ŚRODKOWO-POMORSKIE TOWARZYSTWO NAUKOWE OCHRONY ŚRODOWISKA
Rocznik Ochrona Środowiska
Tom 14. Rok 2012 ISSN 1506-218X 132–145

Lublin Experience with Co-incineration of Municipal Solid Wastes in Cement Industry

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1. Introduction

The flagship initiative for a resource-efficient Europe under the Europe 2020 strategy supports the shift towards a resource-efficient, low-carbon economy to achieve sustainable growth. It is strategy for all EU policies which sets out how we can meet the needs of present generations without compromising the ability of future generations to meet their needs.

There is no simple answer to question how sustainable is the method applied because the sustainability relates to all aspects of human activity. In according to Pawlowski [23] analysis of sustainability should take into account its multi-dimensional nature from supply of raw materials to interpersonal relations.

One of the most important issue is climate change [17] bound to clean energy [4, 9, 12].

Equally important are economical [12, 13, 18, 22, 25, 35], environmental [15, 19, 24, 27], social [3, 30, 33, 34] and even philosophical, mainly ethical aspects [2, 5, 7, 11, 14, 15, 20, 21, 24, 26, 34].

In all of these areas one can observe tensions created by the unsustainable development paths in the present world. The almost geometric growth of our technical abilities to change the world leaves behind the development of social sciences which would allow the question of what values these changes serve to be answered. The fact that resources are becoming less and less available makes it all the more serious. A lot has been said and written in recent years about climate change, but much less about the fact that the main source of anthropogenic carbon dioxide emission into the atmosphere, i.e. the burning of fossil fuels is associated with the depletion of fossil fuel resources. For the world, the consequences of energy shortage could be much more severe than the greenhouse effect.

Current estimates indicate that, at the current level of consumption, there is enough oil left for about 40–50 years, natural gas for 60–70 years and coal for about 140–150 years. This shows that the two main primary energy sources necessary to uphold human civilization will be exhausted within a single generation. Even if we assume a large error in the estimates, one must accept that a major crisis will occur in accessing conventional energy sources within a short time, measured in decades. This means that one of the cardinal rules of sustainable development, namely intergenerational justice, is at stake. The present generation seems to live at the expense of future generations. Moreover, the second rule of sustainable development, justice within generations, is not respected either. Nowadays the development path of our civilization makes the crisis even deeper. Following the fall of socialism, liberal capitalism, with its chief paradigm of grow-or-die became the leading socio-economic system [6]. As a consequence, the consumption of all environmental components increased, including that of non-renewable resources. The phenomenon is accompanied by the global concentration of economic power, associated with numerous ties to political influence. Appealing to ruthless competition, with disregard to cooperation, it has a disintegrating influence on social bonds and creates an atmosphere, which favors the struggle for dominance, especially economic dominance, associated with political power. Fotopolous [6] claims that the economic and political elite, with strong internal bonds, alienates itself from the rest of society to the extent where ordinary people have little or no influence on social and economic processes.

As Hart [10] indicates, in 1960 the wealthiest 20% of the population owned 30 times as much wealth as the poorest 20%, whereas this ratio reached 60 in 1991 and 78 in 2004. A UNDP report [29] provides information which tells us that the annual income of the 500 richest people in the world is equal to that of the 400 million impoverished people; Kofi Annan [1], Secretary-General of the UN, stated that almost half of the population has an income of less than $2 a day. All the above clearly point out that the development of modern civilization is highly unsustainable. In reference to the term "humanity's ecological footprint", which sets the smallest area of the Earth's surface necessary for the human population to survive [31], it has been proven [8] that our planet's capacity to sustain our population was exceeded in approximately 1986. This means that the present course of development of human civilization actually makes any reduction in poverty impossible as there is no surplus of resources. In this case stopping the excessive consumption in wealthy societies becomes a vital issue [16, 25, 28]. That consumption results not only from the essential needs but also from artificial needs created by advertising. Advertising largely creates an ever increasing demand for a number of goods that do not actually improve the quality of life. It is derived from the rule grow-or-die, which is deep-rooted in modern liberal capitalism and mainly concerns organizations, which gives rise to ever bigger international corporations. In order to grow, they need to increase demand for products, whose percentage profit enhances further growth. This means that in order to sustain growth, which is the essence of the currently dominant socio-economic system, it is crucial to create a self-generating consumption rate, which not only provides a high standard of living in developed societies, but even, via advertising, starts to produce demand for numerous gadgets which have no actual impact on the quality of a human life [16, 33]. Such a situation is reflected in the way development is measured using Gross National Product (GNP). It grows with the movement of goods and, as such, gives a very inadequate picture of the situation of societies, i.e. it does not include degradation in the quality of human life.

2. The Problem of Waste Management

At every stage of resource consumption: mining, processing and use, part of the resource becomes waste. Growth in wastes is one of the major problems of the present world, not only because part of the resources are wasted but also their transportation negatively affect the quality of the environment through degradation of the planet's surface, polluting water, air and even contributing to climate warming through the emission of greenhouse gases from landfills.

The Waste Framework Directive (2008/98/EC) is the primary legislation regarding waste management in the 27 European Member States (EU 27). One of the key provisions made in the 2008 directive was the expansion of the waste hierarchy from a three-stage hierarchy into a fivestage one. Prevention is prioritized above reuse, recycling, other recovery e.g. energy recovery and disposal.

One of the easiest ways to recycle is the waste-to-energy approach.

In EU27 the total energy produced from waste accounts for 26 billion KWh of electricity (used by 12 million inhabitants) and 65 billion KWh of heat (enough heat for 11 million inhabitants).

However, incinerating municipal solid waste also has a negative effect. The installation is expensive and substantial amounts of secondary hazardous residues are produced such as ash and dust. More economically attractive and environmentally friendly, is the use of the segregated part of municipal solid wastes as an alternative fuel in cement production.

The combustion of wastes in a cement kiln is a very attractive available option. In this case, the energy recovered is used for the production of clinker, thereby reducing the consumption of culm. In addition, it neutralizes the products of incineration, which are the ashes permanently sintered into the structure of the clinker, as well as the acidic components (SO_2, NO_x, HCl and HF) of the combustion gases, which react with the alkaline particulates and are retained in the electro-filters.

An example of such an approach is Lublin's municipal solid waste management in Poland.

3. The Management of Municipal Solid Waste in Lublin

Lublin has a population of 348,450 inhabitants, who produce 136,052 tonnes of municipal solid wastes i.e. 390 kg per person (the average is 316 kg per person in Poland and 513 kg per person in the European Union).

To enhance the segregation of the municipal solid wastes by individuals in residential areas containing detached houses, residents were asked to separate out only the so called dry fraction (paper, glass, metal, wood, plastic) and bags of this fraction is collected weekly free of charge. The remaining fractions are accumulated in special containers and also collected weekly, but residents are charged for these wastes depending on the size of the container. The fee from the smallest capacity to the largest is: 16.50 PLN for 120 litres, 24.20 PLN for 240 litres and 806.25 PLN for a 15 m^3 container (1 PLN = 0.40 USD). This system works pretty well.

In the case of flats where about 80% of Lublin's population live the situation is more complicated. They deposit mixed municipal solid wastes in collective containers.

The City Council also deploys tanks for the various types of waste such as glass, paper, medicine, electronics but only a small fraction of these are deposited in these containers. Most are deposited as a common trash mixture. The mixed wastes are collected and sent to the segregation plant, where they are segregated into three fractions:

- combustible – paper, wood, plastic, organic residues and food residues,
- metals,
- during summer, grass and other green garden wastes are segregated and used in the production of compost.
- the remaining residue is deposited in landfill sites.

The combustible fraction, amounting to 44,084 tonnes, is broken up and used as fuel in cement production. Its calorific value varies between 17–18 Mg/kg, so the total recovered energy is between 0.75–0.79 PJ with an average of 0.77 PJ, equivalent to 35,066 tonnes of culm. The cement plant pays 50 PLN per tonne of municipal solid waste, so the profit for Lublin's municipality is 2.204 million PLN, whilst the profit for the cement plant is much higher at about 5.51 million PLN.

However, what is most important is that 32.5% of Lublin's municipal solid wastes are incinerated without producing any secondary wastes.

4. The Performance of a Cement Kiln

Figure 1 shows the flowsheet for the production of clinker. Fuel is introduced into the rotary kiln from the lower, so-called "hot" end, most often in the form of culm. At the most elevated, upper end, raw material is introduced in the form of a mixture containing marl and limestone, with a certain amount of iron oxides compounds.

As this mixture passes through successive temperature zones it undergoes a number of transformations, the most important of which are:

- Calcination at a temperature of 850°C as it passes through successive temperature zones. The most important of these are the breakdown of limestone with the production of CaO and large amounts of CO_2

- Sintering at temperatures in the range 1400–1500°C during which the following oxides Al_2O_3, CaO, SiO_2 and Fe_2O_3 react to form what is known as clinker.

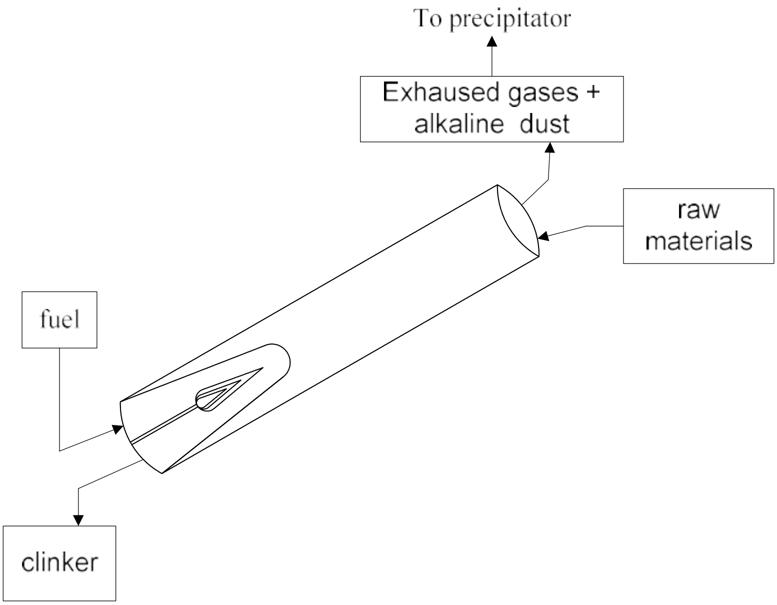

Fig. 1. Flowsheet of clinker production
Rys. 1. Schemat produkcji klinkieru

Figure 2 depicts the way wastes are introduced into the cement kiln. Figure 3 depicts the system we developed for delivering the waste packages. In the kiln mantle there is a hole which is closed by a spring valve. Waste under the influence of its own weight opens the spring valve and the waste package drops into the cement kiln. The valve is then closed by the spring.

With the help of the experimental setup built in accordance with our patent it is possible to introduce about 1.2 tonnes of waste per hour into the section of the kiln having a temperature of 1250°C.

For the introduction of medical waste, so-called pneumatic discharge, see Figure 4 which allows for the injection of three 10–15 kg packages of waste per minute i.e. 1.8–2.7 tonnes per hour. The waste is introduced into the section of the kiln having a temperature of 1400°C.

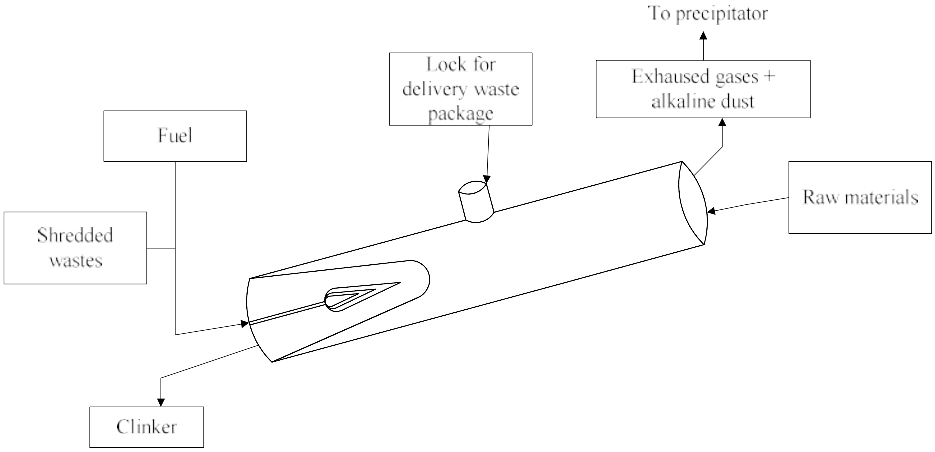

Fig. 2. Flowsheet of clinker production depicting a way an alternative fuels are introduced to cement kiln
Rys. 2. Schemat produkcji klinkieru z miejscem wprowadzania paliw alternatywnych do pieca cementowego

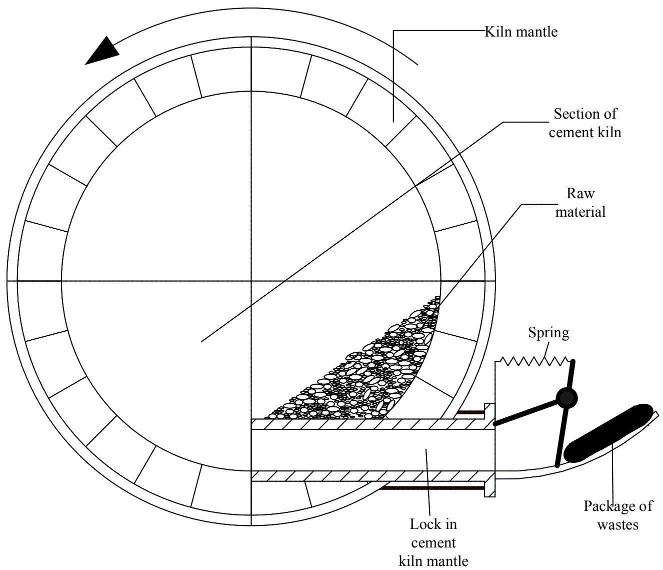

Fig. 3. Characteristic of lock mounted on cement kiln
Rys. 3. Charakterystyka blokady zamontowanej w piecu cementowym

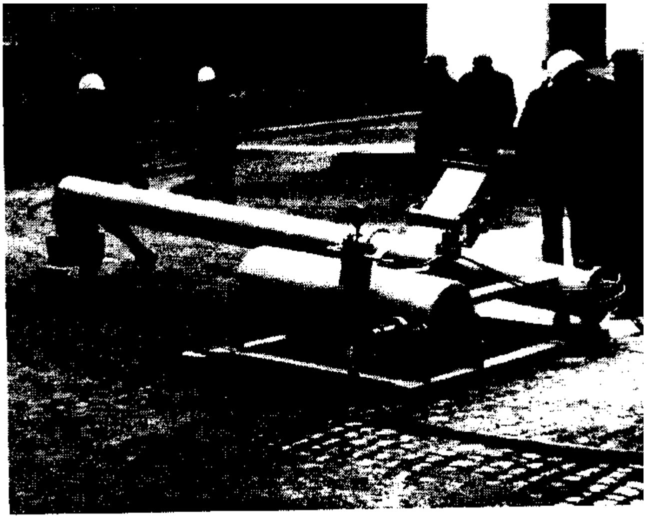

Fig. 4. A view of pneumatic discharge
Rys. 4. Widok zrzutu pneumatycznego

5. Results and Discussion

There are many problems with the neutralization of ashes from conventional incinerators, or even more so, from hospital-waste incinerators. However, the matter looks very different where wastes are combusted in a cement kiln. For the sake of clarity, we divide the compounds used in the production of clinker into 2 groups:

- the raw materials i.e. CaO, Fe_2O_3, Al_2O_3 and SiO_2 and in most cases culm as a fuel which are processed into a final residue product in the form of clinker,
- the trace metals, which are impurities contained in raw materials, fuels and wastes,
- the emitted gas.

From Table 1 it can be seen that most metals fuse into clinker, therefore their emission is low.

Table 2 portrays the dust and gaseous emission concentrations. Tables 1 and 2 show that the emission of impurities from a cement kiln is low, and in the case of NO_x, CO, TOC, dioxins and furans even lower when 30% of municipal solid wastes were added.

Table 1. Characteristic of retention of selected metals
Tabela 1. Zestawienie retencji wybranych metali

Metal	Amount [kg/h]	Retention [%]
Cr	0.2558 to 4.6247	99.8553 ± 9.3990
Pb	0.7149 to 19.1765	99.8531 ± 0.2008
Ba	15.00194 to 34.4508	99.8781 ± 9.2339
Cd	0.0392 to 0.1789	≥ 99.5550 ± 0.4413
As	0.0068 to 2.9891	≥99.8868 ± 0.2916
Be	0.00014 to 0.3253	≥99.8681 ± 1.3278
Se	0.00327 to 0.6082	≥95.4002 ± 1.7779
Ag	0.0199 to 0.2256	99.8420 ± 0.1839
Ni	0.8839 to 2.2794	≥99.9574 ± 0.0108
Sb	0.1602 to 0.3011	≥99.7690 ± 0.0785
Zn	4.1610 to 16.2374	99.7869 ± 0.2598
V	2.2492 to 14.2009	≥99.9922 ± 0.0007

Table 2. Characteristic of dust and gaseous impurities emission
Tabela 2. Zestawienie emisji pyłu i zanieczyszczeń gazowych

Impurities	Culm [mg/nm^3]	Culm + 30% Municipal soild waste [mg/nm^3]	Emission limit [mg/nm^3]
Dust	5–20	5,0–6,0	30
HCl	0,2–4,0	0,7–8,0	10
HF	0,02–0,5	1,0–2,0	1,0
NO_x	250–600	250–600	800
SO_2	0–33	0–20	50
TOC	1	0,3–2,0	10
CO	600–1000	500–800	2000
Cd+Tl	0,0002–0,005	0,0001– 0,003	0,05
Hg	0,00004–0,003	0,00003–0,0040	0,05
Total metals (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V)	0,003–0,06	0,002–0,05	0,5
Dioxins and furans	0,001–0,09 ng/nm^3	0,005–0,08 ng/nm^3	0,1 ng/nm^3

As the data in Table 1 shows the fusion of metals into clinker is very high.

Our investigations show that the amount of dust emitted from the rotary kiln remained almost constant when 30% of the municipal solid wastes were co-combusted with culm (8.32 kg/h) compared to when only culm was burnt (8.30 kg/h). A similar situation was found with gas emissions. During co-combustion, gas emissions were 32.1 m^3/s at a temperature of 443°C compared to 32.6 m^3/s and 446°C respectively when only culm was burnt.

Again, a similar situation with NO_x emissions which were 16.48 kg/h during the co-combustion of 30% solid municipal waste with 70% culm compared to 16.61 kg/h when only culm was burnt.

However, SO_2 emissions were significantly lower (6.78 kg/h) when a mixture of 30% municipal wastes and 70% culm were incinerated compared to 8.32 kg/h for pure culm. It means that the sulphur content in the culm used was higher than in the municipal solid wastes.

The reason for having such good results is explained in Figure 5. The gas retention time in temperatures above 1200°C is 10 seconds whilst the material retention time in temperatures above 900°C is even longer.

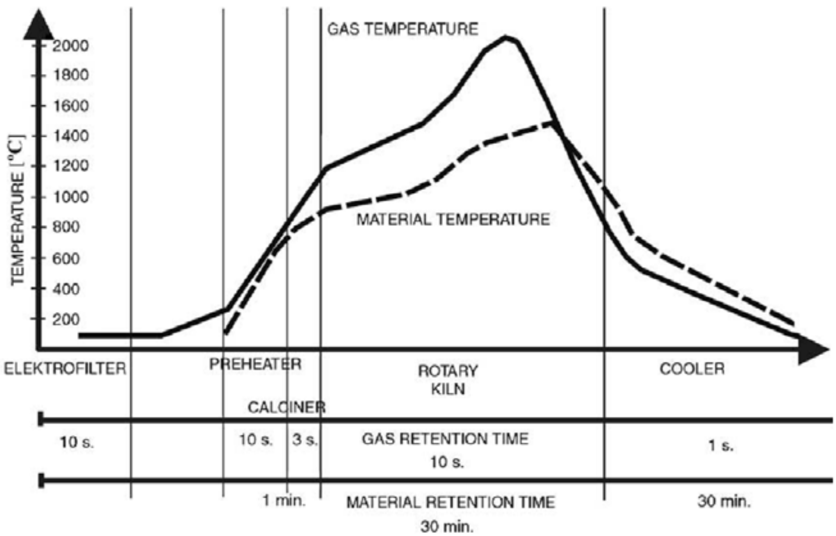

Fig. 5. Characteristic of gas and material temperatures along cement kiln
Rys. 5. Charakterystyka temperatury gazu i materiału w piecu cementowym

I have made a personal contribution to the reasonably widespread use of wastes as a substitute for culm in the Polish cement industry. During the 1995–1997 period I researched into using cement kilns for neutralizing wastes. The results obtained in the laboratory were tested for the first time on a fully industrial scale in 1996 at the Rejowiec Cement Plant with good results. It was the first place I helped to improve the economy of the plant which was at that time close to bankruptcy. Now it is doing quite well. Other cement plants have become interested in the incineration of wastes and the percentage of waste used as a fuel since 1997 has increased steadily (see Figure 6).

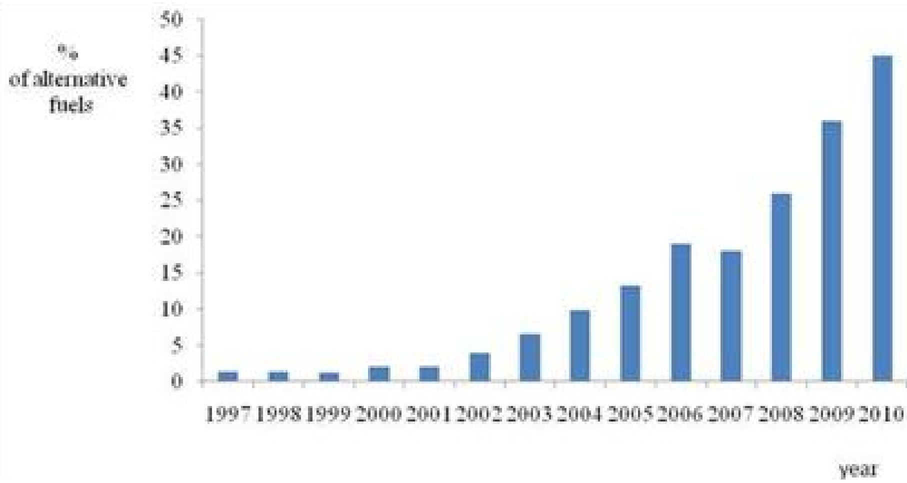

Fig. 6. Characteristic of an use of wastes as an alternative fuel in the cement plants in Poland
Rys. 6. Wykorzystanie odpadów jako paliwa alternatywnego w polskich cementowniach

6. Conclusions

In Lublin 32.5% of the municipal solid waste is separated and converted into fuel for the cement kiln. It allows a saving of 35,060 tonnes of culm annually.

There are no secondary wastes because:

- The neutralization of acidic gases: SO_2, NO_x, HCl, and HF by the active lime in the kiln load takes place, therefore no additional scrubber system is required. In addition, all clinker production facilities are equipped with a dust collection system (electrostatic precipitator or baghouse). This collects any escaped dust and is designed to meet local and national standards. All collected dust (cement kiln dust or CKD) is than recycled and reintroduced into the process.

- Heavy metals, the majority of which come from raw materials and wastes, are sintered into very stable silicates forming clinker, and are directly integrated into its chemical structure. These metals have no impact on the physicochemical properties of the clinker.
- By-products, such as cinder ashes or liquid residues from gas cleaning are not produced.
- Fossil fuel use is diminished.
- The calorific value from the waste is extracted.
- There is a high flame temperature of 2000°C which prevents the formation of dioxins and furans.

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Lubelskie doświadczenia we współspalaniu odpadów komunalnych w przemyśle cementowym

Streszczenie

Najbardziej zrównoważonym sposobem zagospodarowania stałych odpadów komunalnych jest współspalanie frakcji palnych w piecu cementowym. Pozwala to zwiększyć odzyskiwania energii i zmniejszyć wpływ na środowisko, poprzez immobilizację wszystkich popiołów w strukturze klinkieru oraz neutralizację kwaśnych gazów w środowisku alkalicznym w piecu cementowym. W przypadku Lublina około 32,5% lubelskich komunalnych odpadów stałych jest stosowany jako alternatywne paliwo do produkcji cementu. Umożliwia to odzyskanie około 0,77 PJ energii co pozwala zaoszczędzić 35066 Mg paliwa. Zyski to 2,204 mln zł dla gminy Lublin i aż 5,51 mln zł dla cementowni.