Climate analysis Subcoal®

Subcoal® from coarse rejects of the paper industry as fuel for limekilns

Report
Delft, June 2011

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Publication Data

Bibliographical data:

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Delft, CE Delft, June 2011

Waste disposal / Paper industry / Residue / Fuel / Lime / Incineration oven / Energy / Carbon emissions / Analysis

Publication number: 11.2483.44

CE-publications are available from www.cedelft.eu

Commissioned by: Qlyte.
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CE Delft's solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

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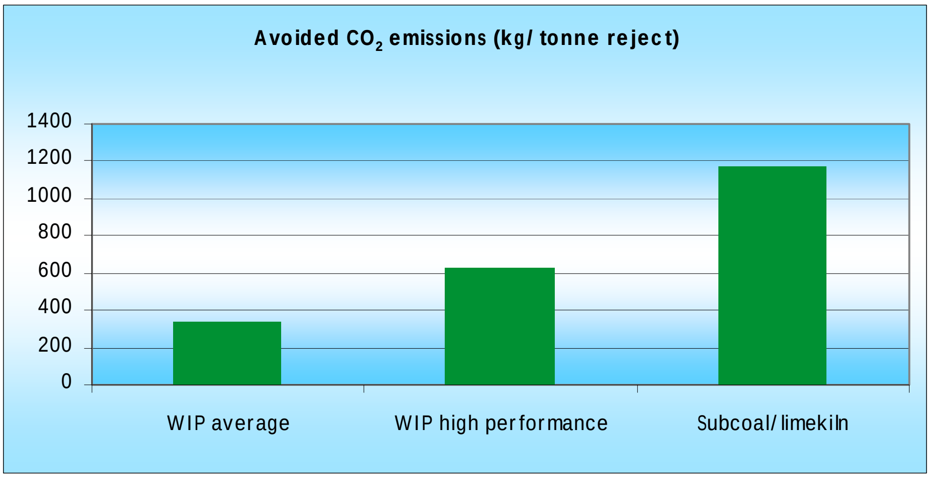
Summary

This study compares the climate effects of the processing of coarse rejects from the paper industry by the Subcoal® route with incineration of the rejects in a waste incineration plant (WIP). A previous study by CE Delft revealed that for the paper-plastic fraction of household waste, the Subcoal® route has a better climate and overall environmental score as compared to the incineration in a waste incineration plant. This report shows how the climate change comparison between the Subcoal® and WIP route works out for coarse rejects from the paper industry. Also for coarse rejects from the paper industry the Subcoal® route has a significant lower impact on climate change than the WIP route. Per tonne of reject the Subcoal® route avoids 828 kilo CO_2 extra as compared to an average WIP and 545 kilo CO_2 as compared to high performance WIP (Figure 1).

Figure 1 **Avoided CO_2 emissions of rejects processed in the Subcoal®/limekiln route compared to the avoided emissions by incineration in WIPs**



For the production of lime this means that when Subcoal® is co-fired at 30% (on caloric base), the CO_2 emission of the lime production process can be reduced by 17-18%.

1 Introduction

Subcoal® Technology is used to process paper plastic waste fractions into a substitute for coal or lignite. The fuel pellets can be used as secondary energy source in industrial furnaces, such as limekilns and cement kilns, coal-fired power plants and blast furnaces. Subcoal® has a caloric value comparable with lignite.

In a previous study by CE Delft (CE, 2000), the Subcoal® route for paper-plastic fractions (PPF) of a waste sorting installation has been environmentally analysed and compared to alternative waste disposal routes like incineration in a waste incineration plant. The study revealed that the Subcoal® route reduces climate change effects and other environmental impacts of the PPF waste as compared to the waste incineration route.
At the new plant of Qlyte in Farmsum, approximately 45,000 ton of Subcoal® is produced annually from coarse rejects of the paper industry. The Subcoal® is used to substitute lignite in limekilns. As compared to the PPF of a waste sorting plant, rejects from the paper industry have a different constitution and most importantly contain much more water. Qlyte has asked CE Delft to update the climate change analysis of the Subcoal® route in comparison with incineration for coarse rejects of the paper industry in a waste incineration plant. The update includes the improvements of the energy conversion efficiency of waste incineration plants since 2000. Furthermore the climate impact on lime production is assessed.

2 Summary previous study

In CE, 2000 the effect of substituting coal by Subcoal® derived from paper-plastic fractions (PPF) of municipal solid waste has been compared with two other treatments:

1. Co-firing of PPF in a cement kiln, substituting lignite.
2. Incineration in a waste incinerator plant.

In case of the Subcoal® route the PPF is shreddered, dried and pelletized. In case of recovery in the cement kiln the PPF is baled before exporting and shreddered at the cement kiln.

Due to the focus of the research on the environmental friendly ways to recover plastic packages, only the plastic fraction of the PPF was assessed. The study compared the integral incineration of plastic in household waste to treatments in which 36% of the plastics was separated out and processed either in the cement kiln route or the Subcoal® route. A summary of the main results is presented in Table 1.

Table 1 Environmental score

Route	Way of processing	Environmental indicators (10^{-9} year per ton plastic in RDF) (lower=better	CO_2 emission (kg/tonne plastic in RDF) (lower=better)
Subcoal®	35% plastic Subcoal® route 65% plastic in waste incinerator	15.7	704
Cement kiln	35% plastic in cement kiln 65% plastic in waste incinerator	17.1	659
Waste incinerator	100% plastic in waste incinerator	28.5	1,600

The routes of Subcoal® and cement kiln have similar environmental impacts. Due to the pre-treatment the Subcoal® has a somewhat lower overall impact on the environment mainly due to lower acidification impacts. The use of plastic in the cement industry has a somewhat lower effect on climate change.

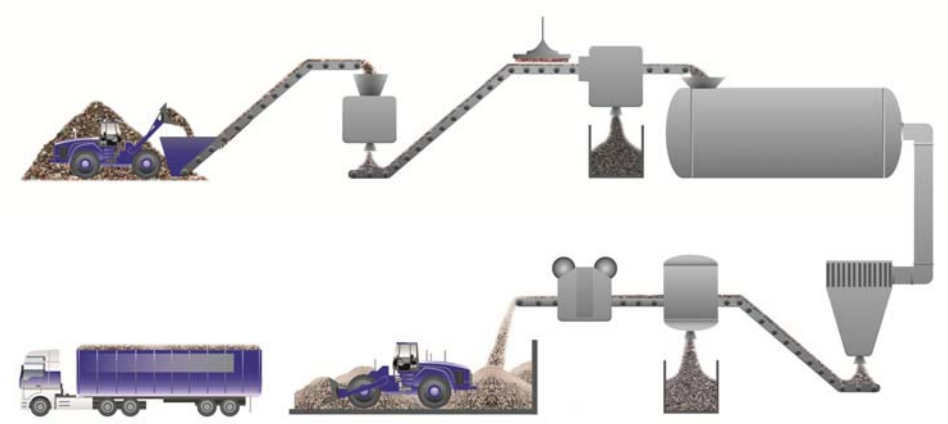
Overall it was concluded that the Subcoal® process and recovery in a cement kiln results in a 50% reduction of the total environmental effects compared to the waste incinerator route. This result is mainly due to the direct substitution of coal in the two routes, and therefore the severe environmental impacts of coal use.

3 Subcoal® process

Figure 2 gives an overview of the production of Subcoal® fuel from coarse rejects of paper production.

After shreddering the rejects (45% water content), a sifter separates out heavy part such as stones and metals. By means of water press excess of water is removed after which the material is further dried thermally to a water content below 10%. The water vapour is released into the atmosphere via a cyclone and an air scrubber. During the process ferro and non-ferro materials are removed by Eddy current separators and magnets. PCV is being removed by optical separation techniques. Finally the product is pelletized.

Figure 2 Simplified process diagram of the Subcoal® production process

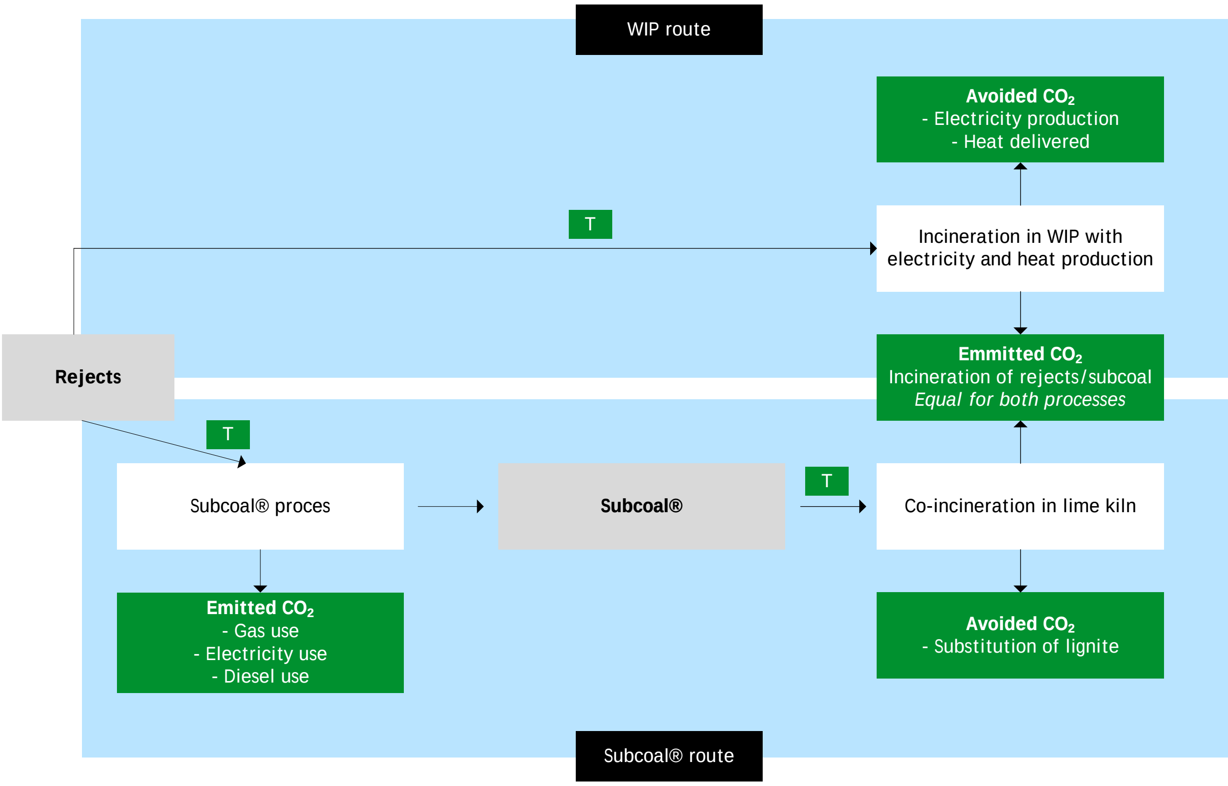


4 Climate effects of Subcoal® from rejects of the paper industry

4.1 System boundaries comparison

Figure 3 gives an overview of the (avoided) CO_2 emissions involved with treatment of rejects in the Subcoal®/limekiln route on the one hand and the waste incineration plant (WIP) route on the other hand.
The CO_2 emissions in the WIP route concern the CO_2 emission of transport of the rejects to the WIP, and emissions of incineration of the rejects. On the other hand emissions are avoided through net electricity production and heat supply by the WIP.
The CO_2 emissions in the Subcoal® route concern the CO_2 emission of transport of rejects to the Subcoal® production plant, CO_2 emissions of gas, diesel and electricity consumption in the Subcoal® production process, and emissions of incineration of the rejects. Emissions are avoided through the substitution of lignite by co-incineration in a limekiln. The CO_2 emissions of incineration are equal in both processes and will therefore be left out of the comparison.

Figure 3 Scheme CO_2 emission of WIP and Subcoal® route



* T indicates the CO_2 emissions of transport.

For clarity reasons the (relatively low) CO_2 emissions related to the use of additives (NaOH, $Ca(OH)_2$ and NH_4OH) for flue gas cleaning in the WIP and the avoid use of additives of flue gas cleaning of electricity production in a power plant are not shown in Figure 3. These CO_2 emission, however, are accounted for in the analysis below.
Also omitted for clarity reasons are the CO_2 emissions related to the removed ferro, non-ferro parts (2% of rejects) and PVC parts (3% of rejects).
PVC contents in both routes are (finally) incinerated in a WIP. The related CO_2 emissions are therefore the same. Ferro and non-ferro parts in both routes are separated out and send for recycling. It is assumed that the processing efficiency of the metal parts in both routes is comparable and that the related CO_2 emissions are the same.[1]

Waste incineration plants vary in their energy recovery efficiency and therefore the avoided CO_2 emissions vary per installation. In the following analysis the Subcoal®/limekiln route will therefore be compared to both an average Dutch WIP and a high performance WIP.

4.2 Background data

4.2.1 Caloric values Rejects and Subcoal®,

The amount of electricity and heat generation in a WIP and the amount of substituted lignite depends on the caloric value of the reject and the caloric value of the Subcoal® produced from it, respectively. The caloric values on their turn depend on the dry material and water contents. Data on the composition of the reject and Subcoal® are given in Table 2. In the Subcoal® process 5% of the rejects is removed as metal or PVC and 41% as water, leaving 54% of the reject mass as Subcoal®, containing 8% of water.

Table 2 Composition rejects and Subcoal®

	Content (mass%)
Moisture content rejects	45%
PVC and metal content rejects	5%
Dry content rejects excl. PVC and metals	50%
Subcoal® content in rejects	54%
Moisture content Subcoal®	8%

Source: Qlyte.

Given the caloric value of 22 megajoules per kilo for Subcoal® the other caloric values in Table 3 were calculated. The reject (excl. PVC) in the WIP route delivers 11.0 megajoule per kilo reject. In the Subcoal® route 12.0 megajoule per kilo is delivered. Due to the water removal the delivered caloric value of the rejects is increased by 1.0 megajoule per kilo reject.

1 In reality the Subcoal® route might be more efficient in separating out metals from the rejects than the WIP is in separating out metals form the incineration slags. A 20% higher efficiency in the Subcoal® route might be realistic and would result in 20 kg CO_2 extra avoided emission for the Subcoal route as compared to the WPI route.

Table 3 **Caloric values rejects and Subcoal®**

		Source
Net Caloric value Subcoal® (MJ/kg)	22.0	SGS
Net Caloric value Subcoal® on dry basis (MJ kg)[2]	24.1	SGS/calculated
Net caloric value rejects (MJ/kg reject)[3]	11.0	Calculated
Caloric value Subcoal® (MJ/kg reject)[4]	12.0	Calculated

4.2.2 Energy consumption and avoided energy consumption Subcoal® and WIP route

The electricity, gas and diesel consumption in the Subcoal® production process and the average assumed transport distances are given in Table 4.

Table 4 **Electricity and fuel consumption of Subcoal® process**

Electricity consumption Subcoal® process (kWh/tonne reject)	69	Qlyte
Gas consumption Subcoal® process (m^3/tonne reject)	20	Qlyte
Diesel consumption Shovel (liter/tonne reject)	0.38	Qlyte
Truck transport to Subcoal® plant (km)	230	Utrecht-Varmsum
Sea transport (km)	1300	Qlyte

In the Subcoal® route, every kilo of reject delivers 12.0 MJ of Subcoal® substituting 12.0 MJ of lignite and the corresponding CO_2 emissions (Table 6).

In the WIP route every kilo of reject delivers 11.0 M J of fuel in a WIP. Table 5 gives the conversion factors for electricity and heat production of an average Dutch WIP and of a high performance WIP with theoretical energy efficiency of 1.[5] The net electricity and heat production by a WIP avoids conventional electricity and heat production.
In addition Table 1 gives the additives consumption for a WIP and for (avoided) electricity generation and the transport distance.

2 24.1 MJ kg for Subcoal® dry was calculated from 22.0, taking 2.44 MJ/kg for the evaporation enthalpy of water, as follows: (22+2.44* 8%)/(1-8%).

3 Not included is the caloric value of 3% PVC. The value of 11.0 MJ/kg is calculated from 24.1 MJ/kg for Subcoal® (dry), taking 2.44 MJ/kg for the evaporation enthalpy of water, as follows: 50% · 24.1 - 45% · 2.44.

4 12.0 MJ/ was calculated as follows: 54%··22.

5 The chosen electrical and thermal efficiency contribute both for 50% to an overall Energy efficiency of 1 according to the R1 formula as defined by (Lap2, 2009) . A WIP with energy efficiency of 1 matches the efficiency of standard electricity or heat generation in the Netherlands (Lap2, 2009).

Table 5 **Input values WIPs**

Energy consumption Subcoal® process	Value	Source
Net electric efficiency WIP Dutch average	14%	Agentschap NL, 2011
Net heat delivered WIP Dutch average	16%	Agentschap NL, 2011
Net electric efficiency high efficiency WIP	19%	Assumption EE=1 [5]
Net heat delivered high efficiency WIP	44%	Assumption EE=1 [5]
NaOH use WIP (kg/ton reject)	6.2	AOO, 2002/SGS
$Ca(OH)_2$ use WIP (kg/ton reject)	3.2	AOO, 2002/SGS
NH4OH (25%) use WIP (kg/ton reject)	0.7	AOO, 2002/SGS
Avoided $Ca(OH)_2$ use power plant (kg/GJ_e)[6]	0.26	AOO, 2002/SGS
Avoided NH4OH (25%) power plant (kg/GJ_e)	0.16	AOO, 2002/SGS
Truck transport to WIP (km)	40	AOO, 2002

4.2.3 CO_2 emission factors

The comparison of the CO_2 emission of the WIP route and the Subcoal® route involves avoided CO_2 emissions of electricity and heat generation, avoided use of lignite, the CO_2 emission from electricity gas and diesel use, the CO_2 emission factors for the use of additives in a WIP and the CO_2 emissions of transport. The emission factors for these components are given in Table 6.

Table 6 **CO_2 emission factors**

CO_2 emission factors	Value	Source
Electricity mix NL (kg CO_2/MJ_e)	161	Agentschap NL, 2010
Heat generation NL (kg CO_2/MJ_t)	63	Ecoinvent 2.2
Lignite fired in power plant DE ((kg/CO_2/MJ)	112	Ecoinvent 2.2
Gas fired (kg/CO_2/MJ)	60	Ecoinvent 2.2
NaOH 20% in water (kg CO_2/kg NaOH)	0,440	Ecoinvent 2.2
$Ca(OH)_2$ (kg CO_2/kg $Ca(OH)_2$)	0,758	Ecoinvent 2.2
NH4OH 25% in water (kg/CO_2/kg)	0,5	Ecoinvent 2.2
Diesel consumption (kg CO_2/litre Diesel)	3.32	CE, 2008
Truck trailer GVW 40 tonne (kg CO_2/tkm)	76	CE, 2008
Product sea tanker-2 tonne capacity (kg CO_2/tkm)	53	CE, 2008

4.3 Results

Table 7 gives an overview of the CO_2 emissions for the comparison of the WIP and Subcoal® route. Table 7 makes clear that the difference in avoided CO_2 emissions between WIP and Subcoal® route is crucial for the comparison. The extra CO_2 emission of the subcoal process and transport are relatively small as compared to the extra avoided emissions in the Subcoal® route. The direct substitution of lignite in the Subcoal® route results in high avoided CO_2 emissions. In the WIP route the electricity and heat produced by the WIP substitute conventional electricity and heat that are generated with fuels with a lower CO_2 intensity than lignite. Moreover an average WIP is less efficient in energy conversion than conventional power plants.
Per tonne of reject the Subcoal® route avoids 828 kilo CO_2 extra as compared to an average WIP and 545 kilo CO_2 as compared to high performance WIP.

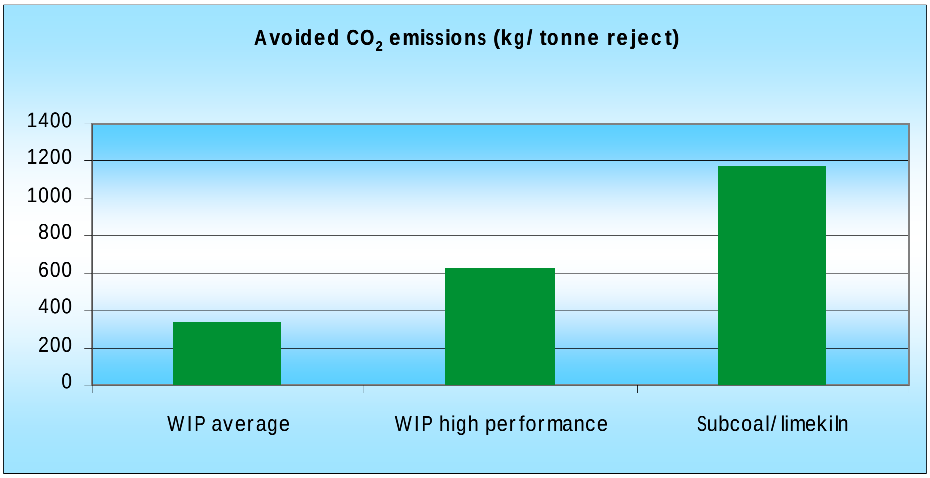
[6] Assumed is 25% electricity generation in a coal-fired power plant.

Table 7 **Overview CO_2 emissions WIP and Subcoal® route**

	WIP average	**WIP high performance**	**Subcoal®/ limekiln**
Avoided CO_2 emissions (electricity and heat production and substitution lignite)	- 352	- 635	- 1,339
Emission of processing (use of additives, gas, diesel and electricity)	5	5	81
Transport CO_2 emissions	3	3	86
Total emissions	**- 344**	**- 627**	**- 1,172**

Figure 4 illustrates the difference in avoided emissions of the Subcoal® route and the two kinds of WIPs. CO_2 emissions of transport, and electricity and gas consumption have been subtracted from the avoided emissions.

Figure 4 **Avoided CO_2 emissions of rejects processed in the Subcoal®/limekiln route compared to the avoided emissions by incineration in WIPs**



5 Effects of Subcoal® on CO_2 emissions of lime production

5.1 Energy consumption and CO_2 emissions of lime production

The production of lime involves the use of energy-intensive processes. The lime burning process is the principal user of energy. Energy use depends on several factors including the quality of limestone used, moisture content, the fuel used and the design of kiln. Table 8 gives an overview of the thermal energy consumption for several types for kilns according to best available technique (BAT) standards (EA, 2010). The electricity consumption of a limekiln is in the order of 375 MJ_e per tonne of lime (Ecoinvent 2.2).

Table 8 **BAT associated thermal energy consumption for various kiln types**

Kiln type	Thermal energy consumption1 GJ/t
Long rotary kilns (LRK)	6.0–9.2
Rotary kilns with pre-heater (PRK)	5.1–7.8
Parallel flow regenerative kilns (PFRK)	3.2–4.2
Annual shaft kilns (ASK)	3.3–4.9
Mixed feed shaft kilns (MFSK)	3.4–4.7
Other kilns (OK)	3.5–7.0

Source: EA, 2010.

The lime production process involves CO_2 emissions of the decomposition of limestone (calcium carbonate) on the one hand and the CO_2 emissions of combustion and electricity consumption on the other hand.
The manufacture of one tonne of (quick)lime (calcium oxide) involves the decomposition of calcium carbonate, with the formation of 785 kg[7] of CO_2. In some applications, such as when used as mortar or PCC[8] this CO_2 is reabsorbed with the formation of limestone ($CaCO_3$).
The CO_2 emissions of electricity consumption are around 50 kg per tonne of lime[9]. The CO_2 emissions of combustion depend on the thermal energy consumption and the fuel used. Typically, Subcoal® is co-fired in rotary kilns fired with lignite. For the range of energy consumptions in Table 8 the CO_2 emissions for a rotary kiln fired 100% on lignite the CO_2 emissions are in the range of 570-1,030 kg CO_2 per tonne of lime (excl. CO_2 of electricity consumption and CO_2 process emissions from limestone decomposition).
The CO_2 emissions for the production of lime in a lignite fired rotary kiln are summarized in Table 9.

7 Molar weight CaO = 56 molar weight CO_2 = 44. Per ton CaO 44/56*1,000 kg CO_2 is released.

8 Precipitated calcium carbonate.

9 Assuming 140 kg CO_2/GJ electricity medium voltage EU average.

Table 9 **CO_2 emission lime production in a rotary kiln**

CO_2 emission rotary kiln	kg CO_2/tonne lime
Emissions of lignite combustion	571-1,030
Emissions of electricity consumption	50
Emissions of $CaCO_3$ decomposition	785

5.2 Effect of Subcoal® on the CO_2 emissions lime production

Per tonne of reject the Subcoal® route avoids 828 kilo CO_2 extra as compared to an average WIP. This figure corresponds to 69 kilo CO_2 per gigajoule substituted lignite.[10] Subcoal® can be co-fired in a lignite-fired limekiln up to a caloric value of 30%. This means that for every gigajoule fuel, 0.3 gigajoules lignite can be substituted by Subcoal®. The CO_2 emissions of 112 kg CO_2 per gigajoule fuel (100% lignite) can therefore be reduced by 21 kg CO_2.[11]
This means that the CO_2 emissions of fuel combustion in a rotary kiln can be reduced by 19% when Subcoal® is co-fired to the maximum extent.
For the range of energy consumption in a rotary kiln given in Table 8 this corresponds to a reduction of 106-191 kilo CO_2 per tonne lime. As compared to the total CO_2 emissions in the production process (excl. decomposition) this corresponds to a reduction of 17-18%.

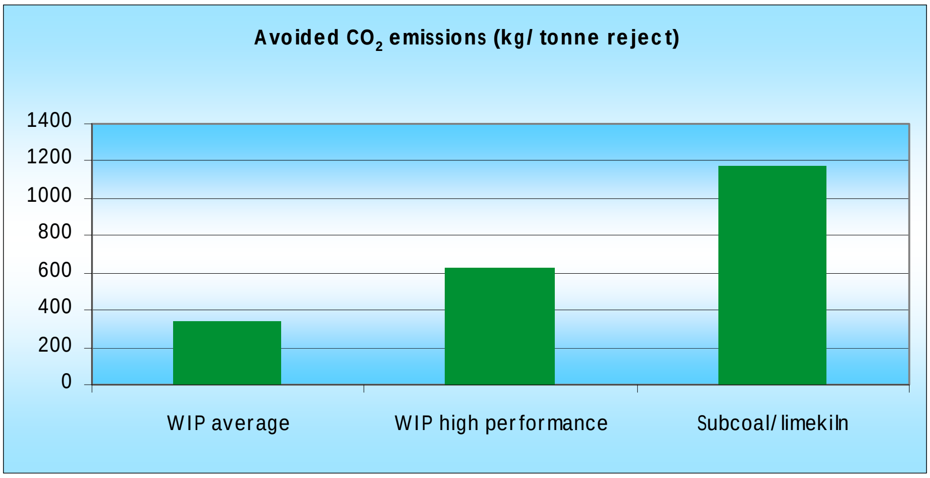
10 The reject in the Subcoal® route delivers 12.0 gigajoules pet tonne.

11 69 kg/GJ * 0.3 GJ.

6 Conclusions

In this study the climate effects of the processing of coarse rejects from the paper industry through the Subcoal® route have been compared with incineration of the rejects in a waste incineration plant (WIP). As has been shown in a previous study by CE Delft, the Subcoal® route has a lower impact on climate change than the WIP route.
Per tonne of reject the Subcoal® route avoids 828 kilo CO_2 extra as compared to an average WIP and 545 kilo CO_2 as compared to high performance WPI (Figure 5).

Figure 5 Avoided CO_2 emissions of rejects processed in the Subcoal®/limekiln route compared to the avoided emissions by incineration in WIPs



For the production of lime this means that when Subcoal® is co-fired at 30% (on caloric base), the CO_2 emission of the lime production process can be reduced by 17-18%.

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