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Dear Readers,

Here we are now; it is the end of 2019 and you are reading this year's last edition of the Co-Processing Magazine. But there is more to this moment! It is not only the end of the year, but also the end of a whirlwind and revolutionary decade in many aspects, which has brought a variety of changes not only to our personal lives but also to the whole industry.

Let us take a moment to reflect and look back. What might seem like a blink of an eye in retrospective, consists of a myriad of experiences and special moments.

For me, personally, the last 10 years were marked by unprecedented ups and downs. The decade began with the birth of my youngest daughter, led me through a time of complete hair loss – gave it back to me - and ended with a final goodbye to one of my closest family members. While it certainly was not what I expected, it felt "full" in every aspect, and most importantly, it has brought me a new outlook on life.

For MVW Lechtenberg & Partner, the last decade brought just as many changes. From 10 employees in 2010 and our offices in Mülheim, the team has evolved steadily and we moved to the greatest inner port of Europe, to Duisburg. We supervised projects on every continent in the world and successfully initiated the Alternative Fuels Symposium, which gathered around 150 experts and professionals for the sixth time in 2019. It brings me great pleasure to see our work bearing fruit and to see alternative fuels become a mainstream solution in many countries to date.

This is also due to a general increase in environmental awareness worldwide. We experienced seven of the warmest ten years on record in this decade [1]. Of course, there are doubters of climate change and general scepticism towards imperative adaption, that we all will eventually face. These often root in fear of change. However, the last decade shows the impact first movers can have, and the bandwagon effect will follow eventually: Just look at the youth movements of 'Friday's for Future' which only started this year.

The same applies to the cement industry and the implementation of alternative fuels. Compared to 15 years ago, where high total substitution rates for alternative fuels where counted with some 10% for international cement groups, some have reached regional rates up to 80%. The global average was at about 17% in 2016 [2]. You will read more on the top 10 cement manufacturers according to their substitution rates on page 25 of this edition.

Sometimes all it requires is a motivating kick, such as increasing fossil fuel prices, and rationality will follow. A best-case example from the Alternative Fuel Award Winner of 2018 is described on page 21.

And since the switch to alternative fuels naturally also bears costs, an approach to financial risk analysis is described in an article by Dr. Hansjörg Diller, starting on page 4.

To sum up the last decade: it leaves me optimistic for our future – on a global scale and for our industry.

Now, let's take a breath, let the last decade and our experiences sink in, collect our thoughts and gird ourselves for what is ahead. Meanwhile, enjoy reading this edition!

The whole MVW Lechtenberg team wishes you and your families a great start to the new year.

References:

[1] NOAA: "Global Climate Report – Annual 2017". Retrieved 16 December 2019 from https://www.ncdc.noaa.gov/sotc/global/201713.

[2] Cement Sustainability Initiative CSI, 2016: "Getting the Numbers Right".

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How Monte Carlo Puts More Confidence to the Decision-making Process on Capital Budgeting for RDF Production and Utilization

By Dr. Hansjörg Diller, MVW Lechtenberg & Partner

1. Introduction

Rising fossil fuel prices as well as regulations from governments urge cement plants to reconsider their fuel portfolio. Consequently, cement plants seek for alternatives to substitute parts of coal, natural gas or heavy fuel oil, and hence, to reduce costs.

A competitive alternative to fossil fuels can be found in waste-derived alternative fuels which have been used in many cement plants, in particular in European facilities, for many years. However, in most of the countries across the globe there is no infrastructure or production opportunities for alternative fuel deliveries. In many cases there is nothing left but to deal with alternative fuel production by the cement operator.

Once the feasibility study supports the technical viability of the project (contemplating waste sources, necessary technical equipment, influences on kiln process as well as on clinker quality and emissions), the financial evaluation of the entire project must show that the project is also profitable. In this paper, Dr. Hansjörg Diller describes an approach to financial risk analysis for use with a common MS-Excel spreadsheet program, which requires no more information than is used in the sensitivity analysis of a discounted cash flow model. It is based on the excellent papers from Clarke/Low [3] and Lifland [4] that afford pedagogical examples of simple approaches with detailed spreadsheet walkthrough. This paper at hand, however, enhances the simple approaches by applying a variety of cost change rates which are linked to historic statistical data.

2. An exemplary setup

We consider an exemplary setup, where combustible fractions (i.e. mostly plastics, paper, and cardboard, as well as some minor wood and textiles) are extracted from municipal solid waste (MSW) to obtain refuse derived fuel (RDF) for calciner firing. The yield of RDF is supposed to be around 26% by weight, and its net calorific value would achieve some 3,800 kcal/kg. Some 70,300 tonnes of RDF are expected to be obtained. The RDF production line would operate in two lines, each consisting of bag openers, drum screens, shredders, wind shifters, and magnets.

The RDF plant would be erected adjacent to the landfill, for waste trucks arrive daily at this central point. This is advantageous, because fractions not being useable for RDF, like wet organic matter, rubble, street sweepings etc., could be diverted to the nearby landfill. It is anticipated that power connection is available to provide 800 kW for the electrical consumers. Once produced, RDF would be carried on the road to the cement plant.

The downstream equipment for feeding RDF consists of a storage, feeding hopper, conveyor to the calciner in the preheater tower, weighfeeder including buffer hopper and rotary valve, and a pneumatic line to the calciner. This exemplary setup is designed to produce and feed some 12 t/h of RDF.

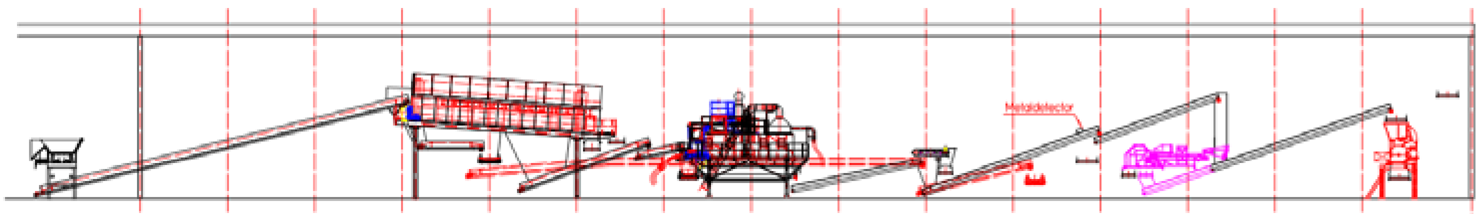

Figure 1: *Typical layout of an RDF production facility.*

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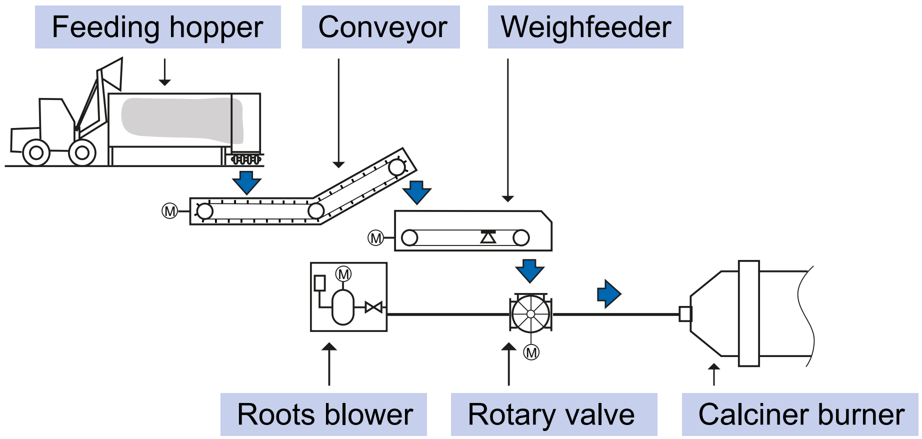

Figure 2: *Typical arrangement of the feeding and dosing equipment.*

How Monte Carlo Puts More Confidence to the Decision-making Process on Capital Budgeting for RDF Production and Utilization

3. Financial feasibility

3.1. Basic settings

The financial feasibility of an RDF production plant including equipment at a cement plant site depends on several variables:

1. Cost of infeed material: The input material is waste that would otherwise end up in a dumpsite or landfill. The diversion of that waste stream to a fuel production plant avoids fees for landfilling. Hence, that waste stream should be available at least with no charges. In the following, infeed waste is considered to be available for free.

2. The exemplary RDF plant at landfill site, plus feeding and dosing equipment in the cement plant as depicted in the figures above, would require a CAPEX of some €5.1 million.

3. The assumed operating expenditures (OPEX) per year are shown in the table 1. For simplification purposes, the detailed basics to obtain the figures are omitted, because for the scope of this article, only the yearly OPEX is decisive. It is assumed that within the start-up phase in the first year, the RDF production plant operates at 80%, and achieves 100% output in the following years. For simplification purposes, OPEX is assumed to be 80% in the first year.

4. RDF would be carried on the road from the RDF production plant to the cement plant. The assumed transport rate is 10 €/t.

5. The cement plant uses coal having a net calorific value of 6,300 kcal/kg. The RDF would achieve a net calorific value of 3,800 kcal/kg. Thus, 1 kg of RDF would substitute 0.60 kg of coal. The output of the RDF plant is around 70,351 tonnes (at 100 % capacity), which is equivalent to 42,434 tonnes of coal. Assuming coal cost of 100 €/t, the annual savings would amount to €4.24 million

3.2. Discounted cash flow assessment (DCF)

When evaluating any capital expenditure project, assumptions must be made concerning a multitude of future variables. The discounted cash flow method is widely used to measure the net present value (NPV) of CAPEX projects. This method is used to estimate the value of an investment based on its future cash flows by finding the present value of expected future cash flows using a discount rate. NPV assumes an initial required interest rate (discount rate) and discounts all future cash flows to present value. The sum of the discounted cash flows is the net present value (NPV). The internal rate of return (IRR) is the interest rate where the net present value equals zero. To make an

	RDF production	Feeding, dosing	Total @ 100 % capacity	Total first year @ 80% capacity
OpEx	x 1000 €	x 1000 €	x 1000 €	x 1000 €
Electricity stationary equipment	395	15	410	328
Maintenance, wear, spare parts stationary equipment	520	5	530	424
Diesel for mobile equipment	385		385	308
Maintenance, wear, spare parts mobile equipment	60		60	48
Staff	185		185	148

Table 1: *Assumed OPEX in Euro for RDF plant in the landfill and feeding and dosing equipment in the cement plant.*

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Year	0	1	2	3	4	5	6
		80% capacity	2nd year and beyond: 100% capacity				
Electricity cost stationary equipment (k € annual)		-328	-410	-410	-410	-410	-410
Maintenance, wear, spare parts stationary equipment (k €)		-424	-530	-530	-530	-530	-530
Maintenance, wear, spare parts mobile equipment (k €)		-48	-60	-60	-60	-60	-60
Mobile equipment: Diesel cost (k € annual)		-308	-385	-385	-385	-385	-385
Staff cost (k € annual)		-148	-185	-185	-185	-185	-185
Raw material costs for RDF production (k € annual)		-563	-704	-704	-704	-704	-704
Savings in coal cost (k € annual)		3,395	4,243	4,243	4,243	4,243	4,243
EBIT (Operating Profit (k €))	0	1,576	1,970	1,970	1,970	1,970	1,970
Capital Expenditures (CapEx) (k €)	-5,100	0	0				
Operating Cash Flow (k €)	-5,100	1,576	1,970	1,970	1,970	1,970	1,970
Accumulated Cash Flow (k €)	-5,100	-3,524	-1,554	416	2,385	4,355	6,325

IRR	28.2%
Payback (return on investment ROI) (years)	3.2
Discount Rate	7%
NPV (k €)	3,921

Table 2: *Result of the discounted cash flow assessment. Numbers are expressed as thousand Euros (k€).*

investment project financially attractive, the NPV must be above zero, and the IRR above the discount rate. Corporations often use the weighted average cost of capital when selecting a discount rate for their financial decisions, which is a blend of the cost of equity and after-tax cost of debt.

Table 2 shows the result of the DCF assessment using the numbers from the previous chapter. It is based on an anticipated discount rate of 7%.

The numbers show a high profitability of the project, as it has a positive NPV and an IRR far greater than the discount rate. However, expected cash flows are only a point estimate of a large number of possible realizations. The discounted cash flow of the predicted future revenues and expenses, as well as its resulting financial metrics are very sensitive to changes in the basic assumptions of the project. Operating cost (e.g. labour, energy, spare parts), and fossil fuel prices will not remain static across the period of assessment. In the course of time, changes of these costs are likely to happen.

The common element in financial risk assessment is that key variables of a project are altered from their assumed central values by a certain factor. One key variable (for instance annual operating cost of the RDF production plant) is increased by a factor of say 5%, 7% or 10%, whilst all other variables remain unaltered, and the effect on financial metrics recorded. Sensitivity analysis is useful in highlighting parameters that require more careful specification, like the volatile prices for electrical energy or fossil fuels. In the DCF model above, applying an adjustment factor of 10% to the coal price would result in an NPV of 9,180 million Euro, IRR of 44%, and payback would be achieved after 2.7

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years. As those values increase, so does the financial attractiveness of the RDF project.

Such sensitivity tests require that adjustment factors for all other parameters, like electricity prices, labour cost, diesel, maintenance, etc. be set constant. Reality showed, however, that annual cost change rates or energy price change rates are not constant from one year to another. Applying all the alterations to the discounted cash flow computation scheme would result umpteen financial metrics which might confuse rather than being informative. To overcome the confusion, the Monte Carlo method provides an intriguing solution.

4. Monte Carlo simulation

4.1. Background

The name Monte Carlo simulation comes from the computer simulations performed during the 1930s for neutron diffusion experiments, and, later on in the Manhattan project during the 1940s to estimate the probability that the chain reaction needed for an atom bomb to detonate. Faced with very limited supplies of uranium and plutonium, they turned to simulation to compute reliable probabilities, and thus reduced the amount of raw material needed for testing. The physicists involved in this work were big fans of gambling, so they gave the simulations the code name Monte Carlo [1, 2]. In the following decades it has turned out that Monte Carlo simulation can not only be used in science, and engineering, but also in business for risk and decision analysis, to help make decisions given uncertainties in market trends, fluctuations, and other uncertain factors.

For a Monte Carlo risk analysis, a number of changes have to be introduced to this set up. First, each cost factor is allowed to vary at random between set limits. The range between the set limits may be a specific distribution of the values, as it will be discussed in the next chapter. The extent of the ranges can be viewed as uncertainty of each of the cost factors. Secondly, all factors are allowed to change simultaneously. The random selection process is repeated many times to create multiple scenarios. Each time a value is randomly selected, it forms one possible set of financial metrics. Together, they give a range of possible solutions, some of which are more probable than others. When repeated several thousands of times, the average solution will give an approximate answer. The accuracy of this answer can be improved by more iterations. Thus, a very large number of financial metrics will be generated and collected. Ultimately, so-called frequency distributions of the financial metrics may be mapped out which will aid to interpret their most probable result.

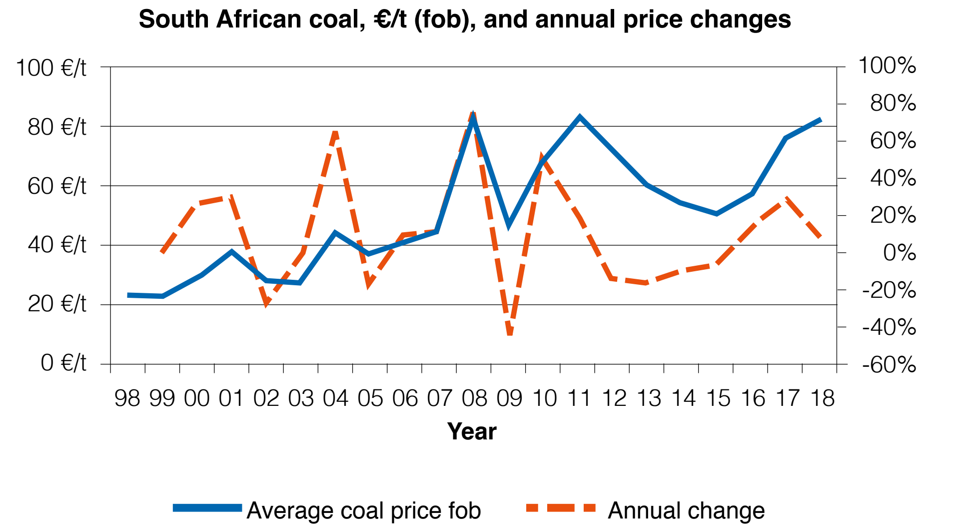

Figure 3: *South African coal: Average free on board (fob) prices (€/t) and annual change rates of coal prices on the right axis (%). Annual coal prices have been calculated from monthly prices from [ref. 6].*

4.2. First step: Probability distributions of cost and price change rates

One of the strongest levers affecting the profitability of an RDF project is the trend in fossil fuel prices. The higher the fossil fuel prices, the more its substitution by RDF pays off. In profitability analysis we consider an annual change rate of the coal prices. To get an idea of the future probable annual change rates, we refer to historic data, as shown in Figure 3. The analysis of change rates in annual average prices show results as given in the graph.

The chart shows impressively, that, for example, coal prices of South African coal have been subject to hefty fluctuations. Over the past 20 years, average coal prices have been changing within the range of around -40% and +80% from one year to the other. To use the percentages of annual changes in the DCF model, the frequency of each of the numbers has to be

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ascertained, or in other words: what percentage number would be the most probable, and what is their range? A visual assessment of the annual price change rates may be obtained by determining their frequencies using a bin size of, for example, 10% (Figure 4).

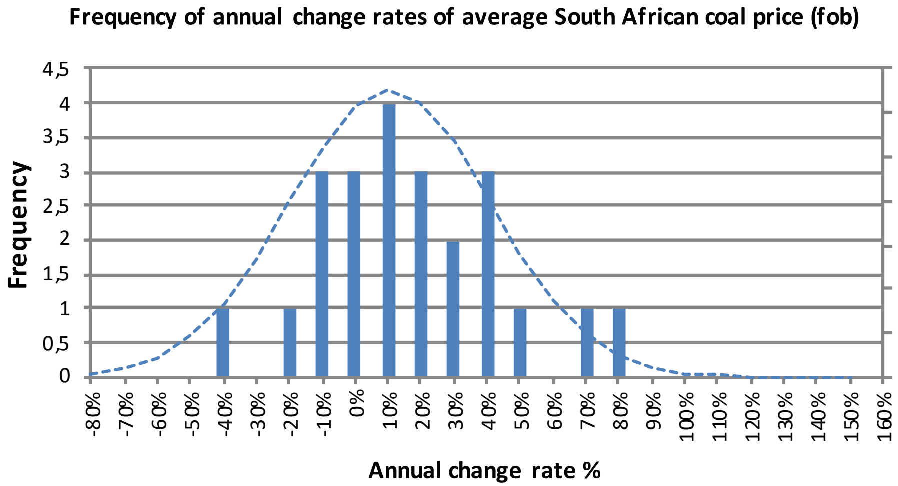

Figure 4: *South African coal: Distribution of annual change rates of average coal prices.*

The distribution data of annual change rates of coal prices will be used in the Monte Carlo simulation of the DCF model by varying the coal price randomly and independently, as well at the same level of variability in all years of the project. To enable the calculation, a specific probability distribution must be adhered to the observed numbers. The dotted line in Figure 4 indicates the underlying normal or Gaussian distribution the observed values would follow. Assuming normal distribution, the average of the annual changes of coal prices is 10.6%, and the standard deviation is 30.5%. This means that there is approximately a 68% chance the annual price change in a given year will be between -19.9% and +41.1% (this is the average plus/minus one standard deviation), and there is approximately a 95% chance the annual price change will be between -50.4% and +71.6% (this is the average plus/minus two times standard deviation). By using a range of possible values from such a distribution, instead of a single guess, one can create a more realistic picture of what might happen in the future to developments in coal prices.

Items	Reference	Probability distribution	Average	Standard deviation	Minimum	Most likely	Maximum
Coal prices	[ref. 6]	Normal	11.3%	32.1%			
Cost factors							
Electricity stationary equipment	[ref. 7]	normal	4.5%	8.7%			
Maintenance, wear, spare parts stationary equipment	[ref. 9]	Normal	2.24%	1.18%			
Diesel for mobile equipment	[ref. 8]	Normal	2.7%	11.9%			
Maintenance, wear, spare parts mobile equipment	[ref. 9]	Normal	2.24%	1.18%			
Labour	[ref. 10]	Normal	1.81%	0.41%			
Road transport	Best estimate	Triangle			0%	5%	10%

Table 3: *Summary of statistical metrics that will be used in the Monte Carlo simulation.*

The same procedure can be applied to the cost factors which are listed in Table 1. Labour cost, electrical energy prices, etc. may be estimated by sources with statistics to incorporate. Table 3 shows all the items as well as their sources, and chosen statistics to incorporate for the exemplary RDF project.

The analysis of the statistical numbers showed that they follow normal distribution, except for transport cost, where no statistical data could

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be retrieved. In this case we use a triangular distribution, since there is no idea about the actual distribution but there is some idea regarding the minimum and maximum value for the variable, and an idea about the most likely value. In this case, we assume a 5% change rate per year to be the most probable, with boundaries at 0%, and 10% having the lowest probabilities.

4.3. Second step: Running Monte Carlo

The frequency distributions and statistical metrics of the coal prices as well as those of the cost factors from Table 3 are applied to the DCF model (Table 2) in such a way that costs are varied randomly and independently and that the same level of variability would apply in all years of the project. Table 4 shows a snapshot of the Monte Carlo DCF model where yearly cost adjustments are expressed as change rate in percent. The numbers are randomly drawn from the underlying distribution, and in every year of the project the rates are independently drawn at random.

To obtain the growth factors from their normal distributions, an Excel built-in function can be used together with the probability and average value as well as standard deviation from Table 3: NORM.INV(rand(),average, standard deviation). In lieu of probability, the built-in "rand()" is placed which generates a random number that is equally likely to assume any value between 0 and 1.

For triangular distribution (in this project case it is the row "Transport RDF: price changes",

Year	0	1	2	3	4	5	6
		80 % capacity	2nd year and beyond: 100 % capacity				
Electricity price adjustment			20.8%	-1.5%	-6.3%	-1.8%	-3.6%
Electricity cost stationary equipment (k € annual)		-328	-478	-471	-441	-433	-418
Maintenance, wear, spare parts stationary equipment cost change			3.3%	2.7%	2.0%	3.9%	3.4%
Maintenance, wear, spare parts stationary equipment (k €)		-424	-544	-559	-570	-592	-613
Maintenance, wear, spare parts mobile equipment cost change			3.7%	3.4%	2.1%	3.4%	2.6%
Maintenance, wear, spare parts mobile equipment (k €)		-48	-62	-64	-65	-67	-69
Mobile equipment: Diesel price change			1.6%	12.5%	-6.2%	-20.2%	20.7%
Mobile equipment: Diesel cost (k € annual)		-308	-390	-439	-411	-328	-396
Staff cost changes (%)			1.6%	1.8%	1.1%	2.3%	1.3%
Staff cost (k € annual)		-148	-187	-191	-193	-197	-200
Transport RDF: price changes			5.5%	5.5%	5.6%	5.2%	4.7%
Transport of RDF to the cement plant: €/t		10 €/t	10.6 €/t	11.1 €/t	11.7 €/t	12.4 €/t	12.9 €/t
Raw material costs for RDF production (k € annual)		-563	-742	-783	-826	-870	-910
Coal price: change rate			19.7%	-39.6%	8.9%	-9.7%	-12.3%
Coal price incl. transport: €/t		100 €/t	120 €/t	72 €/t	79 €/t	71 €/t	62 €/t
Savings in coal cost (k € annual)		3,395	5,078	3,069	3,341	3,015	2,644
Capital Expenditures (CapEx) (k €)	-5,100	0	0				
Operating Cash Flow (k €)	-5,100	1,576	2,674	563	833	527	38
Accumulated Cash Flow (k €)	-5,100	-3,524	-850	-288	545	1,072	1,110

Table 4: *Discounted cash flow model including randomly selected growth rates from the respective probability distributions of the cost factors and coal prices. The numbers shown are merely a snapshot within the Monte Carlo simulation.*

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	NPV (*1000 €)	Payback (years)	IRR
1	11,595	3.3	45%
2	20,841	2	74%
3	10,203	2	50%
4	26,933	2	85%
5	14,837	2	61%
6	11,077	3	47%
7	1,768	4	19%
8	4,544	3	32%
9	2,358	4	20%
10	-6,491	>10	#ZAHL!
11	2,784	4	23%
12	45,649	2	92%
13	33,236	2	82%
14	10,967	3	44%
15	6,601	2	44%
16	-699	7	1%
17	5,182	2	36%
18	3,373	4	24%
19	1,127	>10	16%
……	……	……	…….
100.000	2,298	3.4	21.5%

Table 5: *Resulting financial metrics from the first 19 out of 100,000 trials or runs of Monte Carlo simulation (truncated results).*

see table 4), there is no Excel built-in function. However, the formula can be obtained from [13] which also uses the random number generator.

Refreshing the spreadsheet setup repeatedly will result in numerous "snapshots" similar to the outline above. When putting the resulting financial metrics into a table, it would look as shown in table 5.

The outcome is a frequency distribution of the financial metrics. The more repetitions or trials, the better the simulated output frequency distributions of the financial metrics. Low trial numbers result in poor distribution shapes and give a wider spread of average values or standard deviations. In our showcase, we have applied 100,000 trials or repetitions to the Monte Carlo discounted cash flow model. In MS-Excel, this calculation takes only some 20 seconds.

4.3.1. Net present values

The frequency distribution of NPVs bears all possible results from the variations of the input factors. The probability for rejection of the investment, and therefore the risk, can be ascertained from the frequency distribution. In other words: The frequency distribution of the outcome tells about the probability for acceptance or rejection of the CAPEX project.

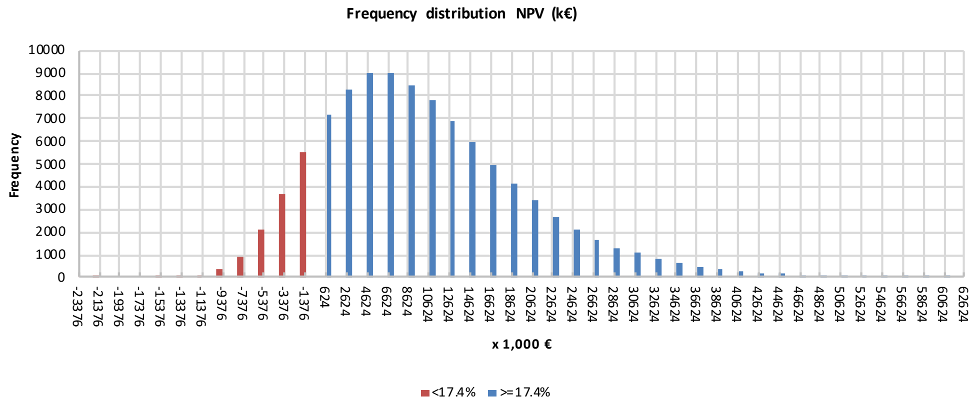

Figure 5: *Resulting frequency distribution of NPVs from 100,000 Monte Carlo trials. The red bars (each having bin size of 2,000 €) indicate negative NPVs.*

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The chart of the resulting NPVs (Figure 5) shows that there is a 17.4% chance of negative NPVs which indicate the risk of the investment to not pay off. In the chart, negative NPVs are highlighted in red. Whilst the investor has to decide the amount of risk he is willing to take with this project, almost 82.6% of the probability mass is between zero and around €66 million; the latter, however, with very low probability in a long-tailed curve (highlighted in blue).

The mode value is around €6 million, which reflects the most frequent NPV. Since the frequency distribution is not symmetric, but skewed to the left, the average NPV of €9.1 million does not coincide with the most frequent value.

4.3.2. Payback (ROI)

Another primary output of the Monte Carlo simulation is the distribution function of payback years with the probability of a payback within the projected time (6 years) at nearly 81%, and, vice versa, some 19% probability of payback periods beyond the project's time line. The most frequent ROI is at 2.2 years (Figure 6). The probability of faster payback periods than the mode value of 2.2 years is 23.5%.

When looking at Table 5 there are figures like ">10" in column "payback", indicating no return on investment within 10 years. This is corroborated by the respective high negative NPV, showing that future cash flows will be negative, and the project shall be rejected. Such ">10" values are not numerals and cannot be considered in the statistical assessment and visualisation. Hence, whenever such a figure occurs in the table, it is not considered for statistical evaluation.

4.3.3. Internal rate of return

The internal rate of return is a widely used tool for evaluating cash flows. However, IRR has to be handled with care, for it is subject to well-known difficulties and flaws. Normally, the cash flow shows a pattern in which cash flows change sign only once, i.e. all net cash outflows occur at the start of the project, followed by all net cash inflows. In other words, there are continuous streams of net cash inflows or net cash outflows [11], as it is the case in Table 2, and one IRR will be obtained. However, when net cash outflows may occur at the start of the project, followed by net cash inflows, followed by further net cash outflows, then two or more IRRs may be obtained [11]. When multiple IRRs are found there is no rational means for judging which of them is most appropriate for determining economic desirability. Ultimately, cash flow streams can even have no real-valued internal rate at all [12]. Because of these deficiencies, IRR will not be considered in this case.

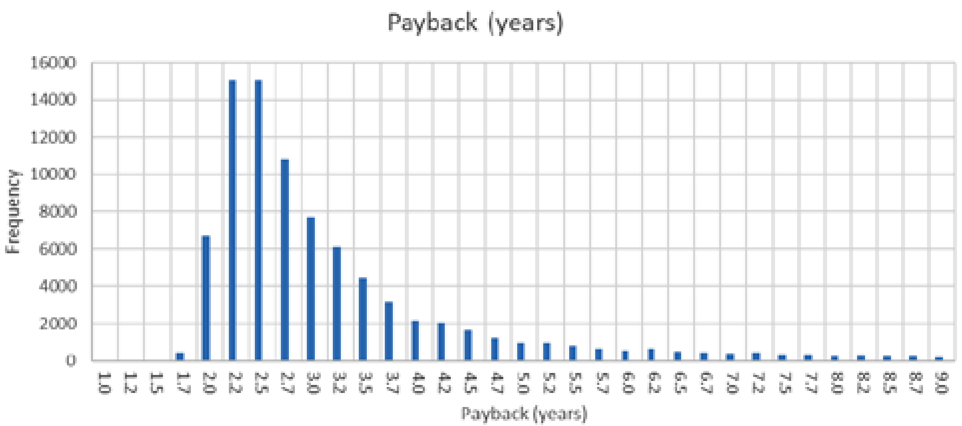

Figure 6: *Resulting frequency distribution of payback years, with bin sizes of 3 months.*

	Simple DCF model	Simple DCF model where coal price changes by +10% (sensitivity analysis)	Monte Carlo simulation
Reference	Table 2	Table 2	Table 4
Outcome	Point estimates	Point estimates	Probability distributions
NPV (million Euro)	3,921	9,180	17.4% probability that NPV is <0
Payback (years)	3.2	2.7	23.5% probability that ROI is faster than 2.2 yrs.
IRR (%)	28.2	44	Ambiguous IRRs, to be rejected

Table 6: *Summary of financial metrics of the discussed discounted cash flow models.*

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5. Conclusion

The purpose of this article is to demonstrate the usefulness of Monte Carlo simulation and the incorporation of risk into an RDF project. In the traditional discounted cash flow model, forecast revenues and cost rely on single point estimates. To account for the uncertainty in the estimates for revenue and cost increases, usually one makes a separate calculation for each combination of revenue and cost. The Monte Carlo simulation technique enables to forecast the entire range of results possible for a given situation. For the example given in this paper, the traditional discounted cash flow model as well as the Monte Carlo simulation results in the numbers as shown in table 6.

Financial modelling using MS-Excel is a useful tool for visualizing and quantifying the effects of uncertainty and risk on capital budgeting decisions. Stochastic values for operating costs of an RDF facility and feeding and dosing equipment as well as coal prices were incorporated into the discounted cash flow model using historical statistical data to forecasting change rates of annual costs and coal prices, thus facilitating a simulation risk analysis. While it is a much more complete picture of a project's potential than the traditional sensitivity or scenario analysis, it is only as effective as the estimates of numbers and distributions and the awareness of the weaknesses. Monte Carlo simulation will not give an explicit accept/reject decision criterion, it simply produces probabilities based on the inputted distributions; there is always going to be unaccounted for and unforeseeable risk.

Care has to be taken in interpreting the usual financial metrics. Cash flows can have more than one IRR or even no IRR (the latter results in a computing error), thus misleading in any decision for approving the project. Due to the problems inherent in IRR methodology, NPV in combination with ROI is the preferred capital budgeting tool.

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Figure 1: *SRF in a screw conveyor*

Co-Processing Magazine of Alternative Fuels & Raw Materials

How Certain Are Numbers From Carbon Dioxide Emissions?

By Dr. Hansjörg Diller, MVW Lechtenberg & Partner

1. Introduction

One method to encourage and regulate companies to reduce the greenhouse gas emissions resulting from their activities is mandatory reporting of these greenhouse gas emissions. In Europe, for instance, there are the Scheme for GHG Emission Allowance Trading Directive as well as the Monitoring and Reporting Regulation (MRR) in place as basis for the European Union Emissions Trading System (EU-ETS). Among other provisions, the MRR sets out reporting requirements, including calculation methods for greenhouse gas quantification. The Monitoring and Reporting Regulation (Regulation 601/2012 / EU, MRR) lays down rules for the monitoring and reporting of greenhouse gas emissions and activity data [1].

Emissions information typically is obtained either through direct on-site emission measurements or by using engineering emission techniques that are based on appropriate equations, models, or emission factors describing the physical process (article 21, MRR [1]). To obtain emissions information from combustion processes, calculation-based approaches by using the so-called standard methodology are widely used in the industry. Standard methodology requires measurements of the fuel consumption and the fuel properties like carbon content, net calorific value, and biomass content (Art. 24, MRR [1]). Measurement data are always subject to uncertainties, so are the calculated carbon dioxide emissions. In this paper Dr. Hansjörg Diller examines two case studies in which lignite dust and solid recovered fuel (SRF) are being combusted, with the range of fossil carbon dioxide emissions that can be expected from the associated measurement uncertainties.

2. Calculating fossil CO_2 emissions

If the quantity of carbon dioxide from combustion is not determined by a continuous emission monitoring system of the exhaust gases, volumes of CO_2 can be derived from the chemical analyses of the fuels combusted and their weights.

2.1. Analyses values and tonnages

The values from laboratory analyses are displayed in figures 1 and 2. The figures also contain the delivered fuel volumes which are attributed to the analysis values.

In this paper, numbers from laboratory analyses always refer to the fuel "as received", i.e.

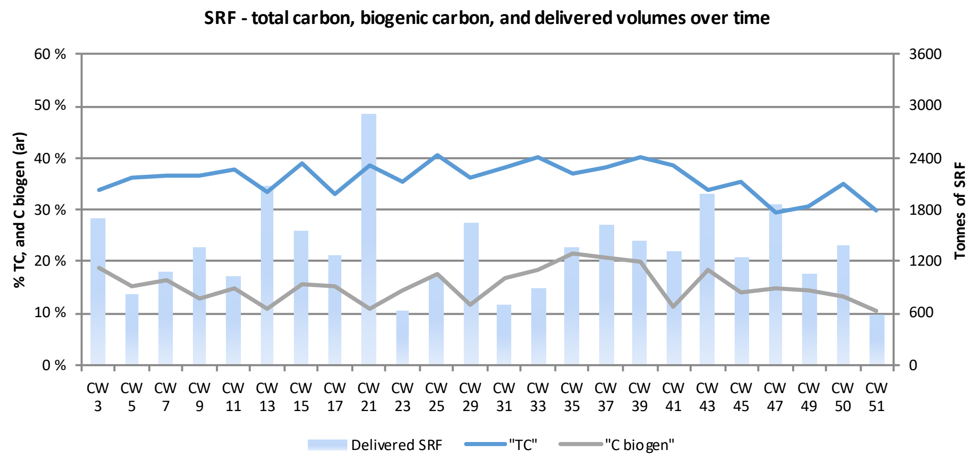

Figure 2: *Plot of TC and* C_{biogen} *of SRF as well as delivered volumes over timeline of 1 year (CW = calendar week; ar = as received)*

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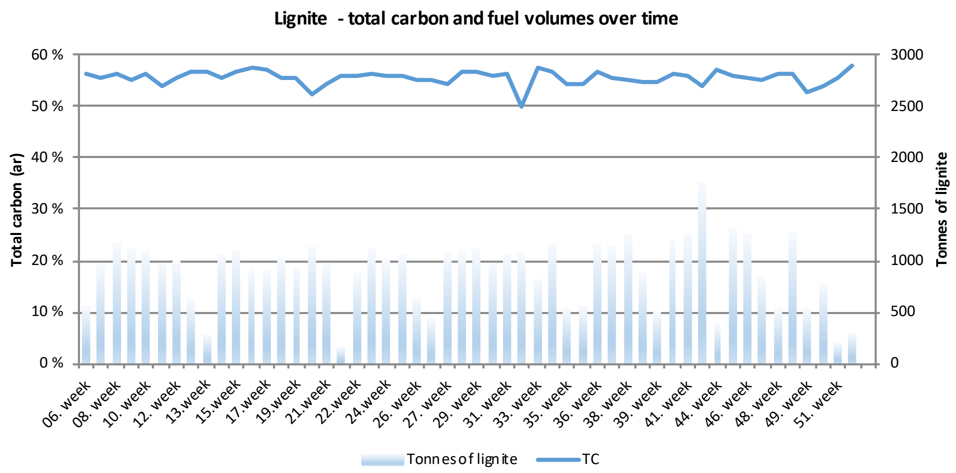

***Figure 3:** Plot of TC and delivered fuel volumes of lignite within 1 year (ar = as received)*

including moisture, to keep the computations of carbon dioxide simple.

2.2. Calculation of annual tonnes of fossil CO_2 emissions

In addition to the analysis's values, the above-mentioned figures also show the tonnages of lignite dust and SRF. Deliveries of lignite and SRF are not constant from one week to the other. The analysis data are allocated to the respective fuel volumes in the respective calendar week, as fuel samples have been taken in each calendar week to represent the assigned fuel "batch". To calculate carbon dioxide emissions of the entire year, the **weighted averages** rather than arithmetic averages of carbon contents (total carbon TC, and biogenic carbon, C_{bio}) have to be used to calculate annual tonnes of CO_2. Table 1 shows the respective statistical values.

The weighted average not only includes the average of a collection of numbers (i.e. the TC and C_{bio}), but also considers their "weight", or importance, as they are allocated to a greater tonnage than other numbers. Those TC and C_{bio} which are allocated to smaller tonnage of fuel "weigh" less than others. The use of arithmetical averages can only be justified if all

Lignite: 46,837 t x 55.48%/100 x 3.664 = 42,775 t fossil CO_2

SRF:
a) Total CO_2: 32,613 t x 35.98%/100 x 3.664 = 42,994 t
B) Biogenic CO_2: 32,613 t x 15.22%/100 x 3.664 = 18,186 t
C) Fossil CO_2: 42,994 t – 18,186 t = 24,808 t

"batches" of fuel have the same weight [3]. The same rationale applies to the standard deviation which has to be calculated as weighted standard deviation.

The annual tonnes of CO_2 from the data in table 1 are being calculated easily. Only the carbon contents (total and biogenic) as well as the fuel volumes are needed.

The factor 3.664 represents the 3.664 tonnes of CO_2 yielded by burning one tonne of carbon. It is mostly taken for granted that fuels are combusted completely, i.e. all carbon is converted into CO_2. Hence, the oxidation factor is always equal to 1. No energy-related emission factors are needed, as it is required by [1], as the amount of carbon dioxide depends only on the carbon content and amount of fuel.

3. Fuel data and uncertainties

When calculating GHG emissions, it is always necessary to evaluate and quantify the uncertainties of the estimates. Uncertainty analyses help operators of industrial installations and competent authorities identify how accurate the estimations are and the likely range in which the true value of the emissions fall.

	Lignite		SRF		
	Tonnes	TC (ar)	Tonnes	TC (ar)	Cbiogen (ar)
Sum of fuel deliveries	46,837		32,613		
Weighted average		55.48%		35.98%	15.22%
Weighted standard deviation		1.39%		3.0%	3.27%
Relative weighted standard deviation		2.5%		8.4%	21.5%

***Table 1:** Fuel volumes and analyses data covering one year*

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In case of the standard methodology, laboratory analyses on the fuels (total carbon (TC), as well as biomass fraction) have to be carried out regularly. Every measurement is connected with some uncertainty, such as data quality and reliability of the resulting number of CO_2 emission, which is actually an average tonnage associated with an unknown uncertainty.

In general, the uncertainty of carbon dioxide emissions from the stack is not assessed. Exempted from this are installations where continuous emissions monitoring systems (CEMS) are in place to determine the amount of greenhouse gas emissions. In other cases, installations apply the so-called "fall-back methodology" [2]. This paper shows an assessment of variations in final fossil-derived carbon dioxide emissions which have been calculated from the weights of the fuel as well as from the analyses results from fuel samples.

3.1. Uncertainty of weights

Any measuring device, whether it is a scale or chemical or physical analysis device, is associated with measurement uncertainty. For instance, weighing uncertainty means that no measurement is perfect; it is always distorted by random errors and unknown systematic errors. It is often expressed as an error associated with the weight. In the case studies at hand, the volumes of lignite and SRF entering the facility by trucks are being determined by calibrated vehicle weighbridges with an uncertainty of ±0.2% at 60 tonnes peak load, or ±50 kg. It can be assumed that all weights within the error margin have the same probability, thus following a rectangular distribution. To convert the linearity contribution of the weighbridge to a standard uncertainty, one computes:

$$\frac{50\text{kg}}{\sqrt{3}} = 28.9 \text{ kg}$$

This standard uncertainty is valid for every single truckload entering the facility. When weighing multiple truckloads, the uncertainty increases. In the case of SRF, 32,613 tonnes have been carried by 1,305 trucks. The combined uncertainty is 1,305 x 0.0289 t = 37.67 t. In the case of lignite dust, 1,874 trucks have carried 46,862 tonnes. The combined uncertainty for the whole lignite volume is 54.1 tonnes.

3.2. Uncertainty of analyses data

Sampling puts a far greater contribution to uncertainties of the results of the laboratory analyses than the laboratory analyses themselves. This becomes particularly more important with heterogeneous material, like SRF. With lignite dust, heterogeneity is less than alternative fuels, and uncertainty obtained from analyses results is lower.

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When looking at Figure 2 and Figure 3, it is very obvious that analyses values from SRF fluctuate to a far greater extent than those from lignite dust. The extent of fluctuations can be expressed by the relative standard deviations (RSD) which are shown in Table 2. The RSD of total carbon of lignite is 1.39%/55.48% = 2.5%, which is far less than that from SRF (8.4% for TC). RSD of C_{biogen} is very high: 21.5%. To recap: The standard deviation is a measure that is used to quantify the dispersion of a set of data values. A low standard deviation indicates that the data points tend to be close to the average (or the mean) of the set, whilst a high standard deviation indicates that the data points are spread out over a wider range of values. When comparing standard deviations from different data sets it is of use to compare their relative standard deviation. It compares the "regular" standard deviation to the mean of a data set to draw conclusions from the relative difference.

Proper sampling is the utmost important step before carrying out any laboratory analyses. It helps minimizing the fluctuations on analysis results and adds more confidence to the values. SRF is heterogeneous by nature, and representative sampling is much more challenging than sampling of more homogeneous lignite. However, since the aim of the paper at hand is not the description of proper sampling, the reader may find appropriate guidelines in [4].

Intuitively, such variations of the analyses' values, and, ultimately, also the small variations from determination of the fuel weights must have some influence on the final value of fossil CO_2 emission. At the end of the day, the calculation of CO_2 as shown above in chapter 2.2 is an estimation, for the calculation considers weighted averages of the carbon contents, and averages are always being considered as best estimates of a range of numbers.

3.3. Method to obtain the range of CO_2 emissions from frequency distributions

The Monte Carlo approach can be applied to derive the range of fossil CO_2 emissions. It in-

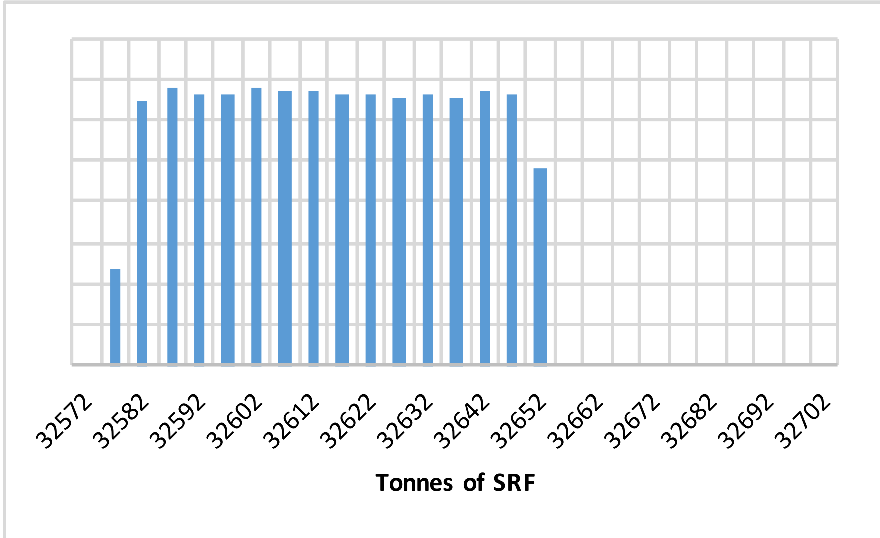

Figure 4: *Rectangular frequency distribution of weights of delivered SRF.*

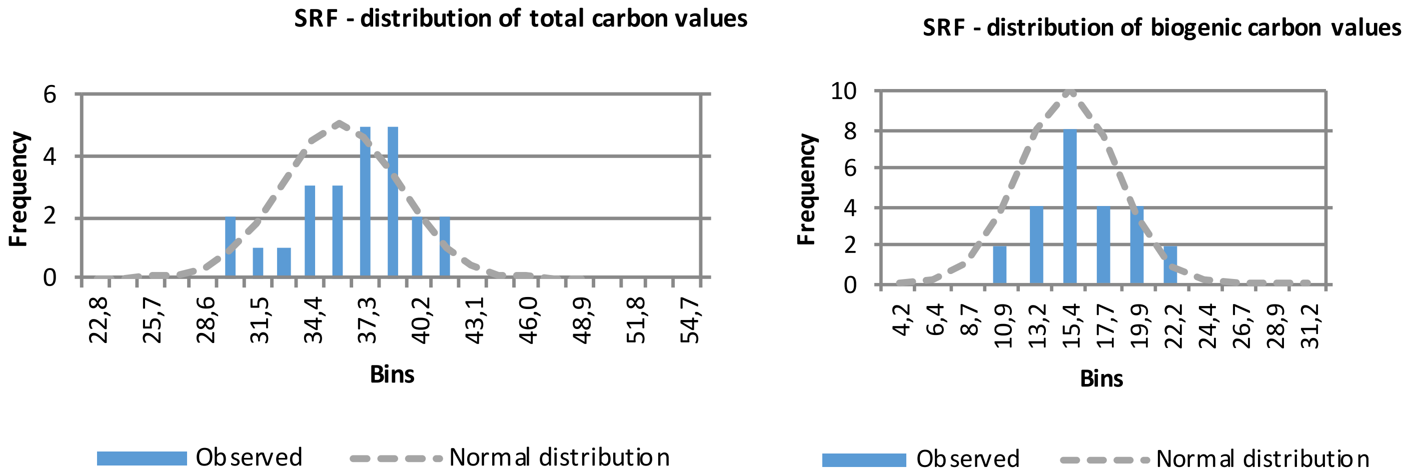

Figure 5: *Frequency distribution of analyses values from SRF (from Figure 2)*

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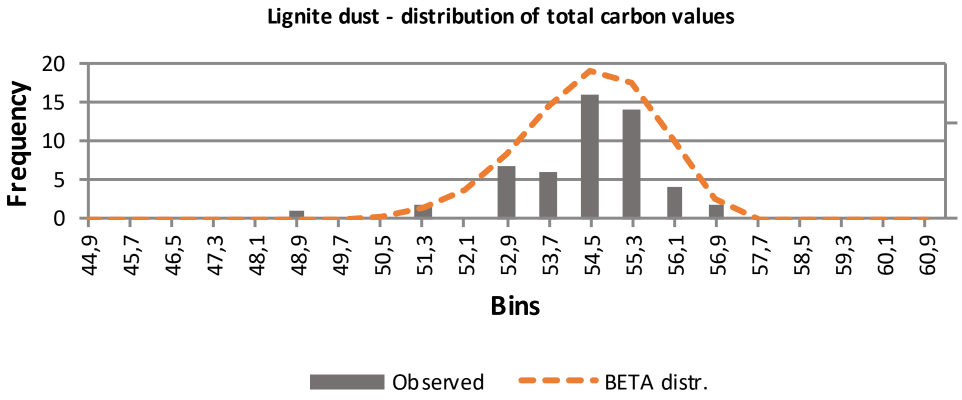

Figure 6: *Frequency distribution of analyses values from lignite (from Figure 3)*

volves the repeated simulation of samples within the frequency distributions of the analyses and weighing data.

As explained in chapter 3.1, weights of truckloads follow a rectangular frequency distribution, which is shown in the figure 4.

The analyses numbers from and figure 2 and figure 3 are converted into the frequency distributions in figure 5.

The bar charts show the distribution of the analyses value from TC and C_{biogen}. Frequency distributions show how many values in a block fall within given value intervals or bins. For example, the bin "15.4%" in the chart showing the distribution of biogenic carbon, reads: 8 analysis values lie between 13.2% and 15.4%. The dotted lines indicate the underlying normal or Gaussian distribution the observed values would follow.

The respective chart of frequency distribution of total carbon values from lignite is shown in figure 6. The distribution of the analysis results is somewhat skewed to the right with a long tailing on the left. The values are not normally distributed, but rather follow a so-called beta-distribution, which is indicated by the dotted line.

4. Running Monte Carlo

The Monte Carlo procedure uses randomly generated numbers (generated by the Excel built-in function rand()) which are then forced to follow the prescribed probability distributions as described in chapter 3.2.

For a normal distribution, the spread of random numbers is predetermined by its weighted average and standard deviation. For a beta distribution, the spread is defined by the so-called shape factors alpha, and beta, as well as predefined minimum and maximum values. The respective Excel built-in functions are shown in Table 3. The basic statistical numbers which are used in the Monte Carlo simulation model are summarized in table 2.

The Monte Carlo procedure generates a numeric value drawn at random from the respective frequency distributions of the analyses' numbers and fuel weights. Numeric values derived in this manner are produced for all inputs according to the computations in chapter 2 to produce a single numeric CO_2 tonnage as

	SRF			Lignite	
Parameter	**TC % (ar)**	**Cbiogen % (ar)**	**Tonnes**	**TC % (ar)**	**Tonnes**
Distribution	Normal	Normal	Rectangular	Beta	Rectangular
Min				46.00 %	
Max				59.70 %	
weighted average	35.98%	15.22%			
weighted stand. dev.	3.01%	3.27%			
Alpha				15.92	
Beta				5.87	
Total tonnes			32,613 t		46,861 t
Combined standard uncertainty of vehicle weighbridge			37.67 t		54.1 t

Table 2: *Basic statistical numbers from frequency distributions (Figure 3, Figure 3), and uncertainty of delivered fuel volumes (chapter 3.1, 3.3).*

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Trials	TC % (ar)	Cbiogen % (ar)	SRF (tonnes)	CO_2 total (tonnes)	CO_2 biogen (tonnes)	CO_2 fossil (tonnes)
1	37.77 %	17.93 %	32,589 t	45,101 t	21,413 t	23,687 t
2	36.46 %	12.58 %	32,637 t	43,597 t	15,043 t	28,554 t
3	37.52 %	16.60 %	32,612 t	44,830 t	19,835 t	24,995 t
4	35.69 %	13.72 %	32,607 t	42,641 t	16,386 t	26,254 t
5	37.29 %	19.36 %	32,577 t	44,511 t	23,109 t	21,402 t
6	38.98 %	14.42 %	32,643 t	46,616 t	17,251 t	29,364 t
7	36.38 %	14.42 %	32,622 t	43,483 t	17,236 t	26,246 t
8	31.35 %	16.63 %	32,627 t	37,478 t	19,876 t	17,602 t
…..	…..	……	…..	…..	…..	…..
…..	…..	……	…..	…..	…..	…..
100,000	36.96 %	11.72 %	32,638 t	44,199 t	14,021 t	30,178 t
Formula:	A)	A)	A)	TC*Tonnes/100*3.664	Cbio*Tonnes/100*3.664	CO2total-CO2bio

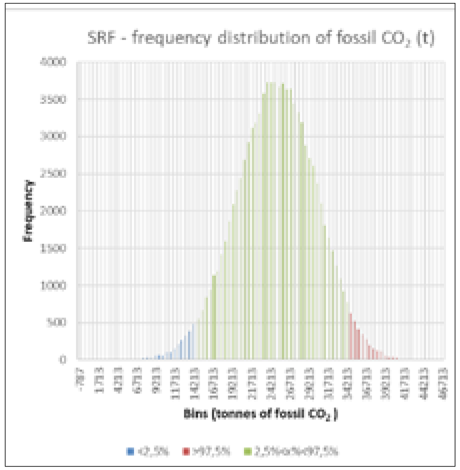
The simulated CO_2 fossil values in each of the 100,000 rows (trials) are derived from the input variables from Table 2:
Column "TC": *norm.inv(rand();35.98;3.01).* Column "Cbiogen": *norm.inv(rand(); 15.22;3.27).*
Column "Tonnes": Total tonnes + 2 x (37.67 * (rand() – 0.5))

Table 3: *Excel spreadsheet representation showing an extract of 100,000 trials for the quantity of CO_2 from SRF.*

output. This process is repeated 100,000 times to produce a stable set of simulated CO_2 tonnages as output.

Table 3 shows an excerpt of an Excel spreadsheet using Monte Carlo simulation to derive fossil CO_2 from SRF. The spreadsheet for lignite is omitted, for it contains the same computation scheme, with the exception of omitting the calculation of biogenic CO_2 (for there is no biogenic carbon in lignite), while TC of lignite is simulated using *beta.inv(rand();alpha;beta;min;-max)* because of its beta distribution.

The mean and standard deviation for the 100,000 fossil CO_2 trials provide an estimate of the true value and its coverage interval. A visual assessment of the outcome of the simulations from SRF and lignite may be obtained by determining the frequency of the simulated fossil CO_2 values using bin sizes of 500 or 200 tonnes, respectively, as shown in figure 7.



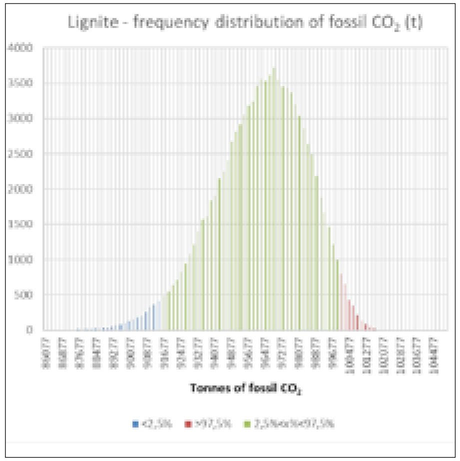


Figure 7: *Results of Monte Carlo simulation: annual volumes of fossil CO_2 from SRF (above), and lignite (below).*

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According to IPCC [5] a 95% confidence interval should be calculated as a definition of the range of uncertainty. In figure 7 the green bars indicate tonnes of fossil CO_2 which are between the $2,5^{th}$ and $97,5^{th}$ percentile values. The bars represent 95% of the simulated CO_2 values.

The uncertainty of fossil CO_2 is obtained by the formula $100*(97.5^{th} -2.5^{th}$ percentile) *0.5/ average value. In case of SRF, the uncertainty of simulated fossil CO_2 is high, namely 41%, while in the case of lignite dust the respective uncertainty is low, only 4.4%.

The large uncertainty of simulated fossil CO_2 emission volumes from SRF is nearly tenfold than uncertainty of fossil CO_2 from lignite. This results from the high standard deviations of the analyses values of TC and C_{biogen} (see Table 2) of SRF. Hence, the confidence in the average fossil CO_2 number from SRF is lower. Uncertainty of the number of fossil CO_2 emissions can only be reduced by improving the sampling procedure. As commonly known, sampling is the decisive factor for the extent of variations of results from laboratory analyses [4].

5. Conclusion

Monte Carlo simulation is a powerful method to ascertain and visualize the extent of the uncertainty of CO_2 emission numbers, which are usually obtained only from mean values of a series of various chemical analyses numbers of combusted fuels as well as their weights, and can be easily carried out by means of standard spreadsheet software. Visualisation of the simulation results shows impressively that higher standard deviations of analyses numbers result in broad distributions of final fossil CO_2 emission values, which means that such numbers are connected with high uncertainties, and vice versa. Reducing uncertainties of fossil CO_2 being emitted to the environs can only be achieved by putting more effort into proper sampling of the fuels, in particular when using inhomogeneous alternative fuels. This will for sure reduce the fluctuations of the analyses results, thus by smaller standard deviations, and will put more confidence into reported CO_2 numbers.

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3rd Alternative Fuel Award 2018

Interwaste: Waste Derived Fuel Implementation Case Study

Interwaste Pty Ltd., South Africa, won the third prize in 2018's Alternative Fuels Award competition. The award is presented annually during the Alternative Fuels Symposium to companies, cities, institutions and individuals promoting the idea of sustainable alternative fuel's production and use and to encourage the acceptance of the ecological responsibility on both social and individual levels. The following article is an excerpt of Interwaste's award application.

On August 2013, a legislation banning the disposal of hazardous waste with calorific values greater than 25 MJ/kg and total organic content >6% to landfill was released (GNR 636 of 23 August 2013). The complete ban is set to take a period of 15 years from the date of issue thus compelling waste generators to reduce, reuse, recycle and recover chemical and hazardous waste with parameters above the set limits. With the objective of complying with the new regulations, Interwaste has constructed a blending platform facility, where suitable hydrocarbon and chemical hazardous waste from various industrial generators are stored and subsequently blended to generate an alternative fuel. This alternative fuel will be combusted at an Afrisam cement kiln in Lichtenburg, North West, South Africa. The banning of the disposal of certain waste types to landfill offers an advantage to waste managers since the process of recycling, recovering and disposal of chemical and hazardous waste incurs high costs on the generator.

This project description focusses on the waste derived fuel project undertaken by Interwaste Pty Ltd in partnership with Afrisam SA Pty Ltd. In addition, the environmental impact assessment process completed as well as the problems and issues encountered in the project will be described.

The goal of the project is to supply 1,000 tonnes per month of consistent fuel to Afrisam and to progress from trial to permanent implementation. Subsequently, the project aims to maximise the use of alternative fuels in cement kilns across the country.

Co-processing in cement kilns

The use of certain hazardous and chemical waste as an alternative fuel source in cement production originates from the 1970s. Subsequently, a global shift in cement companies to substitute fossil fuels with alternative fuels has been observed. This follows the continued pressure on cement companies to mitigate and reduce their carbon emissions. About 5% of the global carbon emissions is generated by cement industries (Metz et al., 2007).

Chemical and hazardous wastes are ideal for co-processing as they generally have a higher calorific value. Hazardous waste, such as electronic waste, whole batteries, radioactive waste, explosives, mineral acids, and corrosives, are not suitable for co-processing and thus cannot be blended (GTZ and Holcim, 2006). Co-processing in cement kilns is effective as the high temperatures and longer residence time allows for the complete destruction of the fuel. The alternative fuel used in cement kilns is waste that would have otherwise been incinerated or landfilled resulting in additional emissions.

Furthermore, the process has been shown to contribute to the reduction of greenhouse gas emissions (Georgiopoulou and Lyberatos, 2017)

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Figure 1: *Industry chemical hazardous waste stored at the blending facility prior to blending.*

as well as reduce operational and economic costs for cement companies.

The blending platform facility / waste derived fuel

Interwaste is one of the founding companies to introduce the production of liquid fuels for co-processing in South Africa. The company has proven experience in blending hydrocarbon and chemical hazardous wastes and has now commissioned a blending platform facility at one of its sites in Germiston, South Africa. A total of 6 to 7 million rand was invested in the project and the facility is 100% solely owned by Interwaste Pty Ltd.

A blending platform facility is where suitable hydrocarbon and chemical hazardous waste from various industrial generators are stored and subsequently blended to generate a fuel (Figure 1).

The characteristics of the waste required for blending is in the form of liquid or sludge. The fundamentals of the blending procedure require the waste blended to match the calorific value of the fossil fuel utilised at the cement kiln (Loulos, 2008).

The facility blends hydrocarbon and chemical hazardous waste of varying calorific values (Figures 1 & 2).

The Afrisam cement kilns require fuels with calorific values between 18-20 MJ/kg. The coal currently fuelling the cement kiln has a calorific value of 26MJ/kg. Thirty tonnes per month of waste derived fuel have been generated during March to May 2018. This eventually ramped up to 1,000 tonnes per month when the trial phase at Afrisam has been completed.

Prior to blending, a 500ml representative sample is submitted to an onsite laboratory to be tested and analysed for parameters such as heavy metals, moisture content, calorific value and flashpoint, to determine the compatibility of the waste to be blended. The waste is then blended and re-analysed. This process ensures that the WDF complies with the requirements of the cement kiln. Once the desirable combination is achieved, the WDF is transported by road in 30kl tankers to a cement kiln at Afrisam in Lichtenburg, South Africa. This fuel will be utilized in conjunction with coal for cement production. Excess fuel generated is stored in six large storage tanks constructed on the Interwaste site (Figure 3). Safety measures and precautions are exercised to ensure the safety of all operators involved.

Permitting procedure

Section 24 of NEMA (South Africa National Environmental Management Act) requires that certain listed activities may not commence

Figure 2: *Hydrocarbon waste stored on site.*

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Figure 3: *Onsite tanks for storing excess fuel generated*

without authorisation from a competent authority (Department of Environmental Affairs). Furthermore, section 24 (1) of NEMA requires an EIA of these activities to be carried out. Schedule 1 under NEM:WA (GN. R.921 of November 2013) provides a list of these activities that have or are likely to have a detrimental effect on the environment and for which licensing is required. These activities include the storage, treatment and disposal of chemical and hazardous waste.

A detailed scoping and EIA were conducted and submitted to the following authorities for licencing approval: The Department of Environmental Affairs (DEA), Department of Water and Sanitation (DWS), Gauteng department of Agriculture and Rural development (GDARD).

Interwaste currently holds the following licenses:

- Integrated Environmental Authorisation and Waste management licence in terms of Section 20(b) of the NEM:WA (NEMWA)
- Environmental Authorisation in terms of Section 24 of NEMA (Act 107 of 1998, as amended)

The cement company (Afrisam) holds the following licenses:

- Atmospheric Emission Licence (Act 39 of 2004)
- Licence to store alternative fuels on site

Stakeholder negotiation

Parties representing the following sectors of society were invited to provide comments and register as the interested and affected parties (IAP) for the project:

- National, provincial and local government
- Industrial sectors including landowners
- Commerce
- Research institutes and
- Other

To engage with stakeholders, several measures have been taken:

- Advertising the proposed project and EIA process in the local newspapers on 18 and 20 September 2013 with clear indications on where to submit comments.
- Placement of 4 site notices: site gate, primary school, clinic, taxi rank in the adjacent neighbourhood.
- Distribution of letters of notifications and background information documents to surrounding businesses and industries, IAPs, key stakeholders and other commenting authorities on the 18 September 2013.
- The draft scoping was made available to key commenting authorities for a period of

WDF process at the blending platform facility

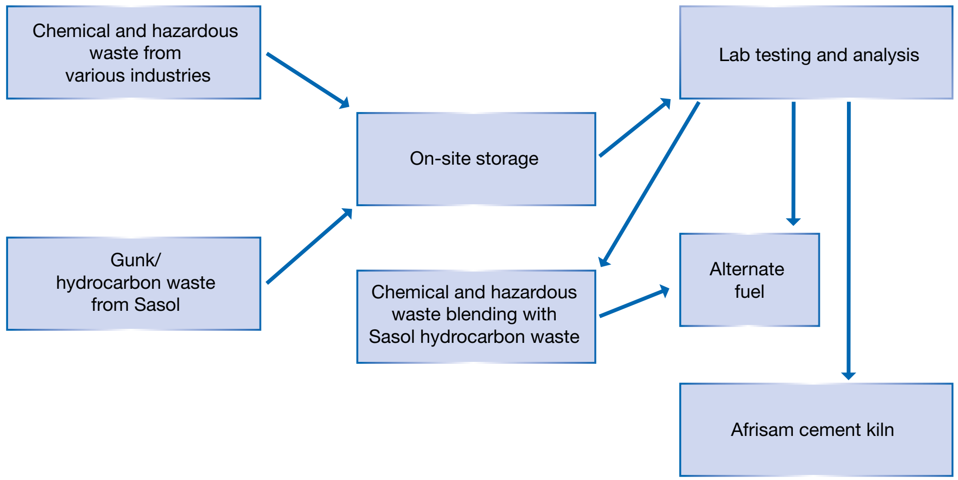

Figure 4: *Chemical and hazardous waste blending process*

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40 days for review and comment for from 31 March to 15 May 2014.

- The draft EIA and EMPR were made available for comment by IAPs and other key stakeholders for a period of 45 days between 4 June 2015 and 20 July 2015 at the main site entrance, via email, hardcopy and CDs.
- Public notices indicating availability of the EIA draft for review and comment were placed at the site entrance and the Dukathole Primary School, taxi rank and clinic. A brochure with the project summary was made available at Dukathole Primary School, taxi rank and clinic.

Problems encountered and solutions

On the way to implement a consistent fuel supply to Afrisam, Interwaste encountered a few problems which the company successfully resolved as follows:

With their successful project, Interwaste Pty Ltd, South Africa, sets a great example of how even some types of hazardous waste can be utilized in the cement industry.

Problem	Solution
Blending – Acquiring the right combination of ratios or blend is always dependent on the type of waste provided.	Waste is tested and analysed for calorific values, flashpoint, moisture content and heavy metals to ensure compatibility of the waste blended.
The initial blending of liquid fuel with coal at Afrisam will pose a challenge until the right combination is attained.	Interwaste must ensure the correct calorific values are attained at all times. In addition, Afrisam is constantly adjusting their plant to ensure it caters for alternative fuel processing in conjunction with coal.
Minimising transport costs from Germiston to Lichtenburg (520km round trip).	Interwaste has designed carrier trucks with two carriage compartments where fuel is transported in one compartment to Afrisam and upon returning, the truck loads cement bags in the other compartment and transports and delivers them on behalf of Afrisam. This assists Interwaste in saving costs.
Variations in the initial and final flashpoint of waste due to waste reactions upon storage.	Interwaste ensures that the waste is monitored and analysed at all times and that any changes are recorded and dealt with to prevent accidents or unforeseen circumstances.
Spillages during the blending process.	Operators ensure all the transfer pipes are properly installed and fitted before any transfer of waste or fuel commences.

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Figure 1: *Holcim (previously Cemex) cement plant Beckum-Kollenbach, Germany, which achieves an average TSR of 80%.*

The Greenest 'Grey Giants'

Alternative Fuels Substitution in Cement Companies

By Marie Lechtenberg, MVW Lechtenberg & Partner

Cement accounts for almost a tenth of anthropogenic emissions of greenhouse gases [1]. At the same time, energy-related expenses in the cement sector, mostly on fossil fuels and electricity, account for 30 to 40% of the industry's cash costs [2]. And energy prices are expected to continue to increase in the long term. In recent years, the cement industry has successfully reduced its operating costs and improved its carbon footprint by, amongst others, increasing alternative fuels use.

This article gives an overview on the thermal substitution rates of global cement manufacturers. In the following, all numbers included have been retrieved from the respective company's annual or sustainability report from 2017/2018, unless stated otherwise.

The first major use of alternative fuels in the cement manufacturing industry emerged during the mid-1980s. The primary goal in substituting fossil fuels was to enable the industry to remain economically competitive, since fuel consumption accounts for almost one-third of the cost of producing clinker [2].

Especially in the last ten years there has been a general increase in environmental awareness. Next to the cost-cutting benefits of alternative fuels, their use can contribute greatly to the environmentally responsible disposal of waste and to the reduction of greenhouse-gas emissions. Therefore, key cement players started to consider using alternative fuels to improve their contribution to sustainable development and as a key component of corporate social responsibility.

By now, the majority of large, global cement producers have made commitments for future co-processing rates and thereby begun to make significant progress in reducing their CO_2 emissions. This is not only the case in developed countries anymore. Many cement producers from Asia or India set these goals despite the challenges their countries' lack of waste management infrastructure might bring. Dalmia Cement, for example, has recently revealed its commitment to cover 100% of its fuels need by bamboo matter and RDF by 2030 in line with its new 'Future Today' branding [3]. At group level, the company reached a 4% thermal substitution rate (TSR) in 2018, compared to nearly zero only five years ago. Meanwhile, some of its plants already achieve a TSR of roughly 18%.

Cement plants leading the way as best-case examples for alternative fuels substitution can by now be found everywhere in the world. However, the majority of these pockets of excellence are located in central Europe, which belongs to the early adopters of AF use. The average TSR in Germany is around 67.5% in 2018 [6], while Austria achieves a remarkable average TSR of around 81% [7]. Some plants (temporarily) reach co-processing rates as high as 100%. In Germany, the share of alternative fuels in cement-specific energy consumption has grown from 282kJ/kg of cement in the 1990s to 1,901kJ/kg of cement in 2018 [4]. On a global scale, the average TSR was around 17% in 2016 and is expected to rise steadily, according to the CSI's "Getting the Numbers Right" [5].

Currently, CRH is leading the ranks of highest co-incineration rates among cement manufacturing companies. The full ranking is listed in table 1. Interestingly, CRH's TSR on group level dropped from 38.6% in 2017 to 30.3% in 2018. However, the group achieves a 48% co-processing rate in Europe, using 2.2 million tonnes of alternative fuels – mainly solid recovered fuels (SRF), waste tyres, solvents, used oil and carbon-neutral biomass - in the EU and more than 7 million tonnes on a global scale. Petcoke only represents 12% of the fuel mix at CRH in 2018.

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Company/Group	Country	Thermal Substitution Rate	Capacity (Mt/yr)	No. of plants
CRH	Ireland	30.3%	50.5	34
Votorantim	Brazil	28.0%	52.8	33
Cemex	Mexico	27.1%	93	56
Buzzi	Italy	27.1%	40	35
Vicat*	France	25.6%	60	16
Secil*	Portugal	22.4%	9.75	n.a.
HeidelbergCement	Germany	22.0%	129.9[1]	143
Cementir Holding	Italy	20.0%	13,1	11
LafargeHolcim*	Switzerland	18.0%	318	270
Intercement	Brazil	15.8%	38	35

All data retrieved from the respective company's sustainability / annual report 2018 unless stated otherwise.
* Data from sustainability / annual reports 2017
[1] Sales im million tonnes 2018

***Table 1:** Thermal substitution rates in global cement manufacturing companies in 2017/2018.*

Votorantim Cimentos is closely following CRH on the second rank. A leader in co-processing in Brazil, the company closed 2018 with more than 700,000 tonnes of processed waste, and the replacement of 28% of fossil fuels for fuels from renewable sources. The increased use of AFR to replace fossil fuels is a global strategy of the company, which has significantly been expanded in other geographies in projects to increase the use of these materials in Spain, Turkey, and Tunisia.

Cemex Mexico and Buzzi Italy are following Votorantim in the top three ranks, each substituting 27.1%. For Cemex, this equals a total of 3.3 million tonnes of waste co-processed and an increase of 4% compared to 2016. It allowed the company to reduce its CO_2 emissions by more than 21% at a 1990 baseline and generated fuel cost savings of US$150 million, according to its sustainability report 2018. Cemex aims to cover 35% of its total energy demand using alternative fuels by the year 2020.

In 2017, Vicat France reached a TSR of 25.6%. The Reuchenette plant (Switzerland) and the Créchy plant (France), the Group's most advanced cement plants in this respect, even recorded substitution rates of 87.3% and 77%, respectively. At Vicat's French cement manufacturing sites in general, biomass and repurposing of waste replaces 50% of the previously used fossil fuels, with a target of a 60% rate by 2020.

The co-processing rate of capacity giant HeidelbergCement was at 22% in 2018, a 2% increase compared to 2016. HeidelbergCement's goal is to reduce its specific CO_2 emissions per tonne of cement by 30% compared with the 1990 level by 2030. In 2018, a reduction of around 20% was achieved. In line with this goal, the group launched an "Alternative Fuel Master Plan" project in 2018. The project is being led by a working group comprising experts from various group areas and departments, aiming to explore additional possibilities for the use of alternative fuels. Like other groups, HeidelbergCement also targets an ideal co-incineration rate for the future – in this case 30% until 2030.

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Egypt

AICCE24 in Cairo – Hot Topic: Alternative Fuels

The 24th Arab International Cement Conference and Exhibition (AICCE24) organized by the Arab Union for Cement and Building Materials (AUCBM) took place in Cairo, Egypt, from 24 – 26 November 2019. More than 500 experts from the international cement industry had the opportunity to inform themselves about new developments and market potentials in lectures and the accompanying exhibition and to exchange views and information.

Among other conference topics - such as grinding technology for clinker, the burning process, filtration and de-dusting, solutions for bypass dust – the focus was put on alternative fuels use and technology, as well as sustainable development. The interest in cost-saving alternative fuels is rising in the Middle East and in AUCBM member countries due to cement overcapacities.

The use of municipal solid wastes in Egypt was a highly debated topic. Prices for imported coal and regional petcoke are currently extremely low which weakens the RDF producers' competitiveness in the market. This is also due to the lack of recycling or "gate fees" paid by the Egyptian municipalities.

The Egyptian Government does not sufficiently support the implementation of a successful waste treatment system in the country, which has been initiated and promoted by the local cement industry in previous years.

Without governmental subsidisation, RDF producers will not sustain. Previous efforts by the government, such as introducing a minimum substitution rate of alternative fuels of 30%, have not succeeded for various reasons.

In current public tenders regarding MSW collection and processing, some Egyptian municipalities demand the waste to be paid for. According to Dirk Lechtenberg, this can be qualified a dubious measure: "Without clear governmental guidelines aiming at minimum substitution rates and a strictly defined 'polluter-pay-principle', any efforts undertaken by local cement plants and their service providers in the field of waste processing are taken ad absurdum."

United Kingdom

Lancashire Waste Boosts SRF Capacity

Alternative fuel production specialist Lancashire Waste Recycling has halved plant wear costs and further boosted manufacturing capacity with an investment in its sixth UNTHA shredder.

The firm has been making a high-specification Solid Recovered Fuel (SRF) at its Fleetwood site since it was established in 2013. An UNTHA XR2000 pre-shredder fed two TR3200s secondary shredders, to produce a renewable energy source for the cement industry.

Lancashire Waste worked with the UK division of UNTHA to understand how to leverage the potential that next-generation technology could bring. When Lancashire Waste opened its second SRF production plant 46 miles away in Burnley, a single UNTHA XR3000C was installed at its heart. This slower speed equipment could produce a quality 40mm fuel in a single pass, without the concerns surrounding downtime or damage when higher speed machines encounter unshreddable items.

In 2019, the growing company wanted to further strengthen its alternative fuel production capabilities. Advanced trials with UNTHA ensued and it became clear that the all-new UNTHA XR3000XC could achieve an on-specification 30mm particle with slightly more throughput than the two TRs combined.

The two Fleetwood post-shredders have now been switched, so that the original XR2000 feeds the XR3000C and the new 85rpm XR3000XC machine. A capacity of 30tph has been achieved. A 65rpm XR3000XC has also been added to the Burnley line to take hourly throughputs on this site to 20tph.

Lancashire Waste's founder Jim Entwistle commented: "As a business, we're constantly looking to progress, so consistency and capacity are key to our operation. We work with three UK cement kilns and one export offtaker, and the better quality the fuel, the more our clients seek. We've doubled our supply to one kiln, for example, over the past 18 months, so the impact on our business – from savvier waste shredding – is vast. Add to this 40% less energy costs, halved wear costs and only minimal damage repairs as we've moved away from high speed machines, and the business case for our shredder investment is extremely strong."

Source: www.businessupnorth.co.uk (December 6, 2019): Lancashire Waste boosts SRF production capacity with new UNTHA shredders".

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APPCB to Re-route Solid Waste to Cement Factories

Controlling the pollution emitted from the tonnes of solid waste generated every day in municipal areas has become a major challenge for the Andhra Pradesh Pollution Control Board (APPCB), reports Times of India. While moves to establish these plants have been blocked in the past, APPCB still believes it's the best way to dispose of solid waste.

An APPCB study found that 70 % of solid waste generated in municipal areas can be used as a fuel for the waste to energy plants. The previous government had planned to establish these power generation plants at multiple locations but only two projects worked out.

"Waste to energy plants are the best way to curb the piling solid wastes in municipal areas. But banks denied the proposals of majority units and only the Guntur and Vishakapatnam projects were approved," said APPCB chairman BSS Prasad.

The APPCB is also looking at implementing the Vijayawada Municipal Corporation (VMC) model of handling solid wastes. VMC authorities biomined around 300,000 tonnes solid wastes accumulated at Ajith Singh Nagar dumping yard and sent the wastes to cement projects which utilised them as fuel in kilns. According to BSS Prasad, it is a win-win situation for both civic bodies and cement factories. "Civic bodies have to spend around Rs 25,000 per tonne on scientific disposal of solid wastes. Instead, they transfer this garbage to cement projects which costs roughly Rs 2,000 per tonne. Cement projects also save a huge amount on coal by using solid waste as fuel instead".

VMC authorities are looking to continue bio-mining and segregate around 200 tonnes solid wastes generated every day.

Source: www.timesofindia.indiatimes.com (November 11, 2019): "APPCB to reroute solid waste to cement factories".

All-India RDF Tender Targeted at Cement Companies

The North Delhi Municipal Corporation has floated an all-India tender inviting industrial units to utilise the RDF recovered from biomining of the Bhalswa landfill.

According to the Solid Waste Management Rules of 2016, RDF should form at least 5% of the fuel combination of such units that have a landfill in 100 km vicinity.

About 20,000 metric tonnes of waste have been segregated and neatly piled up in rows at the Bhalswa landfill near GT Karnal Road since October 1. Six trommel machines (large cylindrical sieves) were used to sort the waste on orders of the National Green Tribunal (NGT). The entire landfill, in place since 1984, holds 7 million metric tonnes of waste.

"We have a pre-bid meeting for it tomorrow and will see how many companies from across the country come and decide what the financial dynamics of the project would be," said the north corporation commissioner, Varsha Joshi.

A senior corporation official said they are hoping that the trash would meet the companies' desired calorific value. A sample of the RDF will be sent to laboratories to test if its caloricity falls between the required 1500-4500 kcal/kg.

Another apprehension officials have is that interested companies may ask the north body to incur cost of RDF transportation to far-off states. "Delhi-NCR doesn't have any cement kilns while coal-based thermal power plants here, Badarpur and Indraprastha, have been shut. The nearest cement plants we have are in Kotputli (Rajasthan) and Bilaspur (Himachal Pradesh)," said an official. Transporting the RDF would add considerable costs.

Source: www.hindustantimes.com (December 09, 2019): "Eyeing cement, power companies to burn Bhalswa combustible waste, North body issues bid".

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Thailand

Research Supports Cement Industry's Role in Marine Plastic Waste Reduction

Research at the Asian Institute of Technology (AIT) confirms that using plastic waste as a fuel additive in the cement industry can help with a substantial reduction in marine plastic pollution in Thailand. Instead of converting plastic into electricity, AIT researchers estimated the potential of converting plastic into heat. While the efficiency of converting plastic into electricity was a mere 22%, the efficiency goes up to 85% when the same plastic is converted into heat.

Early last year, AIT researchers selected two dumpsites (one in Saraburi, the other in Nakhon Nayok) to analyse the dynamics of plastic waste. These dumpsites are currently used by INSEE Ecocycle, a subsidiary of Siam City Cement Group to process plastic waste for the cement industry and this is where the cement industry comes into the picture.

Based on the two case studies, the amount of plastic waste in dumpsites in Thailand is estimated to be almost 100 million tonnes, with plastic accounting for 42% of the total waste. There are 110 landfills in Thailand along with 2,380 dumpsites. Based on their studies, the AIT researchers concluded that if the dumpsites and landfills are put together, the plastic waste recovery potential in Thailand is almost 190 million tonnes.

AIT and INSEE Ecocycle will continue to document the environmental benefits of this practice, as partners in the Norwegian funded project called "Ocean Plastic Turned into an Opportunity in Circular Economy." This regional project seeks to showcase that the involvement of Resource and Energy Intensive Industries, like cement manufacturing, will increase the treatment capacity for non-recyclable plastic wastes and constitute a win-win concept and a fundamental pillar in circular economy – and reduce the release of microplastics to the ocean.

The project is managed by the Norwegian Foundation for Industrial and Scientific Research, SINTEF, which is one of Europe's largest research organizations. Lessons learned from country pilots will be shared through a regional multi-stakeholder forum enabling awareness raising, capacity building and efficient replication across the continent.

Source: www.scandasia.com (December 6, 2019): "Can the Cement Industry Help Reduce Marine Plastic Waste?".

Poland

LafargeHolcim to Invest € 10 Million in Kujawy

CemNet reports that Lafarge Holcim will be investing €10 million in its Kujawy cement plant in Poland. The investment will, amongst other things, serve to increase the use of alternative fuels at the works.

At present Cementownia Kujawy's substitution rate is between 80 to 85%, or around 190,000 tonnes, but Lafarge plans an increase to 90% by 2021.

The Kujawy cement plant has an annual capacity of approximately 2 million tonnes.

Source: www.cemnet.com (2019, November 27): "Lafarge-Holcim plans EUR10m investment in Kujawy".

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USA

NuCycle Ramps Up Florida Renewable Fuel Plant

US-based NuCycle Energy's new facility in Plant City, Florida, will produce alternative fuels exclusively for Cemex. Plans are to build more facilities in Miami, Greater Atlanta and Massachusetts.

The plant, which came online in April, is now fully operational and ramping up to process 150,000tpa of post-industrial materials, primarily process and packaging residuals. Among suppliers are major brands, such as Walmart, PepsiCo, Coca-Cola, Tropicana and Williams-Sonoma.

The 30-ton-per-hour automated process involves shredding and grinding material to a finished particle size of 4-inch minus. Next, ferrous and nonferrous metals are removed, and then begins the densification process to compact the material into the finished product—Enviro-Fuelcubes that replace coal as power to make cement. One ton on average replaces .9 tons of coal.

Source: www.waste360.com (2019, December 4): "NuCycle Ramps Up Florida Renewable Fuel Plant, Plans to Build More".

Carbon Capture Storage: Lehigh Cement and the International Knowledge Centre Pioneer Feasibility Study

According to different news outlets, Lehigh Cement and the International CCS Knowledge Centre announced a feasibility study of a commercial-scale carbon capture and storage (CCS) project as a definitive solution to reduce greenhouse gas emissions.

The study targets the feasibility to capture the majority of CO_2 from the flue gas of Lehigh's Edmonton, Alberta cement plant; significantly reducing its process and combustion GHG emissions. The study will encompass engineering designs, cost estimation (at an AACE Class 4) and a fulsome business case analysis.

It is a North American first in the cement industry to examine the feasibility of full-scale CCS as a definitive solution to cut GHG emissions. The feasibility study at Lehigh's Edmonton plant is in advanced development, positioning it to be a world's first to implement full-scale carbon capture in the cement industry. The study will target a 90 to 95% CO_2 capture rate, with the foundational learnings from the Boundary Dam 3 CCS Facility (BD3) – a world first in full-scale CCS (from a coal-fired power plant).

Source: www.finance.yahoo.com (2019, November 28): "Lehigh Cement and the International Knowledge Centre Pioneering a Feasibility Study of Full-Scale Carbon Capture Storage (CCS) on Cement"

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