 levy. The Swiss ETS currently includes greenhouse gas-intensive companies from the cement, chemicals and pharmaceuticals, refineries, paper, district heating, steel, and other sectors.

Estimation of the free-of-charge allocation of emission allowances (benchmark approach)

ETS companies are allocated emission allowances free of charge on the basis of benchmarks. The free-of-charge allocation is calculated on the basis of product, heat or fuel benchmarks as well as, where appropriate, in accordance with process emissions. Regardless of its actual greenhouse gas emissions, the free-of-charge allocation an ETS participant receives is individually calculated as a function of production volume, the heat generated or the amount of fuel used and quantity of emission allowances per unit defined by the respective benchmark. The risk of relocating production abroad due to CO_2 costs ("carbon leakage") is also taken into account in this calculation.

Estimation and use of the maximum available quantity of emission allowances ("cap")

The absolute quantity of emission allowances in the system ("cap") for the 2013-2020 period was determined on the basis of historical data from the years 2008-2012 (Annex 8 CO_2 Ordinance). Because an emission allowance authorizes the emission of one-tonne CO_2 equivalent (CO_{2eq}), this also corresponds to the permissible greenhouse gas emissions in the system. For 2013, the cap was 5.63 million tonnes CO_{2eq} and will decrease annually by the same absolute amount (1.74% of the 2010 baseline) to around 4.9 million tonnes CO_{2eq} in 2020. 5% of the cap is reserved each year for free-of-charge allocation to new market entrants and capacity expansions. This, on the one hand, entitles only plants newly built after 2013 and on the other existing plants with substantial capacity expansions. Emission allowances that have not been allocated free of charge will be auctioned off.

If the sum of all calculated individual allocations exceeds the available quantity of emission allowances (95% of the cap), then the allocations are reduced linearly by the same factor (cross-sectoral correction factor). In 2013, the reduction was 0.09% and increases to 9.91% by 2020. The need for a cross-sectoral correction factor is partly due to the fact that companies were able to optimize their free-of-charge allocation by choosing the reference period and almost all companies were classified as vulnerable to carbon leakage, which resulted overall to higher free-of-charge allocations. In addition, emissions from CO_2-neutral fuels such as wood, for example, were not included in totaling the cap. Companies that use CO_2-neutral fuels are rewarded because they nonetheless receive a free-of-charge allocation based on the emission factor of natural gas. Emission allowances thus were also allocated for the combustion of CO_2-neutral fuels that were not taken into account in determining the cap. The correction factor reduces the individual allocation of individual companies but does not step up the emission target in the ETS, which is determined solely by the cap and the reduction path of 1.74% per year. The correction factor has no influence on these elements. But it ensures a linear reduction of the free-of-charge allocation so that the emission target is met in the ETS.

Reporting and obligation to surrender emission allowances and emission-reduction certificates

All ETS participants must report their annual greenhouse gas emissions to the Confederation. As a result, emission allowances or, if permitted, emission-reduction certificates, in the amount of these greenhouse gas emissions are need to be sended to the Confederation.

2.7. Industry monitoring

During the construction of the capacity, it is recommended the company to use the best available technologies (BAT) to prevent pollution of the environment.

As stated above, in Switzerland, enterprises are required to provide the results of the internal monitoring of emissions. Depending on the industry, the frequency of reporting may vary from once per six months up to once per two years. The obtained data are compared with the data obtained from meteorological stations and sampling stations for water/air in the region where the enterprise is located. If the data obtained from the company is in great discrepancy with the data from the local monitoring stations for the emission of harmful substances into the air or water, then an official request for clarification of the data and the term for which it is necessary to specify them is sent to the enterprise. If there is no reaction from the enterprise, and emissions and emissions data continue to differ from the displays of local stations, an official order on the need for an audit is sent to the enterprise. At the same time, a commission arrives at an enterprise at any time to verify the causes of exceeding the permissible emission limits.

Weights of influence

The main levers of influence on the company are:

1. Work with associations - internal regulation. Constant work with associations, a dialogue on the need to reduce the impact on the environment leads to the internal regulation of the sector. Companies that meet all the requirements will be interested in clearing the sector from unfair competition. So, the association will be on its own to search companies that do not comply with the requirements of the current environmental legislation on an equal basis with others.

2. Constant control - external influence. Black and white business listings are created. Whitelisted companies that strictly adhere to the rules of environmental legislation and clearly fulfill their obligations to the state and the public. Such companies are less likely to come to the test, which further motivates other companies. Blacklists include companies that violate the rules of the current

legislation. Checking for such companies is sent more often, and their reports are checked more thoroughly.

3. Public discussion - PR company. One of the most dangerous offenders for the company is a public hearing about the discrepancy of its work with ecological standards. By spreading information about environmental pollution by the company in mass media, public opposition can greatly affect the reputation of the company and its place on the market. Public discussion is the last resort when an enterprise does not respond to formal requests and commitments.

2.8. Monitoring of pollutant emissions and operational parameters

Monitoring of pollutant emissions and operational parameters a continuous measurement of the following parameters [48] is recommended for controlling the process in a cement kiln (European Commission 2001):

- pressure;
- temperature;
- O_2 content;
- NOx content;
- the content of CO and, possibly, SOx, if the content of sulfur oxides is high;
- SO_2, (a method for optimizing CO with NOx and SO_2 is being developed).

In addition, it is necessary to ensure control of mercury content (at high mercury content, in waste). The best available method for obtaining accurate quantitative estimates of emissions is to carry out continuous measurements of the following parameters (if the values of these parameters can change beyond the measurement point used for process control, it may be necessary to re-measure):

- the volume of waste gases (it can be calculated, but some consider this calculation too complex);
- humidity;
- temperatures at the inlet of the particle trapping device;
- dust / particles;
- O_2;
- NOx;
- SO_2;
- CO.

The best available method is regular periodic monitoring of the following substances:

- metals and their compounds;
- total organic carbon / organic compounds;
- HCl, HF;
- NH_3;
- PCDD and PCDF.

From time to time, under special operating conditions, the following measurements may be necessary:

- efficiency of destruction and removal of persistent organic pollutants in case of their destruction in cement kilns;
- content of benzene, toluene and xylene;
- content of polycyclic aromatic hydrocarbons;
- the content of other organic pollutants (the main hazardous organic compounds, for example, chlorobenzenes, PCBs and related compounds, and chloronaphthalenes).

When using waste with a high metal content as feedstock or fuel, it is especially important to measure the metal content.

2.8.1. Dioxin concentration

Dioxins and furans are present in our environment, beginning with the era of industrial development. Their influence on human health is studied for several decades [49]. Limit values for the safe effects of dioxins were established in studies conducted by representatives of the US Army in relation to the orange substance widely used during the Vietnam War, which was dioxin. The American army has determined the equivalents of the toxicity of 210 molecules of dioxins and furans. The most dangerous of them was taken as a basis (events in the city of Seveso). Norms range from 1 to 0.001. Attitude to the results of the studies conducted by the army in order to determine the limit of the impact that soldiers might have been subjected to in wartime can be exceptionally skeptical!

After more than 40 years, the results of these studies should be reviewed and new limits established. In the normative legal basis, a limit value of 0.1 ng/m^3 was recorded. Equivalence of toxicity (ET) is the sum of measurements of the weight of 210 molecules. In the first approximation, 0.1 ng/m^3 has a multiplicity of the order of 10-13. Some molecules have an ET of about 0.001, so in order to take into account the measurement data, it is necessary to provide a sensitivity of the order of 10-16. To obtain two significant digits, the multiplicity should be 10-18. In order for the measurements to be meaningful, the same level of purity should be present throughout the sampling and measurement chain. However, this is impossible even in the conditions of the ultra-white room used for research on virology. We need this quality to take samples at the exit of the chimney at a height of 70 m. It is good that there is a limit value of 0.1 ng/m^3, but it is impossible to measure it.

2.8.2. Burning waste gives secondary waste

As a result of incineration, secondary wastes are formed. Slag is 20 – 25% of the incoming waste [49]. If they contain less than 2% carbon, they can be used for paving. Otherwise, such wastes should be transported to the landfill for household waste. As long as among household waste we find batteries, galvanic cells and electrical appliances, heavy metals will be present in the slags at high concentrations. The fly ash after the smoke cleaning is 2 to 5% of the incoming waste and is more dangerous than the slag. It must be stabilized (mixed with cement and lime to produce concrete). You need to export it to landfills for hazardous waste [49].

Results [50] indicate that the type of fuel burned does not affect the release of organic micropollutants, and the emission of metals and chlorides from the cement kiln does not increase when burning hazardous waste. These studies show that the emissions of particles (polycyclic aromatic hydrocarbons and other organic hydrocarbons) are more dependent on operating conditions than on the type of incinerated waste. For hazardous wastes fed to the furnace, the following rules should be followed: for the supply of waste containing organic components that can evaporate, provide a calcining zone; ensure that the furnace operates in such a way that the gas is at 1123 K for 2 seconds; increase in temperature to 1'373 K, if hazardous wastes containing halogenated organic substances are present; The supply of waste should be carried out continuously and continuously. The disadvantages of using a cement kiln include the complexity of launching after a stop, the need to re-equip the gas cleaning system [51].

3. TYPES OF ALTERNATIVE FUELS

3.1. Limits for alternative fuels

Examples of types of waste and alternative fuels In a number of countries, substitution of fossil fuels for alternatives has become widespread practice. In a number of countries, waste has been used as an alternative fuel for almost 30 years and some national governments are actively promoting this approach, provided compliance with stringent regulations for control of waste, technological processes and emissions. However, in other countries, legislation and stakeholders consider this approach from the same positions as combustion. In those countries where this practice is well established, special attention is paid to which materials are most suitable for use in cement kilns. Such materials include:

- worn tires;
- meat, bone meal, animal fat;
- plastics;
- impregnated sawdust;
- wood, paper, cardboard, packaging;
- sewage sludge (waste paper production, effluent);
- agricultural and organic waste;
- slate, combustible shale;
- coal pulp;
- residues of distillation;
- finely divided fractions of coal or coke/anodes/chemical cokes;
- waste oil, water with oil content;
- used solvents.

It is important to monitor the parameters of the waste (calorific value, moisture content, ash content, chlorine content, heavy metals content).

When selecting waste and materials for incineration, such additional, interrelated factors should be taken into account, such as [48]:

- impact on CO_2 emissions and fuel consumption;
- influence on the cost of fuel;
- influence on other emissions, such as NOx, SO_2, particulate matter, other POPs, heavy metals, CO, organic substances;
- influence on mining and quarrying;
- stability of the furnace (which is affected by factors such as heat of combustion and moisture content);

- influence on product quality (for example, limiting the chlorine content in cement to <0.1%).

Requirements to the quality of products, in particular, the limitation of the chlorine content in cement to below 0.1%, impose restrictions on the parameters of combustion (melting), while monitoring the chlorine content in the incoming materials.

3.2. List of wastes not suitable for burning in cement kilns

Co-incineration should only be applied if not all individuals, but all existing conditions and requirements of environmental, socio-economic, operational criteria are met, as well as health and safety criteria. Accordingly, not all types of waste are suitable for co-incineration. The following is a list of waste not recommended for co-firing in cement kilns [52]:

- Nuclear waste;
- Waste of electronic equipment;
- Explosives;
- Inorganic acids;
- Wastes containing asbestos;
- Wastes containing high concentrations of cyanide;
- Infected medical waste;
- Chemical or biological weapons;
- Holistic batteries;
- Unsorted household waste or other waste of unknown composition.

Waste of electronic equipment consists of computers and computer accessories, electronic entertainment equipment, electronic communications, electronic toys, as well as electronic kitchen appliances or medical equipment. On the average, the waste of electronic equipment consists, on the one hand, of materials harmful to health and the environment, such as Cl, Br, P, Cd, Ni, Hg, PCBs and brominated flame retardants, which are contained in high concentrations, often exceeding the threshold thresholds. From the arc side, the waste of electronic equipment has a high content of rare precious metals, which is highly recommended to be recovered. Co-incineration of plastic waste parts of electronic equipment could be an interesting opportunity, but this requires prior dismantling and sorting of such wastes. The above list is not exhaustive. In general, waste with a low calorific value and a very high content of heavy metals is not suitable for combustion in a cement kiln. Solid domestic waste must not be co-incinerated in cement kilns because of their unpredictable composition and parameters. In addition, individual companies, subject to local conditions, can expand the list of exceptions by adding additional positions to it.

3.3. Factors significant in the selection of waste for combustion in cement kilns

In cement kilns, the following waste was used as alternative fuel [53]: waste tires, plastics, impregnated sawdust, wood, paper, cardboard and packaging waste, waste oils and sludge, refined solvents. In the event that the caloric value of the waste is too low, the addition of the initiating fuel, which supports the combustion process (lightweight materials that are well supported by the process of combustion or combustion of waste), is effective. Such waste can include waste oils, rubber waste, waste wood, etc.

Significant practical interest is also the use of peat as an alternative fuel. The calorific value of peat is 11.7 ... 12.4 MJ, the ash content varies within 18 ... 19% of mass [54]. At the same time, optimizing the mixture for alternative fuels should take into account a fairly high moisture content in peat at a level of 14 ... 19 %. Non-flammable part of fuel - ash affects the process of the firing of clinker, as it stays on the material and changes its chemical composition. Ash from burning alternative fuels can contain: 3 ... 10% Al_2O_3, 10 ... 60% SiO_2, 1 ... 10 % Fe_2O_3, 5 ... 10% CaO, 0.5 ... 4% MgO, 5 ... 30% SO_3. As the inorganic part of secondary fuel materials predominates SiO_2, Al_2O_3, Fe_2O_3, then when the ash enters the portland cement clinker, its saturation coefficient decreases and the silicate module is increased. Ash formed after burning peat has a different chemical composition, represented predominantly by the following oxides: 30 % SiO_2; 9% Al_2O_3, 7% Fe_2O_3, 46% CaO, 1% MgO, 3% SO_3, 0.6% K_2O, 0.08% TiO_2. Therefore, the amount of ash must be taken into account when calculating the raw material mixture to obtain the clinker of a given composition. The use of multi-core fuels can cause the formation of rings in a rotary kiln or impair the quality of clinker and cement [54].

When using alternative fuels, the raw material, except for the four main oxides, always contains a number of other elements that come from ash fuels of secondary fuel materials. Secondary impurities may be modifiers of the properties of the liquid phase: increase its amount, rate of reaction, affect the dissolution kinetics of CaO and C_2S; Modifiers of the structure of the clinker: to improve the hydraulic properties due to isomorphic substitution in the clinker minerals or change in the growth rate of the crystals; Mineralization of reactions in the solid phase: to increase the decomposition rate of $CaCO_3$, the rate of solid-phase diffusion processes, to form intermediate compounds. Rotating cement kilns have significant advantages over classical rotary furnaces for combustion of waste: raw materials and formed gases move in different directions, which leads to thorough mixing; the high temperature of burning (more than 1'450 ^{o}C) and the long stay of the material in such conditions (5-7 s) are provided; all organic pollutants made with fuel are destroyed; heavy metals and solid residues (ash) from the waste are immobilized into the structure of the clinker. Secondary fuels can be used both in the main burner of the rotary kiln and in the secondary burner in the calciner of raw meal. Taking into account the high temperature during the firing of clinker (about 1'723 K), which is needed for reasons of its quality and the necessary excess oxygen, the main burner is provided with ideal conditions for the burning of alternative fuels. In the secondary burner of the decarbonizer, since the temperatures necessary for decarbonization need not be so high, it is possible to use both low-calorie or lump types of fuel. The following methods of supplying alternative fuels are implemented at the Dry Method of Production (OJSC "Ivano-Frankivsk Cement") [54]: 1. Fuel supply to the combustion zone in combination with conventional fuels or an additional burner. In this way, liquid, dusty or finely crushed alternative fuels are fed. It is desirable that such fuels are high-calorie and do not reduce the temperature of the flame in the furnace. This way of feeding fuels is the best since the incineration temperature reaches 2273 K. In this way it is necessary to burn fuels containing thermally stable organic compounds. This alternative fuel feed method is used in wet and dry furnaces. 2. Fuel supply from the cold end of the cement kiln. Fuel is fed through specially built and mounted cybers. This method of supplying alternative fuels is widely used in dry furnace installations equipped with cyclone heat exchangers. The gas temperature at the fuel supply site in the furnace is 1'373-1'573 K, and the temperature of the combustible material is 1103-1123 K. Fuel along with the raw material moves towards higher temperatures, burns out and gives heat to the burning material. In this way, you can burn alternative fuels, regardless of their physical state. These may be whole worn-out automobile tires, as well as crushed fuel in bulk and in packages. The amount of fuel burned in this way is limited and depends on the oxygen content in the gases circulating inside the cement kiln. 3. Feed fuel to the calciner. The calciner is an additional combustion chamber, which is located in front of the furnace behind a cyclone heat exchanger in modern dry-cement plants. An additional air is supplied to this chamber, so the burning process in it is independent of the burning process in the furnace. The temperature in the calciner is about 1'273-1'373 K. The calciner can feed liquid or crushed alternative fuels in different amounts. 4. Supply of alternative fuels to the calcining zone. This method of feeding alternative fuels is used in long rotary kilns in a wet manner. The fuel is fed through a special gateway (sider), which is built on the body of a cement oven at a distance of one third its length from the hot end. Fuel is supplied in packages, for example, in small plastic containers of 236 [54]. In this way, solid alternative fuel is supplied. At the point of delivery, the temperature of the gases inside the rotary kiln is 1'473 - 1'673 K and the temperature of the material is about 1073 K. The amount of fuel burned in this way is limited and depends on the oxygen content in the gases circulating inside the cement kiln. The researches of the chemical and mineralogical composition of Portland cement clinkers fired with the use of various types of alternative fuels on the basis of industrial and municipal waste (worn car tires, waste pulp and paper production, sawdust wood, as well as peat), found that the burning material has a remediation environment and The acid components of gases, such as SO_2, formed during the combustion process, and the compounds which occur in this process are part of the clinker; the fuel additive does not significantly affect the processes of clinker formation in the cement furnace, and heavy metals that are contained in a small amount in the products of combustion are immobilized in the structure of minerals of portland cement clinker. In this case, the necessary physical and mechanical properties of Portland cement-based on clinkers obtained with the use of alternative fuels are provided.

The selection of waste for incineration in cement kilns is a complex process, for which various factors, such as the furnace operation regime, the nature of the waste, the total environmental impact, required clinker quality and the likelihood of formation and release chemical substances listed in Annex C to the Stockholm Convention, as well as other emissions into the environment. The operator must develop an evaluation and acceptance procedure of different types of fuel. On the basis of this procedure, an assessment is made of the impact of that or other fuel to the level of emissions, as well as an assessment of the possible need for new equipment or technologies to prevent negative effects on the environment. Variables to be taken into account when selecting fuels and raw materials for combustion in cement furnaces are discussed below.

Operation of the furnace

1. Content of chlorine, sulfur and alkali: these materials can accumulate in the furnace system, in resulting in their accumulation, clogging of the furnace and instability of work; As a result of excess chlorine or alkali in the furnace or branch pipes, dust that must be removed, recycled or disposed of properly way;

2. Moisture content: a high moisture content can reduce productivity and efficiency of the furnace system;

3. Calorific value (fuel): calorific value is the key parameter for calculating the energy received as a result of the technological process;

4. Ash content: the ash content affects the chemical composition of the cement, which is why it may be necessary to adjust the composition of incoming raw materials;

5. Significant additional factors, such as processing power and the volume of waste gases;

6. Stability of operation (eg, CO peaks), as well as the state (liquid, solid) preliminary preparation (grinding, grinding) and uniformity of waste.

Quality of clinker and cement

1. Phosphate content: it affects the setting time of the cement;

2. Content of chlorine, sulfur and alkali: these components affect the overall quality of the product;

3. Thallium and chromium: these components are important for the formation of dust in a cement kiln, and also for the quality of cement; they can also cause allergic reactions in sensitive people.

Emissions of pollutants into the atmosphere

1. High sulfur content in raw materials and used fuels and wastes: may lead to emissions of SO_2;

2. Emission control: when installing an additional tap-off system for alkaline materials, it is necessary to establish appropriate controls on this system emissions to the atmosphere, similar to those that are installed on the main smoke pipe;

3. Chlorides in raw materials or fuel: can react with alkalis, also present in the incoming material, to form solid particles a substance consisting of alkaline chlorides that are difficult to control; at In some cases, chlorides react with ammonia present in supplied to the limestone furnace, as a result of which noticeable interlayers are formed a finely dispersed material consisting essentially of ammonium chloride;

4. Metals in fuel or raw materials: raw materials and fuels always contain metals in various concentrations. The behavior of these metals in the combustion process depends on their volatility. Non-volatile metal compounds remain in the process and leave the furnace part of the cement-clinker composition. The compounds partially pass into the gas phase at agglomeration temperatures and condense on the raw material in the colder parts of the kiln system. This creates a cyclic effect inside the furnace system (internal cycles), which is increased to the level of achievement and maintaining the equilibrium between input and output materials through cement clinker. Volatile metal compounds condense on particles of raw materials at lower temperatures and can form internal or external cycles, if not released with the exhaust gases of the furnace. Thallium and mercury, and also their compounds, evaporate particularly rapidly; somewhat less volatile are cadmium, lead, selenium and their compounds. (European Commission 2001).

5. The concentration of metals in the cement kiln dust depends on the incoming materials and recirculation in the furnace system. In particular, the use of coal and fuel from waste can increase the level of metals in the process. Devices Dust collection can only be delayed by heavy metals associated with solid particles. The level of capture of the gaseous fraction of volatile metals, such as mercury, is very

low. Therefore, the supply of such components to the furnace system must be limited. This must be taken into account when co-incineration waste containing volatile heavy metals such as mercury, lead, or cadmium. When burning wood treated with substances containing copper, chromium, arsenic, etc., special care must also be taken with respect to efficiency flue gas cleaning systems.

6. The choice of fuels can also affect greenhouse gas emissions. For example, replacing fossil fuels with biomass leads to a reduction of CO_2 emissions.

7. The nature of the waste can also affect NOx emissions, depending on the composition waste and moisture content in them.

Analysis of the flows of the feed material

Operators of cement kilns should develop criteria for the acceptance of raw materials, including waste, and should introduce a procedure for continuous monitoring, which includes the following items:

1. Name and address of the supplier, origin of the waste, the volume of waste, content moisture and ash, calorific value, the concentration of chlorides, sulfur fluorides and heavy metals;

2. Each supplier of materials should be required to provide, as initially, and at periodic intervals subsequently, representative samples fuel, on the basis of which this fuel will be evaluated before supply to the operator of cement kilns;

3. The supplier should also provide information with detailed instructions chemical and physical properties of the supplied fuel, with separate indication factors of the impact of this fuel on safety, human health and environment during transportation, transshipment and use;

4. The physical and chemical parameters of the samples provided must be subjected to testing and compliance testing. It is necessary to implement a clear system of quality management and regulation, including periodic sampling and analysis of materials actually supplied to the cement plant, and also ensure that the levels of significant pollutants are within established standards.

Pre-treatment and storage of waste used as alternative fuels

The storage conditions for secondary fuels depend on the type of material. In the general case, attention is needed to minimize emissions of pollutants and technical and hygienic requirements.

Initial storage: In accordance with hygienic norms and regulations, materials with a high content of biological substances and high humidity (up to 40%) should be stored in special containers. Bone flour should be stored in completely enclosed systems.

It is delivered in containers, the contents of which are uploaded to the storage with the help of pneumatic or mechanical devices. Liquid secondary fuels (used oils and solvents) should be stored in special containers designed so that allow leaks and explosions. It is necessary to develop and implement special measures safety (taking into account, for example, the probability of an explosion).

Interim storage at fuel conditioning plants is designed to check the quality of alternative fuels after their preparation. For such storage, containers.

The initial storage and preparation of various types of waste for use in the quality of fuel is usually handled by waste suppliers or special preparation before the receipt of waste at the cement plant. Such a centralized solution is advantageous to the cement kiln operator, since its main task is to manufacture clinker for the production of cement. However, in accordance with good practice, such fuel should be subject to quality control by the receiving party. This means that The pre-sorted and treated waste must only be stored and mixed in the proper proportions for feeding into the cement kiln. Because the deliveries of waste suitable for use as fuel are usually unstable, since markets for waste materials are developing rapidly, warehouses and waste treatment plants it is desirable to design from the outset as universal (Karstensen 2006b). In the year 2003, the Council of Europe has taken measures to standardize solid regenerated fuels based on non-hazardous waste.

Stirring of waste in order to meet certain requirements, resulting, however, as a result of the concealment of environmental impact due to the concentration of pollutants, cannot be considered an acceptable practice.

The efficiency of decomposition of hazardous substances in waste

Combustion of hazardous wastes can only be carried out if the specific requirements for control of incoming waste, control of the technological process and emission control. One of the significant in this context technological parameters is the oxygen content in the off-gases. Destruction organic waste requires not only high temperatures and long retention times, but also the presence of sufficient oxygen, ensuring proper supply to the furnace intended for the destruction of organic substances, as well as proper mixing of these substances with oxygen. When using cement kilns for these purposes, critically. The proper design and operation of the furnace are-important.

In many cement kilns, waste is incinerated on a commercial basis (that is, taken for incineration from outside) and are used to replace other fuels in the production of portland-clinker. Liquid wastes are usually injected from the hot end of the furnace, and solid waste. Some plants are introduced into the calcination zone. In the case of long furnaces, this means that they should be introduced in the middle part of the furnace, and in a furnace with a preheater or precalciner, solid wastes are usually introduced on the feeder shelf in the hot zone of the furnace.

In the case of hazardous waste, it is necessary to ensure complete decomposition of toxic substances, particulary halogen compounds. Wastes fed to the main furnace are decomposed in the zone primary combustion at temperatures above 2073 K, and wastes supplied to the auxiliary. The furnace, preheater or precalciner, burn at lower temperatures, although the expected temperatures in the combustion zone of the precalciner exceed 1273 K.

4. PRE- AND CO-PROCESSING

4.1. Pre-Processing technology overview

The information in this paragraph is based on the information from the [55]. The preliminary stage of the preparation of RDF, the so-called "front-end" is common to all methods of its production. The composition of the front-end equipment in developed countries, that is, the presence of separation of strong non-combustible materials, including magnetic, shredders, screens, air classifiers, ballistic separators, separation using infrared and X-rays, etc., as raw materials. In fact, at this initial stage, there is a primary enrichment of MSW and its preparation for the next stage. The existing practice of production of RDF from municipal solid waste (MSW) in the world shows that the production scheme consists of a number of different processes, which generally include: primary separation at the source of solid waste (at the site of collection, a part of glass, metal, paper and cardboard products and food waste in separate containers); transportation of solid waste to the processing site and storage; sorting (automatic, semi-automatic or manual) or mechanical separation; reduction in size (crushing, grinding and grinding); separation and screening (with the return of large fractions over 50 mm for re-grinding); mixing of the whole pulverized mass; drying and production of pellets or briquettes (this process may include preliminary heat treatment, and the type of final product is determined by the technical conditions of the consumer); packaging and warehousing, **Figure 2.2.**

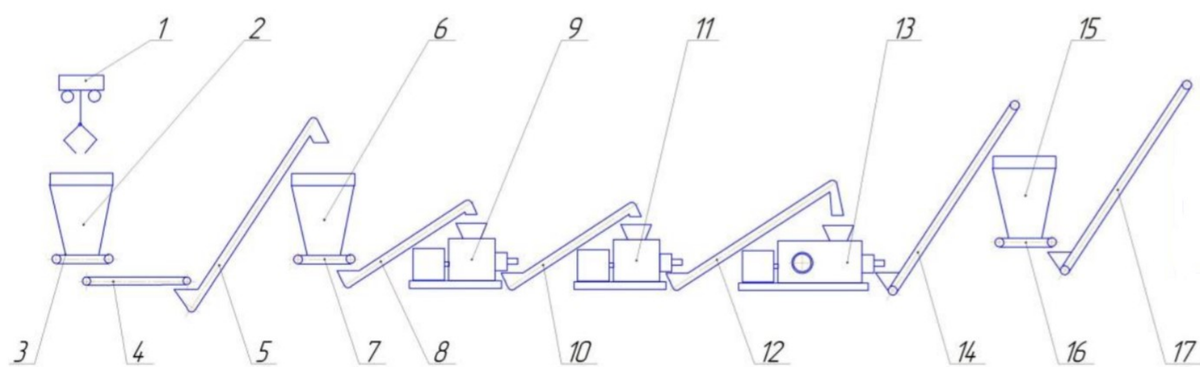

Figure 2.2 – Technological scheme of production of briquettes from sorted solid waste: 1 - grab loader; 2 - receiving waste bunker; 3 - batcher; 4 - manual sorting of solid waste; 5 - auger transporter; 6 - bunker accumulator shredder; 7 - batcher; 8 - auger transporter; 9 - mechanoactivator number 1; 10 - auger transporter; 11 - mechanoactivator number 2; 12 - auger transporter; 13 - auger piston press; 14 -

belt conveyor; 15 - bunker accumulator of the finished briquette; 16 - batcher; 17 - belt conveyor

Typically, prior to grinding, the blended material (TBT) is screened to recover the recyclable portion (eg, metals), the inert portion (such as glass), and the wet organic biomass is rotted (e.g., food and vegetable waste) having a high humidity and ash content. The last part, that is, the wet organic biomass can be sent for further processing, such as composting or anaerobic digestion, and can be used for soil improvement or simply buried. In some cases, the organic material can be dried in the process of biological treatment (the so-called "dry stabilization" process). Large fractions are either discarded or returned to grinding. Medium fractions containing paper, cardboard, wood, plastics and fabrics can be burned as raw crude fuel (c-RDF) or dried and pelletized (or briquetted) into dense RDF (d-RDF). The pellet processing solution is usually taken from the storage conditions and the availability and characteristics of the means for burning them. The main indicator of fuel quality RDF for the consumer is its heat of combustion and it is more dependent on the content of combustible fractions in the waste. The average values of the calorific value of fuel RDF lie in the range from 12 to 18 MJ / kg. There are methods to increase the heat of combustion of fuel at the final stage of the process of its production. It can be supplemented with artificial components, which have a higher calorific value. This can increase the scope of RDF, but at the same time the cost of the final product also grows. The next important indicator of the quality of RDF fuel during its production and use are the environmental consequences when it is used. A serious analysis of the components that make up the fuel and the products of its utilization (combustion or gasification conditions) should be carried out. In this case, when analyzing the morphological and elemental composition of the original MSW, it is necessary to predict both the composition of RDF and the conditions for its utilization for economic evaluation, which is more advantageous, by eliminating the entry of harmful substances into the RDF or power plant equipment with additional purification means. An important factor is also the quantitative indicator of the production of RDF produced from one ton of MSW, which varies depending on the type of collection (MSW composition) and the quality requirements for the processing process. Information from the review [56] showed that the level of production of RDF from TBT varies between 23 and 50% of the weight of the waste, depending on the processing process used in this country. Depending on the composition of the grinded and separated MSW, the following stage of RDF preparation can be chosen one of the following methods: thermal processing; biological processing (aerobic or anaerobic digestion). Biological processing is not considered here, since the purpose of this article is to consider proposals for the production of briquettes from solid waste in an installation integrated into the gasification scheme. At the same time, in the process of manufacturing of briquettes from solid waste, the heat obtained during the gasification of these briquettes in gasifiers of a dense layer is used. There are two approaches to heat treatment:

- Torrefaction ("roasting" of the material without access to the oxidizer) of ground separated wastes. In turn, there can be two schemes: - "Roasting" of the material is carried out in a rotating drum furnace equipped with a burner in the prechamber, where part of the generator gas is burned. The mode is maintained automatically by the temperature of the exhaust gases behind the furnace. The gas is burned in the prechamber so that the material does not come into contact with an open flame. Then the material is sent for briquetting.
- The second source of thermal energy for torrefac- tion can be a part of the exhaust flue gases behind the second zone of a three-zone gas generator (remote combustion chamber), the structure of which is described in [57]. In this case, the thermal treatment (torrefaction) is accompanied by heating in an inert medium to 200-250 ^{0}C, at which a certain dehydration of the semi-finished product takes place, wood begins to be charred and melted polyethylene, polypropylene plastics and other plastics. Briquetting of grinded separated MSW with maximum heating of briquettes and using internal heat obtained during gasification. When the briquetted mass is heated to 200-250 0C, the briquetting process occurs without the addition of binders - this function is performed by a soft plastic material.

The input raw material for briquetting can be, as past separated operations, ground wet TBT, and torrefaktsirovanny material from solid waste. In a simplified form, the process of briquetting torrefaktsirovannogo material MSW for subsequent gasification will look as follows [58]:

- In the first case, input raw materials come in the form of grinded solid waste without inclusions of glass, metal, non-combustible building materials. The maximum humidity is up to 35-40%, the size of the paper, fabric, polyethylene particles is about 30 mm, while the particle size of the material is 20 to 30 mm, does not exceed more than 20-25%. The inclusion of wood is allowed with a particle size of not more than 4-5 mm, and in an amount not exceeding 10%. The raw material is loaded into the hopper and from there it enters the auger-piston mechanoactivator with the function of partial dehydration, and then to the screw-piston press, with an adjustable heating of the output nozzle.

After the cutting device, the briquettes are calibrated to the storage hopper and big-bagger or to gas-generator production.

- In the second case, the embrittled torrefaccated TBW material is ground to a fraction (size) of 3 mm with a predominant particle content of up to 1 mm. This can be done with a hammer crusher or vibrating mill. For grinding, it is possible to use mechanoactivators. Further, the ground material and the binder are fed into a hopper equipped with dispensers with a vibroactivation system to prevent the material from hanging.

After the primary grinding and averaging, the humidity of the solid waste, according to the data [56], will be 50-65%. Further, with a screw transporter, this mass is fed into the mechanoactivator No. 1, with the function of partial dewatering, grinding, compaction, mixing. The output nozzle (nozzle) or housing is equipped with a heater (electric, gas or steam). At this stage, the calculated moisture content should be reduced to 40-45%. Obtained partially dewatered in the mechanoactivator No. 1 mixture of TBT, humidity ~ 40-45%, is sent by a screw transporter to the second mechanoactivator for further mixing, heating, compaction, dehumidification. At the output of the second mechanoactivator, the mass of the semi-finished product is obtained, with a residual moisture content of 30-35%. Then the received mass of solid waste, the screw conveyor, through the controlled frequency drive, is uniformly fed to the high-pressure screw press, with adjustable heating of the forming nozzle. In this case, the moisture content of the material is further reduced to the level of 12-15%, and the result is agglomerated fuel, briquettes of specified sizes, with a temperature of 90-95 °C. The received briquettes are conveyed to the hopper by a belt conveyor, where they cool down and where the final drying takes place to humidity of 7-8%.

4.2. Cost estimation of Mechanical Pre-treatment lines of Municipal Solid Waste

It was assumed that the mechanical sorting process of unsorted municipal solid waste would produce RDF, recycled raw materials (glass, metal (Fe), aluminum (Al)), biodegradable waste that can be used for further treatment, and the rest of the waste to be disposed in the landfill. The income from the selling of materials have been defined using the publicly available waste material prices in Latvia: RDF material – 14 euro per t, non-ferrous metals – 1 100 euro per t, metals – 180 euro per t, glass – 7 euro per t. Considering current prices for collection of waste at the landfill effective in Latvia (2013), it was assumed that the fee for disposal of one ton of municipal solid waste is 28 euro. The transportation costs have been established for a delivery distance of up to 100 km based on the cost of 1 vehicle- kilometer – 1.16 euro – indicated in the Transport Development Guidelines for 2014–2020 in Latvia. Management costs are calculated considering prices in Latvia in 2013. The estimated equipment service time is 10 years (Heyer, 2001), whereas that of constructions – 30 years. It is assumed that the construction depreciation ratio is 3.33%, equipment depreciation ratio – 5%, energy price – 0.20 euro per kWh, 1 l of fuel – 1.20 euro. The annual employee salaries have been estimated in three groups: a director – 16 000 euro, engineers – 12 000 euro, employees – 8 000 euro. The planned number of working hours is 2 000 h per year. The average equipment prices have been obtained collecting the offers provided by equipment producers or distributors in different projects and tenders in Latvia, as well as using available sources of literature (Tchobanoglus, Theisen, & Vigil, 1993; CalRecovery & PEER Consultants, 1993; Caputo & Pelagagge, 2002; Eunomia Research & Consulting, 2002; FCM, 2004; Tsilemou & Panagiotakopoulos, 2004, 2007). **Table 4.1** shows the ranges of the values of the characteristic capacities and costs for the equipment analyzed in this article.

Table 4.1 – The ranges of the values of the characteristic capacities and costs for the equipment [59]

Position of costs	Data from literature (Tsilemou, 2007)		Data for article (for planned capacities)	
	Capacity ($t\ h^{-1}$)	Purchase Price (EUR)	Capacity ($t\ h^{-1}$)	Purchase Price (EUR)
Shredders	0.4-30	11700-103600	10-80	270000-950000
Bag breakers	3-35.2	48-00-157500	10	150000
Screens	15-191.2	35300-218600	10-80	160000-1200000
Magnetic separators	4.3-40	7300-54300	10-80	60000-200000
Eddy current separators	1.3-35	29300-108600	10-80	120000-240000
Manually sorting cabin	-	-	10-80	120000-180000
Ballistic separator	-	-	10-80	220000-750000
Post-shredder	-	-	10-80	80000-350000
Press, baler	31	74000	10-80	150000-350000
Front-loader	-	-	-	125000
Universal loader	-	-	-	60000
Containers	-	300000	-	28500-88500

To assess the costs for different mechanical pre-treatment (MP) equipment sets and estimate the amount of the resulting recovered waste material, Scenario I (the planned waste quantities – 20 kT yr^{-1}; capacity 10 t h^{-1}) with constant capital costs analyses the costs of four additional options. Material fractions acquired as a result of the operation of sorting lines are estimated on the basis of previous studies by the first author regarding the content of waste after its mechanical pre-treatment (Arina & Orupe, 2012, 2013).

4.3. Co-Processing technology overview

Co-processing is defined [60] as the use of waste as raw material, or as a source of energy, or both to replace natural mineral resources (material recycling) and fossil fuels such as coal, petroleum and gas (energy recovery) in industrial processes, mainly in energy-intensive industries (EII) like cement production. In Co-processing, the combustible waste is utilized as fuel (Alternative Fuels) into the kiln system for maintaining the high temperature during clinker production, see **Figure 4.1**.

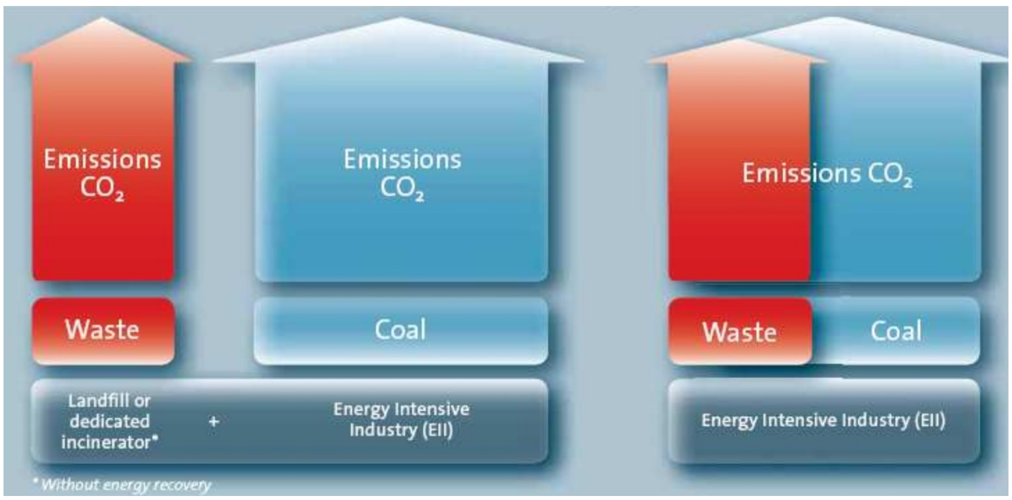

Figure 4.1 – Comparison of emissions scenarious [14]

Some of the waste streams like biomass, small quantity waste streams, etc which have suitable quality parameters may be directly fed into the kiln system. However, majorly waste streams, especially when volumes are more, are fed after pre-processing which makes it homogenized to reduce the process fluctuations. Various equipment are utilized for feeding the pre-processed AFR into the kiln system. Automated mechanical extraction machines such as walking Floor and various belt conveyors as mentioned above are utilized for transporting material from processing area to feeding point. Different kinds of volumetric and gravimetric dosing machinery are utilized for feeding the AFR material into the kiln in a controlled manner. Various safety equipments like Rotary Air Lock, Safety shut off valves & gates & Double slide gates are utilized into the feeding mechanism to avoid any back fire due to pressure build-up inside the kiln. Bag filters are utilized at transfer points to avoid any dust emission into the atmosphere in case of feeding fine AFRs. For optimal performance (co-processing without additional emissions), waste materials (pre-processed or as received) should be fed to the cement kiln through appropriate feed points, inadequate proportions and with proper waste quality and emission monitoring systems. Different feed points can be used to feed the waste materials into the cement kiln for co-processing. The most common ones are:

- Main burner at the rotary kiln outlet end;
- Rotary kiln inlet end;
- Pre-calciner;
- Mid kiln (for long dry and wet kilns).

Appropriate feed points have to be selected according to the physical, chemical and toxicological characteristics of the waste materials. Wastes of high calorific value have to be always fed into the high temperature combustion zones of the kiln system. Wastes containing stable toxic components and also wastes containing more than 1.5% chlorine should be fed to the main burner to ensure complete combustion in the high temperature and long retention time.

Alternative raw materials containing constituents that can be volatilized at operating temperatures in the pre-heater system have to be fed into the high temperature zones of the kiln system. Coal feeding circuit and raw material feeding circuits of the cement plant must not be utilized to feed any type of wastes for co-processing unless a trial is performed to demonstrate the suitability of the same and specific approval from the SPCB is obtained along with the authorization. SPCBs may consult CPCB in specific cases in this regard. Feeding of alternative raw materials containing volatile (organic and inorganic) components to the kiln via the normal raw meal supply should be avoided unless it has been demonstrated by trial runs in the kiln that there is no VOC emission from the stack. Such trial runs should be carried out with permission from SPCBs. SPCB should consult CPCB if they feel that trial is needed in specific difficult cases. Destruction of waste materials that are covered under the Stockholm Convention and Montreal Protocol such as PCBs, Expired or obsolete pesticides, Ozone Depleting Substances etc. must however be undertaken in a given kiln only after obtaining specific approval from SPCB and other concerned organizations. For this, SPCB in consultation with CPCB will provide steps to be followed including implementing a trial as per a defined protocol.

4.4. Pre- and Co-Processing value chain structure

The pre- and co-processing value chain can be fully integrated and managed by one entity or each main step e.g. waste collection, pre-processing, co-processing can be managed by separate entities, **Figure 4.2** [61]. In mature waste markets, which means collection/transportation and pre-processing infrastructure already exists the steps can be managed successfully by different entities. In low developed waste markets, the involvement of less entities allows a better control over the whole value chain and reduces contract and price negotiations and prices. Disadvantages are that waste management is not the core business of the cement industry and there is a risk for a focus on the most valuable waste streams and therefore the integration into an overall waste management concept might be more difficult.

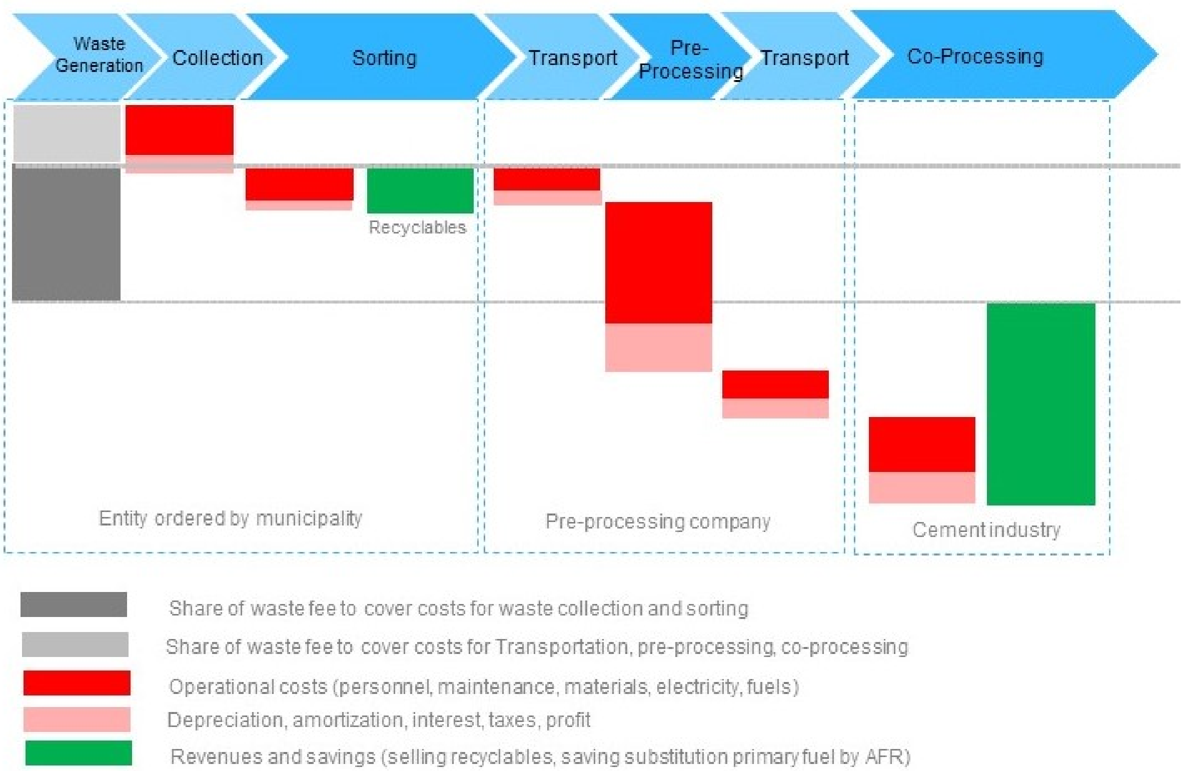

Figure 4.2 – Cost profit waterfall of pre- and co-processing

With several separate entities in the value chain, each entity needs to calculate based on their cost structure the required revenues to provide the service. This can lead to competitive and efficient supply chains. Additional risks are a growing administration and loss of transparency of the material flows.

The commitment of the cement company will depend on AFR being cost competitive with the substituted fuels and raw materials, and therefore depend on market prices. The same holds true for the waste streams, the competing treatment options and affordability. Entities can be public or private and formal or informal.

Table 4.2 – CAPEX and OPEX for pre- and co-processing of alternative fuel [62]

Alternative fuel	Pre-processing and Co-processing	
	CAPEX	OPEX
Hazardous Spent Solvents	€5 to €10 million	€10 to €20 per ton
Waste Oil and Industrial Oil	€1 to €3 million	€5 to €10 per ton
Wastewater	€1 to €3 million	€5 to €10 per ton
Used Tires and Rubber Waste	€2 to €4 million	€20 to €50 per ton
Industrial Sludge	€2 to €4 million	€15 to €30 per ton
Non-hazardous Industrial Waste	€5 to €15 million	€5 to €20 per ton
Municipal Solid Waste	€13 to €20 million	€5 to €15 per ton
Municipal Sewage Sludge	€2 to €4 million	€5 to €10 per ton
Construction and Demolition Waste	€5 to €15 million	€5 to €20 per ton
Biomass and Green Wastes	€5 to €15 million	€5 to €20 per ton
Animal Meal	€0,5 to €1 million	€5 per ton

The strategy of coworking of mentioned entities could be the next, **Figure 4.3**.

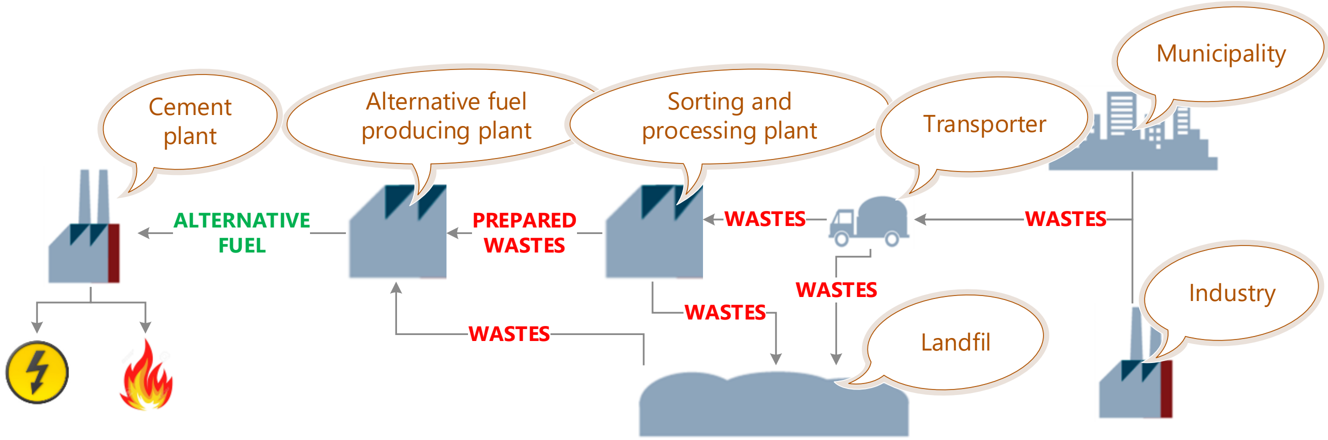

Figure 4.3 – Strategy of producing alternative fuel for cement industry

The risk of monopoles for a process step could however endanger the overall business case. That’s why this process could be regulated by Energy and utilities the National Regulatory Commission of Ukraine, which will control prices at the market of alternative fuels.

5. RISK ASSESSMENT

In recent years, cement industry has faced the challenge to adapt to the ever-growing demand of biomass as “alternative energy” or as an “environmental friendlier fuel” [63]. From wood pellets to refuse-derived fuel (RDF) and dried sewage sludge (DSS), each solid fuel has unique characteristics that classify it as high-, medium- and low-risk in terms of fire and explosion.

Alternative fuels are prone to self-oxidation and at the same time fire incidents have been proved very hard to extinguish. Therefore, it is of great importance, that storage facilities are equipped with reliable and well-designed early detection and effective fire suppression systems based on a comprehensive fire protection study.

Experienced engineers can provide consulting services for the inherently-safe design of new alternative fuel installations and assess existing installations for their suitability to handle alternative fuels, based on material characteristics, such as granulometry, calorific value, moisture and ash content, after observation and evaluation of the actual handling process on-site and/or laboratory analysis. A thorough explosion risk assessment, that covers every step of the process, will result in certain technical solutions and organizational measures, proposed to effectively address identified hazards and help the facility make a safe transition to the alternative energy era.

The main contributing factor in the majority of accidents and incidents in the industry is human error, thus, setting human performance and behavioral based safety (BBS) as key factors. Through a Human Reliability Assessment, measures can be taken to reduce the likelihood of errors occurring within a system and therefore to lead to an improvement in the overall level of safety. Indicative methods implemented by our Industrial Safety Department include the following [63]:

- Hazard Identification Techniques (Human HAZOP, Technique for Human Error Assessment, THEA, etc.);
- Expert Judgement Techniques (Absolute Probability Judgment, APJ, etc.);
- Bow Tie Method in Human Reliability Assessment.

Job Safety Analysis is a powerful tool for keeping workplaces safer and associated costs from Lost Time Injury (LTI) down. By observing a worker actually performing the job, an occupational risk assessment can be prepared complemented by measurements of physical and chemical agents, when necessary. In this way, assessment of personal exposure according to CSI guidelines can be conducted and an action plan can be drawn based on risk prioritization in order to proactively address specific workplace hazards such as [63]:

- Slips, trips and falls from height;
- Warehouse safety assessment (racks, forklifts, cranes, fire protection);
- Confined space entry (e.g. silos etc.);
- Waste handling and storage related hazards;
- Exposure to chemical substances (dust, respirable crystalline silica, etc.);
- Exposure to physical agents (vibration, noise etc.);
- Manual handling, repetitive tasks and poor workstation design hazards.

More and more cement plants worldwide are choosing the Selective Non-Catalytic Reduction (SNCR) as a cost-effective method to meet the legislative demand of reducing NOx emission from combustion installations that burn coal, biomass and waste. If ammonia or ammonia solution is chosen to be the reducing agent, there are certain hazards that need to be addressed in order to effectively manage explosion, toxic release, occupational and environmental risks.

In this context, an SNCR Risk Analysis can consist of:

- As-built HAZOP & human HAZOP (PHA-pro software);
- Explosion Protection Verification (ATEX);
- Consequence Modelling (EFFECTS software);
- Quantitative Risk Assessment (RISKCURVES software);
- Ammonia Hazards and Emergency Procedure Training.

6. BATs

For new plants and plants undergoing radical reconstruction, the best available methods for the production of cement clinker are the use of a dry process in furnaces with multistage preheating and precalcination. At existing plants, this or that degree of reconstruction may be required [48].

Basic measures and optimization of the technological process

Process optimization [48]

- Providing quick cooling of the furnace flue gases to temperatures below 200 ºC.
- Identify the parameters of good operation and use them as a basis for improving other performance characteristics. Having determined the proper operating parameters of the furnace, reference data should be specified by adding controlled portions of waste, observing the changes, and determining the required measures and practices to reduce emissions.
- Control of the process of the furnace operation to ensure and maintain the stability of operating conditions, for example, by optimizing process control (including the use of computerized automated control systems) and the use of modern gravity solid fuel feed systems.
- Minimizing the energy consumption of fuel by using preheating and precalcination as completely as possible, reviewing existing furnace system configurations, using modern clinker coolers, and ensuring the maximum heat recovery of flue gases.

Preparation of hazardous waste [48]

Pre-treatment of waste, including hazardous wastes, in order to improve their homogeneity and increase the stability of the combustion conditions, may include drying, grinding, mixing and grinding, depending on the type of fuel derived from waste. It is important to pay serious attention to:

- Good services, economic activities and the introduction of technological procedures to ensure the safe reception, transfer and storage of waste upon their arrival at the production site, as well as the availability of properly designed rooms for temporary storage, taking into account the hazards and characteristics of each type of waste;

- Good service, business management and implementation of technological procedures, as well as the availability of properly designed facilities for the storage of alternative fuels.

Management of materials that are loaded [48]:

- To maintain the stability of the technological process, sufficient long-term (no less than one month) reserves of secondary fuel or waste are needed;
- Substances supplied to the furnace must undergo careful monitoring and selection; standards must be implemented based on product / process characteristics or emission parameters, and compliance with these standards should be monitored;
- Continuous supply of alternative fuels indicating the content of heavy metals, chlorine and sulfur;
- The fuel obtained from the waste should never be used at the start-up and shutdown of the furnace;
- A feed mixture containing waste with organic components that can act as precursors of contaminants should be avoided;
- Halogenated waste must be fed into the furnace through the main furnace;
- In general, the waste must be fed to the furnace equipped with a preheater / precalciner, either through the main furnace or through a second furnace. When feeding through the second furnace, it is necessary to make sure that the temperature in the combustion zone is maintained at> 850 °C for a sufficient holding time (2 s);
- Wastes containing organic components that can serve as precursors to hazardous contaminants should not be fed as part of the raw meal;
- The fuel obtained from the waste should never be used at the start-up and shutdown of the furnace.

Stabilization of process parameters [48]

To ensure proper combustion and maintain the stability of the process, it is necessary to ensure:

- Persistence of the characteristics of fuels (both fossil and alternative);
- Constancy of the fuel feed rate or the regularity of the feed intervals of batch-loaded materials;
- Maintain a sufficient excess of oxygen to achieve adequate combustion;
- Providing monitoring of CO concentrations in the off-gases and control over the non-exceeding of the established levels due to inadequate combustion conditions.

Modification of the technological process

It is necessary to carefully monitor the dust content of the off-gas (also called cement kiln dust) [48]. In many cases, the dust can be returned to the furnace, but to the extent that it is practical and will avoid unnecessary emissions of volatile metals and alkali salts. The maximum use of such recirculation can lead to a reduction in the amount of dust to be removed. Dust, which can not be returned to the process, must be removed in a way that is safe to check. Depending on the level of hazardous pollutants (such as heavy metals, persistent organic pollutants) such dust in some cases it may be regarded as hazardous waste, in which case it will require special measures for handling and disposal of these wastes.

Basic measures

As a rule, the main measures considered above are sufficient to ensure a level of emissions with flue gases below 0.1 ng I-TEQ / Nm^3 both at new and existing facilities [48]. If all these measures do not allow achieving emission reductions to a specified level, the application of the additional measures described below can be considered.

Additional measures

The additional measures considered below are usually applied to control emissions of other pollutants than unintentionally generated persistent organic pollutants [48].

Further reduction of dust emissions and recycling

Such measures do not lead to any significant reduction in levels of chemicals in the off-gas [48]. Accordingly, the effectiveness of this strategy is reduced with increasing temperature levels in the particulate trapping system. When switching from systems without recirculation of kiln dust to systems with complete recirculation, the chemical composition of the dust will gradually change with an increase in the alkaline content, which will entail operational problems; some of the collected dust needs to be removed, and at such a high level of recycling the dust is likely to be enriched semi-volatile and volatile heavy metals, which would require special handling procedures and safe removal of the enterprise, specially designed for treatment or storage of hazardous waste. This approach has general applicability; the technical complexity of its implementation is moderate; The capture of chemicals associated with particulate matter is well ensured. Rotary furnaces are usually equipped with electrostatic precipitators due to relatively high temperatures of the off-gases. Fabric filters are also used, especially on heaters, where the temperature of the waste gases is lower. Shaft furnaces are usually equipped with fabric filters. Sometimes wet scrubbers are used. At the plants for grinding lime, fabric filters are installed to collect products and to dedust the exhaust air. Hydration installation, in which the exhaust gases saturated with water vapor at 90ºC, typically equipped with wet scrubbers, although increasingly used fabric filters, where the incoming lime has high reactivity. According to the European Commission (2001), particulate matter from point sources can be effectively removed by applying [48]:

- Electrostatic precipitators with control devices and urgent measurements for CO monitoring;
- Tissue filters with multi-sector cleaning and rupture detectors. The emission levels corresponding to the best available methods are 20-30 mg dust / m^3 on average per day. This level can be achieved by installing electrostatic precipitators or fabric filters on various cement kilns.

Injection of activated carbon

When fabric filters are used to trap solid particles, it is possible to achieve ~~a~~ high efficiency of trapping metals and organic compounds by injecting powdered activated carbon prior to entering the fabric filter. The capture of pollutants occurs due to the adsorption on the surface of dispersed carbon particles in the flue gas stream, and also when gases pass through the filter cake formed on the inner surface of the tissue bags. Low operating temperatures are critically important for the successful application of this method since temperatures in the de novo range of activated carbon synthesis (523-673 K) can serve as a source of carbon for the formation of PCDD / PCDF. Activated carbon also has a better ability to adsorb metals and PCDD / PCDF at temperatures below 200ºC. At the same time, the temperature should be maintained above the dew point for the off-gases in order to avoid condensation and sealing of the bags. Usually, an operating temperature of about 433 K is used, although with careful monitoring, lower levels can also be maintained. Temperature control is usually achieved by evaporative cooling and coal is usually injected into the evaporative cooler or immediately after it. It should be noted that when returning cement kiln dust to the furnace, such a technique will not be highly effective for controlling mercury emissions, since the collected mercury will be released in the furnace and, to achieve adequate control, a significant part of the cement dust stream must be sent for removal.

This technique has general applicability for the control of chemicals with a high capture efficiency (more than 90%) with proper optimization of operating temperatures; requirements for technical reconstruction are minimal or moderate; This technology is more suited to the possibilities of modernizing an existing enterprise than the two following technologies [48].

Activated Carbon Filters

Filtration using activated carbon is characterized by a high efficiency of removing some pollutants (> 90% on average,> 99% for some substances). Adsorption on activated carbon allows the removal of pollutants such as sulfur dioxide (SO2), organic compounds, metals, ammonia (NH3), ammonium compounds (NH4 +), hydrogen chloride (HCl), hydrogen fluoride (HF) and residual (after an electrostatic precipitator or a fabric filter) dust. At cement plants in Europe, an activated carbon filter is installed only in Ziggental (Switzerland) on a kiln with a capacity of 2,000 tons of clinker per day with a 4-stage cyclone preheater. The measurements showed its high efficiency with respect to SO_2, metals, PCDDs and PCDFs (European Commission 2001) [48].

Selective catalytic reduction

Selective catalytic reduction systems are mainly used to control NOx emissions. In this process, NO_2 and NO are reduced to N_2 using NH_3 as a reducing agent in the presence of an appropriate catalyst at a temperature of about 573-673 K, which requires heating the flue gases from a standard cement kiln. Only a portion of the catalysts capable of reducing nitrogen oxides are also suitable for the destruction of pollutants, such as PCDD / PCDF. So far, this selective catalytic reduction method for controlling NOx emissions has been tested only on preheater systems and semi-dry kilns (Lepol), but may also be applicable to other furnaces (European Commission 2001). The relatively high cost of capital investment, as well as the significant cost of energy consumption for heating flue gas, can make it economically unjustified for large scale applications. The first full-scale plant, which uses this method (Solnhofer Zementwerke), has been operating since the end of 1999 [48].

Injection of activated carbon, new technology

Injection of powdered activated carbon in front of the dust filter can be effective for removing metals and organic compounds. However, the following points should be noted:

- Low operating temperatures <433 K are critically important for the successful application of this technology;
- At the same time, the temperature should be kept above the acid dew point to avoid condensation or corrosion;
- In the event that furnace dust returns to the recycling oven, as is usually done, this technology will not be effective in controlling mercury emissions, since mercury will be released again in the furnace;
- There was no evidence of the effectiveness of this carbon injection technology to control PCDD / PCDF emissions from cement kilns; this technology was used only in installations for incineration of domestic wastes.

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8. ANNEX A – CASES

Kunda Nordic Cement [64]

Kunda Nordic Cement uses organic waste, including hazardous waste, as an energy source for cement production.

Table A.1. Kunda Nordic Cement case

Country	Estonia
Company name	Kunda Nordic Cement
Owner	Owners of AS Kunda Nordic Cement: Heidelberg Cement Sviden AB (Sweden), which owns 75% of the shares, and CRH Hurup Holding BV (the Netherlands), which owns 25% of the shares.
Contacts	E-mail: knc@knc.ee Web: www.heidelbergcement.com/ee Tel: +372 32 29 900 Fax: +372 32 21 546
Technology	
Method of processing	Burning of waste oil and various hazardous organic wastes
Capacity	Information is not available
Energy producing	Information is not available
License / Permit Information	
Licensing organization	The Council on the Environment
Supervisory authority	Environmental Inspectorate
Authorization No.	01.07.2011 V 8-4/11/22596-1
Permit validity period	04.01.2012 – 03.01.2017
Acceptable types of waste	Organic hazardous and non-hazardous waste with some restrictions
Limitations on waste types	Explosive and radioactive wastes are not accepted. Limitations on the concentration of halogen
Restrictions on the import of waste from other countries	In accordance with EU Regulation No. 1013/2006 on Waste Transport and the Basel Convention

Continuation of the **Table A.1.**

Requirements for the supply and acceptance of waste	Waste must be declared before acceptance
Emission control	Emission control based on Estonian Regulation No. 66 of 4 June 2004 issued by the Ministry of the Environment and Directive 2000/76 / EC.
Sewage control	The discharge of wastewater after the flue gas cleaning is regulated by the Estonian Regulation No. 66 of 4 June 2004 issued by the Ministry of the Environment and Directive 2000/76 / EC.
Remains	Information is not available
Controlling, monitoring and reporting	Information is not available
The cost of processing / Passage for hazardous wastes	Information is not available

CEMEX Latvia, Brocenes [64]

Waste is used as an alternative fuel for the operation of cement kilns. High-temperature incineration of waste.

Table A.2. CEMEX Latvia case

Country	Latvia
Company name	CEMEX Latvia, Brocenes
Owner	CEMEX, Mexico
Contacts	E-mail: ilonija.audere@cemex.com, informacija@cemex.com Web: www.cemex.lv Tel: +37167033500 Fax: +37167033514
Technology	
Method of processing	Waste is used as an alternative fuel for a cement kiln. Waste incineration at high temperature
Capacity	Volumes of alternative fuels are not specified in the resolution

Continuation of the **Table A.2.**

Energy producing	Information is not available
License / Permit Information	
Licensing organization	Riga Regional Commission for Environmental Protection
Supervisory authority	The Latvian Agency for Environment, Geology and Meteorology
Authorization No.	Nr. RI 09 IB 0013/20.3.2009
Permit validity period	Valid until 19.3.2014
Acceptable types of waste	Information is not available
Limitations on waste types	Information is not available
Restrictions on the import of waste from other countries	In accordance with EU Regulation No. 1013/2006 on the transport of wastes and the Basel Convention
Requirements for the supply and acceptance of waste	Information is not available
Emission control	For air emissions, reference is made to air quality standards for carbon monoxide, nitrogen dioxide, sulfur dioxide and particulate matter PM10, Regulation CM No. 588, adopted on October 21, 2003, "Regulations on air quality" 1, 2, 3 and Annex 7. In accordance with EU Directive 2000/76 / EC.
Sewage control	In accordance with EU Directive 2000/76 / EC.
Remains	Remains of products returned to production: 8500 tons per year. Remains of products not returned to production: approximately 17 tons per year.
Controlling, monitoring and reporting	Annual report by February 15 of each year with information on the amount of waste and other parameters.
The cost of processing / Passage for hazardous wastes	Information is not available

Norcem Brevik [64]

Norcem Brevik uses alternative fuels in the production of cement. The amount of alternative fuel based on the waste is more than 130'000 tons per year, or about 50% of all the fuel needed for cement production. Approx. 15% of the fuel from recycled wastes - based on fossil minerals, including industrial hazardous organic waste.

Table A.3. Norcem Brevik case

Country	Norway
Company name	Norcem Brevik
Owner	Heidelberg Cement Group
Contacts	E-mail: david.verdu@norcem.no Web: http://www.heidelbergcement.com Tel: +47 35 57 20 00 Fax: +47 35 57 17 47
Technology	
Method of processing	Burning in a cement kiln
Capacity	50'000 tons of hazardous organic waste per year 15'000 tons of waste oil per year
Energy producing	Information is not available
License / Permit Information	
Licensing organization	The Agency for Climate and Environmental Pollution (Klif)
Supervisory authority	The Agency for Climate and Environmental Pollution (Klif)
Authorization No.	2004.057.T/8.12.2004, the last reduction 18.4.2012
Permit validity period	Until further notice
Acceptable types of waste	Hazardous organic waste
Limitations on waste types	For waste oils used as fuel, the maximum PCB content is 50 mg/kg, the maximum halogen content is 1'000 mg/kg, the thermal equivalent is at least 30 MJ, the ignition point is less than +55 °C. Radioactive and explosive wastes are not accepted.
Restrictions on the import of waste from other countries	In accordance with the Basel Convention and the relevant regulations of Norway and the EU

Continuation of the **Table A.3.**

Requirements for the supply and acceptance of waste	Notification of waste before shipment required
Emission control	Emission control is carried out in accordance with the resolution (see above) and the latest edition of the permit of 18.4.2012.
Sewage control	Direct discharges of process wastewater are not produced
Remains	There are no residues from hazardous wastes; everything is mixed in the products. Dust collected from chimneys and refractory bricks and similar waste are stored on a special range of "Norcem".
Controlling, monitoring and reporting	Internal control and regular reports to the supervisory authority, depending on the substance, either annually or twice a year. Periodic independent control.
The cost of processing / Passage for hazardous wastes	Prices are only offered for actual shipments of waste. The general price list is not available.

SITA Starol [64]

"Sita Starol" produces alternative fuels for burning in cement kilns from various types of waste, including hazardous organic waste and used oil. The company operates two facilities: in Chorzov and in Tarnów Opolski; The second installation is smaller and is only used for processing liquid waste.

Table A.4. SITA Starol case

Страна	Poland
Country	Sita Starol
Company name	Swiss Environment Group
Owner	E-mail: starol@starol.com Web: www.starol.eu Tel: +48 (32) 203 76 74 Fax: +48 (32) 203 76 80

Continuation of the **Table A.4.**

Contacts	
Technology	On the site in Chorzow an alternative fuel is produced: the company produces an alternative solid fuel based on crushed solid waste and on the basis of a mixture of absorbents with solid, pasty and liquid waste.
Method of processing	Total production: 235'000 tons per year; At the R15 process - up to 120'000 tons per year, at the D13 process - 105'000 tons per year, liquid waste - 10'000 tons per year.
Capacity	Energy production is not carried out
Energy producing	Is not providing
Licensing organization	Head of the Silesian Voivodship
Supervisory authority	Inspectorate of the Voivodship for the Protection of the Environment (Silesia)
Authorization No.	Decision No. 866 OS / 2009 of 11.03.2010. Integrated permit for operation of a waste management plant in Chorzow.
Permit validity period	Valid until 11.03.2020.
Acceptable types of waste	An extensive catalog of hazardous and non-hazardous waste (more than 800 different types of waste)
Limitations on waste types	Asbestos, medical waste, electronics waste, batteries, radioactive waste, explosive and flammable waste (tested by the laboratory)
Restrictions on the import of waste from other countries	The permission of the Chief Inspectorate for Environmental Protection (GIOS)
Requirements for the supply and acceptance of waste	Samples of waste are taken for analysis, eg, on the heat of combustion, moisture content, content of heavy metals. Only after this waste can be qualified for a certain process; After the delivery of waste to the enterprise, the tests are performed once more. (Also, the fuel shipped from the enterprise is tested).

Continuation of the **Table A.4.**

Emission control	Limits on dust and a number of hydrocarbons are established
Sewage control	Not applicable in this case
Remains	Metal scrap is sent for processing to metallurgical plants; stone, hard fragments, etc. are separated for later use.
Controlling, monitoring and reporting	Data on received and processed waste (quantitative and qualitative) are recorded in accordance with the classification of waste and are included in the reporting. Atmospheric emissions are measured twice a year. Noise monitoring is carried out once every two years. Monitoring of groundwater is carried out once a year. The measurements and results of analyzes are stored in the archive; the reporting is sent to the Administration of the Province and to the Inspectorate of the Voivodeship for the protection of the environment in accordance with the legislation of Poland.
The cost of processing / Passage for hazardous wastes	Prices vary depending on the type of waste 150 - 1'000 PLN per ton (36-245 EUR). The average price does not exist.

9. ANNEX B – CASE STUDIES

Case Study 1 – Madukkarai city [65]

ACC Limited - the oldest cement company in the country - has a Clinker and Cement manufacturing facility near Madukkarai (city with a population of about 40'000 people). Initially, the waste collectors, the households & the other waste generating establishments were given awareness on proper management of the wastes for putting it to good use. As a system design, the door to door collection waste collection drive was started after training the waste collection team in segregating it properly in different fractions. The waste collecting team initiated the collection and segregation process in which the household waste was segregated into bio-degradable, recyclable and non-recyclable wastes. The street sweeping and drains cleaning job which included sweeping, cleaning, collection and transportation was assigned to a totally separate team so that the door to door collected material does not get contaminated with the inert materials by design. The door to door collected waste in a segregated manner is them transported to a Material Recovery Centre (MRC) where in the biodegradable waste is converted into bio compost and vermi compost and sold to the farmers. The recyclable materials such as plastics, paper, cloth, metals, batteries etc are sold to the recyclers. The balance material contained different fractions such as non-recyclable plastics, leather, rubber, soiled clothes, soiled paper and other similar materials. Usually, this material tends to get dumped or land filled in normal course of operations. The plastic material out of this non-recyclable material, that can be utilized in the road construction activity, is shredded and sold for that purpose. The remaining non-recyclable plastics and other material which can be called as non-recyclable Segregated Combustible Fraction (SCF) is sent across to the cement plant of ACC after bailing it. In the cement kiln of ACC Cement plant, this SCF gets co-processed as Alternative Fuels and Raw material (AFR) in the cement making process. The use of this kind of waste as AFR helps ACC cement plant to reduce its coal consumption and also reduces the amount of greenhouse gas emissions from the operations. The above initiative is being implemented by the Madukkarai Town Panchayat successfully and sustainably for the past six years without any interruption and has achieved the status of zero landfill town.

Source: https://www.youtube.com/watch?v=A8qldAu9BQ4

Case Study 2 – Vapi city [65]

Vapi is a city, where allocated many Small scale and Large scale Paper mills. These Paper Mills generate non-recyclable Plastic waste which were earlier sent for landfill or it was stored in the premises of the paper mill in large quantum. Because of the non-biodegradable and impervious nature of plastic, landfill was not a suitable solution for the disposal of the plastic waste. In 2010, Gujarat Pollution Control Board issued a note wherein it was instructed to all paper industries to explore possibilities of co-processing plastic waste in industries at high temperatures. Ambuja initially signed an MoU with Paper Mills. The summary of the MoU was long term understanding between the 2 parties that the total quantity of plastic waste generated by the Paper Mills will be consumed by Ambuja for co-processing (AFR) in their cement kilns. Accordingly, plastic waste is being regularly sent by Paper Mills for co-processing to the Kodinar unit of Ambuja Cements Ltd from all paper mills in Vapi. From the year 2012 to the year 2016 1,54,018 MT of plastic waste is being Co-processed from paper mills of Vapi. A bar chart (is shown in **Figure B.1.**) showing the year wise data from 2012 to 2016 of plastic waste co-processed at Ambuja Cements Ltd, Kodinar.

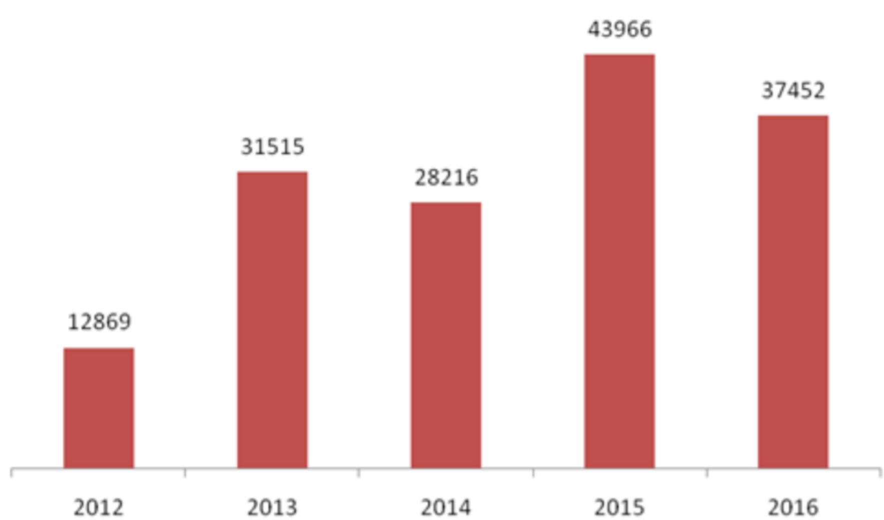

Figure B.1. Data from 2012 to 2016 of plastic waste co-processed at Ambuja Cements Ltd

Case Study 3 – Greece [66]

Greek Titan Cement is the largest player in the local cement industry, and of Greek origin. It has 3 plants in Greece and also operates plants in Egypt, North America, Eastern and Southeastern Europe: LafargeHolcim (2 plants) and Italcementi (1 plant). The major part of Greek cement and clinker is being exported (68% in 2014); it is sent mainly to North Africa. As a result, Greece has a very high clinker production per capita (504 kg/capita in 2012). After several years of decrease in production, the industry has been recovering well from a low in 2011, despite the continuous shrinking of the country's GDP.

As of 2012, substitution rates in Greece of waste-derived alternative fuels were very low; on average between 6-7% (compared to EU average 36%), due to:

– limited availability of suitable materials;

– uncertain and lengthy permitting process for co-processing.

However, the investment barrier for increased use of waste-derived alternative fuels is already being lifted for at least part of the Greek cement industry:

– Based on an interview held with Greece cement industry expert one plant already reaches over 20% substitution;

– the sector should be ready to increase its substitution rate up 30% in a short period of time if other barriers are mitigated.

In 2015, Greece introduced its new National Waste Management Plan, aiming to reduce generated waste per capita, prepare more than 50% of Municipal Solid Waste for reuse and limit landfilling to a maximum of 30% of total generated waste. Energy recovery only considered a complementary treatment option after other recovery options have been exhausted:

- Production of Refuse-Derived Fuel (RDF) and Solid Recovered Fuel (SRF) is not considered to be an appropriate waste treatment option as those materials should be recycled according to the plan;
- Utilization of waste-derived fossil fuels is considered as a process of high environmental impact;
- There is no distinguishing between co-processing in cement kilns and other ways of energy recovery.

Implementation of the National Plan is, however, facing a number of obstacles:

- Economical – Greece, currently facing an economic crisis, will struggle to deploy more advanced waste treatment methods than landfilling (such as energy recovery or recycling) as these are costly. On the other hand, co-processing could help alleviate part of this burden;

- Administrative - responsibilities for co-ordination of national and regional waste management are shared under different ministries, causing difficulties for the actual implementation of the plan;
- Logistical and infrastructural – Greece's geographical spread over many islands makes it hard to efficiently collect and process waste;
- Attitude of local stakeholders - local residents often have a "not in my backyard attitude," which complicates construction on new sanitary landfills. In combination with insufficient landfill capacity, this results in illegal dumping of waste.

Case Study 4 - Poland [66]

Most players in the Polish cement sector are multinationals, these include: HeidelbergCement, LafargeHolcim, CEMEX, CRH, Buzzi Unicem and Miebach Group. Poland has 11 Portland cement plants: 10 plants are fully integrated and one is a grinding plant. Majority of cement is consumed domestically. Clinker production peaked in 2011 at over 13.6 Mtonnes (Cement production was close to 19 Mtonnes). The fuel substitution rate in Poland was above EU average in 2012: 45% (compare to EU average 36%). It is estimated that as of 2015, the substitution level has risen to 50-55%. Co-processing is encouraged by Polish government and viewed positively by society. The cement industry is the largest consumer of processed waste as a fuel (1.2 Mtonnes/year). Between 70% and 80% of alternative fuels used are of MSW origin, the other alternative fuels are used car tyres and sewage sludge. Consumption of RDF can grow to between 1.7 Mtonnes/year and up to 2 Mtonnes/year in the coming years. Two cement plants already have substitution rates of over 80%.

Poland uses a recent National Waste Management Plan (KPGO 2014) to formulate its Policy which aims to:

- Increase the number of Mechanical Biological Treatment plants to aid recycling and waste processing;
- Reach thermal conversion of 25% of mixed municipal waste in "Waste to Energy" facilities by 2020;
- Reduce landfilling of MSW to less than 10% by 2025;
- Invest heavily in the coming years, including construction and modernization of up to 100 composting and fermentation plants, 28 new Mechanical

Biological Treatment plants (with processing capacity of 1.2 Mtonnes), 27 sorting plants (with processing capacity of 1.8 Mtonnes), and 6 “Waste to Energy” plants. (4,5,6).

In the National Waste Management Plan, RDF/SRF is considered a product of recycling and Mechanical Biological Treatment operations. Production of RDF/SRF in Mechanical Biological Treatment plants, for specific use in cement production, “Waste to Energy” or district heating plants is seen as a key outlet product. For use in the cement industry, the quality of RDF needs to improve. The cement industry has a need for high quality fuels, which are only partially being met at present. Today the cement industry is the main RDF customer, even with “Waste to Energy” plants coming online in the coming years it is expected that up to 2 Mtonnes of RDF will be used by the cement industry in the future. Common waste collection standards and source separation in waste collection, overseen by the municipalities, is seen as a key challenge for high recycling rates.

Case Study 5 – Germany [66]

Germany had 22 companies producing cement in 2014. The market consists of a mix of global players (HeidelbergCement, LafargeHolcim, Buzzi Unicem, CRH, CEMEX) and a larger number of SMEs (like Seibel und Söhne, Miebach, Märker, Spenner, Rohrdorfer, etc.). In 2014, a total volume of 32.1 Mtonnes cement and 23.9 Mtonnes clinker were produced; roughly 20% of which was exported. 55 plants were operational in 2014 – 21 were cement grinding plants and 34 were fully integrated. A total of 52 kilns were in production.

Current substitution rate in Germany by waste-derived alternative fuels is very high, reaching 62% substitution in 2012 and the potential to grow to a level of 80% by 2020:

- Heavy investments have been made over the years: in permits, installations and abatement technology (emissions reduction and monitoring).

Both government and society, see co-processing in a neutral and sometimes critical manner:

- The federal government is appreciative of reduced greenhouse gas emissions as a result;
- Society is willing to pay for waste processing and sustainable solutions.

A waste industry with advanced waste processing plants can supply alternative fuels to a high standard. Most AF originates from the processing of commercial, industrial or 'separated' waste streams (packaging, etc.). In 2005 Germany abolished landfilling of MSW:

- Landfilling of untreated biodegradable matter and of municipal solid waste containing organics ceased on 1 June 2005;
- Today, MSW is mainly treated in MBTs or sorting plants; providing feedstock for further energy recovery in WtE plants or other plants undertaking energy recovery (like the cement industry) or the materials produced are recycled for reuse;
- Alternatively, MSW is brought to incinerators for end disposal.

German policy execution has led to a waste sector with a high level of recycling, no landfilling (of MSW), and many options for energy recovery or incineration:

- Almost 57% of municipal waste and 58% of production waste is recycled;
- The remainder is incinerated or used in energy recovery (like co-processing);
- There already seems to be an excess capacity in "Waste to Energy" and incineration, which led to waste being imported for both incinerators and "Waste to Energy" plants.

But, Incinerators and "Waste to Energy" plants are excluded from the EU-ETS, unlike cement plants, this is seen as a future disadvantage for the cement industry, due to expected shortages of emission rights. Biomass to Power and Biomass to Heat is privileged under the Renewable Energy Act (EEG) and Renewable Heating Act (EEWärmeG), which puts the cement industry at a disadvantage for using waste biomass based alternative fuels (sewage sludge, waste wood, etc.).