2010 Energy Intensity
(Cement Sector)

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Systems Analysis Group, RITE

RITE has estimated energy intensity in the cement sector in major regions. The estimated energy intensity at the time of 2000 has been published on our website under the title “International Comparisons of Energy Efficiency; Sectors of Electricity generation, Iron and Steel and Cement” [1]. Our paper (Oda et al. [2]) shows estimated intensity for 2005.

In this paper, energy intensity in the cement sector is estimated and summarized, based on the most recently released data. The estimates of energy intensity (shown in this paper) in each country are regarded as the very crucial study, reflecting the technological levels as accurately as possible so that concrete and effective emission reduction measures can be encouraged

1. Introduction

(1) Overview of the cement sector

Cement production process has three large divisions, such as ‘raw material’, ‘clinker production’ and ‘cement finishing’ processes. In addition to limestone, the main ingredient, clay, silica stone, and blast furnace slag are ground and mixed in ‘the raw material process’. The next step, in ‘the clinker production process’, clinker is made of those preheated raw materials through the rotary kiln[1]. Clinker is an intermediate product which is the main raw material of cement and the core of the cement manufacturing process, because the ‘sintering step’ that is clinker production consumes the most energy required for the whole cement manufacturing process. Cement is finally produced through grinding of clinker and mixing with gypsum (in the case of average Portland cement) in ‘the finishing process’. When blast furnace cement is produced, about 40% of blast furnace slag is often used in the "finishing process"[2].

The basic flow of cement production is as above, but in fact a variety of by-products and wastes as raw materials and fuel is put in. (see Table 1)[3] The total of these by-products and wastes amounts to 481kg per one ton of cement. (the case of Japan in FY2012) As a lot of by-products and wastes are used in some areas, we have to be careful when we estimate energy intensity.

[1] NSP kilns (rotary kilns with preheaters and precalciners) calcinate more than half of materials in precalciners and the calcinating rate in the rotary kiln is rather small.
[2] The ratio of blast furnace slag is 5% to 70%, depending on the type of blast furnace cement.
[3] When by-products and wastes put as clinker materials have an effect on limestone eviction, process-derived CO2 emissions associated with CaCO3 decomposition can be reduced.

Table 1 Examples of by-products and wastes put in cement manufacturing process (Japan)

Role	'Raw material process'/ 'calcination process' (input before clinker production)	'Cement finishing process' (Input after clinker production)
Materials	raw sludge, sludge, steelmaking slag	fly ash, blast furnace slag
Fuel	waste oil/waste plastic	
Materials/fuel	waste tires, wood chips, meat-and-bone meal	

(2) Overview of estimates

The thermal energy input per 1 ton of clinker production is estimated. This is because from the point of view of energy consumption clinker production is the core of the cement production process. Following the thermal energy required for clinker production, 'the raw material process', 'the sintering step', and 'the finishing process' consume high energy which is electricity. Electricity input is necessary mainly for grinding and mixing clinker and raw materials as well as transportation of clinker and raw materials. In this paper, we focus thermal energy (GJ / t clinker) for clinker production, since the electricity consumption is less than thermal energy clinker production [4] and the data are not generally available.

In order to estimate the efficiency of thermal energy consumption in clinker production, we mainly use two methodologies in this report. One is to refer to WBCSD Cement Sustainability Initiative (CSI) [4]. WBCSD CSI [4] aggregates and publishes data that each company reports based on the boundary which has been set by region or country, though the numbers themselves seem to be robust. With reference to WBCSD CSI [4], IEA Energy Technology Perspectives 2012 [5] also shows the energy intensity potentials of the world by region. On the other hand, WBCSD CSI [4] does not cover the production scale which depends on regions (details below), which requires to combine WBCSD CSI [4] with other methods.

The other methodology is to estimate the thermal energy of regional clinker production by widely accumulating individual information. The followings are specific methodologies.

- To estimate based on the production system or production scale, etc.
- To refer to the environmental reports of companies, etc.
- To refer to publications of the regional cement associations, etc.
- To calculate based on peer-reviewed publications (regional energy intensity data)

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[4]According WBCSD Cement Sustainability Initiative (CSI) [4], the global average consumption of CSI member companies is 104kWh / t cement in 2012. This corresponds to 1.12GJ / t cement, converted to primary energy at 1kWh = 3.6MJ ÷ 0.333 = 10.8MJ. While, the thermal average input for clinker production of CSI member companies accounted for 3.53GJ / t clinker, and this corresponds to 2.64GJ / t cement, converted at the CSI average ratio of clinker cement, 74.7% in 2012. Thermal energy consumption accounted about 2.4 times as much as the electricity consumption on the basis of primary energy. Thermal input for clinker production accounted for the main axis of the energy consumption in the entire cement manufacturing process. [4]

[5]IEA Energy Technology Perspectives (ETP) [5] covers a large area of the world, but shows aggregated data of the whole Europe, it is necessary to estimate the national data within EU in other ways.

The specifics of the ‘approach based on the WBCSD CSI’ and ‘approach by aggregating data’ are below.

2. Referred intermediate values

(1) Approach based on WBCSD CS1

WBCSD Cement Sustainability Initiative (hereinafter referred to as CSI) is a private organization which the major cement companies in the world participate in and manage on a voluntary basis. CSI is intended to develop sustainability and social responsibility for CO2 emissions and fuel consumption is cited as one of the activities. Basically CSI member companies are supposed to report CO2 emissions and fuel consumption of their company in accordance with the format that has been defined by the CSI [4].

CSI [4] shows the thermal energy input par ton clinker produced by CSI member companies in Fig.1 and Fig.2. Fig.1 shows the transition by key region in the world and Fig.2 shows the transition by country in Europe. Since the numerical value of individual companies becomes apparent when it is presented by country in case of the limited CSI member companies of such as Japan, Australia and New Zealand, CSI presents only the transition of the average of the three countries. These three countries are inferior to CSI member companies of India in energy intensity, but superior to member companies of Europe.

Figure 2 shows the transition of CSI member companies by country in Europe. Poland and UK have improved energy intensity since 1990. On the other hand, looking at the trends since 2000 or 2005 of the closer point of time, energy intensity has deteriorated in many countries of Europe. Figure1 also shows the trend that the average energy intensity of CSI member companies in Europe, Japan, Australia and New Zealand tends to rather deteriorate slightly. This is believed due to the fact that they have been active in the acceptance of more by-products and wastes.[6]

[6]To be more accurate, energy intensity is affected by the amount of accepted by-products and wastes as well as by the quality. In other words, if the cement plants accept dry by-products and waste that was pretreated in a separate dry site, the thermal energy consumption of rotary kiln does not result in worsening so much. On the other hand, if they accept the wet by-products and waste without pre-treatment, thermal energy consumption becomes more.

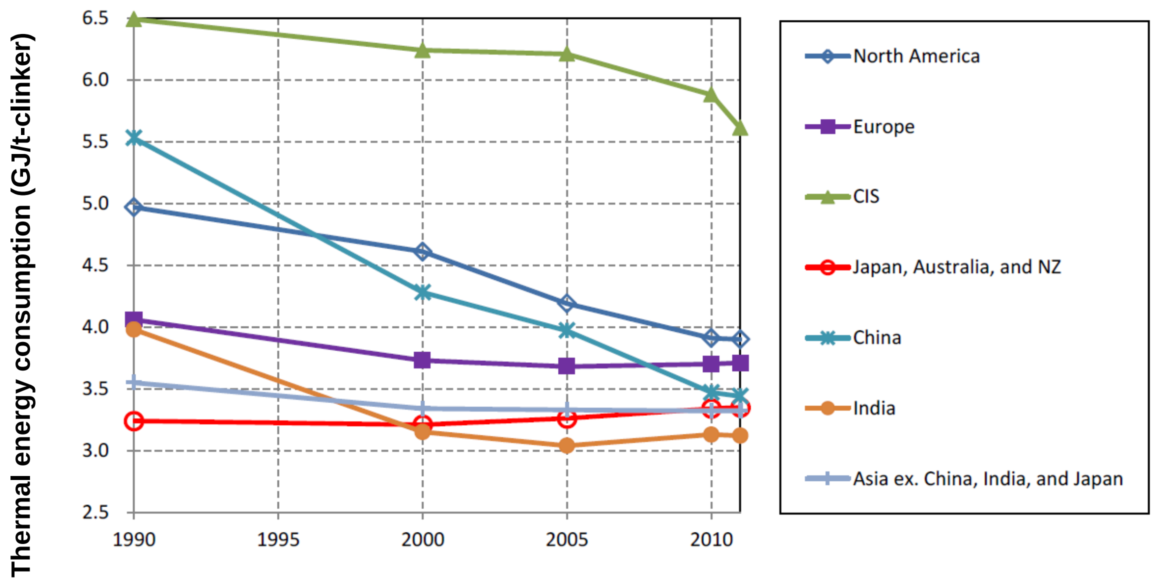


Fig.1 The thermal energy input par ton clinker produced by CSI member companies

Source: WBCSD CSI [4]
Note: Thermal energy consumption includes not only fossil fuels but also input by-products and wastes.

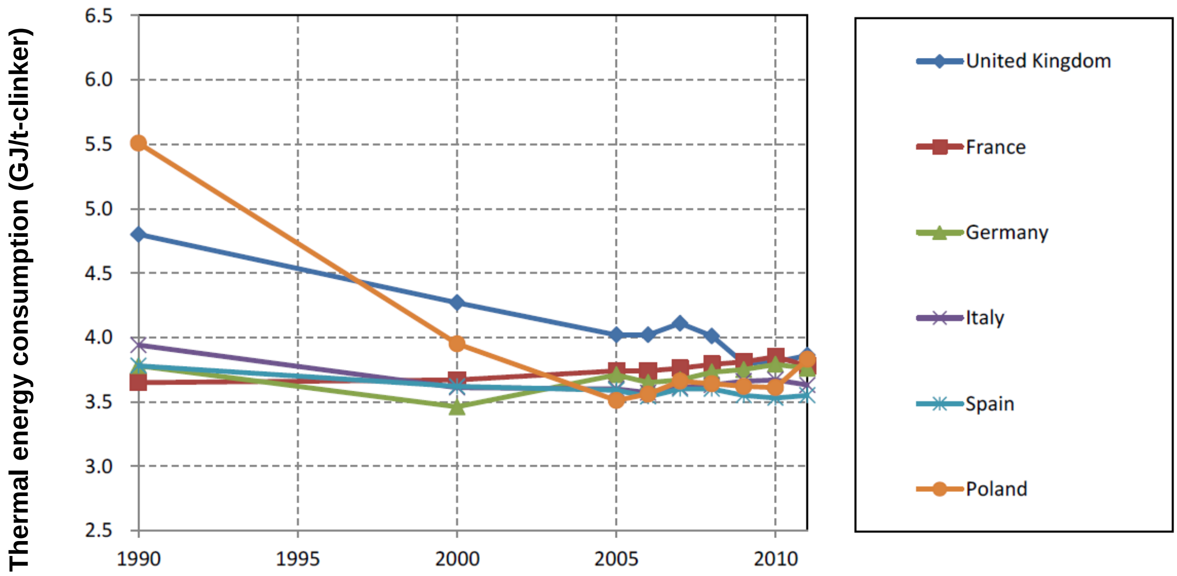


Fig.2 The thermal energy input par ton clinker produced by CSI member companies (by country in EU)

Source: WBCSD CSI [4]
Note: Thermal energy consumption includes not only fossil fuels but also input by-products and wastes.

Data of CSI member companies shown in Fig.1 and Fig.2 are based on the boundary of the CSI and the numbers themselves seem to be robust. With reference to CSI [4], IEA ETP (2012) [5] indicates the regional energy saving potential of the world. Those reports serve as useful reference, however, the regional cement production coverage ratios by CSI member companies stay at a low level in some regions, as shown in Fig.4. The ratios of Asia such as China, the Middle East and the former Soviet Union are about 5% from 50% and the ones of North America and Latin America also remain from 60% to 70%. IEA ETP 2012 [5] covers the entire world regions but lumps EU, so it is necessary to separately estimate the state by country.

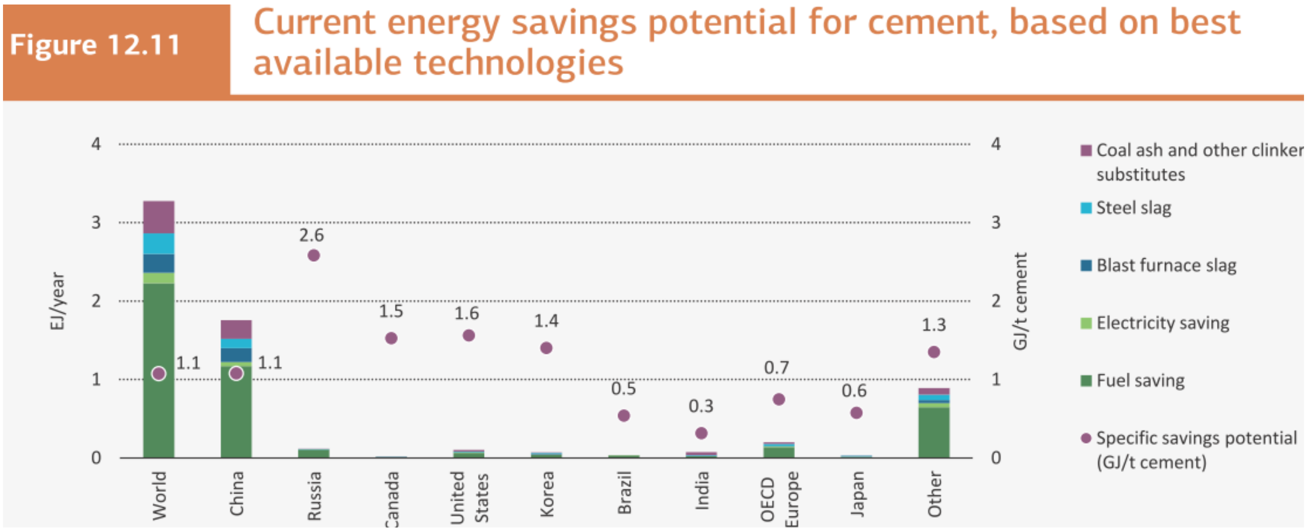


Fig.3 Regional energy saving potentials

Source: IEA ETP 2012[5]
Note: In IEA ETP 2012 [5], a measure to lower the clinker-cement ratio by mixing blast furnace slag after clinker production is also counted as energy-saving potential. Let me note that this is different from the framework in this report.

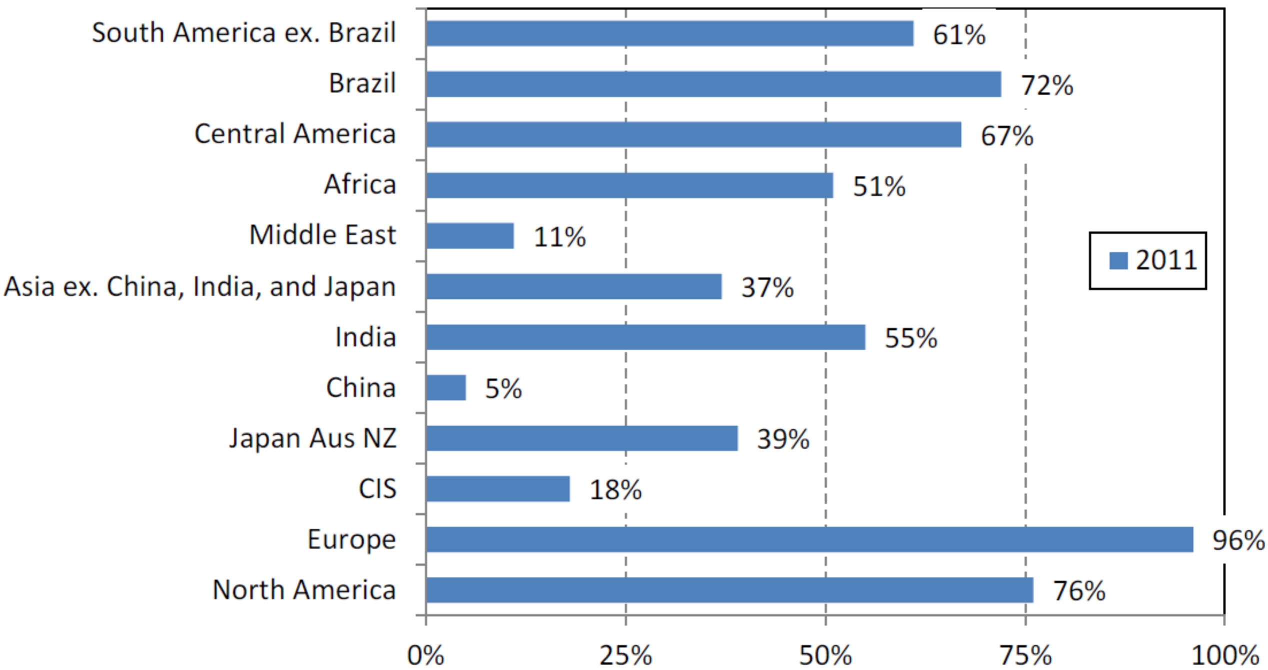


Fig.4 2011 regional coverage of cement production by CSI member companies

Source: WBCSD CSI[4]

(2) Bottom up approach

Bottom-up approach is a methodology to estimate thermal energy intensity for clinker production by region by widely accumulating collected individual information. This approach based on accumulated data is useful to understand the transition of energy intensity by region and the specific reasons, but we need to note that there is a possibility that the estimate methodologies (such as the boundary of the production process) vary depending on papers. The followings are specific methodologies.

- To estimate based on the production system or production scale, etc.
- To refer to the environmental reports of companies, etc.
- To refer to publications of the regional cement associations, etc.
- To calculate based on peer-reviewed publications (regional energy intensity data)

Bottom-up approach was referred to large number of papers, among which some data are effective to understand the regional current status and to estimate intermediate values. The results are shown below.

Fig.5 and Fig.6 show the capacity and cardinal numbers of each clinker production facility in India, which we estimated based on the data of CEMBUREAU [6]. Though the evaluation covers the year of 2002 fairly dated back, some facts based on this information are found: (1) capacity of the main facilities is 2000 ~ 4000 t-clinker/day; (2) The number of small-scale production facilities, 300 t-clinker/day or less, is large but as viewed in the production capacity, the small facilities do not largely account for the capacity; (3) The capacity of wet (or semi-wet) rotary kilns is just partial as viewed in the production capacity. Based on CEMBUREAU [6], Fig.6 suggests the situation in India is very different from in China, as India has a few small facilities and wet or vertical kilns.

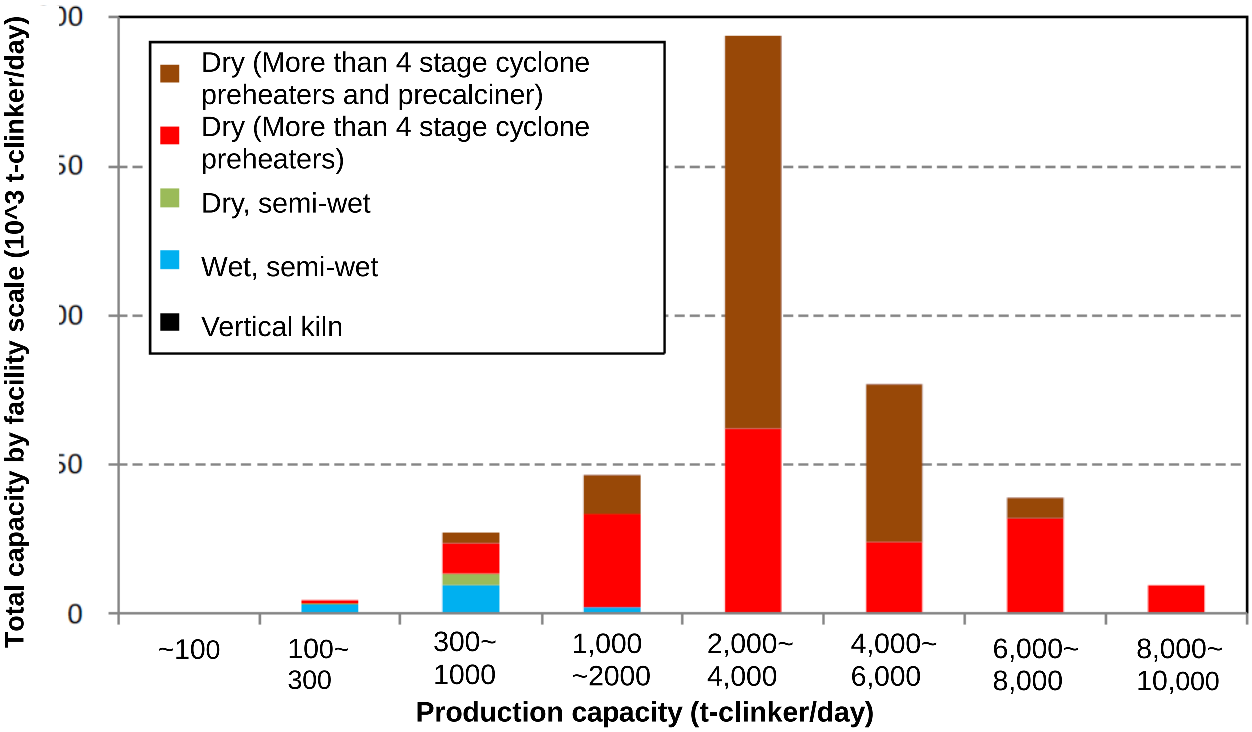


Fig.5 Total capacity by facility scale in India (2002)

Source: RITE estimate based on CEMBUREAU[6]

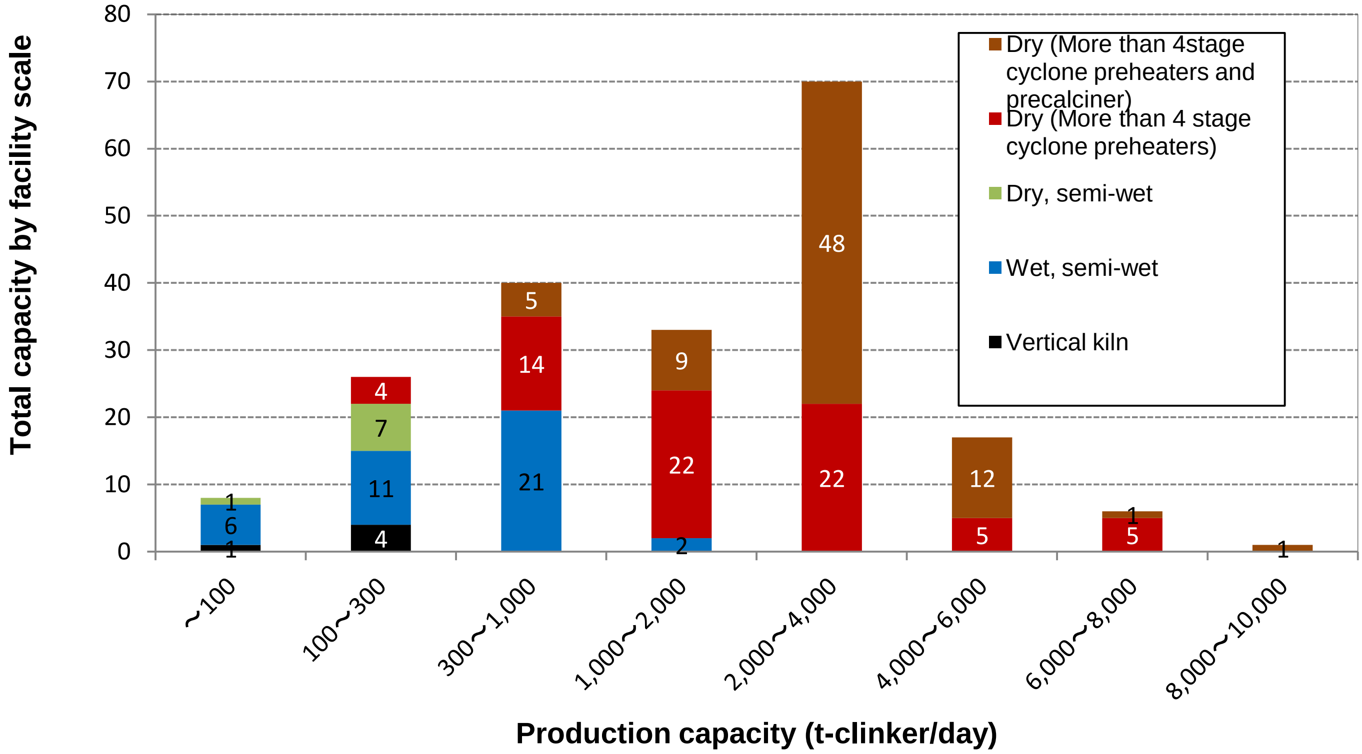
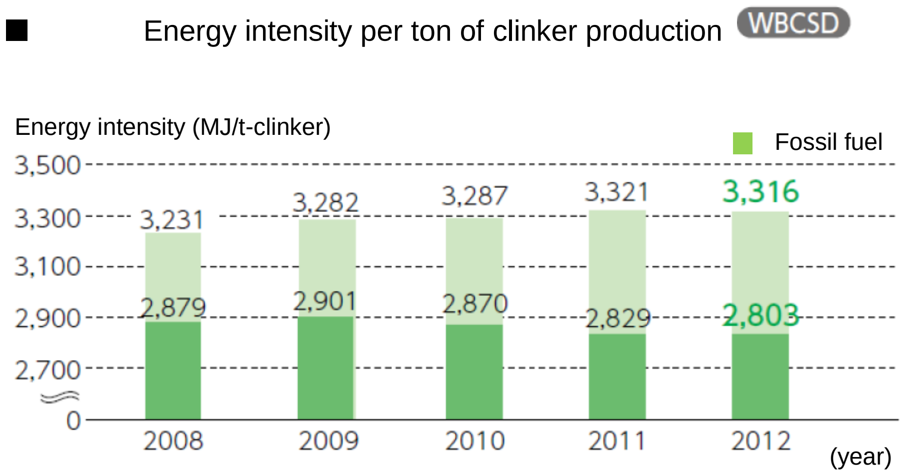


Fig.6 Cardinal numbers by production capacity in India

Source: RITE estimate based on CEMBUREAU[6]

As an example of the data based on the CSR reports of companies, energy intensity of Taiheiyo Cement Corporation is shown in Fig.7 (heat input per a ton of clinker production). Fig.7 can be of some help[7] to show fossil fuel and an alternative to fossil fuels separately[7].

In addition, as an example of the data released by Cement Associations in individual countries, Japanese energy intensity presented by Japan Cement Association is shown in Figure 8(heat input per a ton of cement production)[8]. The average energy intensity of fiscal 2008 from fiscal 2012 was achieved with 3.428GJ / t cement in the article of Japan Cement Association The energy intensity is per cement not per clinker, but the information can be also useful.



Reference Guidelines: WBCSD-CSI "cement CO2, energy protocol Ver.30" (Ver. 2.0 prior to fiscal 2010)

Fig.7 Energy intensity for clinker production of Taiheiyo Cement Corporation

Source: Taiheiyo Cement Corporation [7]

[7] Note that Figure 7 (potentially) includes not only domestic cement plants in Japan, but cement plants in US and Asia under the management by Taiheiyo Cement Corp and it would be necessary to organize together with other data.

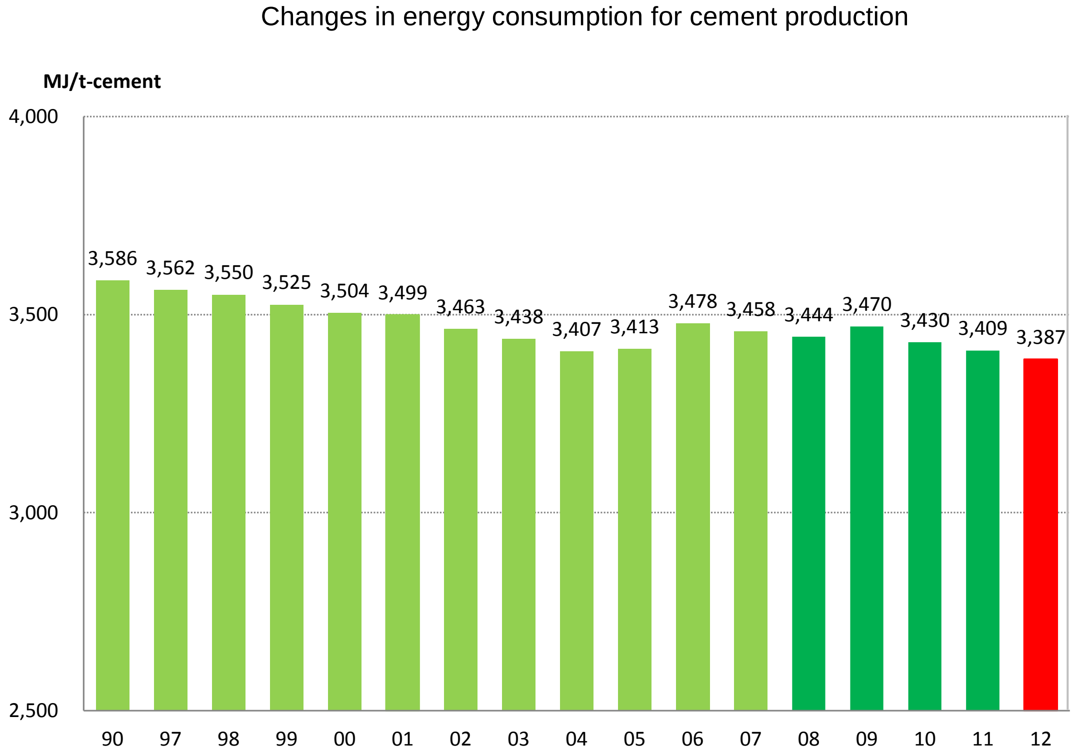


Fig.8 Thermal energy consumption for cement production (Japan)

Source: Japan Cement Association [8]

One of the peer-reviewed papers referred is Hasanbeigi et al [9]. Based on the paper, energy intensity of 16 plants of Shandong Province, China (all NSP[8]), about 3.3GJ / t clinker at least, 3.7GJ / t clinker at average and 4.3 GJ / t clinker at most (of 2008) could be found. Also, according to Zhang et al.[10], fuel-related CO2 emissions of cement production in China in 2000 were about 330 kg CO2 / t cement, compared to about 270 ~ 280kg CO2 / t cement in 2005 and 2008. Based on data related to China, Table 2 shows fuel consumption by production system estimated by RITE. China has successively constructed new cement factories, so that such information as energy intensity by production system (intermediate estimate) is effective.

Table 2 Share of clinker production and thermal energy consumption by kiln in China

	Share of clinker production	Thermal energy consumption
Dry rotary kiln	73.6%	3.7GJ / t clinker
Wet rotary kiln	1.8%	5.7GJ / t clinker
Other rotary kiln	3.9%	3.9GJ / t clinker
Vertical kiln	20.7%	5.1GJ / t clinker
China total	100%	4.0 GJ / t clinker

Source: RITE estimate based on papers, [9] and [10]

[8]NSP stands for new suspension preheater. Rotary kilns with preheating and calcinating furnaces. If existing equipments without the calciners are remodeled to this NSP, production capacity is expected to improve as well as energy efficiency.

3. Summary

While intercomparing the intermediate estimates of thermal energy consumption for clinker production (GJ / t clinker) obtained by each method above, the final thermal energy consumption based on the consistency and relative reliability is estimated. Figure 9 shows the result. The figure shows both existing estimates of 2005 and estimates of 2010.

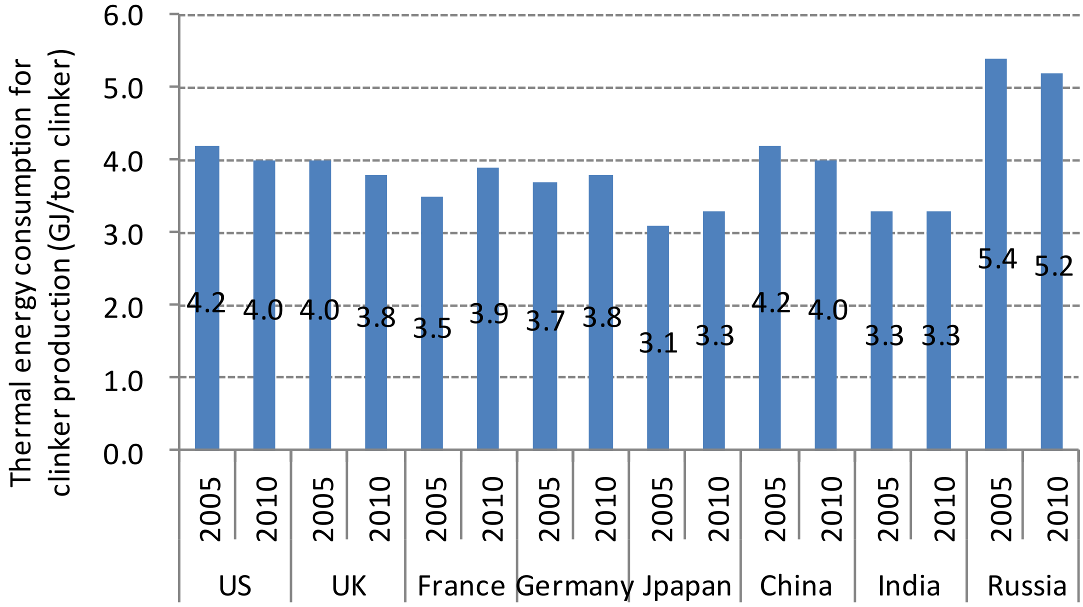


Fig.9 Estimates of thermal energy consumption for clinker production (2005, 2010)

Note 1) the heat input includes not only fossil fuels, but by-products and wastes.
Note 2) in some regions, electricity has also been generated by the clinker cooler waste heat and preheater (preheating furnace) waste heat. This figure includes the effective use of waste heat (without correction of "subtracting effective use of waste heat from the heat input").[9]

Fig.9 (and analyses above) indicate the followings about thermal energy consumption for clinker production.

- Looking at the wide world, signs of improvement can be seen in some regions where energy intensity was high (the United States, China, Russia, etc.).
- This is possibly due to disposal of conventional wet rotary kilns and diffusion of state-of-the-art dry rotary kilns.
- Japan, Germany and France are relatively excellent in energy intensity, which suggests that those countries have been working on energy saving, such as the introduction of dry rotary kiln for the first time in the world.

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[9] Waste heat from clinker coolers and pre-heaters (pre-heating furnace) can cover 30% of the total power consumed by cement plants. Using the preheater waste heat for power generation, in terms that reduce the number of stages to 4 stages is economically rational, (if not, it is desirable to have a 5 or 6 stage SP for the energy efficiency). Japan has actively engaged in the waste heat power generation, but Figure 9 does not include the correction of "subtracting the heat used for waste heat power generation from heat input" (ie adverse way to show energy intensity for Japan in Figure 9). However, Figure 9 shows the good heat energy consumption of Japan so that we could say the real energy intensity of Japan is the top level in the world.

- Japan, Germany and France are relatively excellent in energy intensity, which suggests that those countries have been working on energy saving, such as the introduction of dry rotary kiln for the first time in the world.
- However, since 2005, the influence of aggressive acceptance of byproducts and waste becomes more pronounced and thermal energy intensity is assumed to have deteriorated while slightly.

It is required that cement sector will correspond to two social demands which include the reduction of CO2 emissions with the energy intensity improvements and alternative fuels and further acceptance of by-products and wastes[10]. However, there are trade-offs between a large amount of acceptance of byproduct and wastes as raw material and acceptance of byproduct and wastes as fuel, which makes it more difficult to accept the by-product and waste as a fuel[11].

With consideration of such trade-offs, it is crucial to widely study on which regions have energy potentials and which concrete measures can be effective for the reduction of CO2 emissions.

References

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[7] TAIHEIYO CEMENT CORPORATION, Corporate Social Responsibility Report 2013, p.42 (in Japanese)

[8] Japan Cement Association, Action Plan for Low-carbon Society in Cement Sector, 2013 (in Japanese)

[9] Ali Hasanbeigi, Lynn Price, Hongyou Lu, Wang Lan, Analysis of energy-efficiency opportunities for the cement industry in Shandong Province, China: A case study of 16 cement plants, Energy, 35(8), pp.3461-3473, 2010.

[10]The acceptance of the by-products and wastes, if the main raw material of clinker, limestone has eviction effects would lead to reduction of process-derived CO2 emissions.

[11] Such a trade-off exists for the cement production with defined quality (various properties required by the type of cement, specifically fluidity during construction, the initial strength and long-term strength, chemical resistance, seawater resistance, water-tightness, etc.).

[10] Wenyu Zhang, Dinil Pushpalal, Yoshihito Shigeno, Yutaka Tonooka, Life Cycle Assessment of the Environmental Impact in the Regional Cement Industry of China, Journal of Japan society of Energy and Resources, 33(1) pp.11-22, 2013.

Contact to:
Junichiro Oda, Kohko Tokushige, Keigo Akimoto
Systems Analysis Group
Research Institute of Innovative Technology for the Earth (RITE)
9-2 Kizugawadai, Kizugawa-shi, Kyoto 619-0292 JAPAN
PHONE: +81-774-75-2304 FAX: +81-774-75-2317 E-mail: sysinfo@rite.or.jp