MASTER’S THESIS

UTILIZATION OF REFUSE DERIVED FUEL
IN CEMENT INDUSTRY - A CASE STUDY IN CHINA

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Abstract
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Cement industry is energy intensive. Global cement production, requiring significant amounts of energy and materials, is responsible for 5% of global CO$_2$ emissions. On the other hand, municipal solid waste (MSW) generation is greatly increasing globally and causing environmental burden. Using RDF as an alternative fuel in cement kilns saves fossil fuels such as coal and petroleum coke and reduces GHG emissions. The fly ash and bottom ash from incineration of RDF can be used as alternative raw materials for cement production.

China has some policies to promote and regulate co-processing of MSW in cement kilns. “Notice on carrying out the pilot work of co-processing of MSW in cement kilns” (Joint section of Industry and Information Office No. 28, 2015) aims to develop available technologies through study on six pilot projects in China before co-processing of MSW in cement kilns is promoted in the whole country. Later Guizhou province was selected as the pilot province for co-processing of MSW in cement kilns and eight projects in Guizhou were chosen to be pilot projects. In “Technical policy for pollution control on co-processing of solid waste in cement kilns” (Ministry of Environmental Protection, Notice No. 72, 2016),
co-processing of MSW is seen as an important supplementary technology for incineration and landfill.

In China, Conch, Jinyu and Huaxin are primary leading companies in co-processing of MSW in cement kilns. Conch’s technology treats shredded MSW in gasification furnace and transports flammable gases from the furnace to the cement kiln for further incineration. Huaxin produces RDF in pretreatment plants and uses RDF in cement kilns. Jinyu uses RDF for direct incineration in cement kilns or gasifies RDF and uses gases in cement kilns according to its heating value.

A case study is done in a Huaxin’s cement plant which has a RDF plant. The example plant uses 45 000 tonnes of RDF and 50 000 tonnes of coal per year. 46 144 tonnes of CO\textsubscript{2}eq emissions are reduced per year in the example plant. If all cement plants in China use RDF and the share of heat provided by RDF is similar to that in the example plant, 307 million tonnes of MSW per year would be directed from landfills to RDF production and 138 million tonnes of RDF would be used in cement kilns. Annual reduction of GHG emissions would be 142 million tonnes CO\textsubscript{2}eq.
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List of Abbreviations and Symbols

RDF  
Refuse Derived Fuel

WEEE  
Waste Electrical and Electronic Equipment

MSW  
Municipal Solid Waste

GHGs  
Greenhouse gases
1 INTRODUCTION

We are facing challenge of managing a large amount of MSW. It is expected that annual worldwide MSW will increase to 2.2 billion tonnes by 2025 (Daniel and Perinaz, 2012). The environment impact of such a large amount of MSW is significant. Landfill has been the most available disposal method. Landfill requires large area of land and may cause pollution of groundwater and surface water. Landfilled waste generates direct emission of greenhouse gases (mainly dispersive release of methane), up to 1 000 kg CO$_2$eq/t dump waste, 300 kg CO$_2$eq/t for conventional landfill of mixed waste, 70 kg CO$_2$eq /t for low-organic-carbon landfilled waste (Manfredi et al., 2009).

Cement production consumes lots of energy and raw materials. Cement manufacturing process requires high temperature thus it consumes considerable energy. It consumes 3 000-6 500 MJ heat energy to produce one tonne of clinker (depending on fuel types and fuel quality, and production technologies). The heat consumption is 3 530 MJ/t clinker in 2012, 3 510 MJ/t clinker in 2013 and 3 510 MJ/t clinker in 2014 on average worldwide (CSI, 2017). On average, fuels represent 30% - 40% of the total cost of cement production. Most cement kilns use coal and oil coke as main fuels (WBCSD, 2005). It is estimated that 5% - 7% anthropogenic carbon dioxide emissions which cause global warming are from cement industry (Chen et al., 2010).

One of the biggest environmental challenges that our world is facing is global warming. The planet is already suffering from effects of global warming. Rising temperature has impacted many species. For instance, researcher Bill Fraser noticed and recorded that the numbers of Adélie penguins on Antarctica had decreased from 32 000 breeding pairs to 11 000 in 30 years. Some foxes, alpine plants and butterflies have moved to further north, higher or cooler areas. Some invasive species are thriving. Precipitation (rain and snowfall) has increased globally on average. Global sea level has been rising more rapidly over the past century. (National Geographic, 2017) To fight with global
warming, we must reduce GHG emissions. The EU 2020 Climate & Energy Package sets the target to reduce the GHG emissions to the level that is 20% lower than the 1990s (Climate action, 2017).

Use of RDF in cement kilns reduces landfilled waste and environmental impacts related to landfill, saves fossil fuels and decreases GHG emissions. Replacing fossil fuels (lignite and hard coal, petroleum coke and heating oil, etc) with RDF in cement manufacturing contributes to reduction of GHG emissions, because methane emissions from landfills are reduced and part of RDF is renewable fuel.

The potential of use of RDF in cement industry in China is considerable because the cement industry in China is the largest in the world. The cement used in China 2011-2014 are more than those used by USA for 100 years. 2.49 billion tonnes of cement was produced in 2014 and 2.36 billion tonnes of cement was produced in 2015 in China (National Data, 2017).

This thesis analyzes production of RDF and collects information about the situation of use of RDF in cement industry in China. Policy is a very important factor related to co-processing of MSW in cement kilns so policies in China are introduced. The aim is to evaluate the status of use of RDF in the cement kiln in China and estimate the potential of use of RDF in cement production in China.
2 USE OF REFUSE DERIVED FUEL IN CEMENT INDUSTRY

This chapter discusses cement manufacturing process, production technologies of RDF and the approach how RDF is utilized in cement production.

2.1 Cement Manufacturing Process

Cement manufacturing process includes raw materials mining, crushing, prehomogenization, grinding, preheating, calcination, cooling, storage, mixing with additives and cement grinding. Raw materials such as limestone and clay are mined, transported, crushed. Prehomogenization makes raw materials a more homogeneous mixture for grinding. There are four steps after grinding. Firstly, rawmix is preheated. Secondly, fine grinding makes rawmix very fine power (maximum 100 micrometers) which is known as raw meal. Thirdly, raw meal is heated with the temperature up to 1500 degrees Celsius before it is suddenly cooled by bursts of air. Raw meal is fed into kiln tail and clinker comes out from kiln head. Supplementary materials such as fly ash, sand or ironstone are used to achieve desired composition of clinker. (Understanding-cement, 2017) At last, additions such as gypsum is added to control how cement is set. A cement production line is illustrated in Figure 1. The shares of components are given in Table 1.

Table 1. Main compositions of clinker and their shares (Ghosh, S. N. (Ed.), 2014).

<table>
<thead>
<tr>
<th>Composition</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>63-67</td>
</tr>
<tr>
<td>SiO₂</td>
<td>21-24</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>4-7</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2-4</td>
</tr>
</tbody>
</table>
CO₂ is generated in cement production directly or indirectly. Limestone, which is primarily composed of calcium carbonate breaks down into calcium oxide (lime) and carbon dioxide during a chemical process called calcination when it is heated. Calcination produces CO₂ directly in cement kilns where raw materials are heated. It accounts for around 50% of all CO₂ emissions from cement production. Indirect CO₂ emission from cement manufacturing is partially caused by combusting fossil fuels such as coal, natural gas, oil or petroleum coke. This accounts for around 40% of all CO₂ emissions from cement manufacturing. Electricity used to power machines in cement plants is another indirect source of CO₂ emission from cement manufacturing. (State of the plant, 2012)

2.2 Production of Refuse Derived Fuel
RDF is high calorific fractions from waste. It can be produced from almost all solid waste from households, forests, agriculture and industry. For example, RDF can be produced from waste oil, scrap tires, food byproducts (fats, animal meal, etc.), used solvents and viscose plant offgas, waste wood, sewage sludge, high calorific fractions from mechanical–biological treatment (MBT) and/or plants mechanical–physical treatment (MPT), shredder lightweight fractions (e.g., from used old vehicles, electrical and electronic equipment (WEEE)), calorific fractions of household and commercial waste, (Sarc and Lorber, 2013), residues from waste recycling (Hasan and Hassan, 2015), MSW reject fractions (Gallardo et al., 2014), waste plastics, textiles, wood (Punin et al., 2014) among others. RDF can be processed to pellets or in a fluffy form as Figure 2 shows.

![RDF in pellet form and in fluffy form. (Itrimpiani, 2017)](image)

RDF can be used as an alternative fuel in cement production to substitute partly fossil fuels in cement production. Alternative fuels include solid fuels and liquid fuels. Solid alternative fuels include sludge (municipal sludge, papermaking sludge), bone card-
board, paper, wood, tires, meal and animal fat, meat, plastics, dipped sawdust, distillation residue, petroleum coke of refining, RDF; shale, oil shale, packaging waste, agriculture and organic waste. Liquid alternative fuels consist of waste oil and water containing oil, solvent, dangerous liquid fuels and others. (WBCSD, 2005)

2.2.1 Description of RDF production steps

(1) Primary shredding
Primary shredding reduces the particle size of waste. Besides, primary shredding is used for homogenizing waste and handling large and hard waste. It is also used to open the closed plastic bags in the input waste stream. (Nasrulla, 2015) Figure 3 shows Untha XR2000/3000 as an example of waste shredder (Untha, 2017).

![Figure 3. Untha XR2000/3000 waste shredder (Untha, 2017).](image)

In a specific type of shredder (M&S 4000 by Metso), the shapes (illustrated in in Figure 4) and the movement of knives are specially designed. Two sets of knives move in
different directions with equal speed and torch. The knives run at variable speed and shred asynchronously in both directions. The open knife table enables metals and stones to fall and not to cause wear. (Metso, 2017)

(2) Screening
Screening is to separate waste into different size categories. The components with particle size $D_{95} < 15$ mm are separated out. Those components with the size over 300 mm are separated out to be shredded again. The waste components with the size between $D_{95}15$ mm and $D_{95}300$ mm are treated by further steps (Nasrullah, 2015). After primary shredding, waste is processed with screening. The separation rate by screening for different waste fractions are listed in Table 2 (Havukainen, J., 2016). Separation rate means the share of a waste fraction removed from the waste stream. For example, 48% of food waste is removed from the waste stream so the separation rate for food waste is 48%.
Table 2. Separation rate by screening for different waste fractions (Havukainen, J., 2016).

<table>
<thead>
<tr>
<th>Waste fraction</th>
<th>Separation rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food waste</td>
<td>48 %</td>
</tr>
<tr>
<td>Paper</td>
<td>3 %</td>
</tr>
<tr>
<td>Plastic</td>
<td>7 %</td>
</tr>
<tr>
<td>Textile</td>
<td>4 %</td>
</tr>
<tr>
<td>Wood and bamboo</td>
<td>7 %</td>
</tr>
<tr>
<td>Metal</td>
<td>8 %</td>
</tr>
<tr>
<td>Glass</td>
<td>83 %</td>
</tr>
<tr>
<td>Mixed</td>
<td>12 %</td>
</tr>
</tbody>
</table>

In screening, the separation rate for glass is the highest (83%) and that for paper is the lowest (only 3%). The separation rates by screening for textile, plastic, wood and bamboo, metal are low, most of them are under 10%.

(3) Air classification

Light weight/density waste fractions (i.e. plastics, paper and cardboard, textile, foam, etc.) are separated out by an air classifier (also called air separator, wind sifter and wind shifter). The advantage of this installation is that it guarantees high separation efficiency (up to 90-95%) for lighter fractions. An air separator is illustrated in Figure 5.

Figure 5. Air separator (N. W. Hilig, 2017)
The components of an air separator are illustrated in Figure 6.


![Figure 6. Air separator. (Walair, 2017)](image)

The waste is transported by the high-speed conveyor, then is processed by the air separator. Heavy waste passes short chute then it is transported to the conveyor. The other waste goes to the material separator that is connected to the fan separator. The rotary valve transports waste to a conveyor in a pressureless way. To meet specific installation requirements and to adapt to characteristics of waste, the equipment can be adjusted from following aspects: the declining angle and the speed of the conveyor belt; and the amount and speed of air (N. W. Hilig, 2017).

(4) Magnetic separation and Eddy current separation
Magnetic separators recover most of the metals from a waste stream. There is a magnetic rotor at one end of a rapidly rotating conveyor belt. The magnetic rotor generates
a magnetic field. Non-ferrous metals will be thrown forward from the belt into a product bin by the magnetic field when they reach the vicinity of the magnetic field and move to the outside of the separator while inert materials fall into another container by gravity. (Myer Kutz, 2007)

(5) Near-infrared sorting
Near-infrared scanner inspects the input waste stream. The nozzle at one end of the conveyor uses air to separate desired waste components into RDF stream. Near-infrared sorting can be used for recycling i.e. plastics from household waste. Polymers account for 80-95% of output of a near-infrared sorter (WRAP, 2010). The characteristics of the input waste stream greatly influence the effectiveness of near-infrared sorting. The structure of a near-infrared separator is illustrated in Figure 7.

![Near-infrared sorting system](image)

Figure 7. Near-infrared sorting system. (Global Environment Centre Foundation, 2011)

(6) Secondary shredding
Secondary shredding is a very important step to reduce the particle size of the waste stream treated after primary shredding, screening, magnetic separation, air classification and near-infrared separation. The equipment and principles for secondary shredding are similar to that for primary shredding. Processing waste to smaller size contributes to more homogeneous waste and to ensure steady heat supply.
(7) Drying

① Bio-drying

Within bio-reactor, excess aeration and the heat released from aerobic digestion process of readily biodegradable waste are used to dry waste. Molecular diffusion and air convection are the main mechanisms for the loss of moisture. It needs to be noticed that the air convection is induced by the engineered airflow through the matrix. The air brings the water evaporated from the surface of matrix particles. The process of bio-drying is illustrated in Figure 8. (Velis, C. A., et al, 2009)

![Figure 8. A process with biodrying box (Velis, C. A., et al, 2009).](image)

Aerobic digestion happens in an enclosed box (1). Air (2) is forced through the waste in a box (1). The waste is dried by the air (2) and the heat generated from aerobic digestion of readily decomposable waste fractions. A leachate collector (3) collects leachate for further treatment. A forced aeration system (4) is used for mixing ambient air and conditioned process air. The biodrying system also include a heat exchanger (5), a cooling tower (6), a vapour condensate (7) and an excess air treatment device (8). (Velis, C. A., et al, 2009)
2. Evaporative drying

Saturated RDF is fed into a pre-mixing and pre-heating hopper to initiate evaporative drying. RDF to be dried is delivered onto the moving drying bed on which RDF flows in a PulseWave motion for mixing and converting material for a consistently dry and uniform output. A flux of warm and dry air flows from an air control module up through ventilated moving drying bed directly into RDF for achieving desired moisture content. (Stronga, 2015)

(8) Odor treatment

Odor generates in RDF production plants in the mechanical treatment and the biodrying. It happened in China that some residents who were influenced by odor from a near RDF plant required to remove the RDF plant because they thought waste gas was emitted to the environment and would cause cancer and other diseases to them. Because residents in the neighbor of a RDF plant will be impacted by the odor, it must be well controlled.

2.2.2 Description of RDF production process

The whole RDF production line is described in this subchapter. RDF production is accomplished through successive treatment stages of shredding, screening, size reduction, separation, classification, drying and densification among others. (Caputo et al., 2001) Shredding reduces the particle size of waste. Magnetic separation separates ferrous metals from the main waste stream. Eddy current separation comes after magnetic separation, it separates non-ferrous metals from the waste stream after magnetic separation. Air separation separates lighter fractions such as paper, plastic bags and heavier fractions. Secondary shredding makes waste more homogeneous and finer. An example of waste refining process (for RDF production) by BMH is illustrated in Figure 9.
Drying is used for waste with high moisture content. Bio-drying (biological treatment) or evaporative drying (using warm air for drying) may be used as the drying method. In Huaxin’s plants, drying follows shredding. The RDF production line of Huaxin is illustrated in Figure 10. MSW is firstly weighed up and detected for radioactivity and then it is pre-shredded. Shredded waste is dried and stabilized by drying. The waste is transported to a biological fermentation tank for aerobic digestion. Air is forced to matrix of waste in the fermentation tank for faster growth of microorganisms. Biodegradable materials in waste are decomposed into small molecules. Waste are dried by aeration and heat generated in aerobic digestion. After treatment for 10 to 20 days, most of moisture are removed from waste. The moisture content of waste declines to 10% - 30%. Mechanical treatment system is used to treat dried waste and divide them into inert materials, combustible materials, ferrous metal, non-ferrous metal, harmful materials. Selected combustible materials are shredded to smaller size. Leachate, waste gas and waste water from fermentation tank are treated separately.
2.3 Literature Review on Utilization of RDF in the Cement Kiln

Fuels from waste have been used in many countries for over 20 years. It is suitable for cement manufacturing. For example, in Poland, alternative fuel has been used in cement manufacturing since the early 1990s. The cement plant owned by Lafarge in Kujawy was the first cement plant utilizing alternative fuels in Poland in the 1990s. It uses alternative fuels from waste. (Mokrzycki et al., 2003; Puertas and Bulanco-Varela, 2004)

Table 3 is used to compare the LHV of RDF with conventional fuels.

<table>
<thead>
<tr>
<th>Type of fuel</th>
<th>LHV (MJ/tOS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional fuels</strong></td>
<td></td>
</tr>
<tr>
<td>Lignite and hard coal</td>
<td>29 400</td>
</tr>
<tr>
<td>Petroleum coke</td>
<td>30 760</td>
</tr>
<tr>
<td>Heating oil</td>
<td>41 700</td>
</tr>
<tr>
<td><strong>Refuse Derived Fuel</strong></td>
<td></td>
</tr>
<tr>
<td>Scrap tyres</td>
<td>28 630</td>
</tr>
<tr>
<td>Animal fat&amp; bone meal</td>
<td>18 000</td>
</tr>
<tr>
<td>Used solvent</td>
<td>22 480</td>
</tr>
<tr>
<td>Waste oil</td>
<td>34 760</td>
</tr>
<tr>
<td>SRF</td>
<td>18 000–23 000</td>
</tr>
<tr>
<td>MSW</td>
<td>6 900 – 7 740*</td>
</tr>
</tbody>
</table>
*: The data is from questionnaire with a cement plant with RDF production line.

Since the early 1990s, China has been engaged in research work on co-processing of solid waste in the cement kiln. Wanan, Conch, Jinyu and some other cement companies have carried out a large number of studies of co-processing of solid waste in the cement kiln. Now landfill and incineration are still the dominant methods for MSW management in China. During “12th five-year plan (2011-2015)” the number of waste incineration power plants grew very rapidly because of various policy incentives and financial support in China. The share of MSW used in cement kilns is small in total MSW. There are less targeted policies to increase use of MSW in cement kilns than that for waste-to-energy plants. It is used as a supplementary technology to incineration and landfill so its development is relatively slow. At the end of 2015, the number of waste incineration facilities reached 224 in China. The total MSW treatment capacity of incineration is 207 800 t/d. Meanwhile, the number of cement production lines that co-process MSW is only 11 in China by the end of 2015, with much less MSW treatment capacity than incineration facilities. (He. J., et al, 2016)

Five types of cement kiln co-processing technologies represented by Conch, Huaxin, Sinoma, Jinyu and China Resources have been formed in recent years. The technologies have shown their respective advantages in specific projects. Technologies include pre-gasification before entering the kiln, pre-burning before entering the kiln, pre-fermentation before entering the kiln and combusting RDF in the kiln. They have been used in pilot projects already. (Snsqw, 2015) As the development experience of co-processing in cement kilns worldwide shows, combusting RDF in the kiln is expected to be the mainstream technology of co-processing of MSW in cement kilns in China.

2.4 Advantages of Use of RDF in the Cement Kiln and Restraints on It
Using RDF as alternative fuels can save fossil fuels and using combusted material as alternative raw materials can save raw materials in cement production. Bottom ash and fly ash from MSW incineration contain CaO, SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ which are part of raw materials of ordinary Portland cement. Besides saving fuels and raw materials, it reduces CO$_2$ emissions. CO$_2$ emission factor of RDF is lower than fossil fuels because of renewable carbon. Co-processing of MSW in cement kilns reduces the amount of landfilled waste and avoids problems that are caused by landfill. Building landfill sites need large areas of land, and landfill leachate may pollute soil and underground water. Release of the methane generated in landfills contributes to global warming.

Substituting fossil fuels (coal, petroleum coke, etc) with RDF contributes to conserving non-renewable resources, which is very important for energy security. By the end of 2016, it is verified that the reserves of oil in the world is around 1.7 trillion barrels, which will meet the demands for approximately 50 years of global production. The proved reserves of natural gas in the world are around 190 trillion m$^3$ at end of 2016, which will meet the demands of global production for 53 years. The proved reserves of coal in the world are around 1100 billion tonnes, which will meet the demands of global production for 150 years.

The high chlorides in MSW restrains the utilization of RDF in cement manufacturing because the chlorides in ash may cause serious corrosion in cement kilns. Therefore, the chlorides in cement kiln must be controlled. Using organic acid to wash MSW incineration fly ash and bottom ash could reduce the chlorides in them by over 90%. Because the limit required by cement plants for chloride content is 100 ppm in raw meal, the maximum amounts of acid-washed MSW incineration bottom ash and fly ash that can be added to substitute clay component of raw materials are 3.5% and 1.75%, respectively. Addition of the bottom ash or the fly ash from MSW incineration does not have effect on the quality of clinker but the setting time of the cement which becomes
longer. (Pan, J. R., et al, 2008) If all MSW is processed into RDF, the chloride content in RDF can be high because the chlorides are not separated out. To use higher share of RDF, the waste must be selected so that it has low chloride content. (SciCem, 2017)

Profit is another issue that must be discussed in co-processing of MSW in cement kilns. There are some examples helping us to get to know this issue. China Cement Network special commentator Gao Changming once estimated costs and benefits for a cement kiln co-processing MSW. He found that government subsidies make co-processing of MSW in cement kilns economically feasible, but many local governments don’t have resources to give enough subsidies to enterprises. Yang Hongbin (the manager of Huaxin Environmental Engineering Company) said the income of Huaxin Environmental Engineering Company which produces RDF from MSW was divided into two parts: government subsidies and the benefits of selling RDF to cement plants. The direct sale of RDF produced by Huaxin Environmental Engineering Company to Huaxin's own cement plants is a forced rebalancing of economic benefits and costs within the group. Whether an enterprise co-processing MSW can run in a good state is directly related to the level and way of subsidies from the local government. If the local government cannot give a reasonable subsidy policy, the enterprise runs more difficultly.

According to the current subsidy policy, the subsidies for co-processing of MSW in cement kiln can be €7.7 - 10.3 (60 - 80 yuan) per tonne. There are no electricity subsidies for co-processing in cement kilns. And the government subsidies for operation costs of co-processing MSW in cement kilns are often lower than that for waste incineration for power generation. The average costs of co-processing of MSW in cement kilns is around €16.7 – 19.3 (130-150 yuan) per tonne, so subsidies are not enough for covering the costs. It is difficult for companies co-processing MSW in cement kilns to achieve break even. They are running at a loss most of the time and it is not good for
development of co-processing MSW in cement kilns. Therefore, the amount of subsidies used to promote the comprehensive utilization of co-processing MSW in cement kilns will be an important factor. It is unlikely that cement kilns co-processing MSW obtains as many subsidies as MSW incineration plants in the future. Because there are many ways to treat waste, it is impossible to give the same amount of subsidies to each way. To solve the problem that producing RDF from MSW is not profitable, some experts suggest that Chinese government should increase policy supports, improve incentive mechanisms, give preferential tilt in tax, electricity, land among others.

The positioning of co-processing of MSW in cement kilns should be accurate and clear. Liu Haiwei, the chief expert of waste-to-energy at Enfei Engineering Co., Ltd., said that cement production and waste treatment belong to different fields with different purposes. It is very clear that the basic principles of co-processing of MSW in cement kilns are to ensure the quality of cement products and to meet the environmental requirements of waste treatment. Co-processing of MSW cannot decrease cement quality or cause environmental burden. The primary purpose of waste treatment is to ensure that waste is treated in a safe and reliable way. Waste treatment facilities as infrastructure are required to be operated safely and reliably every day. The main purpose of cement plants is producing cement. Sales of its product is greatly influenced by the market, the season and other factors. It is difficult to ensure cement kilns treating waste continuously and stably all year around. (Cenews, 2017)

When it comes to the relationship between cement kiln co-processing and local waste incineration power plants and landfill sites, Yang Hongbin said, in some small and medium cities, the total amount of MSW produced every day is not large, there will be a more obvious contradiction between different waste treatment approaches. In some small cities, the amount of MSW cannot meet the minimum requirement of a waste incineration plant. Using RDF in cement kilns is suitable for waste treatment in those
small cities. In large cities which generate large amount of MSW, landfill, waste incineration and co-processing can be used together to exert their respective advantages and achieve complete and harmless treatment of MSW. For example, when the power generation facilities are regularly overhauled, the RDF pretreatment plant can temporarily increase processing capacity in that period. (Sohuª, 2017)

As a representative of people who going against co-processing MSW in cement kilns, Xu Haiyun, the chief of China Urban Construction Research Institute, worried about some people had the idea of burning waste in cement kilns to avoid them to be shut down under the background of overcapacity in the cement industry. He said that more than 10 years ago, the government planned to shut down many small thermal power plants and the managers of some small thermal power plants launched the idea of burning waste as part of fuel for power generation to avoid the power plants being shut down. Today it seems that the cities trying the idea are bearing the consequences, and some of these waste incineration power plants had to be reconstructed.

2.5 Chinese Cement Companies with Cement Kilns Co-processing Technologies

The projects of co-processing of MSW of leading companies are introduced and the characteristics of their technologies are discussed in this subchapter. Conch, Jinyu, Huaxin, China Resources and other cement producers built and developed cement kiln co-processing technologies in China (Sohuª, 2016). The Conch’s project of co-processing MSW in cement kiln in Zunyi City, Guizhou Province is primarily completed in 2015. When it is completed it is expected to treat 280 000 t/a of MSW, two-thirds of MSW in central districts of Zunyi city. It will save around 17 000 tonnes of coal annually. (Conchventureª, 2015) The Conch’s project of co-processing of MSW at Pingliang cement plant is its third demonstration project in China and the first in the Northwest
region of China. The cement plant can treat 100,000 tonnes of MSW and save 13,000 tonnes of standard coal per year (it is defined that the LHV of standard coal is 29.3 MJ/kg (7,000 kcal/kg) in China). (Conchventure\(^b\), 2014) At present, Huaxin is developing projects of co-processing MSW in cement plants in Hubei province, Hunan province and Sichuan province. The Huaxin’s project of co-processing MSW in Wuxue City, Hubei province was completed at the end of 2010. The cement plant can handle 100,000 tonnes of MSW per year, saving more than 20,000 tonnes of standard coal. (D cement, 2010) The MSW treatment capacity and the amount of coal saved in the three projects are in Table 4.

### Table 4. The MSW treatment capacity and the amount of coal saved in three projects.

<table>
<thead>
<tr>
<th>Project</th>
<th>Conch (Zunyi City)</th>
<th>Conch (Pingliang City)</th>
<th>Huaxin (Wuxue City)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSW</td>
<td>280,000 t/a</td>
<td>100,000 t/a</td>
<td>100,000 t/a</td>
</tr>
<tr>
<td>Coal savings</td>
<td>17,000 t/a</td>
<td>13,000 t/a</td>
<td>Appx. 20,000 t/a</td>
</tr>
<tr>
<td>Ratio (coal/MSW)</td>
<td>0.06</td>
<td>0.13</td>
<td>0.2</td>
</tr>
</tbody>
</table>

#### 2.5.1 Conch

Conch had conducted field research to the domestic and international waste treatment technologies since 2007 and developed the technology of MSW co-processing in dry cement kilns in 2010 (referred to as “CKK system”). CKK system include some sub-systems: pre-treatment and feeding system, waste gasification system, ash processing system, waste water treatment system, chlorine removal system, etc. Main equipment of CKK system is waste grab crane, shredder, gasifier, hot-blast stove, magnetic separator, dilution cooler, gas cooler, etc. Waste is collected by the waste vehicle and transported to the garbage pit. Then it is stirred to be more homogeneous. After shredding, the waste is fed into the waste feeding system and transported to the gasification furnace. The waste is in full contact with the high temperature fluidized sand in the furnace where some waste is combusted to provide heat to the flow medium. The other waste
is gasified to produce flammable gases which are sent to the cement kiln for further incineration. The harmful substances in the gas are decomposed by the decomposition furnace. The decomposed products are absorbed and solidified by alkaline materials in the cement kiln. The remaining exhaust gas is cleaned by the exhaust gas cleaning system before it is discharged. The incombustible fractions in waste settle down in the flow medium and are discharged when they reach the bottom of the furnace. Metal is separated from the discharged slag, and the remaining bulk materials are used as alternative raw materials for cement manufacturing. Waste water in the garbage pit is collected and treated by water filtration system. Then it enters the upper part of the gasification furnace and the cement kiln decomposing furnace for oxidative decomposition.

2.5.2 Jinyu

Jinyu's technology of MSW co-processing in cement kilns treats waste according to its quality. The technology combines gasification of RDF and direct incineration of RDF. RDF may be combusted in the cement kiln directly, or gasified and combusted in the cement kiln depending on the quality of it. Pretreatment of MSW produces RDF with higher calorific value and RDF with lower calorific value for different uses. RDF with higher calorific value is directly fed into the cement kiln. RDF with lower calorific value is treated in a vertical rotary gasifier for pyrolysis, gasification and incineration. High temperature gases are introduced into the cement kiln. It achieves the goal of saving coals, increasing the share of MSW treated by co-processing in cement kilns, and reducing nitrogen oxides emissions.

(1) Technical characteristics

(a) Strong adaptability to raw materials. The gasification incinerator is suitable for MSW with a calorific value 1 000 kcal/kg ~ 1 850 kcal/kg (4.2 MJ/kg – 7.7 MJ/kg), moisture content <50%, ash content <30%, the largest particle size <200 × 200 × 200 mm. RDF can be directly combusted in the cement kiln with a calorific value
≥ 2500 kcal/kg (10.5 MJ/kg), moisture content <30%, the largest particle size <50mm × 50mm × 50 mm.

(b) The impact on operation of the cement kilns is small. RDF with a lower calorific value is gasified and incinerated. The hot flue gas in gasifier and incinerator is introduced into cement kilns. It greatly reduces the impact of moisture, particle size, ash of RDF with a lower calorific value on incineration of it in cement kilns.

(c) Energy conservation and reduction in GHG emissions are achieved. Coal and ammonia are saved because gases burn more intensely than solids and the concentration of nitrogen oxides in cement kiln is reduced.

(d) Project model is flexible. Existing waste treatment facilities can be utilized, or new pretreatment facilities can be built.

(2) Main technical equipment

Pretreatment system mainly includes a shredder, a biological drying facility, a magnetic separator and an air separator. Cement kiln co-processing system mainly includes a bridge crane, a waste feeding silo, a speed belt scale among others.

2.5.3 Huaxin

Huaxin introduced the waste treatment technology of Holcim Group and developed integrated solutions of RDF pretreatment and combustion of RDF in cement kilns which are suitable for the characteristics of MSW, municipal sludge and industrial hazardous
waste in China. In an enclosed waste pre-treatment plant, MSW is shredded, dried and high heating value compositions are mechanically sorted out as RDF which is used as an alternative fuel and alternative raw materials for cement manufacturing. The heat released from combustion of RDF is directly used for calcination. The waste-derived raw materials are used to replace part of raw materials for cement production or raw materials for the adjustment of the proportion of cement constituents. The technology achieves “reduction, harmless, resource” treatment of MSW. “Reduction, harmless, resource” is popular slogan for waste treatment in China. “Reduction” means reduction of landfilled waste. “Harmless” means treating waste with less environmental impact. “Resource” means using waste for energy and material recovery. Huaxin’s technologies of MSW co-processing in cement kilns have some advantages.

(1) Technical process and equipment

There are several systems in the process of RDF pretreatment and co-processing of MSW in cement kilns, including receiving and primary shredding, drying, sorting and secondary shredding, deodorization, leachate treatment and treatment of RDF in kilns. MSW is processed and divided into five categories: RDF, inorganic inert materials, leachate, odor and metal. (Sohu\textsuperscript{b}, 2016)

Combusting RDF in the cement kiln is the most widely used system for co-processing of MSW in cement kilns. RDF is transported and weighted by measuring devices. After that it is fed into the decomposition furnace of the new dry cement kiln, replacing part of the coal. Inorganic dross (components similar to limestone, clay) is used as a raw material for production of cement. Huaxin’s technologies effectively reduce the formation of toxic and harmful substances such as dioxins / furans. The emission parameter (0.02ng-TEQ/Nm\textsuperscript{3}) in Huaxin is lower than the limit in China standards and EU standards (0.1ng-TEQ/Nm\textsuperscript{3}). (Sohu\textsuperscript{b}, 2016)
(2) Technical characteristics

Huaxin’s technologies of co-processing MSW in cement kilns can successfully deal with several issues (odor, leachate, waste residues, dioxins, furans and GHG emissions) in MSW treatment, and ultimately achieve the utilization of MSW. (Sohu\textsuperscript{b}, 2016)

Odor origins mainly from decomposition of organic matter in waste. The pretreatment process is in enclosed space with negative pressure, the odor produced in drying is treated by biological treatment system and released to atmosphere. The entire waste pretreatment process produces a small amount of leachate. The leachate is treated by the leachate treatment system and emitted meeting emission standards. Or leachate is discharged directly into the rotary kiln for incineration. The soil slag collected from MSW can be used as alternative raw materials for cement production. Metals are recycled by the recycling station. MSW is treated by drying and sorting among others. The combustibles in RDF are incinerated in the cement kiln with high temperature. Because of the strong convection, the vortex flows, the strong alkaline and the reducing atmosphere in the cement kiln, all toxic and harmful substances are completely decomposed, and dioxins/furans are not produced. The unique quenching and feeding method of the cement kiln can effectively suppress the formation of dioxins/furans from the organic fragments decomposed from MSW. The trace elements e.g. heavy metals in MSW are solidified in the crystal lattice of the cement clinker in the form of solid compounds in high-temperature incineration, which will not have impact on cement quality and ecological environment (Huaxin\textsuperscript{b}, 2013; Sohu\textsuperscript{b}, 2016).

2.6 Policies Related to Co-processing of Solid Waste in the Cement Kiln in China
“Notice on carrying out the pilot work of co-processing of MSW in cement kilns” (Joint section of Industry and Information Office No. 28, 2015) was jointly issued by Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development, National Development and Reform Commission, Ministry of Science and Technology, Ministry of Finance, Ministry of Environmental Protection in April 2015 (MLr, 2015).

Table 5. The first batch of cement kilns co-processing MSW pilot enterprises (He. J., et al, 2016).

<table>
<thead>
<tr>
<th>No.</th>
<th>Region</th>
<th>Name of MSW pretreatment company</th>
<th>Name of cement company</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anhui province</td>
<td>Anhui Tongling Conch Cement Co., Ltd</td>
<td>Anhui Tongling Conch Cement Co., Ltd</td>
</tr>
<tr>
<td>2</td>
<td>Guizhou province</td>
<td>Guiding Conch Panjiang Cement Co., Ltd</td>
<td>Guiding Conch Panjiang Cement Co., Ltd</td>
</tr>
<tr>
<td>3</td>
<td>Zunyi Xinhuan Waste Treatment Co., Ltd/Zunyi Sancha Lafarge Ruian Cement Co., Ltd</td>
<td>Zunyi Sancha Lafarge Ruian Cement Co., Ltd</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Hubei province</td>
<td>Huaxin Environmental Engineering Co., Ltd</td>
<td>Huaxin Cement (Wuxue) Co., Ltd</td>
</tr>
<tr>
<td>5</td>
<td>Hunan province</td>
<td>Huaxin Environmental Engineering (Zhuzhou) Co., Ltd</td>
<td>Huaxin Cement (Zhuzhou) Co., Ltd</td>
</tr>
<tr>
<td>6</td>
<td>Jiangsu province</td>
<td>Liyang SINOMA Environmental Protection Co., Ltd</td>
<td>Liyang Tianshan Cement Co., Ltd</td>
</tr>
</tbody>
</table>

It is expected to study the main issues of the development of cement kiln co-processing of MSW for putting forward the feasible policy advices for it and promoting its orderly development. Some built projects of co-processing of MSW in cement kilns were selected as pilots. Evaluation of their operations were conducted as a basis to scientifically and objectively analyze and solve the problems with technology, equipment, standards, policies and other prominent problems in co-processing of MSW in cement kilns. Analyzing and solving current problems lays the foundation for the “13th five-year plan
(2016-2020)” to scientifically promote co-processing of MSW in cement kilns. (Cement\textsuperscript{a}, 2015) Co-processing of MSW should not be used by some of small-scale cement plants with backward technologies to avoid being phased out. At this stage the existing demonstration projects should be improved to meet relevant standards. The implementation of co-processing of MSW in cement kilns in large scale should not be carried out until the technology and equipment is mature. (Cement\textsuperscript{b}, 2017) The first batch of pilot enterprises co-processing MSW in cement kilns are listed in Table 5.

Projects of co-processing of solid waste in cement kilns got special support for energy conservation and reduction of emissions by the Ministry of Industry and Information Technology (MIIT) and the Ministry of Finance (MOF) of China in 2016. The funds for projects of co-processing of solid waste in the cement kiln are mainly financed by the local government. The funds will be used to establish a long-term mechanism for co-processing of solid waste in the cement kiln and to promote the implementation of key projects to ensure long-term continuous and stable operation.

On 25\textsuperscript{th} May, 2016, MIIT and MOF held expert review meeting in Beijing, China, and ultimately determined Guizhou Province as the first pilot province to promote co-processing MSW in cement kilns. The experts in the meeting evaluated the basic conditions of equipment and facilities of enterprises, reliability of industrial technology and provinces’, municipals’ and counties’ supporting policies and other factors. They preferably chose eight projects (two of them are pilot projects already before Guizhou Province was selected as the pilot province) in Guizhou Province as demonstrative projects. The list of the eight projects is in Table 6.
Table 6. Demonstrative projects of co-processing of MSW in cement kilns in Guizhou Province, China. (Sohu*, 2016)

<table>
<thead>
<tr>
<th>No.</th>
<th>Project</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project of co-processing of MSW in cement kilns in the south of Zunyi City</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>Project of co-processing of MSW in cement kilns in central urban area of Zunyi City (subproject in north)</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>Project of co-processing of MSW in cement kilns (200 tonnes/day)</td>
<td>Taiwan Cement (Anshun) Co., Ltd.</td>
</tr>
<tr>
<td>4</td>
<td>Project of co-processing of MSW in cement kilns in Yuping County</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>Project of co-processing of MSW and sewage sludge in cement kilns</td>
<td>Conch Cement (Panjiang) Co., Ltd. In Guiyang city</td>
</tr>
<tr>
<td>6</td>
<td>Project of co-processing of MSW in cement kilns in Shuicheng County</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>Project of co-processing of MSW in cement kilns in Guiding County</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>Project of co-processing of MSW in cement kilns in Xishui County</td>
<td>N/A</td>
</tr>
</tbody>
</table>

To standardize pollution control on co-processing of solid waste in cement kilns, the Ministry of Environmental Protection officially released “Technical policy for pollution control on co-processing of solid waste in cement kilns” (Ministry of Environmental Protection Notice No. 72, 2016) (Appendix I) on 14th Dec. 2016 (Ccementb, 2017). It is not a law nor local legislation, but a guidance document. It made detailed provisions of co-processing of solid waste in cement kilns. For example, emission control of nitrogen oxides, sulphur dioxide and other pollutants should follow “Technical Policy for pollution control in cement industry” (Ministry of Environmental Protection Notice No. 31, 2013). However, most of waste pre-treatment plants for co-processing of solid waste in cement kilns do not meet the provisions. (H2O-China*, 2016)
3 CASE STUDY: UTILIZATION OF RDF IN AN EXAMPLE CEMENT PLANT

3.1 Aim of the Case Study

One of Huaxin’s cement plants that uses RDF as an alternative fuel is used as the example plant in the case study. The example plant is in Hubei province, China. It is a cement plant with an RDF plant (pre-treatment of MSW). The production capacity is 4 000 t/d clinker and 1 600 000 t/a cement with a dry method production line. The advantages of utilization of RDF in cement kilns are shown by the case study. It shows possibility of saving of fossil fuels and reduction of CO₂ emissions in the example plant. The potential amount of RDF that can be used and potential reduction of GHG emissions in the cement industry of China are also calculated.

3.2 Methodology of the Case Study

The main method of the case study is questionnaire survey. Questionnaires were used to collect information and data of utilization status of RDF from the example plant and its parent company. Collected data was used to make calculations.

3.2.1 Questionnaire surveys

The aim of questionnaire 1 is to find out how the example plant and its parent company use RDF. Questions contained in questionnaire 1 are listed in Table 7. Questionnaire 2 contains questions for more details of the status of RDF utilization in the example plant. Questions contained in questionnaire 2 are listed in Table 8. The answers to questions in questionnaire 1 and questionnaire 2 are presented in Appendix II and Appendix III.
Table 7. The questions in questionnaire 1.

<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>What types of fuels are used in the plant?</td>
</tr>
<tr>
<td>Is RDF used in the plant? (Yes or No).</td>
</tr>
<tr>
<td>If RDF is used, what is the source of the waste?</td>
</tr>
<tr>
<td>If RDF is not used in the plant, do you have interest to use it in the plant?</td>
</tr>
<tr>
<td>What are requirements (heating value, moisture content, particle size, ash content, etc) for RDF if you want to use it in the plant?</td>
</tr>
</tbody>
</table>

Table 8. The questions in questionnaire 2.

<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the yearly heat energy consumption (MWh/year)?</td>
</tr>
<tr>
<td>What is the yearly coal consumption (t/a)?</td>
</tr>
<tr>
<td>What is the LHV of coal (MJ/kg)?</td>
</tr>
<tr>
<td>What is the yearly RDF consumption (t/a)?</td>
</tr>
<tr>
<td>How much waste is used to produce RDF (t/a)?</td>
</tr>
<tr>
<td>What is the quality of the RDF (heating value, moisture content and ash content)?</td>
</tr>
<tr>
<td>How much coal is replaced with the RDF (t/a + %)?</td>
</tr>
<tr>
<td>What is the price of the coal?</td>
</tr>
<tr>
<td>What is the gate fee of MSW (subsidy by government)?</td>
</tr>
<tr>
<td>How much is the cost to invest a RDF plant?</td>
</tr>
<tr>
<td>How much is the cost to produce RDF (government subsidy not included, CNY/t)?</td>
</tr>
<tr>
<td>Where is the waste used to produce the RDF from? What is the contribution to local WM (% of produced MSW)?</td>
</tr>
<tr>
<td>What is the motivation to use RDF?</td>
</tr>
<tr>
<td>Is there disadvantage to use the RDF in the cement production? Please describe it if there is.</td>
</tr>
</tbody>
</table>

3.2.2 Calculation formulas

(1) Reduction of GHG Emissions by Using RDF in the example plant

Equations below are used to calculate reduction of GHG emissions in the example plant which uses RDF as alternative fuel. “In the example plant” means the normal condition where RDF and coal are both used in the example plant unless otherwise stated.

\[ E_{\text{reduction}} = E_{\text{no RDF}} - E_{\text{mix}} \]  \tag{1}

\[ E_{\text{no RDF}} = E_{\text{coal, no RDF}} + E_{\text{landfill, no RDF}} \]  \tag{2}

\[ E_{\text{mix}} = E_{\text{coal, mix}} + E_{\text{RDF, mix}} + E_{\text{landfill, mix}} \]  \tag{3}

\[ E_{\text{coal, no RDF}} = m_{\text{coal, no RDF}} \times E_t \text{coal} \]  \tag{4}

\[ E_{\text{landfill, no RDF}} = m_{\text{MSW}} \times E_{\text{landfill, MSW}} \]  \tag{5}
\[ E_{\text{coal, mix}} = m_{\text{coal, mix}} \times E_{\text{t, coal}} \]  
(6)  
\[ E_{\text{RDF, mix}} = m_{\text{RDF, mix}} \times E_{\text{t, RDF}} \]  
(7)  
\[ E_{\text{landfill, mix}} = m_{\text{MSW-RDF}} \times E_{\text{t, landfill, t MSW}} \]  
(8)  
\[ m_{\text{MSW-RDF}} = m_{\text{MSW}} - m_{\text{RDF, mix}} \]  
(9)  
\[ m_{\text{coal, no RDF}} = \frac{q}{LHV_{\text{coal}}} \]  
(10)  
\[ E_{\text{t, coal}} = E_{\text{coal, MJ}} \times LHV_{\text{coal}} \]  
(11)  
\[ Q = m_{\text{coal, mix}} \times LHV_{\text{coal}} + m_{\text{RDF, mix}} \times LHV_{\text{RDF}} \]  
(12)

Where:

- \( E_{\text{reduction}} \) – GHG emissions reduced in the example plant using RDF (t CO\(_2\)eq/a)
- \( E_{\text{no RDF}} \) – GHG emissions in the example plant if RDF is not used and coal is the only fuel (t CO\(_2\)eq/a)
- \( E_{\text{mix}} \) – GHG emissions in the example plant (t CO\(_2\)eq/a)
- \( E_{\text{coal, no RDF}} \) – GHG emissions from coal in the example plant if RDF is not used and coal is the only fuel (t CO\(_2\)eq/a)
- \( E_{\text{landfill, no RDF}} \) – CH\(_4\) emissions from landfilled waste if they are not processed to RDF and goes to landfill in the example plant (t CO\(_2\)eq/a)
- \( E_{\text{coal, mix}} \) – CO\(_2\) emissions from incineration of coal in the example plant (t CO\(_2\)/a)
- \( E_{\text{RDF, mix}} \) – CO\(_2\) emissions from incineration of RDF in the example plant (t CO\(_2\)/a)
- \( E_{\text{landfill, mix}} \) – the GHG emissions from landfill in the case that RDF is used as an alternative fuel (t CO\(_2\)eq/a). It is assumed that waste goes to landfill if it is not processed into RDF.

- \( m_{\text{coal, no RDF}} \) – the mass of coal used in the example plant if RDF is not used and coal is the only fuel (t/a)
- \( E_{\text{t, coal}} \) – the CO\(_2\) emissions from incineration of one tonne of coal (t CO\(_2\)/t coal)
- \( m_{\text{MSW}} \) – the mass of MSW used for producing RDF used in the example plant (t/a)
- \( E_{\text{landfill, t MSW}} \) - CH\(_4\) emissions from one tonne of MSW if it goes to landfill instead of being used to produce RDF (t CO\(_2\)eq/t MSW)
- \( m_{\text{coal, mix}} \) – the mass of the coal used in the example plant (t/a)
m_{RDF,\text{mix}} - the mass of the RDF used in the example plant (t/a)

E_{\text{RDF}} – the CO_2 emissions from incineration of RDF (t CO_2/t RDF)

m_{\text{MSW-RDF}} – the mass of waste not processed into RDF (t/a).

Q – the heat provided for clinker production in the example plant (MJ/a)

LHV_{\text{coal}} – the lower heating value of coal used in the example plant as received basis (MJ/kg)

E_{\text{coal,MJ}} – the CO_2 emissions from incineration of coal for producing 1 MJ heat (g CO_2/MJ)

LHV_{\text{RDF}} – the lower heating value of RDF used in the example plant as received basis (MJ/kg)

(2) Potential of RDF usage in China cement industry

The potential of utilization of RDF in cement industry of China is estimated based on the amount of cement produced in China and in the example plant. The calculation of potential RDF utilization in cement production is based on the ideal condition in which all the cement production in China uses RDF as the example plant does.

\begin{align}
m_{\text{RDF,p}} &= m_{\text{cement,CN}} \times m_{\text{RDF,t cement}} \quad (13) \\
m_{\text{MSW,p}} &= m_{\text{RDF,p}} \times (m_{\text{MSW}}/m_{\text{RDF,mix}}) \quad (14) \\
m_{\text{RDF,t cement}} &= \frac{m_{\text{RDF,mix}}}{m_{\text{cement}}} \quad (15) \\
m_{\text{cement}} &= \frac{m_{\text{clinker}}}{R} \quad (16) \\
m_{\text{clinker}} &= Q/Q_{t \text{ clinker}} \quad (17)
\end{align}

Where:

m_{\text{RDF,p}} – the potential mass of RDF used in cement production in China (t/a)

m_{\text{cement,CN}} – the mass of cement produced in China (t/a)

m_{\text{RDF,t cement}} – the mass of RDF used for per tonne of cement (t RDF/t cement)

m_{\text{MSW,p}} – the potential mass of MSW directed to RDF production in China (t/a)
\( m_{\text{RDF,mix}} \) – the mass of RDF used in the example plant (t/a)
\( m_{\text{cement}} \) – the mass of cement produced in the example plant (t/a)
\( m_{\text{clinker}} \) – the mass of clinker produced in the example plant (t/a)
\( R \) – the ratio of clinker/cement
\( Q_{t \text{clinker}} \) – the amount of heat needed to produce one tonne of clinker (MJ/t clinker)

(3) The potential reduction of GHG emissions in China cement industry

If all cement plants utilize RDF as an alternative fuel as the example plant does in 2020, the potential amount of reduction of GHG emissions in China cement industry is calculated using following equations:

\[
E_{\text{reduction, } p} = m_{\text{cement,CN}} \times E_{\text{reduction, } t \text{ cement}} \tag{18}
\]

\[
E_{\text{reduction, } t \text{ cement}} = \frac{E_{\text{reduction}}}{m_{\text{cement}}} \tag{19}
\]

Where:

\( E_{\text{reduction, } p} \) – The estimated mass of GHG reduced in cement industry in China per year
\( m_{\text{cement,CN}} \) - The estimated mass of cement produced in China in 2015

\( E_{\text{reduction, } t \text{ cement}} \) – for producing one tonne of cement, the reduced GHG emissions because of use of RDF as an alternative fuel in the example plant (t CO\(_2\)eq/t cement)

3.2.3 Data used in the calculations

Data was collected from extensive literature and answers to the questions in the questionnaires. CO\(_2\) emissions from incineration of RDF are calculated. The LHV of coal used in the example plant is 23.0 MJ/kg (5 500 kcal/kg). The LHV of RDF is 6.9 – 7.7 MJ/kg (1 650-1 850 kcal/kg). In the calculation, we use an average value 7.3 MJ/kg (1 750 kcal/kg). The mass of RDF consumed in the example plant is 45 000-50 000 t/a (we used 45 000 t/a in the case study). It is estimated that 100 000 tonnes of MSW is
used to produce 45 000 tonnes of RDF in the example plant. The example plant uses 80 000 – 90 000 tonnes of waste to produce 40 000 tonnes of RDF per year while some RDF plants in neighbour transport some RDF to the example cement plant. The greenhouse effect of methane is 25 times that of CO₂ (Climate change connection, 2017) which means that 1 kg CH₄ is calculated as 25 kg CO₂eq. Shen Lei (IEA, 2017) has presented that the clinker ratio in China will drop to 0.55 due to technology improvement. The amount of cement production in China in 2015 is used as the annual amount of cement production in China in the case study. Data collected from literature and questionnaires are listed in Table 9 and Table 10 separately.

Table 9. Data collected from literature in the case study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions from combusting 1 MJ of coal</td>
<td>Ecoal,MJ</td>
<td>98 g CO₂/MJ (EIA, 2017)</td>
</tr>
<tr>
<td>CO₂ emissions in incineration of RDF</td>
<td>ET RDF</td>
<td>0.67 t CO₂/t MSW (Infohouse, 2017), 92 g CO₂/MJ (calculated)</td>
</tr>
<tr>
<td>Annual cement production in China</td>
<td>mcement,CN</td>
<td>2.36 billion t/a</td>
</tr>
<tr>
<td>Clinker/cement ratio</td>
<td>R</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table 10. Data collected from questionnaires in the case study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Items</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal use in plant C</td>
<td>mc coal mix</td>
<td>50 000 t/a</td>
</tr>
<tr>
<td>Coal LHV</td>
<td>LHV coal</td>
<td>23 MJ/kg</td>
</tr>
<tr>
<td>RDF use in plant C</td>
<td>m RDF mix</td>
<td>45 000 t/a</td>
</tr>
<tr>
<td>RDF LHV</td>
<td>LHV RDF</td>
<td>7.3 MJ/kg</td>
</tr>
<tr>
<td>MSW used for RDF production</td>
<td>m MSW</td>
<td>100 000 t/a</td>
</tr>
<tr>
<td>Energy requirement of clinker</td>
<td>Qt clinker</td>
<td>3 500 MJ/t</td>
</tr>
</tbody>
</table>

Methane from landfilled MSW is calculated using the equation below (Kumar, et al., 2004 & Jensen & Pipatti, n.d.).

\[
E_{\text{land fill t MSW}} = \left(1t \times MCF \times DOC \times DOC_F \times F \times \frac{16}{12} - R_{CH4}\right) \times (1 - OX) \tag{20}
\]

Where:


MCF - Methane Correction factor (fraction). According to IPCC, 0.4 has been used as a default value for the calculation of methane emissions from the landfills of developing countries.

DOC - Degradable Organic Carbon (fraction). 0.19 has been used as IPCC default value for computation.

DOC\(_F\) - It is the faction of DOC converted to landfill gases. 0.77 has been adapted as a default value.

F: Fraction of methane in landfill gas (IPCC default value is 0.5).

16/12: Conversion of C to CH\(_4\).

R\(_{\text{CH}_4}\): Recovered methane (Gg/a). Recovery of landfill gas is not adopted in China, hence the value is set to 0.

OX: Oxidation factor, the IPCC default value is 0. (Pudasaini. S. R., 2014)

\(E_{\text{landfill, MSW}}\) is calculated below.

\[
E_{\text{landfill, MSW}} = \left( t \times 0.4 \times 0.19 \times 0.77 \times 0.5 \times \frac{16}{12} - 0 \right) \times (1 - 0) \times \frac{25t \text{ CO}_2 \text{eq}}{t \text{ CH}_4} = 0.98 t \text{ CO}_2 \text{eq/t}
\]

### 3.3 Results

The results of the calculation are summarized to Table 11. The GHG emissions reduced by directing MSW instead of landfilling to RDF production in the example plant case would be 46 144 t CO\(_2\)eq/a.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value (t CO(_2)eq/a)</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E_{\text{reduction}})</td>
<td>46 144</td>
<td>1</td>
</tr>
<tr>
<td>(E_{\text{no RDF}})</td>
<td>242 894</td>
<td>2</td>
</tr>
<tr>
<td>(E_{\text{mix}})</td>
<td>196 750</td>
<td>3</td>
</tr>
<tr>
<td>(E_{\text{coal, no RDF}})</td>
<td>144 894</td>
<td>4</td>
</tr>
<tr>
<td>(E_{\text{landfill, no RDF}})</td>
<td>98 000</td>
<td>5</td>
</tr>
<tr>
<td>(E_{\text{coal, mix}})</td>
<td>112 700</td>
<td>6</td>
</tr>
<tr>
<td>(E_{\text{RDF, mix}})</td>
<td>30 150</td>
<td>7</td>
</tr>
<tr>
<td>(E_{\text{landfill, mix}})</td>
<td>53 900</td>
<td>8</td>
</tr>
</tbody>
</table>
The results of the calculation of the possible GHG emissions reduced in cement production in China are summarized to Table 12. Utilizing RDF in the cement kilns in China with similar quantity as in the example cement plant would mean that 138 million t/a RDF could be used in cement plants. This would mean 307 million t/a MSW directed to RDF production. The reduction of GHG emissions by using this amount of RDF as an alternative fuel in cement kilns would be 142 million CO$_2$eq/a. It would make great contribution to MSW treatment in China.

Table 12. Results of the GHG reduction potential in cement industry in China when utilizing RDF as an alternative fuel.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\text{RDF,p}}$</td>
<td>138 million t/a</td>
<td>13</td>
</tr>
<tr>
<td>$m_{\text{MSW,p}}$</td>
<td>307 million t/a</td>
<td>14</td>
</tr>
<tr>
<td>$E_{\text{reduction,p}}$</td>
<td>142 million t CO$_2$eq/a</td>
<td>18</td>
</tr>
<tr>
<td>$E_{\text{reduction,t cement}}$</td>
<td>60.0 kgCO$_2$eq/t cement</td>
<td>19</td>
</tr>
</tbody>
</table>
4 CONCLUSION

Cement industry is energy intensive since cement kilns need high temperature to make the limestone to decompose to CO$_2$ and CaO. In order to reduce fuel costs and environmental impact, it is becoming interesting to use RDF as an alternative fuel and alternative raw materials in cement kilns. RDF could be combusted to provide energy as an alternative fuel for cement production. It can save fuels such as coal, petroleum coke and raw materials for producing cement. The waste gas emissions from the cement kiln is low. Producing RDF from MSW and using RDF in cement kilns is an effective supplementary way for treating MSW. It is a better way to treat MSW than landfill. RDF production process includes primary shredding, screening, air separation, magnetic separation, eddy current separation, secondary shredding, etc. Shredding reduces size of waste. Screening separates waste according to their sizes. Air separation is quite useful in separating light waste. Magnetic separation is used to separate ferrous metal. Eddy current is for sorting out non-ferrous metal. Secondary shredding is used to reduce size of waste further. Because moisture content of MSW in China is high, drying is also needed in RDF production.

Utilization of RDF in cement production is not widely applied yet in the whole cement industry in China. Some large cement companies such as Conch, Huaxin, China Resource and Jinyu in China have developed technologies of co-processing of MSW in cement production. For example, Huaxin develops their own RDF production lines and uses them in their own cement plants. Jinyu develops a technology called CKK which includes gasification of waste and use of the produced gases in cement kilns. Because the subsidy is low and the cost to produce RDF is high, this restricts the utilization of RDF in cement kilns in China. The government implemented policies for improving use of RDF in cement production recently.
A case study is conducted to show the reduction GHG emissions by utilization of RDF in cement kilns. Survey questions about the situation of use of conventional fuels and RDF in cement kilns were answered by an employee in Chibi Plant of Huaxin cement company. Using RDF in cement production reduces GHG emissions considerably. CH₄ from landfilled waste is eliminated. The calculation shows that 46 144 t CO₂eq emissions are reduced annually in this example plant by substituting coal with RDF partially. If RDF is used in cement plants widely in China in the future, the reduction of GHG emissions is huge and it will contribute greatly to reducing climate change (mitigation). It is estimated that 138 million t RDF are potentially used in cement industry in China per year and 142 million t CO₂eq GHG emissions can be reduced as a result.
APPENDICES

APPENDIX I: TECHNICAL POLICY FOR POLLUTION CONTROL ON CO-PROCESSING OF SOLID WASTE IN CEMENT KILNS

(Ministry of Environmental Protection, Notice No. 72, 2016)

Chapter 1 General

(1) To carry out the laws and regulations such as the Environmental Protection Law of the People's Republic of China, to prevent and control environmental pollution, to ensure ecological security and human health, to regulate pollution control and management, to promote technical equipment and pollution control technology of co-processing of solid waste in cement kilns, to promote low carbon development of cement industry, the technical policy is developed.

(2) The term “co-processing of solid waste in cement kilns” refers to the process of treating waste harmlessly while producing clinker by bringing the solid waste which meet the requirements of entering kilns into cement kilns or meet the requirements after pre-treatment. The types of solid waste are mainly hazardous waste, municipal solid waste, municipal and industrial sewage treatment sludge, animal and plant processing waste, contaminated soil, emergency waste and so on.

(3) The technical policy is the guiding document, including the source control, clean production, end-of-pipe control, secondary pollution control and new technologies encouraged to develop and other content. It provides guidance for the planning related to environmental protection, standards for pollutant discharge, environmental impact assessment, total control, pollution permits and other work of environmental management and corporate pollution control.
(4) Co-processing of solid waste in cement kilns should be based on the requirements of industrial development, total urban planning, environmental protection planning and environmental sanitation planning, combined with existing cement production facilities, rational planning and orderly layout. The solid waste of cement kilns should be used as an important supplement to the treatment of MSW.

(5) Pollution prevention and control in co-processing of solid waste in cement kilns should follow the principle of pollution control throughout the process which means the combination of the source control, clean production and end-of-pipe control. The policy encourages the use of advanced and reliable production technology, equipment with high energy efficiency, and mature and effective pollution control technology. The policy encourages to strengthen the technical guidance and delicacy management. Co-processing of solid waste in cement kilns should ensure the safe treatment of solid waste to meet the requirements of standards for pollutant discharge, does not impact the cement product quality and stable operation of cement kilns.

(6) The cement companies carrying out co-processing of solid waste in the cement kiln should strengthen their responsibility as the main body responsible for environmental protection, establish and improve the environmental monitoring system and the environmental management system to ensure that the pollutants generated in the whole process of co-processing waste are discharged meeting the standards. The companies should improve management of environmental risk control and management system of environmental emergencies, make feasible reserved plans, and actively prevent and improve the ability to respond to sudden environmental events.

Chapter 2 The source control

(1) Co-processing of solid waste should use the existing new dry cement kilns with raw materials mill and rotary kiln running integrally. Co-processing of solid waste should
be used in cement kilns with the designed capacity of 2,000 tonnes/day and above for one production line. After the technical policy is issued, the cement enterprises newly built, extended or reconstructed that treat hazardous waste should use cement kilns with the designed capacity of 4,000 tonnes/day and above for one production line. The cement enterprises newly built, extended or reconstructed that treat other solid wastes (hazardous waste excluded) should use cement kilns with the designed capacity of 3,000 tonnes/day and above for one production line. The policy encourages the use of cement kilns in compliance with the Cement Industry Standard Conditions (2015) for co-processing of solid waste, which should meet the requirements of “Standard for Pollution Control of Co-processing of Solid Waste in Cement Kilns before it is transformed” (GB30485-2013).

(2) It should be based on the production process and technical equipment to reasonably determine the type of solid waste treated in cement kilns and treatment scale. It is strictly forbidden to use cement kilns for co-processing of radioactive, explosive and reactive wastes, disassembled waste household appliances, waste batteries and electronic products, mercury-containing thermometers, sphygmomanometers, fluorescent tubes and switches, chromium slag, and unidentified wastes with unknown properties.

(3) The enterprises that newly built cement kilns for co-processing of hazardous wastes shall perform the performance tests on the facilities of cement kiln for co-processing solid waste in accordance with Environmental protection technical specification for co-processing of solid wastes in cement kiln (HJ 662-2013) during pilot run period to evaluate the effect of the cement kiln on the removal of organic compounds in the process of co-processing of hazardous wastes and the control on the discharge of pollutants. The use of cement kilns for co-processing medical waste, must meet the relevant requirements of “Environmental protection technical specification for co-processing of solid wastes in cement kiln” (HJ 662-2013).
(4) Treatment of waste of emergency events should select cement kilns with the operating permit for co-processing of the same type of hazardous waste. If the conditions cannot be met, appropriate cement kiln for co-processing should be selected in accordance with the emergency treatment program approved by the local provincial department of environmental protection.

**Chapter 3 Clean production**

(1) Co-processing of solid waste in cement kilns should meet the requirements of “Cleaner Production Evaluation Index System for Cement Industry” (Development and Reform Commission Notice No. 3, 2014), and it shall be regularly audited.

(2) Co-processing of solid waste in cement kilns shall take effective measures such as sealing, negative pressure or other anti-leakage, anti-flying and anti-odor measures in processes such as receiving, storage and transportation, pre-treatment and co-processing in kilns.

(3) Different types of solid waste in cement companies should be stored separately. Storage facilities should be built separately. Solid waste should not be stored with origin fuels for cement production or cement products. Storage of hazardous waste shall also meet the requirements of “Pollution Control Standard of Hazardous Waste Storage” (GB18597-2001) and “Technical Specification of Collection Storage and Transportation of Hazardous Waste” (HJ2025-2012). Unidentified waste should be stored in accordance with the requirements of storage of hazardous waste, a separate temporary storage area and a special access channel should be set up.

(4) The pre-treatment process shall be reasonably determined according to the characteristics of the solid waste and requirements of entering kilns. The policy encourages
sewage treatment plants to carry out sludge drying. Dried sludge shall meet the requirements of directly being treated in kilns. It is appropriate to set up a separate sludge drying system for sludge drying in cement plants. Heat source for drying should use waste heat from waste gas in cement kilns. Raw MSW cannot be directly brought into cement kilns. It must be pretreated before entering kilns. MSW is prohibited from being mixed with hazardous waste in pretreatment processes.

(5) Content and dosage of heavy metals in solid waste treated in cement kilns should be strictly controlled. The limit of leaching of heavy metals in cement clinker should meet the relevant requirements of “Technical Specification for Co-processing of Solid Waste in cement kilns” (GB30760-2014). The detection frequency of leaching concentration of heavy metal of cement clinker should be improved for co-processing of heavy metal waste in cement kilns. The amount of chlorine in the kiln waste shall be strictly controlled to ensure stable operation of cement kilns and the quality of cement clinker, while curbing the production of dioxins.

(6) Where and how the solid waste enters the kiln should be determined based on the operating conditions of the cement kiln and pretreatment of solid waste. It should meet the requirements of Environmental protection technical specification for co-processing of solid wastes in cement kiln (HJ 662-2013). Matching of solid waste is based on the composition of solid waste and calorific value of solid waste to ensure stable operation of cement kilns for co-processing solid waste. Wastes containing Volatile Organic Compounds, stink or cyanide cannot be put into the raw material preparation system but should be put into the high temperature section.

(7) According to properties of waste and requirements for cement production, feeding measurement devices and automatic control feeders shall be arranged.
(8) Synchronous operation rate of cement kilns and raw mill in co-processing of solid waste should be gradually improved. Emission control measures for sulphur dioxide, volatile heavy metals such as mercury should be strengthened during the suspension of the raw material mill. Simple ammonia desulphurization measures should not be used (no recovery of desulphurization by-products).

**Chapter 4 End-of-pipe control**

(1) Bag filter with high efficiency should be used for removal of dust from exhaust gas from kiln tail for co-processing of solid waste in cement kilns. Facilities for co-processing of solid waste which has been put into operation or of which the environmental impact assessment document has been approved before 1st March, 2014, the stability of operation of electrostatic precipitator in kiln tail should be enhanced continuously for improving efficiency of removal of dust and ensuring discharge of pollutants to meet standards continuously and stably. The policy encourages to replace electrostatic precipitator with bag filter with high efficiency. Operation and maintenance management of the dust collector for co-processing of solid waste in cement kilns should be strengthened, to ensure 100 percent synchronous operation of the dust collector and cement kiln production.

(2) The emission of pollutants such as nitrogen oxides and sulphur dioxide in the process of co-processing in cement kilns shall be subject to the relevant requirements of “Policy on Pollution Prevention and Control of Cement Industry” (Ministry of Environmental Protection Notice No. 31 of 2013).

(3) Leachate, the vehicle cleaning wastewater and other waste water produced in the process of co-processing of solid waste in cement kilns can be properly pretreated and sent to the municipal sewage treatment plant for further processing, or treated by separate sewage treatment unit and reused after meeting requirements. waste water can be directly injected into the cement kiln for incineration if the amount of waste water is
small. It is strictly forbidden to directly discharge untreated leachate and waste water in any form.

(4) The cement enterprises shall record the operation process of co-processing of solid waste and the operation of the facilities for environmental protection. If available it shall be included in the enterprise central control system with real-time data query and historical data query. The data records of treatment of hazardous waste should be retained for more than five years, the data records of treatment of general solid waste should be retained for more than a year.

(5) The cement enterprises shall establish a monitoring system and carry out self-monitoring on a regular basis. They should focus on strengthening monitoring for hydrogen chloride, hydrogen fluoride, heavy metals and dioxin pollutants in the exhaust gases from the kiln. On-line monitoring device for air pollutants must be installed on exhaust pipe of cement kilns, monitoring data and information should be published in accordance with the requirements of “The Method for Supervisal Monitoring and Information Disclosure for National Key Pollution Sources (Trial)”. 

(6) Exhaust emissions from bypass air system of cement kiln cannot be directly discharged. They should be mixed with the flue gas from kiln tail for treatment or separately treated. The emission limits and monitoring methods of the bypass air exhaust pipe shall be subject to the relevant requirements of “Standard for Pollution Control of Solid Waste Treatment by Cement Kiln” (GB30485-2013). The inclusion of characteristic contaminants not included in the standard shall comply with the relevant emission limits set forth in the environmental impact assessment.

Chapter 5 Secondary pollution control
(1) Kiln dust of co-processing of solid waste in cement kilns should return to the raw material system, but kiln dust and cement kiln bypass dust discharged to avoid the accumulation of volatile heavy metals such as mercury in the kiln should not be returned to the raw material system. If the kiln dust and bypass dust need to be sent to the factory for treatment, they should be managed as hazardous waste.

(2) Storage facilities of MSW and municipal sewage sludge should have good anti-seepage performance and be equipped with collection devices for waste water. Storage facilities should be operated under negative pressure if there are MSW or sludge inside.

(3) Waste gas produces from sludge drying system, MSW storage and pretreatment of waste should be sent to the high temperature zone of a cement kiln. Or waste gas deodorization facilities in the drying system are installed, waste gas is treated by biological, chemical deodorant technologies among others and emitted meeting standards of emission. When the kiln in down time, waste gas produced in storage and pretreatment of solid waste and sludge drying system should be discharged meeting the standards after treatment of waste gas control facility.

Chapter 6 Encourage the development of new technologies

(1) Pollutant emissions reduction technology in the production process of co-processing of solid waste in the cement kiln.

(2) Efficient technology to improve the capacity of co-processing of solid waste in cement kilns, such as off-line incineration system for large amount of solid waste.

(3) Highly efficient pretreatment techniques for co-processing of solid waste, such as preparation technology for RDF of high quality; and pretreatment techniques to reduce the environmental risk of cement kilns in co-processing hazardous waste. Efficient synergistic removal technology for dust, sulphur dioxide, nitrogen oxides, mercury and other pollutants. (H2O-China, 2017)
APPENDIX II: QUESTIONS AND ANSWERS IN QUESTIONNAIRE 1

What types of fuels are used in the plant?
The main fuel used in the plants is coal.

Is RDF used in the plant? (Yes or No).
Yes.

If RDF is used, what is the source of waste?
The MSW collected by the sanitation department is the main resource for producing RDF.

What are requirements (heating value, moisture content, particle size, ash content, etc.) for RDF if you want to use it in the plant?
These are requirements for the RDF: 1. LHV >8.4 MJ/kg (2000kcal/kg); 2. moisture content <40%; 3. residue on 50mm sieve <10%; 4. ash content <30%; 5. no radiative, contagious, explosive matter, no WEEE and heavy metal, etc.

APPENDIX III: QUESTIONS AND ANSWERS IN QUESTIONNAIRE 2

What is the yearly heat energy consumption (MWh/year)?
3 500-3 600MJ/t clinker. The production of clinker is 1.1 million tonnes per year.

What is the yearly coal consumption (t/a)?
50 000 t/a of anthracite coal.

What is the LHV of coal (MJ/kg)?
23 MJ/kg.
What is the yearly RDF consumption (t/a)?
45 000-50 000 t/a. The RDF plant in city C produces 40 000 tonnes of RDF per year. Some RDF plants in nearby cities or countryside where there are not cement plants transport some RDF to the example plant in city C.

How much waste is used to produce RDF (t/a)?
80 000 – 90 000 tonnes of waste is treated in the RDF plant of the example plant per year.

What is the quality of the RDF (heating value, moisture content and ash content)?
LHV of RDF is 6.9 – 7.7 MJ/kg (1 650-1 850 kcal/kg).
Ash content is 25%.
Moisture content is 42-45%.

How much coal is replaced with the RDF (t/a + %)?
Appx. 30% (depending on the heating value and moisture content of RDF).

What is the price of the coal?
€96.2/t (CNY 750/t).
The price is € 4.1/MJ, LHV of coal is 23.0 MJ/ t (CNY 0.135/kcal, 5 500kcal/t coal).

What is the gate fee of MSW (subsidy by government)?
Appx. €8.9/t (CNY 70/t).

How much is the cost to invest a RDF plant?
€7.6 – 19.1 million (CNY 60 million-150 million).

How much is the cost to produce RDF (government subsidy not included, CNY/t)?
According to used production technologies and amount of waste handled at present, the cost to produce RDF is appx. €11.4/t (CNY 90/t).
Where is the waste used to produce the RDF from?
MSW from city C and surrounding areas, sewage sludge from surrounding water treatment plants and sewage sludge disposed by municipal department.

What is the contribution to local WM (% of produced MSW)?
50 – 75%.

What is the motivation to use RDF?
Using RDF in cement production is for treating MSW safely and reducing landfilled waste. RDF can be used for providing an alternative fuel and alternative raw materials. All MSW in City C is transported to the example plant for producing RDF for cement production.

Is there disadvantage to use the RDF in the cement production? Please describe it if there is.
① MSW may be mixed with some other types of waste i.e. construction waste and medical waste which may cause difficulty for treatment.
② The time for drying waste is long. It is influenced by the seasons and moisture content in waste.
③ The utilization of RDF is influenced by the running condition of the cement production line. When the production line does not function well or when it is during maintenance, RDF cannot be handled in large quantity.
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