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Evaluating Clean Development Mechanism Projects in the Cement Industry Using a Process-Step Benchmarking Approach

Michael Ruth, Ernst Worrell, and Lynn Price

Energy Analysis Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

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Abstract

This report describes the potential use of benchmarking for evaluating Clean Development Mechanism (CDM) projects in the cement industry. We discuss a methodology for comparing proposed projects against a benchmark using a process-step approach. We find that cement production is well suited to a process-step benchmark methodology for evaluating energy use because it consists of a number of discreet steps for which energy use can be measured. There are three primary process steps that can be evaluated with a benchmark: raw material preparation, clinker production, and cement grinding. Benchmark values can be determined for these three major process steps in a number of ways. The most promising methodologies involve analyzing plant performance of recent new plants or modifications and looking to technological estimations of "best practice" for energy use.

We use technological "best practice" estimates for the cement industry as benchmark values to test the process-step benchmarking approach. Two examples are constructed and evaluated against these benchmarks; one uses data from an efficient plant in Thailand and one uses the most efficient values from a range of best available technology estimates. Our examples show that the expected potential financial incentives from CDM credits are small relative to the price of cement. Further research into the economics of cement production would be needed to determine whether CDM credits are significant relative to production costs and therefore offer an incentive to adopt efficient technologies.

We identify some issues relevant to cement production that should be considered when a benchmarking scheme for this industry is designed. These issues include the production of "blended cements", which lower the need for clinker, and therefore present an option for avoiding large amounts of carbon dioxide emissions. Reductions of carbon emissions from blended cements potentially greatly overshadow savings from efficiency improvements, but evaluating blended cement projects with a benchmark introduces some methodological problems. Another issue is that most new plant additions in the cement industry utilize modern, efficient technologies and approaches, so setting a benchmark "strict" enough to exclude non-additional emission reductions may provide only a small economic incentive to improve on the benchmark, depending upon the market value of avoided carbon emissions. Plant modernizations that lower energy consumption are common and provide an excellent opportunity for reducing emissions. Such projects might play a major role in CDM, and can be evaluated at the process-step level using the benchmarks for the whole plant analysis.

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Figures and Tables

I. Introduction

Energy efficiency projects in the industrial sector provide a source for reducing greenhouse gas emissions under a Clean Development Mechanism (CDM) scheme as laid out in Article 12 of the Kyoto Protocol. The CDM offers a mechanism for developed countries to meet greenhouse gas (GHG) reduction requirements by gaining offsets from projects they fund in developing countries. To receive these offsets – known as Carbon Emission Reduction Units (CERs) – the project should demonstrate "real, measurable, and long-term benefits" and the reductions should be "additional to any that would occur in the absence of the project."(UNFCCC, 1997) In other words, energy-efficiency CDM projects must be compared against some baseline to quantify the carbon reduction, and this baseline should reflect, as closely as possible, what would have happened in the absence of the CDM project.

In this report we develop a "process-step" benchmarking approach, in which the important energy-consuming production steps in an industry are assigned a benchmark value. Actual projects are evaluated against these benchmarks at the process level. The advantage of using a benchmarking approach is that it establishes a baseline against which a number of projects can be compared. It eliminates the process of constructing project-specific counterfactual baselines, which can entail high transaction costs and could be influenced by strategic "gaming" by the project planner[1]. (Lazarus et al. 1999) Setting the benchmarks at a process-step level rather than at an aggregate production level creates a more flexible tool that can more accurately measure emission reductions from a range of similar projects.

The energy-intensive industries – e.g. cement, iron and steel, pulp and paper – are well suited for CDM project development. These industries account for a majority of industrial energy consumption, especially in developing countries. Within each of these industries, firms produce a relatively homogenous set of products (or intermediate products) using similar production methods and equipment. The production steps have been studied extensively, so valuable information is available for constructing process-step benchmarks.

In this report we use the cement industry to illustrate the process step benchmark approach. Cement production is an energy-intensive process and is critical for the development of infrastructure in many countries. This report begins with a description of the cement making process and a discussion of the energy requirements. We then describe the process step approach for this industry and present examples using possible benchmarks and CDM projects. We then provide a discussion of selected issues relevant to cement industry benchmarks, including blended cements, plant modernization, and alternative fuel choices. In the conclusion we suggest several areas for further research that would strengthen the process-step benchmarking approach and contribute to a greater understanding of how these benchmarks could be used.

II. Description of the Cement Production Process

Cement production is an energy-intensive process in which a combination of raw materials is chemically altered through intense heat to form a compound with binding properties. The main steps in cement production are illustrated in Figure 1.

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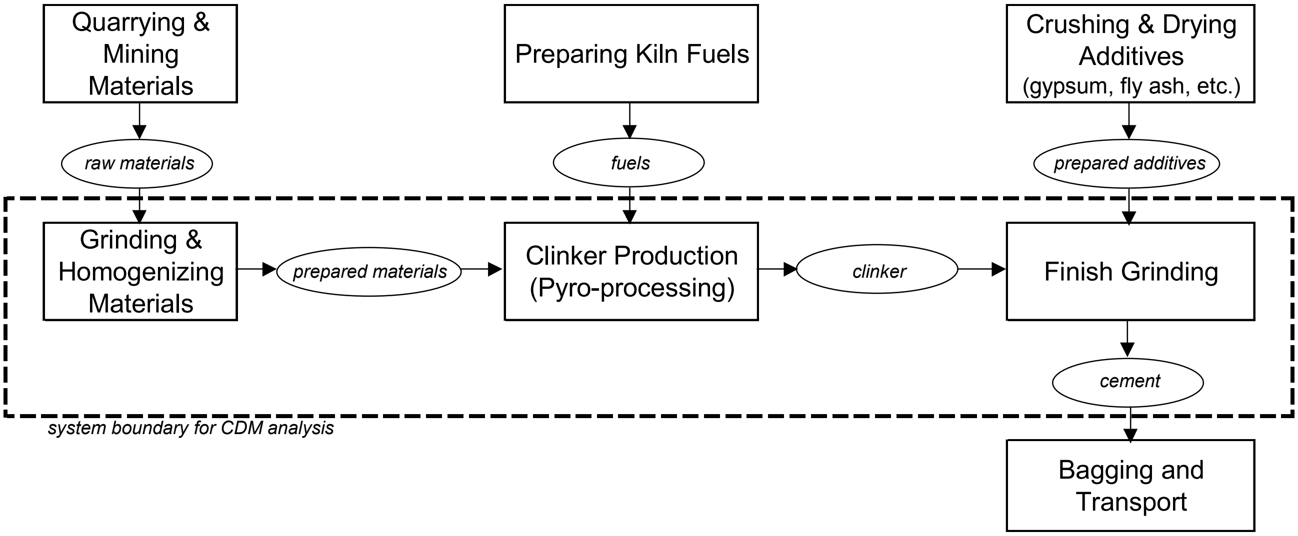
[1] A project developer might "game" a baseline by setting it higher than a counterfactual scenario in order to accumulate the most carbon reduction credit. The use of benchmarks does not eliminate the possibility of gaming, but because benchmarks would be set at a more aggregate level by a higher entity than an individual project counterfactual, the process would be more transparent and open to review.

Raw materials, including limestone, chalk, and clay, are mined or quarried, usually at a site close to the cement mill. These materials are then ground to a fine powder in the proper proportions needed for the cement. These can be ground as a dry mixture or combined with water to form a slurry. The addition of water at this stage has important implications for the production process and for the energy demands during production. Production is often categorized as *dry process* and *wet process*. Additionally, equipment can be added to remove some water from the slurry after grinding; the process is then called *semi-wet* or *semi-dry*.

This mixture of raw materials enters the *clinker production* (or pyro-processing) stage. During this stage the mixture is passed through a kiln (and possibly a preheater system) and exposed to increasingly intense heat, up to 1400 degrees Celcius. This process drives off all moisture, dissociates carbon dioxide from calcium carbonate, and transforms the raw materials into new compounds. The output from this process, called clinker, must be cooled rapidly to prevent further chemical changes. Finally the clinker is blended with certain additives and ground into a fine powder to make cement. Following this *cement grinding* step, the cement is bagged and transported for sale, or transported in bulk.

Figure 1: The Cement Production Process



In cement making, carbon dioxide emissions result both from energy use and from the decomposition of calcium carbonate during clinker production. The most energy-intensive stage of the process is clinker production, which accounts for up to 90 percent of the total energy use. The grinding of raw materials and of the cement mixture both are electricity-intensive steps and account for much of the remaining energy use in cement production. Because these three steps are the most energy intensive and have seen the most technological advancements over time, they are the process steps used for the CDM benchmarking analysis, as shown by the system boundary in Figure 1.

For the benchmarking approach described in this paper, setting this system boundary in an important step. The most energy-intensive steps should be included inside the benchmark, while steps that do now consume much energy or which have extremely difficult or inconsistent data requirements can be left outside the boundary. Two steps that are substitutable should not be on opposite sides of the boundary, since this can lead to leakage effects. For our evaluation, we include the three steps indicated in the diagram, with benchmark values for electricity use at the grinding stages and combustible fuel use in the clinker production stage[2]. We describe the technologies used and the patterns of energy use for these three key cement-making processes below.

Raw Materials Preparation. Roller mills for grinding raw materials and separators or classifiers for separating ground particles are the two key energy-consuming pieces of equipment at this process stage. For dry-process cement making, the raw materials need to be ground into a flowable powder before entering the kiln. There are four main types of grinding systems in use:

- **Tube Mill (or Ball Mill)** – materials are crushed inside a rotating tube – up to 6 m in diameter and 20 m long – containing metal balls that tumble against the materials. *Tube mills are the most energy intensive of the four mill systems*.[3]
- **Vertical Roller Mill** – materials are crushed between a rotating grinding table and 2 to 4 grinding rollers positioned slightly less than 90 degrees from the table surface and pressed hydraulically against it. *Vertical roller mills use 70-75% of the energy used in tube mills.*
- **Horizontal Roller Mill** – materials are crushed inside of a rotating mill tube which also contains a grinding roller that is hydraulically pressed against the inside surface of the tube. *Horizontal roller mills use 65-70% of the energy used in tube mills.*
- **Roller Press (or High-pressure Grinding Rolls)** – materials are crushed between two counter-rotating rollers. These rollers are up to 2 m in diameter and 1.4 m long. *Roller presses use 50-65% of the energy used in tube mills.*

The choice of grinding mill will vary at different facilities due to a number of factors. While power consumption (and hence energy costs) at tube mills are higher, they have lower operating and maintenance costs than the other types of mills. Investment costs are difficult to compare in a general way, because site-specific constraints play an important role. Non-cost factors that affect the decision include the moisture content of the raw materials; vertical roller mills can both dry and grind materials, and so are the most suitable for raw materials with higher moisture content, while roller presses and horizontal roller mills may require a separate dryer. Another factor is the desired fineness of the product. Two types of mills can be operated in circuit to take advantage of the different advantages of each system. For example, a plant in India found an energy-efficient solution by having a first stage of grinding in a roller press and a second stage in a ball mill (Somani et al. 1998). Adding a second mill in circuit with an existing system also helps to expand capacity at an existing plant. A survey of the literature from recent years suggests that the more energy-efficient roller presses are often included in newly constructed cement facilities, but tube mills are still commonly used as well (ZKG, various). For wet-process cement making the raw materials are combined with water and ground in a ball mill. The resulting slurry contains between 24 to 48 percent water.

Another key piece of equipment used in the grinding stage is the separator or classifier, which is used to separate out large particles so that they can be returned for further grinding. Efficiently separating out the material of sufficient fineness decreases the re-grinding of materials and helps lower energy demands. Equipment referred to as ‘high-efficiency classifiers’ or ‘high-efficiency separators’ more accurately separate out large particles that need to be returned to the mill from

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[2] A more detailed or comprehensive analysis may yield a different analysis boundary. For example, if more detail is desired, the use of electricity to rotary the kiln could be included. Also, if projects that introduce a greater proportion of additives in cement are included in the analysis, the additive preparation step could be included. Our boundary is intended as an illustrative example.

[3] The energy comparisons in the section are based on grinding material of the same hardness to the same level of fineness and are taken from Rosemann and Ellerbrock (1998).

the material that can be passed on, so energy use in the grinding mill is decreased. Case studies suggest that at the raw materials preparation stage, 2.8 – 3.8 kWh/tonne raw material can be saved and at the cement grinding stage 1.7 – 2.3 kWh/tonne cement can be saved by use of such "high-efficiency" classifiers (Salzborn and Chin-Fatt 1993, Sussegger 1993).

Clinker Production (Pyro-processing). The heart of the clinker production stage generally is the ***rotary kiln***.[4] These kilns are 6-8 m in diameter and 60 m to well over 100 m long. They are set at a slight incline and rotate 1 to 3 times per minute. The kiln is fired at the lower end and the cement materials move toward the flame as the kiln rotates. The materials reach temperatures between 1400-1500 degrees C in the kiln. Three important things occur with the raw material mixture during pyro-processing. First, all moisture is driven off from the materials. Then the calcium carbonate in limestone dissociates into carbon dioxide and calcium oxide (free lime); this process is called calcination. Finally the lime and other minerals in the raw materials react to form calcium silicates and calcium aluminates, the main components of clinker. This step is known as clinkerization. In all modern cement facilities the early stages of pyro-processing occur before the materials enter the rotary kiln in equipment called ***pre-heaters*** and ***pre-calciners***. Use of this equipment has greatly reduced the energy demands in cement production (Cembureau 1997).

Pre-heaters and pre-calciners can be added to existing plants to greatly improve the energy efficiency of the facility. Adding these features also has the effect of increasing the capacity of the plant by large amounts. Projects of this type have been seen in Italy and the Czech Republic (Sauli 1992, UNFCCC 1998). While sufficient data on plant expansions is unavailable, it appears that significant amounts of new capacity for cement production in developing countries results from both new plants and from expanding capacity at existing plants (ZKG, various).

Once clinker leaves the kiln it must be cooled rapidly to ensure the maximum yield for the compound that contributes to the hardening properties of cement. The main cooling technologies are the reciprocating grate cooler and the tube or planetary cooler. The cooling air is then used for combustion air in the kiln. All modern plants include grate coolers because of their large capacity and efficient heat recovery, and grate coolers are required to provide tertiary air to a precalciner. The efficient heat recovery of these coolers contributes to energy savings in the kiln, estimated around 0.3 GJ/tonne cement (Martin et al. 1999).

Cement Grinding. In the final process step, the cooled clinker is mixed with additives to make cement and ground using the mill technologies described above. The energy used for cement grinding depends on the type of materials added to the clinker and on the desired fineness of the final product. Cement fineness is generally measured in a unit called Blaine, which has the dimensions of cm^2/g and gives the total surface area of material per gram of cement. Higher Blaine indicates more finely ground cement, which requires more energy to produce. Portland cement commonly has a Blaine of 3000-3500 cm^2/g.

III. Energy Use in Cement Production

Table 1 provides technology and energy use values for the three cement-making process steps discussed in the previous section. The first three rows of the table present "best practice" estimates of energy use in cement plants taken from two sources that survey the available technologies for cement manufacturing (Cembureau 1997, Conroy 1994). For raw material preparation and cement grinding, the main energy carrier is electricity, so these estimates are

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[4] Vertical shaft kilns are also used, especially for small-scale production facilities in China and India.

given in terms of kWh per tonne of material throughput. The Cembureau (1997) report gives energy use data for the various available technologies, as discussed in the grinding section above, while the Conroy report focuses only on the most efficient technology, the roller press. Energy requirements for cement grinding are roughly double those for raw material preparation because the cement is harder and need to be ground more finely than the raw materials. An important issue when considering "best practice" energy requirements for grinding is that energy use is related to the hardness of the raw materials and the additives included before cement grinding as well as the desired fineness of the finished product. These features can vary, so it is important to specify the fineness and composition of the product when discussing energy use.

Clinker production accounts for a majority of the energy use in the cement making process. As Table 1 shows, multi-stage preheaters and precalciners are part of any "best practice" cement plant. Using these technologies energy use is around 3,000 kJ per kilogram of clinker produced. Wet process cement making uses much more energy, and even under "best practice" can consume up to 6,000 kJ per kilogram of clinker.

The second half of Table 1 provides examples from actual plant experience worldwide. Data on clinker production, the most energy-intensive step, are generally given, while grinding energy data are less commonly available. The four examples shown all use multi-stage preheaters and precalciners, and all show energy consumption around what is expected from the "best practice" information. In general, the energy use for grinding appears to be higher than the "best practice" estimates, although for cement grinding comparison is difficult because the final products vary.

Wet vs. Dry. Table 1 shows that the dry process requires much less energy than the wet process. This is because wet process cement making includes the addition of water during raw materials preparation, and these materials need to be dried before calcination and clinkerization. There are processes called semi-wet or semi-dry in which the materials are prepared with the addition of water, but steps are added to remove part of the water and form cakes or pellets which then enter the clinker production stage. These are less energy-intensive than the wet process but not as efficient as the dry process. In the past, the wet process was chosen to facilitate raw material grinding, but currently the choice between wet and dry processes usually depends on the raw materials available to the producer. The dry process is most commonly used, while the wet process is only used in exceptional cases, if the available limestone has a high moisture content (>20%). Global data on the moisture content of limestone deposits are not available, but the absence of wet kiln construction in recent history suggests that few areas are likely to require the use of wet kiln technology[5]. Issues on treating wet process cement making under a CDM benchmark will be discussed in Section VI.

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[5] Ireland and the United Kingdom are known to have deposits of limestone with high-moisture content, but they fall outside the discussion of CDM projects.

Table 1: Technology and Energy Use Data for Three Cement Making Process Steps, "Best Practice" and Actual Performance

		Raw material preparation		Clinker production			Finish grinding		Source
	Plant	**Technology**	**Energy use (kWh/t raw meal)**	**Capacity (t/d)**	**Technology**	**Kiln Energy Use (kJ/kg clinker)**	**Technology**	**Energy Use (kWh/t cement)**	
Technical Publications	Cembureau BAT – Dry	Center Discharge Tube Mill (*TMCD)* Airswept Tube Mill (*TMAS*) Vertical Roller Mill (*VRM*)	*TMCD:* **17-20** *TMAS*: **17-20** *VRM*: **13-14**	3000	5-stage preheater precalciner	**2900-3200**	Tube mill in closed circuit (*TMCC*) Vertical Roller Mill (*VRM*) Roller Press(*RP*), Horizontal Roller Mill (*HRM*)	3500 cm2/g: *TMCC*: **36.5** *VRM*: **28.5** *RP*: **24.5** *HRM*: **25.5**	Cembureau, 1997
	Cembueau BAT – Wet	Tube mill in closed circuit (*TMCC*) Wash Mill (*WM*)	*TMCC*: **13.5** *WM*: **5-8**	2000	Wet	Up to **6000**			
	"Modern Plant Design"	Roller Press, static V-separator	**10-11**	5000	4-stage, 2- string preheater, low NOx calciner	Coal: **2990-3010**	Roller Press, static V-separator	Type I, 3600 cm2/g: **25.0**	Conroy, 1994
Actual Plant Data	Lampang, Thailand	Roller grinding mill	**21.4**	5700	5-stage 2-string preheater, PYROCLON precalciner	Fuel oil: **2977** Lignite: **3014**	Tube mill with high efficiency classifier	OPC (3300 cm2/g): **41.76** "Tiger Mix"[6] (4200 cm2/g): **33.70**	Seigert et al., 1998
	Bernburg, Germany	n/a	n/a	5000	6-stage, 2-string DOPOL-90 with precalcination	Lignite: Continuous operation: **3100** Optimal: **3008**	Roller press and ball mill with high efficiency classifier, variable speed drives	CEM I 32.5 R cement: **22.8**	Philipp et al., 1997
	Rajashree Cement, India	Roller press, tube mill, V-separator	**17-20**	3500	6-stage, 2-string preheater, calciner	Coal: **2931** (*expected*)	Roller press, tube mill, high-efficiency classifier	(3000 cm2/g): **31.25**	Somani et al., 1997
	Tepeaca, Mexico	n/a	n/a	6500	5-stage preheater, precalciner	Fuel oil: **3030**	Ball mill, SEPAX separator	n/a	Turley, 1995

n/a = information not available

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[6] Composite cement containing 30% limestone

IV. A Process-Step Benchmarking Approach to Evaluating Energy Use at New Cement Plants

To establish a CDM evaluation tool for cement production that addresses the three stages identified above and uses a benchmarking approach, it is necessary to establish benchmark performance values for each of the three stages. Then a project can be compared against the benchmark to determine the projected level of carbon dioxide reduction the project will accomplish.

The formula for calculating carbon emission reductions at a cement plant is given below. This formula takes into account only energy use at the three key process stages: raw material preparation, clinker production, and cement grinding. A benchmark value is used at each stage to measure the carbon emissions avoided.

$$C(t) = \sum_f m_f q_f \cdot \underbrace{\left(b_K \cdot X_K(t) - K(t)\right)}_{\text{clinker production}} + q_e \cdot \left[\underbrace{\left(b_M \cdot X_M(t) - M(t)\right)}_{\text{raw materials}} + \underbrace{\left(b_G \cdot X_G(t) - G(t)\right)}_{\text{cement grinding}}\right] \qquad (1)$$

$C(t)$ = carbon dioxide emission reduction at the plant in year t (tonnes CO_2)

Carbon contents:

m_f = percentage of fuel f in total primary fuel use for year t (%)
q_f = carbon content of fuel f (tonnes CO_2/GJ)
q_e = carbon content of electricity (tonnes CO_2/kWh)

Outputs:

$X_M(t)$ = output of raw material at the plant in year t (tonnes)
$X_K(t)$ = output of clinker at the plant in year t (tonnes)
$X_G(t)$ = output of ground cement at the plant in year t (tonnes)

Energy Use:

$M(t)$ = total plant electricity use for raw materials preparation in year t (kWh)
$K(t)$ = total plant energy use for clinker production in year t (GJ)
$G(t)$ = total plant electricity use for cement grinding in year t (kWh)

Benchmarks:

b_M = energy benchmark for raw meal production (kWh/tonne raw meal)
b_K = energy benchmark for clinker production (GJ/tonne clinker)
b_G = energy benchmark for cement production (kWh/tonne cement)

In the cement production process, carbon dioxide emissions can be grouped as “energy-related”, referring to emissions that result from the combustion of fossil fuel, and “process-related”, referring to the emissions from the decomposition of calcium carbonate. Process-related emissions are not accounted for in Equation (1) because they are not a matter of efficiency or performance; instead they are related to the total amount of clinker produced and not to the technology used. These emissions can be reduced on a *per tonne of cement* basis by decreasing the amount of clinker per tonne of cement (the clinker-to-cement ratio). This is referred to as “blended cement”. This aspect has been left out of Equation (1) because it presents some difficult issues that will be addressed in Section VI. For now, the calculation is neutral to the clinker-to-cement ratio.

Determining the value to assign as benchmarks for the above equation is not a simple task. To reflect the intent of the Kyoto Protocol, CDM projects should receive credit only if the reductions they cause are additional to what would have happened without CDM. Therefore it is important for benchmarks to represent what would have occurred in the absence of CDM. Cement production is highly competitive and efficient equipment is the norm. It is plausible to consider setting benchmarks for the cement process steps from: (1) average annual performance data from individual plants across the industry, (2) actual performance data from recently constructed plants, or (3) documented best technology information. While the first of these options would allow us to generate a trend of energy performance at newly added facilities over time, and therefore might indicate a future trend for plants, data availability makes this a difficult approach. Following this approach would require performance data at each process step for each plant in a country, as well as information on the vintage or age of each component. This would be extremely difficult or impossible to obtain for most countries. Furthermore, there may not be enough plants built in a given region, or the plants in a region may be too old, for a reasonable trend to be observed.

There is more likelihood of compiling a reliable dataset for the other two options. For example, when new plants are constructed, the manufacturer often gives a "guaranteed" value for the performance of the kiln, and the manufacturer will compensate the facility owner if the value is not met. Thus, actual performance data from recent plants may be available because plant owners are monitoring actual kiln production compared to guaranteed values. Through a thorough literature search on new plants and perhaps communication with manufacturers, it may be possible to collect enough data to use this approach. Documentation on the best available technologies for all processes is obtainable from cement associations, such as Cembureau, the European Cement Association, and may be the most simple method for establishing benchmark values (see Table 1). We use such values for benchmarks in the examples presented in the next section.

V. Examples of the Use of a Process-Step Benchmarking Approach for Cement Plants

In this section we look at two examples to illustrate the benchmarking approach outlined in this report. The energy benchmark values, against which project performance values are compared, are taken from the technological estimates shown in Table 1. We set the benchmark at the highest end (i.e. least efficient) of these estimates. Since most new plants coming on now are more efficient than this value, we assume this is the least strict benchmark that might be set[7]. Therefore our examples give the greatest amount of carbon reduction likely to be credited for a given plant. We evaluate two hypothetical plants using this benchmark. The first one is based on the actual performance data reported for a cement plant in Thailand. For the second example the hypothetical plant performance data are taken from the lowest (i.e. most efficient) technological estimates in Table1.

Performance Data from an Existing Cement Plant in Thailand. In this example, we consider a hypothetical CDM project with a plant having the same performance as an actual plant in Lampang, Thailand. The plant in Lampang was commissioned in 1996, and because it was constructed in ecologically pristine region, it was subjected to particularly strict standards for layout and environmental protection (Seigert et al. 1998). This plant utilized highly efficient technology and is therefore expected to be among the top performing cement plants in the world, particularly at the clinker production stage. Table 2 compares the best available technology benchmark value (from Table 1) to actual performance data from this plant[8].

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[7] Since many recently constructed projects surpass this benchmark value, it is probably not a accurate measure for additionality. We do not endorse using this value and have simply chosen it to illustrate the calculation of carbon credits and to indicate the maximum amount of credits that might be expected.

[8] Due to the incomplete nature of the data, some assumptions were needed to do this analysis. Total annual production was unknown, so the daily production, 5700 ton per day, was multiplied by 350 days, assuming the kiln was shut down only about 2 weeks per year. The amount of raw materials produced was assumed to be 1.7 times the clinker production (at least 1.5-1.75 tonnes raw material are required to produce a tonne

The benchmark values in Table 2 come from the upper range of technology estimates from the European Cement Association (Cembureau 1997), and the performance values come from a study of the Lampang plant (Seigert 1998). Using the assumptions about plant output levels, values for total energy saved with respect to the benchmark can be calculated. This calculation shows that there are no savings at the raw materials preparation or the cement grinding stages. There are, however, savings during the clinker production stage. These energy values can be converted to carbon using the carbon content of the various fuels. For clinker production we use the carbon content of the fuel used in the in the new plant, fuel oil – a more detailed discussion of fuel choice is in Section VI. For electricity, we use the average carbon content of the Thailand electricity grid[9]. The table shows that 9.4 kt of carbon are avoided at the clinker production stage, but this is offset to some extent by the excess carbon emitted at the other stages. In total, the Lampang plant emits 6.8 kt carbon less than the benchmark value per year, equivalent to 3.2 kg C per tonne cement. Therefore, this plant would qualify for credit in a CDM regime that uses this benchmark.

Table 2: Evaluating Carbon Dioxide Emissions from a Hypothetical Plant based on the Lampang, Thailand Cement Plant Using a Technology-based Benchmark.

Process Step	Benchmark	Plant Performance	Plant Output	Energy Saved[e]	Carbon Content	Carbon Avoided[e]
Raw Materials Preparation	20 kWh/ tonne raw material	21 kWh/ tonne raw material	3.4 Mt raw material/yr[a]	-3.4 GWh/ yr	Elec: 0.16 tC/ MWh[b]	-0.6 kt C
Clinker Production	3200 MJ/ tonne clinker	2977 MJ/ tonne clinker	2.0 Mt clinker/yr[c]	446 MJ/ yr	Fuel Oil: 21 tC/ TJ	9.4 kt C
Cement Grinding	36 kWh/ tonne cement[d]	42 kWh/ tonne cement	2.1 Mt cement/yr	-13 GWh/ yr	Elec: 0.16 tC/ MWh	-2.0 kt C
					TOTAL ANNUAL SAVINGS:	**6.8 kt C**
						3.2 kg C /tonne cement

[a] There was no information on the amount of raw material processed at the plant, so this value was derived on the basis of 1.7 tonnes raw material per tonne of clinker.

[b] Calculated from IEA data for Thailand for 1995, the latest data available.

[c] The report gives a production of 5700 tonnes clinker per day. This was multiplied by 350 days to attain this value.

[d] This benchmark is based on the production of Portland cement of 3500 Blaine. The performance data given is for a product with 3300 Blaine. This should lower energy requirements.

[e] These are energy and carbon *savings*, so negative numbers indicate quantities *worse than* the benchmark.

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of Portland cement. Since Portland cement is 95% clinker, 1.58-1.84 tonnes raw material are require per tonne clinker), and the plant was assumed, for this year, to produce only one type of cement, OPC or "ordinary Portland cement", ground to a Blaine of 3300. The benchmark for finish grinding was chosen for a Portland cement of Blaine 3600, so this benchmark could be refined to reflect the difference although we lack the information to make this calculation.

[9] The value for carbon content of electricity to use when calculating carbon reduction is a debated issue. We use the national average for grid electricity to illustrate our calculation. However, it is true that the carbon content of the marginal avoided electricity is more appropriate. This value could be taken from the benchmark derived for electricity generation (Lazarus et al. 1999).

In this example, fuel oil is the energy source at the kiln and is taken as the benchmarking fuel; in other words, the energy savings are recorded at the kiln and multiplied by the carbon content of fuel oil to determine carbon reductions. The way that the benchmark approach is structured now, energy use – not carbon emissions – is benchmarked, and fuel choice is not included in the evaluation. In Section VI we look at various issues related to cement benchmarks, including fuel choice, and this example is revisited there.

Performance Data from "Best Practice" Technologies. Table 3 presents a hypothetical scenario in which the benchmark and performance values are taken from the best-practice estimates in the first 3 rows of Table 1, (Cembureau 1997). Benchmarks need to be strict enough to avoid rewarding for emission reductions that would have occurred anyway, while at the same time allowing some room for improvements so that efficient projects actually receive some incentive. To create this hypothetical scenario, the benchmark value is set at the high end of the best available technology estimates in Table 1. For performance values, the lowest estimates are used; this represents the best possible plant, and therefore the largest potential emissions reduction. By choosing a benchmark at the highest best available technology level and assuming a new plant operating at the lowest best available technology level, the example illustrates the maximum amount of credit that would likely be granted.

Table 3: Evaluating Carbon Dioxide Emissions of a Hypothetical Plant Using a Best Available Technology Benchmark.

Process Step	Benchmark	Performance	Plant Output[a]	Energy Saved	Carbon Content[b]	Carbon Avoided
Raw Materials Preparation	20 kWh/ tonne raw material	10 kWh/ tonne raw material	3.4 Mt raw material/yr	34 GWh/ yr	Elec: 0.16 tC/ MWh	5.6 kt C
Clinker Production	3200 MJ/ tonne clinker	2900 MJ/ tonne clinker	2.0 Mt clinker/yr	600 MJ/ yr	Fuel Oil: 21 tC/ TJ	12.6 kt C
Cement Grinding	36 kWh/ tonne cement	25 kWh/ tonne cement	2.1 Mt cement/yr	23 GWh/ yr	Elec: 0.16 tC/ MWh	3.8 kt C
				TOTAL ANNUAL SAVINGS:		**21.9 kt C**
						10.4 kg C /tonne cement

[a] For this hypothetical plant, plant output was based on the output of the Lampang plant in the previous example.

[b] Calculated from IEA data for Thailand for 1995, the latest data available.

In this hypothetical scenario, there are energy savings over the benchmark at every process step. These savings lead to annual avoided carbon totaling 21.9 kt C or 10.4 kg C per tonne of cement produced. More than half of the savings arise from the clinker production step. The relative importance of this reduction can be seen by using the same assumptions to calculate a carbon intensity per tonne of cement. The carbon intensity is 75.0 kg C per tonne cement for the benchmark assumptions and 64.6 kg C per tonne cement for the performance assumptions. This accounts for energy-related emissions *only*; since we are comparing scenarios with identical clinker production levels, emissions from reactions of calcium carbonate will be equal and so are left out of the calculation.

Carbon Emission Reduction Credits. In a CDM regime, projects would be awarded one Carbon Emission Reduction (CER) unit for each tonne of carbon avoided. If the Thai plant and hypothetical plant were approved CDM projects, they would accrue 0.032 CER and 0.0104 CER per tonne of cement, respectively. In an emissions trading scheme these CERU would have a market value. If the value of the CERs ranges from $10 to $50, then the value per tonne of cement can be calculated as shown in Table 4. This table shows that under the best available technology benchmark used in our examples, the Thai plant might expect to earn emission credits equal to roughly $0.03 to $0.16 per tonne of cement. An optimally performing plant would accrue credit around $0.10 to $0.52 per tonne of cement manufactured.

Table 4: Carbon Emission Reduction Credits for Two Example Plants with Values Over a Range of CER Value

	Lampang Performance	**Hypothetical "Best" Performance**
carbon avoided (kg C/t cement)	3.2	10.4
Carbon Emission Reduction (per tonne cement)	0.0032	0.0104
Value, at $10/CER ($/t cement)	0.03	0.10
Value, at $50/CER ($/t cement)	0.16	0.52

In order to understand the importance of these economics, we would want to compare the investment costs of the standard "benchmark" technology with the additional costs of the projects that are needed to exceed the benchmark performance. The magnitude of this incremental investment can then be compared to the potential revenue from the CERs accrued and other benefits including reduced energy expenses. This would partially answer the question as to whether CDM credits offer an incentive for investing in high-efficiency technology. We did not collect the technology cost information needed for this evaluation for this project. An approximation of the economic importance of these CDM credits can be seen by comparing the range of estimated values to the price of cement – approximately $40 to $80 per tonne, but with large regional variation. The values calculated in Table 4 are roughly 1 percent or smaller than the cement price. Further economic analyses into cement production cost factors and the incremental costs of efficient technologies are needed before it is possible to evaluate the economic implications of CERs at this level.

VI. Issues for Cement Industry Benchmarks

Blended cements

In the finish grinding stage of cement production, clinker is mixed with additives and ground to a fine powder. These additives affect the strength, curing time, and other characteristics of the final product, concrete. The most commonly used cement type in the U.S. – Portland cement – has a clinker-to-cement ratio of 95%. By increasing the amount of additives in the mix, i.e. lowering the clinker-to-cement ratio, less clinker is needed so energy use in clinker production decreases per tonne of cement, even though the efficiency of the process may not have improved. At the same time, lower clinker production means that less CO_2 is emitted from dissociating calcium carbonate during the calcination phase of clinker production. These cements with lower clinker-to-cement ratios are called "blended cements". Increasing the fraction of additives with respect to Portland cement leads to longer curing times, but ultimately greater strength in the final product.

The use of blended cements reduces energy consumption as well as offers an opportunity for improved industrial ecology, since the additives can be waste from steel making (blast furnace slag) or from coal combustion (fly ash). Blended cements are very common in Europe and many developing countries (Hendriks et al., 1999). However, there are some non-technological barriers to expanded use of blended cements. One barrier is that building codes in many countries, including the U.S., dictate the chemical and/or physical characteristics of cement used for construction. Restricting properties such as setting time may limit the use of blended cements, therefore discouraging their production. Another barrier is that the additive materials needed may not be available to many cement manufacturers.

The formula for evaluating carbon reductions given in Equation (1) is neutral to the clinker-to-cement ratio. In other words, reductions resulting from lowering the clinker-to-cement ratio are not quantified in the evaluation. If projects that involve the production of blended cements are to be considered for CDM credits, then a value needs to be introduced to Equation (1) that links clinker production and cement production. This can be done by introducing another benchmark value: the *benchmark clinker-to-cement ratio*. Up to this point, carbon reductions were calculated at the individual process step, based on the how much product was made at that step and how much energy was used. Introducing the benchmark clinker-to-cement ratio changes the calculation slightly. For example, if the clinker-to-cement ratio benchmark is 0.9, then for every 1 Mtonne of cement is produced, we anticipate 0.9 Mtonne of clinker will be produced. If in fact the plant produced cement with a clinker-to-cement ratio of 0.8, then it only needs to produce 0.8 Mtonne of clinker. By avoiding production of 0.1 Mtonne of clinker, the plant saves energy and also eliminates emissions from calcination.

A link can also be made with the raw materials preparation stage, if desired, by introducing a benchmark raw meal-to-clinker ratio. Adding these benchmarks changes the Equation (1) in the following way:

d_K = benchmark clinker-to-cement ratio (tonnes clinker/tonne cement)
d_M = benchmark raw meal-to-clinker ratio (tonnes raw meal/tonne clinker)

then new benchmark values can be calculated on a per tonne of cement basis:

$b_K^* = d_K \cdot b_K =$ energy benchmark for clinker production, cement basis (GJ/tonne cement)

$b_M^* = d_K \cdot d_M \cdot b_M =$ energy benchmark for raw meal production, cement basis (kWh/tonne cement)

Since the clinker share per tonne of cement changes, there are reduced emissions from the calcination process that must be accounted for. The carbon emissions evolved from this process are a fixed stoichiometric value:

q_c = carbon emissions from the calcination process (tonnes CO2/ton clinker)

so equation (1) becomes:

$$C(t) = q_j \cdot \underbrace{\left(b_K^* \cdot X_G(t) - K(t)\right)}_{\text{clinker production}} + q_e \cdot \left[\underbrace{\left(b_M^* \cdot X_G(t) - M(t)\right)}_{\text{raw materials}} + \underbrace{\left(b_G \cdot X_G(t) - G(t)\right)}_{\text{finish grinding}}\right] + q_c \cdot \underbrace{\left(d_K \cdot X_G(t) - X_K(t)\right)}_{\text{calcination}} \quad \mathbf{(2)}$$

There are three important differences between the two equations: (1) the addition of the calcination term in the second equation, (2) the modification of benchmark values to all be on a “per tonne of cement basis”, and (3) the second equation only uses the output of cement (X_G), not that of raw materials and clinker.

The importance of the cement blending issue to carbon reduction and CDM evaluation is highlighted in Table 5 below. This table compares two scenarios for potential CDM projects; in the first each of the process steps is more efficient than the benchmark values (similar to Table 3) and in the second the performance is identical to the benchmark but cement is blended at a clinker-to-cement ratio of 65 percent. The benchmarks for the projects are the same, with the blending scenario having an additional benchmark for the clinker-to-cement ratio. The performance values show the improvements for the efficiency scenario and the lowered clinker-to-cement ratio for the blending scenario. This lower ratio means a difference in total production; the scenarios both depend on the same capacity kiln system, but nearly 50 percent more cement is made in the blending scenario.

Table 5: Evaluation of Carbon Dioxide Emissions Reductions in Two Potential CDM Projects in the Cement Industry

	Scenario 1: Efficiency Improvements, No Cement Blending	Scenario 2: Cement Blending, No Efficiency Improvements
Benchmarks	20 kWh/tonne raw material ground 3200 MJ/tonne clinker 36 kWh/tonne cement ground	20 kWh/tonne raw material ground 3200 MJ/tonne clinker 36 kWh/tonne cement ground 0.95 tonne clinker/tonne cement
Performance	10 kWh/tonne raw material ground 2900 MJ/tonne clinker 25 kWh/tonne cement ground	20 kWh/tonne raw material ground 3200 MJ/tonne clinker 36 kWh/tonne cement ground 0.65 tonne clinker/tonne cement
Production	3.4 Mtonne raw material 2.0 Mtonne clinker 2.1 Mtonne cement	3.4 Mtonne raw material 2.0 Mtonne clinker 3.1 Mtonne cement
Energy Savings	34 GWh from raw material grinding 600 TJ from clinker production 23 GWh from cement grinding	0 GWh from raw material grinding 2,950 TJ from clinker production 0 GWh from cement grinding
Carbon Reduction	13 ktonne C from clinker 9 ktonne C from elec savings	62 ktonne C from clinker 0 ktonne C from elec savings 152 ktonne C from calcination
TOTAL ANNUAL SAVINGS	**22 ktonne 10.4kgC/tonne cement**	**214 ktonne C 69.7 kg C/tonne cement**

The efficiency scenario leads to energy savings at each step which can then be translated into annual carbon reductions – a total of 22 kilotonnes of carbon or 10.4 kg C per tonne of cement. In the cement blending scenario there are no energy savings from efficiency improvements, but because the clinker-to-cement ratio is benchmarked at 0.95, total cement output of 3.1 Mt leads to an expected clinker production of 2.95 Mt. Since the plant operates with a 0.65 clinker-to-cement ratio, 0.95 Mt of clinker are "avoided", saving 2,950 TJ of fossil fuels, or 62 kilotonnes C if fuel oil is used in the kiln[10]. Also, since 165 kg C per tonne are generated through calcination, an additional 152 kilotonnes of carbon emissions are avoided. The blending project avoids 214 kilotonnes of carbon emissions, or nearly 70 kg C per tonne of cement. This is almost 10 times the total amount avoided by the efficiency project or 7 times when taken on a per tonne of cement basis. Whereas the efficiency project would be worth between $0.1 and $0.5 per tonne cement (assuming CER values between $10 and $50), the cement blending project would generate revenue between $0.7 and $3.5 per tonne cement produced.

This example demonstrates that blending cement can lead to significant carbon emission reductions. These savings can be much larger than those that energy efficiency projects may attain. Even lowering the clinker-to-cement ratio from 0.95 to 0.90 leads to greater reductions

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[10] One caveat to this analysis must be stated. The use of additives for blended cements changes the energy requirements in two ways: (1) the preparation of additives, such as drying or crushing, requires more energy since there are more additives per tonne cement, and (2) the finish grinding electricity demand changes depending on the properties of the additives compared to the clinker. More research would be needed to make these adjustments, which are considered small compared to total energy use and carbon emissions.

than the efficiency project in the scenarios above. From the viewpoint of an investor seeking the most CDM credits, projects that lower the clinker-to-cement ratio will be preferred. This means that the clinker-to-cement ratio benchmark will be extremely important in determining the amount of credits earned. Setting this value would be easy if all the current and planned cement plants in a country have the same clinker-to-cement ratio, if this is not the case, then measuring additional reductions is difficult. If the benchmark ratio is set high, where most producers currently are, then blended cement projects would reap large reductions, and there is no certainty that these reductions are additional. If the ratio is set lower, then plants with high clinker-to-cement ratios will never qualify, despite how efficient their processes may be. Further research on specific blended cement projects in the context of a particular country's cement sector could explore whether benchmarking clinker-to-cement ratio is appropriate or if these projects should be evaluated on a case-by-case basis.

Additionality

New Plants. A brief review of the project activities of cement equipment manufacturers over recent years reveals that nearly all new installations of cement plants around the world have included the most up-to-date technologies, including multi-stage preheaters, precalciners, high efficiency separators, and variable speed drives for mills[11] (ZKG, various). If these technologies are most commonly being adopted, there is little room for "additional" carbon reductions from energy efficient technologies. If most new plants coming online have a multi-stage preheater and a precalciner, then kiln energy performance should be around 3.0 GJ per tonne of clinker and the benchmark could be set at this level. However, it is currently unlikely that a plant will attain better than 2.9 GJ per tonne of clinker. This translates to savings of about 2 kg C per tonne cement, with some variation depending of the fuel used. Are these savings large enough to encourage cement manufacturers to aim for the lower intensity? It is difficult to answer that question without knowing the value of the carbon credits and the additional costs of saving that extra 0.1 GJ per tonne. Further research on this topic is required.

Setting the benchmark higher than 3.0 GJ per tonne (as we did in our examples) would allow many existing projects to qualify for CDM credit. This seems to go against the intention of a CDM mechanism, which aims to credit reductions that would not have happened otherwise.

In terms of grinding raw materials and finished cement, there may be more room for CDM to encourage the adoption of advanced technologies. This is because there is a wider range of technologies currently being adopted. Many tube mills, the least efficient of common mills, are still constructed (ZKG, various), and advanced technologies such as horizontal mills, are still being developed and have small market share. This may be where CDM could make a difference.

Modernization. The hypothetical plant example above illustrated that the expected range for energy intensity of cement production is 3.2 to 3.8 GJ per tonne cement if modern, advanced technologies are adopted for new plants[12]. The national averages for cement production around the world are much higher than this range. Cement plants are a large capital investment and can

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[11] An alternative method of cement production uses a *vertical shaft kiln*. These kilns are smaller and require shorter lead times for construction so they have been used to meet rapidly growing demand. They have been built almost exclusively in China. Further market and technological assessment is required to determine whether the benchmark should accommodate shaft kilns as CDM projects or whether they should be excluded from qualifying as projects.

[12] This range is dependent on a raw material to clinker production ratio of 1.7 and a clinker to cement ratio of 0.95.

be used for many decades. Therefore there are many plants operating below the optimal performance level. In the modern competitive cement market, many of these inefficient plants are unable to compete and are being purchased by large multinationals. These companies then face the choice to modernize the facility or to completely rebuild it.

Plant modernization includes a wide variety of measures. Existing equipment can be upgraded, including mills for raw material and cement grinding, clinker coolers, and classifiers. New features can be added, including preheaters, precalciners, heat exchangers, and dewatering equipment for wet process production. Also, management strategies to improve process control and maintenance procedures contribute to plant modernization.

Below are some examples of modernization projects:

- Anhovo, Slovenia – A double branch preheater from the 1960s was replaced with a 5-stage cyclone preheater with a precalciner. Clinker output increased from 1980 tonne per day (tpd) to 2080 tpd and energy use dropped 15%, from 3660 kJ/kg to 3100 kJ/kg (World Cement 1994).
- Rohoznik, Slovakia – A new dynamic air separator was added to the cement grinding mill. Output of the mill rose from 100 tph to 120 tph and specific power consumption decreased from 45 kWh/t to 40 kWh/t for the production of Portland cement (World Cement 1994).
- Hranice, Czechoslovakia – A wet process plant was converted to dry process. The new plant has an output of 2735 tpd and kiln energy consumption of 3125 kJ/kg (World Cement 1994).
- Cizkovice, Czechoslovakia – In the only AIJ project in the cement industry[13], a new cement crusher and a new preheater system were added. Further details and performance data are not available yet (UNFCCC 1998).
- Tasek Cement, Malaysia – An existing preheater was replaced with a 5-stage, 2-string preheater and a precalciner. A planetary cooler was replaced with a reciprocating grate cooler for tertiary air supply. Capacity increased from 2,100 tpd to 5,100 tpd. No energy information is available (Krupp Polysius 1998).
- Testi, Italy – A 4-stage preheater was replaced with a 5-stage preheater and a precalciner. The rotary kiln was shortened and drives were altered to allow for increased speed. Output increased form 1000 tpd to 1800-2000 tpd. Kiln heat requirements fell from 3560 kJ/kg to 3060-3185 kJ/kg (Sauli 1992).
- Alpena, MI, US – 14 ball mills and a drying system for raw materials were replaced with 2 roller presses and flash driers added to the 2 largest existing ball mills. Power consumption for raw material grinding dropped from 20.7 kWh/t to 17.0 kWh/t (Kreisberg 1992).

Crediting modernization projects under a benchmark methodology raises some questions. If the plant would have continued to operate without the modernization, then the "additional" reductions would be the difference in performance between the old and modernized plants. In many cases these plants would have undergone some improvement or have been closed, so it is hard to assess what would have occurred in the absence of the project.

It is possible to use the process-step approach for crediting modernization and to use the same values as benchmarks. It appears from the results above that modernization can improve energy performance to approximately the same level as efficient new plant additions. Rather than benchmark the entire production, however, it may be preferable to evaluate the savings arising from the process step where modernization has occurred. This allows an improvement project to

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[13] Another cement project in El Salvador is being considered in the current round of IJI proposals. Details on the project are not available.

attain credit without the energy requirements of the remaining plant (which may still be substandard) to negatively influence the evaluation.

Fuel Choice

For the calculations of carbon reductions in Section V, the benchmark is given in terms of energy use, not carbon use. For the grinding stage where electricity is the fuel, the amount of electricity savings is multiplied by the carbon content of electricity where the plant is located. The plant cannot use another fuel in place of electricity and has no control over the carbon content of the electricity unless the power plant is located onsite (e.g. cogeneration). For clinker production, the energy reduction is measured from the benchmark and multiplied by the carbon content of the fuel used at the plant. We have not attempted to incorporate fuel-choice options into the benchmark approach, although this could certainly be done by choosing a 'benchmark' fuel and multiplying the energy benchmark by the carbon content of the benchmark fuel. Then the plant's performance would be evaluated by its actual carbon emissions, rather than by its energy use.

The difficult part of this approach is choosing the fuel to be the benchmark fuel. Many different fuels can be used to fire the kiln during clinker production. The choice is often guided by site-specific conditions; for example, in the United States and in Thailand, coal is the most commonly used kiln fuel because of its abundance and low cost. In Argentina, where natural gas is abundant, nearly all cement kilns are gas-fired (Cembureau 1996). Thus, in some areas there is a potential for reducing carbon emissions from cement production by fuel switching. There is also potential for using alternative fuels including landfill gas, used oils and solvents, waste treatment sludge, plastic waste, biomass, and tires (Pizant and Gauthier 1997). These may have related environmental issues that need to be addressed. Although fuel-switching might be beneficial, it will not be possible in all circumstances due to a lack of infrastructure to supply fuels like natural gas, or a lack of reasonable access to alternative fuel sources. In the benchmarking examples in this report, fuel choice has not been taken into account because we currently lack the information on the fuel being used in marginal (i.e. recently added) facilities, which varies by country, and we do not know the infrastructure or accessibility barriers to fuel-switching.

If fuel choice were to be considered in the benchmark, a further exploration of fuel accessibility by country and region would be needed. That task was not undertaken for this analysis, but its application would be straightforward. In every place that a benchmark value is given in energy units, it would be multiplied by the carbon content of the 'benchmark' fuel. Then the total emissions from the plant would be calculated. Clearly, some decision on the emission factors from alternative fuels would be required if they were part of the CDM project.

To illustrate, we return to the first example presented in this report, where the carbon content of fuel oil was used to determine the carbon emission reductions. Data from Cembureau show that the dominant fuel at Thai cement plants is coal; roughly 90 percent of the production capacity in Thailand used coal as the primary fuel. The data do not reveal what the marginal fuel for cement plants is or what the accessibility of natural gas is for cement producers, but it seems likely that the project in the example would save carbon not just through efficiency, but also through the choice of fuel oil as the kiln fuel. If coal was chosen as the benchmark fuel, then the benchmark for the kiln could be expressed in carbon rather than in energy terms by multiplying the energy benchmark by the carbon content of coal. Then the actual emissions from the plant could be calculated as actual energy use multiplied by the carbon content of fuel oil, and this would show that the plant avoids over 41 ktonnes of carbon at the kiln, not 9.3 ktonnes. This is a large difference, so the decision to benchmark the fuel choice should be done only with sufficient information on marginal fuel use.

Certainly one area where fuel choice should be considered is modernization projects that convert a plant from a dirtier fuel to a cleaner fuel. While this raises all the concerns discussed in the section above on modernization projects, it could be easily implemented by multiplying the benchmark energy value by the old fuel carbon content and actual energy performance by the carbon content of the new fuel. The difference would be the carbon emission reduction.

Flexible Benchmarks for Grinding Process Steps

As discussed in Section III on the cement production process, the energy requirements for grinding at the raw material preparation stage and at the cement grinding stage is directly related to two factors that can vary from facility to facility. First, the hardness of the materials being ground can vary. In some cases the raw materials will vary, but this pertains mostly to changes in the additives. For the blended cements, where the additive share increases greatly and the materials can include volcanic rock and blast furnace slag, the energy requirements for grinding can be higher (Patzelt 1995). Second, the fineness of the final product can vary depending on the specifications of the desired cement. Clearly, more finely ground cement will require more energy.

It is conceivable that some formula could be derived that relates the energy benchmark for grinding to the shares of different additive materials and to the fineness of the final product. If research on this topic has been published in the cement industry literature, this approach is feasible, otherwise, it would require a large amount of research to parameterize such a formula. Some preliminary steps can be taken to determine whether the difference in grinding requirements is small enough such that correcting for it in the benchmarking formula would not be worth the effort such a correction would require.

Benchmarks for Wet Process Plant Projects

As discussed above, energy use in wet process cement production will be higher because of the need to dry the materials. Although wet process was once needed for efficient raw materials grinding, this is no longer true. Therefore, any new wet process plant should be considered for CDM status *only* in areas where the raw materials have a high moisture content but then should be compared to a benchmark based on a semi-wet or semi-dry process to encourage the inclusion of a “dewatering” step. There is some potential for converting wet process plants to semi-wet or even to dry processes. These projects could lead to large energy reductions and seem very valid for CDM consideration. These projects are, in fact, plant upgrades and the concerns about additionality and other issues discussed in the section on modernization are equally relevant for these projects.

VII. Summary and Conclusions

This report describes how a process step level benchmarking approach for evaluating CDM projects in the cement industry could be designed. Benchmarking approaches will likely reduce the high transaction costs and potential for gaming associated the using plant-specific baselines. The advantage of creating a benchmarking tool at the process-step level is the flexibility it provides for evaluating plants using different inputs or generating different outputs. This flexibility should lead to better quantification of additionality and more accurate assignment of carbon reduction credits. The disadvantage to this methodology is finding data to generate values for the process-level benchmarks.

We designed a benchmarking tool for cement production that evaluates three process steps: raw materials grinding, clinker production, and cement grinding. Our values for the benchmarks were chosen from published reports on best available technologies in cement production; these values are reinforced by information on recent facility openings published in cement industry literature. We tested our methodology and benchmark values by constructing two examples. These examples show that the potential financial impact of a carbon credit system would be small relative to the price of cement, but further economic investigation is needed to understand the importance of these credits relative to the additional investment costs required for higher efficiency performance.

In the process of building this benchmark scheme, a number of issues arose that would need to be thoroughly investigated before a process-level approach is put in place. These issues include:

- how to deal with blended cements;
- how grinding benchmarks take into account the types of materials ground and the fineness of the product;
- how this methodology would be applied to plant modernization, since these type of projects offer an excellent opportunity for carbon emissions savings;
- how the economics of cement production would be affected by CDM credits of the magnitude identified in this report.

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