Refuse Derived Fuels in the Cement Industry–Potentials in Indonesia to Curb Greenhouse Gas Emissions

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Abstract

Refused derived fuels RDF are increasingly utilized in energy intensive industries and are thereby substituting conventional fossil fuels to a large extent. This applies also for cement works. In many European countries already more than 70% of the overall energy consumption of cement manufactures is covered by RDFs. Besides cost savings for fuels, the utilization of RDF usually goes along with lower CO_2 emissions, as these fuels contain biogenic matter whose combustion is considered climate neutral. In the present study the potential substitution rate for fossil fuels (coal) by the utilization of RDF in Indonesian cement works has been assessed. Based on the quantity and composition of Municipal Solid Waste a maximum production rate of RDF has been derived, which was estimated to 6.3 Million tons/a with an average calorific value of almost 17 MJ/kg. This amount of RDF theoretically derivable from MSW generated in Indonesia could substitute 58% of the coal currently used in cement works. Thereby annual CO_2 emissions of cement plants could be reduced by 3.6 Million tons. Considering in addition also avoided methane emissions by diverting waste from landfills due to RDF utilization, the total savings of greenhouse gases would reach almost 10 Million tons of CO_2 equivalents, which amounts to about 1.3% of Indonesia's overall greenhouse gas emissions.

Keywords: refuse derived fuels, cement industry, Indonesia, Austria, CO_2–emissions, greenhouse gases.

Introduction and Objective

In recent years energy recovery from mixed wastes and refused derived fuels (RDF) has become of increasing importance for energy–intensive industry branches such as cement manufacture or steel production. Especially the cement industry in Europe already substitutes high ratios of conventional fuels (such as coal)by mixed wastes and refuse derived fuels (RDFs) in their kilns to provide the necessary thermal energy. Within the European Union, in 2012 34 % of primary energy carriers in cement kilns are substituted by mixed wastes and RDF(VÖZ 2015b).In some kilns a substitution rate of up to 100 % is reported (Cemex 2011; Schöneberger 2014).

Factors that promote the use of fuels derived from waste in the cement industry are: high temperatures in the kiln, long residence time, oxidising atmosphere, alkaline environment, ash retention in clinker, regional availability of the fuel (Cembureau 1997). Besides these technological factors, there are certain economic and environmental benefits: reduction of costs for primary energy carriers (energy costs account for 30–40 % of the production costs of cement, VÖZ, 2015a), the exploitation of natural resources, and the reduction of fossil CO_2–emissions.

The latter is based on the fact that municipal solid waste (MSW), commercial and industrial waste (and thereof produced RDF) constitutes of a mixture of fossil materials (plastics) and biogenic materials (e.g. paper, cardboard, food residues). The CO_2–emissions of the latter are regarded as not relevant for the climate when they are thermally utilized, whereas plastics are usually produced out of crude oil and thus contribute to the CO_2 footprint when incinerated. Especially emission trading (Directive 2003/87 EC) and national targets for greenhouse gas (GHG) reductions have opened a new scope for the usage of RDF which are partially of biogenic origin (European Parliament, 2003). When using RDF with high a biogenic content, emission certificates can be saved in comparison to using conventional fossil fuels (Lorber et al. 2012; Pieber et al. 2012).

Whereas in developing countries "classic" waste incineration (thermal utilization of mixed waste) as practiced in many European countries, is due to economic (high costs in comparison to alternative waste disposal routes such as landfilling) but also technical constrains (e.g. wet waste with rather low calorific content) not feasible, the production and thermal utilization of RDF represents a mean to increase the overall recovery rate of waste and helps to divert waste from landfills. Furthermore valuable resources such as primary energy carriers can be saved.

In all developing countries, also in Indonesia, the main part of MSW is still deposited on landfills, which are mostly operated as controlled dump sites rather than as sanitary landfills (Damanhuri et al. 2010). Besides landfill leachates that pollute surface and ground waters, uncontrolled emissions of methane and air pollutants (e.g. dioxins) associated with the open burning of waste represent the major environmental hazards emanating from those sites. In order to reduce these negative impacts on the environment attempts are made to better manage existing dumping sites (including the construction of new sanitary landfills) and to better valorize wastes generated, either by composting, recycling or thermal recovery.

In Indonesia waste management is currently in this transition stage from controlled dumping dominated practice to higher valorization practices. The waste management regulation from 2008 stipulates that informal landfills are being closed and negative environmental effects and GHGs from waste management activities are curtailed. In the course of the national action plan for the reduction of GHG emissions a reduction target of 26 % of GHGs until 2020 was established (below the "Business–as–Usual level) (RAN–GRK 2011), whereby the waste sector should significantly contribute to reach this reduction target. The main means to reduce waste related GHG emissions are:

- collection and utilization of landfill gas (in particular methane);
- aerobic treatment (composting) of biogenic waste;
- recycling of paper and cardboard, metals and plastics;
- thermal utilization of the waste fraction (e.g. plastics, paper and cardboard, textiles) characterized by a high energy content (RDF production and utilization).

The main objective of the present paper is to estimate the overall reduction potential for GHG emissions by the production and utilization of RDF in Indonesian cement production.

Thereto in a first step the overall amount and energy content of RDFs theoretically producible out of Indonesian MSW is determined. This data is subsequently used to evaluate the maximum substitution rate of fossil fuels (coal) currently used in cement plants. This substitution rate together with the CO_2–emission factors (emissions of fossil CO_2 per GJ of energy content) of RDF and fossil fuels are then used to assess the potential reduction of GHG emissions in comparison to the status quo. For the latter also avoided landfill gas (methane) emissions by diverting organic matter present in RDF (such as paper) from landfills is considered. Energy required for the collection and transportation of the waste as well as its processing to RDF are however not considered in the present analysis, simply due to the fact that its contributions to the overall GHG emissions are negligible.

Beside the evaluation of RDF utilization in Indonesian cement works with respect to the reduction of GHG emissions, the paper presents data on substitution rates for fossil fuels in cement production in different countries and also provides also valuable information about quality criteria for RDF utilization. It is important to notice that the potential substitution rate for fossil fuel do not only depend on the quantity and energy content of the RDFs generated but also on their composition with respect to the contents of hazardous or unwanted substances such as chlorine or heavy metals. This subject however has not been included in the assessment of RDF utilization conducted for Indonesian cement production.

Qualitative and quantitative aspects of RDF utilization

RDF characterization and quality criteria (in Europe)

Refuse derived fuels (RDF) can be produced from different types of wastes, such as MSW, industrial or commercial waste but can also include liquid and gaseous waste materials. In order to be applied as fuel in co–incineration plants the waste materials usually undergo processing steps such as shredding, separation of ferrous metals, non–ferrous metals and inert materials, drying, sorting or blending. This is done so that the RDF meet certain mechanical (e.g. particle size distribution, bulk properties), chemical (e.g. separation between combustible/non–combustible substances, volatile matter, trace analysis, etc.), calorific (e.g. heating value, air requirement, etc.) and combustion (e.g. combustion behavior, ignition temperature, corrosion potential, etc.) criteria (Beckmann et al. 2012).Apart from legal requirements (e.g. according to national limit values given in Austrian Waste Incineration Directive, Table 1), fuel specifications are usually agreed upon between RDF supplier and plant operator.

Ensuring the necessary quality given in the supply contract and providing legal compliance requires proper monitoring of the RDF before its utilization. This is a challenging task as the waste materials are highly heterogenic and the composition is liable to strong temporal variations. Hence, proper sampling, sampling preparation and analyses are indispensable for reliable analysis results, which represent a perquisite to the utilization of quality–ensured of RDFs in cement works. This is of major importance as the quality of the final product (cement) obviously depends on the quality of the raw materials (including fuels) utilized.

Table 1. Limiting values for heavy metal concentrations in fuels from waste in cement kilns and other co–incineration plants according to the Waste Incineration Directive in Austria (BMLFUW 2010)

Parameter	Unit	Cement kiln	Other co–incineration plants
		Median	Median
As	mg/MJ_{DM}	2	1.5
Pb	mg/MJ_{DM}	20	27
Cd	mg/MJ_{DM}	0.23	0.34
Cr	mg/MJ_{DM}	25	28
Co	mg/MJ_{DM}	1.5	1.6
Ni	mg/MJ_{DM}	10	12
Hg	mg/MJ_{DM}	0.075	0.15
Sb	mg/MJ_{DM}	7	10

MJ_{DM}: Mega joule dry matter

In Europe different standards for the sampling of RDF (e.g. EN 15442:2011–Solid Recovered Fuels–Methods for sampling), for the sample preparation (e.g. EN 15413:2011–Solid Recovered Fuels–Methods for the preparation of the test sample from the laboratory sample) as well as the final analysis have been released and are applied by RDF produces. Such standards provide crucial information for a quality–controlled production and utilization of RDF and are definitely necessary to be also implemented in developing countries

Utilization of refuse derived fuels in the cement industry

Different quality criteria of RDFs

The production of clinker in cement works requires an even combustion of fuels and to maintain certain technical criteria. Thus, besides pollutants certain requirements and quality criteria are typically set by the cement producers (Beckmann et al. 2012; Rahman et al. 2015). These are for example: even particle size distribution, uniform calorific value, low moisture content, lower calorific value >14.0 MJ/kg, chlorine content< 0.2%, sulphur <2.5%, low heavy metal contents. Further the cement quality and its compatibility with the environment must not be impaired, the fuels must be available and economically acquirable (Rahman et al. 2015). In the context of environmental impacts a further quality criteria is the biomass content (i.e. the ratio of biogenic materials such as paper, cardboard). A higher content of biogenic carbon in the fuel goes along with lower fossil CO_2–emissions.With respect to the determination of biomass content in RDFs, three methods are described in the standard EN 15440:2011, namely the manual sorting method, the selective dissolution method (SDM), and the radiocarbon method (^{14}C–Method). In recent works a comparably simply method has been developed and adapted which relies on the analysis of the elementary composition of the RDF (C, H, N, S, O). This method may overcome some limitations of standardized methods, such as high chemical demands, high costs, high uncertainties, high analysis duration (Fellner et al. 2011; Schwarzböck et al. 2016a; Schwarzböck et al. 2016b) and seems thus to be promising for its application also in developing countries.

CO_2–emissions and other environmental aspects of RDF utilization

As the cement industry is accountable for 5–6 % of all CO_2 released by human activities (Rodrigues & Joekes 2011), reduction efforts in this branch can have significant effects on global GHG emissions. The substitution of fossil fuels by alternative fuels, which are (partly) composed out of biogenic materials (such as paper, cardboard, wood) is one way to curb GHG emissions.

In 2014 in Austria the production of cement (550 kg cement/cap/a) contributed around 2.7 % to the national GHG emissions (considering values given in Umweltbundesamt (2015) and VÖZ (2015a)).This equals almost the share of approximately 2.6% assessed for 1990. Thus, all in all reductions in GHG emissions observed for the Austrian cement industry are in line with the overall reduction of national GHGs. Nevertheless specific GHG emissions (CO_2 per ton cement produced) have been significantly decreased also due to an enhanced utilization rate of RDF. Whereas in 1990 around 10 % of the thermal energy in cement works were provided by alternative fuels (based on data given in Hackl & Mauschitz (1995) and Umweltbundesamt (2002)), in 2014 this share has reached more than 75%.

CO_2–emissions from cement production in Indonesia (about 200 kg cement/cap/a)contribute to about 1.8% of overall GHG emissions. The CO_2–emissions from the cement works have soared 4–fold from 1990 to a 2013 (6,8 Mio t CO_2 in 1990, 27,9 Mio t CO_2 in 2013), see Figure 1 (Boden et al. 2016). The per capita CO_2–emissions have more than doubled since 1990 due to the increased cement production. In comparison, in Austria around 10% less CO_2 was emitted from cement industry in 2013 compared to 1990, which corresponds to a decrease of almost 20% per capita CO_2–emissions from cement industry (Figure 1) (Boden et al. 2016). From these CO_2–emissions around 60% originate from calcinations of carbonates, the remaining 40% are attributed to the combustion of fuels for thermal energy supply (Tokheim 1999).

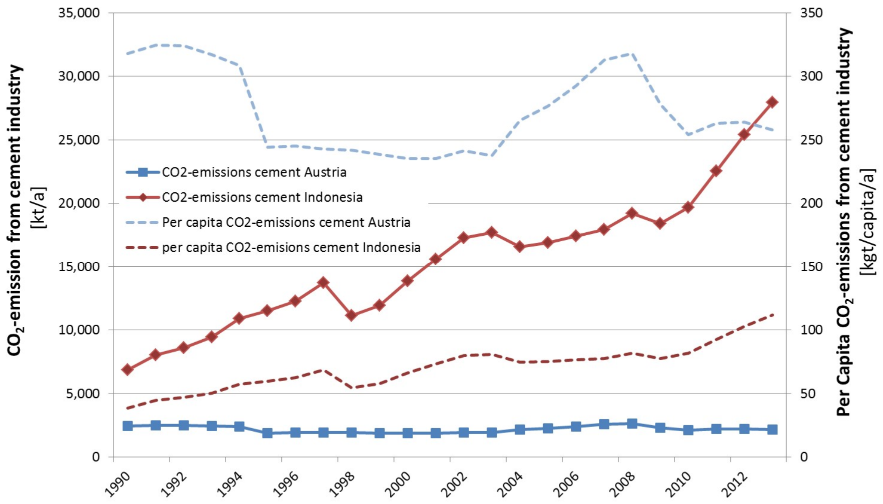

Figure 1. CO_2–emissions from cement industry in Austria (blue line) and Indonesia (red line) based on figures given in Boden et al. (2016)

From an environmental point of view, not only the CO_2–emissions but also other emissions, such as SO_x, NO_x, dioxin, furan or heavy metals need to be considered when alternative fuels are utilized in the cement works. It is reported that a higher sulphur and chlorine content in MSW can lead to increased SO_x emissions and the formation of highly toxic dioxin and furan emissions(Choy et al. 2004; Genon & Brizio 2008; Garg et al. 2009). Further an increase in mercury emissions has been reported(Genon & Brizio 2008). However, some emissions can to a large extent be controlled by adapting and optimising the incineration and process conditions (e.g. lowering flame temperatures) (Rahman et al. 2015).Thus a continuous self–monitoring is crucial.

Substitution rates of fossil fuels in cement industry by RDF utilization

Within the European Union many cement kilns have been adapted to the utilization of alternative fuels and in 2012 already 34% of primary energy carriers were substituted by mixed wastes and RDFs(VÖZ 2015b). Some substitution rates in different countries are summarized in Table 2. In Austria already 75.5% of the thermal energy for the production of cement were provided by RDFs. 100% substitution rates appears feasible (and are already implemented in single plants) if some more efforts are put into the production process of RDFs and cement (e.g. chlorine reduction, optimization of waste mix, drying, grain size reduction, oxygen feed into the kiln) (Pomberger & Sarc 2014). Cement producers in Indonesia report that currently 3 to 9% of the thermal energy in the cement works is provided by fuels derived from waste (Holcim 2014; Semen 2014). A 10% substitution rate in the next few years is put into perspective by the major market player in Indonesia (Semen 2014).

The reported materials thermally utilized are rubber waste, tires, solvents, oils, rice and coffee husk, sawdust, waste shoes and others (Semen 2015; LaFarge NA).

Table 2. Substitution rates of conventional fuels with alternative fuelsin cement plants in selected countries/regions

Country/region	% Substitution	Source	Country/region	% Substitution	Source
Austria (2014)	75.5	a)	China (2012)	1	a)
Germany (2012)	61.1	b)	India (2012)	1	a)
Poland (2010)	62	a)	Philippines (2012)	13	a)
Switzerland(2014)	53.7	c)	Brasil (2012)	18	a)
UK (2012)	44	a)	Thailand (2012)	12	a)
France (2012)	30	a)	Indonesia (2014)	3–9	e), f)
			Australia (2013)	7.8	d)
EU (2012)	34	a)	Global (2012)	14	a)

a) VÖZ (2015b); b) VDZ (2013); c) cemsuisse (2016); d) Rahman et al. (2015); e) Semen (2014); f) Holcim (2014)

Evaluating the potential for CO_2 savings in Indonesian cement industry by RDF utilization

Currently there are 16 major cement plants in operation in Indonesia with a production capacity of almost 67 Mio t cement per year (Cemnet 2004; GlobalCement 2012; Holcim 2015; Semen 2015; GlobalCement 2016; Heidelberg Cement 2016). As seen from Figure 1, the CO_2–emissions from cement industry have tremendously increased over the last 25 years (4–fold increase since 1990). Around 40% of these emissions are estimated to stem from the oxidation of carbon in the utilized fuels (for thermal energy supply) (Tokheim 1999) and can potentially be substituted by alternative fuels with a lower climate relevance than fossil fuels.

In order to assess the potential savings of climate–relevant CO_2–emssions due to the utilization of RDFs from municipal solid waste in Indonesian cement plants, information about the generation rate and the composition of MSW as well as assumptions regarding the transfer of high calorific waste fractions (e.g. plastics, paper) to RDF are combined (see Table 3 and Table 4).

For simplification reasons, it was assumed that RDF for cement works contains only plastics and paper/cardboard present in MSW. Based on compositional data report for Indonesia (MoE 2008) an average content of plastics and paper/cardboard in MSW of 14% and9%, respectively, is used for the analysis performed. Furthermore it is assumed that about 70% of paper and plastics present in MSW can be transferred by mechanical splitting to RDF. This reveals a total available amount of (wet) RDF of around 6.3 Mio t/year. The lower heating value of this RDF is estimated to be in the range of 17 MJ/kg wet matter. It needs to be noticed thatthe heating value is highly influenced by the actual water and ash content of the fuel, which in the present study had to be estimated as no data was available for Indonesia. Combining the potential quantity of RDF with its heating value allows roughly estimating the overall energy supplied by RDF (~ 106.000 TJ/year).

The current energy demand of the Indonesian cement industry is estimated to 180.000 TJ/year assuming a specific energy demand of 2.74 GJ/t cement (VÖZ 2015a) and the overall production capacity of Indonesian cement plants (thus, production on full capacity is assumed). Comparing the energy content of RDF with the energy demand of cement works allows determining a “theoretically” maximum substitution rate for conventional fossil fuels of 58%. This rather low value can be explained by the relatively high water content of Indonesian waste and thus a rather low calorific value (compared to e.g. RDF in Austria with reported heating values of above 20 MJ/kg; Sarc et al. (2014); Sarc et al. (2015); Aldrian et al. (2016)).

By considering specific fossil CO_2–emission from plastic (74.7 kg CO_2/GJ) and paper (0 kg CO_2/GJ) present in RDF (resulting in an average fossil CO_2 emission factor for the RDF considered of about 61 kg CO_2/GJ) and from coal (96 kg CO_2/GJ) potential CO_2–emission savings for different substitution rates can be calculated. The results are show in Figure 2.

Table 3. Characteristics of municipal solid waste in Indonesia and figures considered for cement production (as used for calculations)

Parameter		Source
Total amount of MSW in Indonesia (2008)	38,5 Mio t	MoE (2008)
Content of waste plastics in MSW	14 %	MoE (2008)
Content of waste paper in MSW	9 %	MoE (2008)
RDF production ratio (% of input in RDF plant)	70 %	
Specific energy demand for the production of 1 t cement	2.74 GJ/t	VÖZ (2015a)
Capacity of cement works in Indonesia	66.7 Mio t	Cemnet (2004), Holcim (2015), Semen (2015), GlobalCement (2012); 2016); HeidelbergCement (2016)

Table 4. Assumptions on waste paper and waste plastic present in MSW in Indonesia (used for calculations)

Parameter		Source
Water content of waste plastics	30 %	own estimation based on Kost (2001)
Ash content of waste plastics	15 %	own estimation based on Kost (2001)
Water content of waste paper	40 %	own estimation based on Kost (2001)
Ash content of waste paper	15 %	own estimation based on Kost (2001)
Lower calorific value of waste plastics	8.4MJ/kg	based on Kost (2001) and assumptions on water and ash content
Lower calorific value of waste paper	22.5MJ/kg	based onKost (2001) and assumptions on water and ash content
Lower calorific value of RDF made mainly out of waste plastic (~ 60 %) and waste paper (~ 40 %)	16.8 MJ/kg	calculated
Specific fossil CO_2–emissions of waste plastic	74.7 $kgCO_2/GJ$	based on organic carbon content in packaging waste plastic given in Kost (2001)
Specific fossil CO_2–emissions of RDF	61 $kgCO_2/GJ$	calculated based of emission factor of plastics

Assuming a theoretically possible substitution rate of 58%, fuel based CO_2–emissions of Indonesian cement works could be reduced by almost 3.6 Million tons per year or 21% of the overall energy related emissions, which amount to 17.5 Million tons CO_2/year in case that only coal would be used as energy source. At current RDF utilization rates in Indonesian cement works (fuel substitution rate of 7%) CO_2 savings (in comparison to coal based energy supply) are limited to 0.4 Million tons/a.

Assuming the Austrian fuel substitution rate in the cement industry of 75.5% would theoretically reduce CO_2–emissions by 4.8 Million tons/a or 27%.

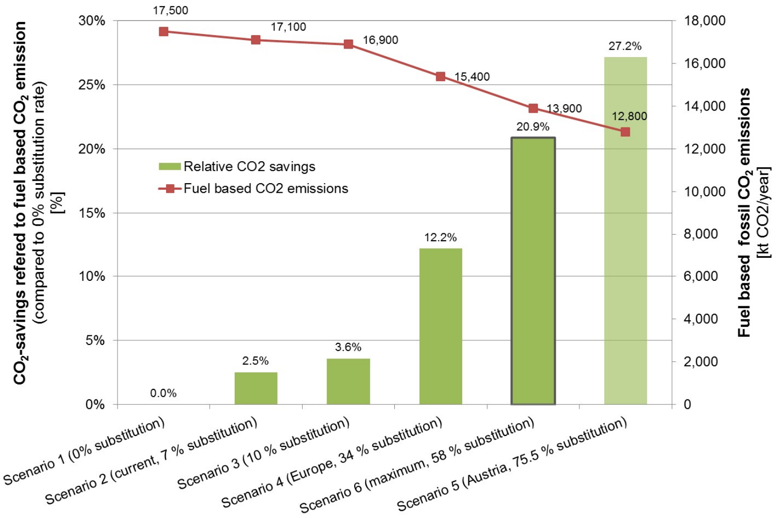

Figure 2. Estimation of possible reductions of fossil CO_2–emissions from Indonesian cement plants by substituting fossil fuels (coal) with refuse derived fuels (from municipal solid waste).

In addition to the direct reduction of CO_2–emissions by the substitution of coal, another saving of GHGs needs to be considered. The generating and utilizing of RDF diverts plastics and paper/cardboard away from landfills. The latter would biochemically decompose at landfills and thereby generate landfill gas, including climate gas methane. At the maximum substitution rate of 58% 2.5 Million tons of paper/cardboard are diverted from landfills. The thereby avoided methane emissions (assuming that 65% of the organic carbon present in paper/cardboard is converted to landfill gas and that 80% of the methane generated at Indonesian landfills is neither collected nor oxidized and thus emitted into the atmosphere) are in the range of 320 Million m^3/a. Considering the GHG potential of methane 28 (IPCC, 2013), this equals to savings of CO_2–equivalents of 6.3Million tons/a.

This result indicates that savings of GHG emissions induced by diverting biodegradable waste from landfills clearly outpaces the savings caused by the substitution of conventional fossil fuels. All in all the potential savings of GHG emissions by the production and utilization of RDF in Indonesian cement works would reach almost 10 Million tons/a, and could thus substantially contribute to a reduction of the overall national GHG emissions.

Conclusions

Refused derived fuels are increasingly used as a low–cost and regionally available energy source for cement works all over the world. In many countries the utilization of conventional fossil fuels (usually coal) in cement plants was thereby significantly reduced. In Austria for instance, RDFs provide more than 75% of the overall energy consumed for cement production. Thereby not only the production costs have been decreased but also the climate impact of cement production, as RDFs usually contain also biogenic matter and thus cause lower fossil CO_2–emission in comparison to most fossil fuels. In the frame of the present study the potential substitution rate for conventional fuels used in Indonesian cement works by the production of RDF has been estimated. It was shown that at maximum 58% of the conventional fuels could be substituted, which goes a long with a reduction of fossil CO_2–emission at cement plants of about 3.6 Million tons/a. In addition RDF production and utilization diverts biodegradable waste (in the present study it was assumed that biogenic matter in RDF includes only paper and cardboard) from landfills, and thereby prevents the generation and emissions of methane from Indonesian landfills. Considering this effect as well, the overall potential savings of GHG emissions increase to about 10 Million tons per years, which equals to about 5% of the total reduction target for GHGs planned by the Indonesian government.

Despite the various benefits (reduction of GHG emissions, saving of primary resources, lower costs for energy, reduction of landfill volume) of RDF production and utilization several challenges need to be kept in mind and are currently preventing many developing countries (including Indonesia) to significantly increase the generation and utilization of refuse derived fuels.

First of all quality aspects, including the calorific value required, the water content, the ash content, the content of chlorine (PVC) or heavy metals are of major importance for a save utilization in cement works. As long as quality standards for RDF cannot be ensured and controlled, its application in production processes is too risky for industries. Another problem arising in Indonesia is the fact that most cement works are located on Java, meaning that RDF from other islands needs to be transported over long distances prior utilization. Hence, besides the construction and operation of RDF production plants (mechanical splitting plants) elaborated transport logistics would be required.

Nonetheless the benefits of RDF utilization prevails over the challenges, meaning that in any case an increased application of RDF in developing countries, including Indonesia, will be observable in the near future.

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