Title	Recommending the use of blast furnace cement to reduce CO2 emission
Sub Title	
Author	Fujiwara, Koichi(Hayami, Hitoshi) 早見, 均(Yoshioka, Kanji) Ikeda, Ayu Suga, Mikio Wong, Yu Ching 吉岡, 完治
Publisher	慶應義塾大学産業研究所
Publication year	1996
Jtitle	Keio Economic Observatory review No.No.8 (1996. 4) ,p.136- 144
JaLC DOI	
Abstract	This paper introduces the input-outp ut approach to environmental analysis carriedout by the Yoshioka team of the Keio University. The paper focused on thecement industry, and the use of blast furnace slag is recommended to reduce CO2emission in the ce
Notes	
Genre	Journal Article
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=AN00390376-00000008-0136

The Keio Economic Observatory Review No. 8, March 1996

Recommending the Use of Blast Furnace Cement to Reduce CO_2 Emission*

Fujiwara Koichi[1)], Hayami Hitoshi[2)],
Ikeda Ayu[3)], Suga Mikio[4)],
Wong Yu Ching [4)] and Yoshioka Kanji[2)]
Keio Economic Observatory Keio University
1) Hirosaki University
2) Keio University
3) Tokai University
4) Graduate School of Keio University

Abstract

This paper introduces the input-output approach to environmental analysis carried out by the Yoshioka team of the Keio University. The paper focused on the cement industry, and the use of blast furnace slag is recommended to reduce CO_2 emission in the cement industry.

Focusing on the issue of 'recycling' in the iron and steel industry, and the cement industry from the national economy point of view, the analytical results revealed that tremendous energy saving effects could be obtained with regards to the above two industries.

1. Introduction

In our previous paper, we have shown that the construction sector plays a crucial role in the reduction of CO_2 emission[1]. It is found that inputs with relatively high levels of CO_2 emission are used in the construction sector, and a large amount of transport activities are also related to the activities of this sector. However, as the construction sector is responsible for the building of infrastructure, it has also an important role to play in the investment of facilities for environmental protection and preservation. Consequently, the issue on how the construction sector could be made 'more friendly' to the environment should be one of the emphases in future environmental policy. We analyzed the issue on how CO_2 emitted from the production of inputs used in the construction sector could be reduced. In this paper, a simulation is carried out to find out ways in which production of inputs used in construction sector could be improved.

A large quantity of cement, iron and steel, and lumber are used as intermediate inputs in the construction sector. Our analysis showed that for every 1 million yen (in 1985 prices) of cement produced, 76 ton (in CO_2 conversion ton) of CO_2 is emitted[2]. Cement has the highest level of CO_2 emission other than energy related goods. The emission of CO_2 from iron ranked second, amounting to 32 ton. Moreover, within the total CO_2 emission of 1000 million ton in Japan in 1985 (in CO_2 conversion unit), 55 million ton or 5.5% of the total are contributed by the cement sector and a further 100 million ton

*Reprinted and corrected from *Keio Economic Observatory Occasional Paper* E.No.21(June 1995).
[1]Yoshioka et al.(1992b)[9]
[2]Yoshioka et al.(1992a) [8].

or 11% are emitted from the iron and steel sector, and hence the CO_2 emission from the above two sectors combined amounted to 17% of the total emission. However, a closer examination of the manufacturing processes in these two industries revealed that with the improvement in efficiency of energy used in production and the extensive use of desulfurization equipment after the energy crisis in Japan, further reduction of CO_2 emission in the respective industry through the improvement in production facilities, may be extremely difficult to achieve as compared to other countries[3]. Therefore we question if it is possible to further reduce the emission of CO_2 by using blast furnace slag, a by-product of the iron and steel industry.

In Japan, one third of the blast furnace slag produced by the iron and steel industry is used in the production of cement. Hence, the aim of this paper is to analyze, to what extend CO_2 emission could be further reduced by increasing the use of blast furnace slag. Our analysis found that out of the 25 million ton of blast furnace slag generated in 1985, 8.6 million ton of it is used in the production of cement. If the total quantity of blast furnace generated from the iron and steel industry is utilized in cement production, 14 million ton of induced CO_2 emission (1985 level) could be reduced.

2. Recommending the use of blast furnace cement for the preservation of the environment

Although limestone is the main input in the production of cement, it can also be manufactured from blast furnace slag, a by-product produced in the manufacturing of iron. Cement manufactured from limestone is termed 'Portland cement' whereas 'blast furnace cement' is the name given to cement manufactured using blast furnace slag as raw material[4]. Although the initial strength of blast furnace cement is weaker than that of Portland cement, it's strength increases above Portland cement 3 months after production. As 64% of the CO_2 emission from the cement industry is contributed by limestone, the use of blast furnace slag has thus the effect of reducing CO_2 emission.

Japan has a long history in the production of blast furnace cement[5]. However, this arises not from the purpose of reducing CO_2 emission but from the common economic rationality in both the iron and steel and the cement industries. Hence, if the CO_2 emission effect of using slag is made apparent, this will help to further promote the use of blast furnace slag in the cement industry. We have carried out a simulation exercise by using the input-output table for environmental analysis to find out the extent of CO_2 reduction obtainable from the use of blast furnace slag in cement production. However, before we begin our explanation on the simulation exercise, we shall first elaborate on the production process of Portland cement and blast furnace cement.

[3] Fujiwara [4].

[4] The standard of blast furnace cement was established in 1950 and there are classified into type A, B and C. In 1990, type B consisted of 95.8%. Blast furnace type B is the major type of blast furnace cement in Japan, it composed of about 55% of Portland cement and 45% of slag. However, in this paper, for the purpose of examining the CO_2 emission reduction through the use of blast furnace slag in cement production, we assumed that blast furnace cement composed of 100% slag.

[5] In 1933, blast furnace cement amounted to 1.7 million ton or 42.1% of the total cement production of 4 million ton. Blast furnace cement was first produced in Japan in 1910 in the government-owned Yawata Iron Work, and the ratio of slag used ranged from 60% to 70%. The utilization rate of blast furnace increased rapidly since around 1975. In 1976, it comprised of 2.7 million ton out of the total cement production of 66 million ton or 4% of the total. By 1990, the share of blast furnace has increased to 14.9 million ton or 17.1% of the total cement production of 86.8 million ton. Information obtained from Cement Association (ed.) [1] and Cement Association (ed.) [2].

3. Production Process of Portland Cement and CO_2 Emission

In this section, we introduce the production process of Portland cement and the sources of CO_2 emission[6]. For the production of Portland cement, it is produced through the chemical reaction of blending and grinding calcium carbonate, silicon oxide, aluminum oxide and iron dioxide in appropriate proportions. The basic production technique consisted of blending and grinding technique and burning technique. The basic production process of cement could be summarized in the following three processes,

1. grinding raw materials process

2. calcination process $\rightarrow$ (clinker)

3. finish grinding process

The process of grinding raw materials involved the blending and grinding of limestone and aluminum oxide. In the calcination process, mixed raw materials is heated in rotary kiln to a maximum temperature of 1,450$^\circ C$, and it is then granulated rapidly to form calcium silicate, also termed as clinker. In the finish grinding process, gypsum is mixed to adjust the hardening process of clinker, thus forming cement.

Next, we shall discuss the sources of CO_2 emission in the production of cement. The source of CO_2 emission in the production of Portland cement can be attributed to the following 2 reasons

(1) CO_2 emission from limestone; and

(2) CO_2 emission from the combustion of fossil fuels.

In (1), CO_2 is emitted from the decomposition of calcium carbonate, the major component in limestone, to calcium oxide and carbon dioxide at approximately 825$^\circ C$.

For (2), CO_2 is emitted from the combustion of fossil fuels, which is used as the energy source needed in the chemical reactions.

Table 1 shows the CO_2 emission in the cement sector by various emission sources. As shown in Table 1, 88% of the output is Portland cement and the remaining 12% composed of blast furnace cement. The total CO_2 emission from the cement sector amounted to 55.4 million ton, within which the CO_2 emission from limestone amounted to 35.6 million ton, constituting 64% of the total CO_2 emission from the cement sector. Therefore, it is clear that limestone is the major source of CO_2 emission. On the other hand, CO_2 emission from the combustion of coal amounted to 16.1 million ton, constituting 29% of the total CO_2 emission from the cement sector. Hence, CO_2 emission originating from limestone and coal constituted 93% of the CO_2 emission from the cement sector.

The energy consumption of the various processes are summarized in Table 2. In terms of the types of energies, it is shown that the energy consumption of the calcination process is extremely large, since out of the total 79.2 trillion kcal of energy consumption used in the whole process, 87% or 69.4 trillion kcal is used in kiln combustion in the calcination process.

Hence, the calcination process is the major source of CO_2 emission in the cement industry, and CO_2 emission are mainly originated from limestone and chemical fuels.

[6] Based on Cement Association (ed.) [1], Daimon[3], and Yamada[11].

Table 1: CO_2 emission by sources in the cement sector(CO_2ton)

Sources	CO_2Emissoin	Composition %
Limestone	35,601,016	64.21
Coal(Domestic)	3,199,336	5.77
Coal(Import)	12,925,268	23.31
Gasoline	691	0.00
Kerosine	7,154	0.01
Diesel Oil	58,676	0.11
Heavy Oil(A)	11,070	0.02
Heavy Oil(B&C)	525,338	0.95
LPG	118	0.00
Hydorocarbon Oil	78,420	0.14
Hydorocarbon Gas	9,561	0.02
Oil Coke	2,989,822	5.39
Coke	35,765	0.06
Coke-oven Gas	1,454	0.00
Blast Furnace Gas	31	0.00
LD-converter Gas	10	0.00
Electric Furnace Gas	572	0.00
Total	55,444,302	100.00

- For the estimation methods, see Yoshioka et al.[8].

Table 2: Anual energy consumption by the cement production processes(10^9kcal/year)

	Grinding Raw Material		Calcination		Finish Grinding		Total	
Total Energy	3,395	(4.3)	71,745	(90.6)	3,521	(4.4)	79,224	
Consumption	1,967	(3.3)	53,554	(91.1)	3,024	(5.1)	58,785	
Electricity	2,848	(3.6)	2,325	(2.9)	3,317	(4.1)	8,490	(11.0)
Consumption	1,825	(3.1)	1,778	(3.0)	2,787	(4.7)	6,390	(11.0)
Fuel	547	(0.7)	69,419	(87.6)	236	(0.3)	70,202	(88.6)
Consumption	142	(0.2)	51,776	(88.0)	204	(0.3)	52,122	(88.6)
Coal	0	(0.0)	38,951	(49.1)	85	(0.1)	39,036	(49.3)
Consumption	62	(0.1)	50,671	(86.1)	100	(0.1)	50,833	(88.7)
Heavy Oil	540	(0.7)	29,083	(36.7)	119	(0.2)	29,742	(37.5)
Consumption	79	(0.1)	474	(0.8)	110	(0.2)	663	(1.2)

- Note: Figures top are the values in 1980, bottom are in 1989.
- Figures in parentheses() are compostion of the various energies from the total energy consumption.
- Sources: Onozaki[1].

Table 3: Ingredients of Portland cement and granulated blast furnace slag(%)

	CaO	SiO_2	Al_2O_3	Fe_2O_3
Portland Cement	63.8	27.5	5.2	2.9
Granulated Blast Furnace Slag	42.2	33.1	13.4	0.0

Source:Japan Cement Association

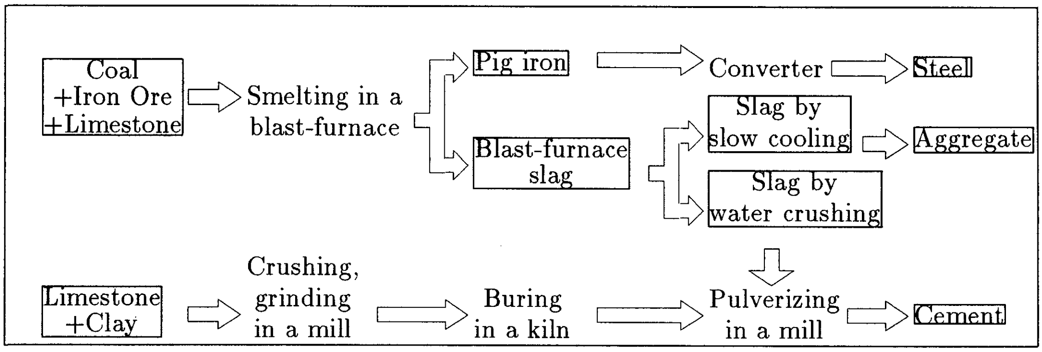

Figure 1: Production Process of Cement

4. Production Process of Blast Furnace Cement

Next, we shall explain the production process of blast furnace cement. As mentioned in the second section, blast furnace slag, a by-product of the iron and steel industry, can be used as input in the manufacturing of cement. Slag produced in the iron and steel industry consisted of 'blast furnace slag' produced in the production of pig iron using blast furnace, and 'revolving furnace slag' produced in the production of steel in revolving furnace. As the use of revolving furnace slag in cement production involved other problems, in this paper we focused only on blast furnace slag. In the case of blast furnace slag, about 300 kg of slag in liquefied form at $1500°C$ are produced with each ton of pig iron manufactured. Granulated blast furnace slag is obtained through rapid cooling by blowing water over it[7]. Table 3 compares the component in Portland cement and granulated blast furnace slag.

As shown in Table 3, the component of granulated blast furnace slag is similar to that of Portland cement, and cement is obtained by grinding granulated blast furnace slag[8]. Consequently, as the calcination process shown in Figure 1 can be omitted in the production of cement, it is expected that considerable reduction effect on CO_2 emission could be achieved.

[7] Slag is classified into air-cooled blast furnace slag and granulated blast furnace slag according to the cooling methods used. Air-cooled blast furnace slag is cooled slowly and the arrangement of atoms are constant, forming massive structure. Air-cooled slag cannot be used as cement but it is used as aggregate of concrete.

[8] However, a small amount of alkaline materials such as nitrate salts and sulphuric salts, etc. is added to slag to give its hydraulic property.

Table 4: Materials and Fuel Inputs for a unit of production

Material inputs per cement(t)	Poltland cement	Slag cement	Fuel inputs per cement(t)	Poltland cement	Slag cement
Limestone(kg/t)	1,149	0	Coal(kg/t)	110	14
Silicon oxide(kg/t)	56	0	Heavy Oil(l/t)	1.1	0
Iron oxide(kg/t)	29	0	Electricity(kWh/t)	110	70
Gypsum(kg/t)	38	0	Water(t/t)	0	7

- Source:Iron and Steel Slag Association[4]

5. Simulation

In 1985, 1012.5 million ton (CO_2 ton) of CO_2 is emitted according to our estimation[9]. Within which, 919.3 million ton is produced in the production process and 93.2 million ton is emitted from final consumption (final demand sector)[10].

A simulation is carried out to find out the amount of CO_2 that could be reduced through increasing the proportion of blast furnace cement in total cement production. First, the input coefficient of the cement sector to be adapted in the simulation exercise is obtained from the input coefficients of the production activities of blast furnace cement and Portland cement receptively and the inverse matrix is calculated by holding the input coefficients of other sectors other than that of the cement sector constant. Next, by using this inverse matrix, we calculate the CO_2 emission when 1 million yen of goods and services are demanded and the CO_2 emission from a given amount of gross national expenditure (GNE).

However, the production activities of blast furnace cement and Portland cement are not separated in the 1985 Input-output Table. Thereupon, as shown in Table 4, based on information on the raw materials and fuels required in the production of 1 ton of blast furnace cement and Portland cement respectively, the cement sector is divided into two parts and the input coefficients are obtained[11].

As shown in Table 4, limestone, silicon oxide, iron oxide, gypsum and crude petroleum

[9] Yoshioka et al.(1992b) [9].

[10] Final demand sector is defined as the household consumption sector and the non-household consumption sector. CO_2 emissions related to energy consumption in special trade, such as army, embassies, foreign vessels are not included.

[11] The cement sector is divided according to the following. From the basic table, with the input from the i th sector to the cement sector as X_{ij}, the input to Portland cement as Xp_{ij}, and the input to blast furnace cement as Xs_{ij}, the following relationship is established

$$X_{ij} = Xp_{ij} + Xs_{ij} \tag{1}$$

and letting the output of the cement sector as x_j, the output of Portland cement as xp_j, the output of blast furnace cement as xs_j, the input coefficient of Portland cement as ap_{ij}, and the input coefficient of blast furnace as as_{ij}, the respective input coefficients of Portland cement and blast furnace cement can thus be represented as follows,

$$ap_{ij} = \frac{Xp_{ij}}{xp_j} \tag{2}$$

$$as_{ij} = \frac{Xs_{ij}}{xs_j} \tag{3}$$

are not needed as inputs in the production of blast furnace cement. Moreover, its coal and electricity requirements are also smaller than that of Portland cement. However, the addition requirement is that on average 7 ton of pressurized water is needed in the production of every ton of blast furnace cement. Further, we also assumed that 1 ton of blast furnace slag is needed in the production every ton of blast furnace cement.

The results of our simulation are as follows. Firstly, we estimated the CO_2 emissions induced from 1 million yen of final demand when the total cement production consisted of 100% Portland cement and 100% of blast furnace cement, respectively.

As slag is a waste product from the iron and steel industry, its output naturally depends on the output size of the iron and steel industry. Consequently, it is not feasible to have 100% of the cement to be supplied by blast furnace cement. However, if the feasibility of using blast furnace slag is taken into account in the calculation, non-linear programming will be needed, which is troublesome. Hence, in our simulation we assumed that the supply of blast furnace slag will be sufficient for the production of blast furnace cement[12].

In this paper, the reduction in the emission of CO_2 refers to the difference in the CO_2 emission from the case of 100% Portland cement and the case of 100% blast furnace cement. Table 5 shows the top 30 sectors which have high CO_2 emission reductions. It shows that the cement sector and the cement related sector occupied the first to the third highest positions. For instance, when the final demand of cement is 1 million yen, the CO_2 reduction effect is 74.5 ton. This is because in the case of blast furnace cement, there is no emission of CO_2 from limestone and the calcination process.

It is worth noting that the 4th to the 15th positions are occupied by the construction sectors. For instance, 0.7 ton of CO_2 is emitted from 1 million yen of final demand in new housing (non-wooden structure). As we have mentioned above, the construction sectors are crucial in the reduction of CO_2 emissions. When the raw materials for the production of cement, the input of the construction sectors, is changed from limestone to blast furnace slag, the CO_2 emission from the final demand of the construction sectors could be largely reduced.

Next, the CO_2 emissions induced from a give amount of final demand are estimated by assuming that the ratios of blast furnace cement in the production of total cement are 0%, 10%, 30%, 50%, 70%, 90% and 100%, respectively[13]. The results of the estimation are summarized in Table 6. Here, the reduction in CO_2 emission is defined as the difference in

[12] The simulation is based on the following formula,

$$c = e \cdot [I - (I - \hat{M})A]^{-1} \tag{4}$$

where c is the vector for CO_2 emission, A is input coefficient matrix, e is the emission coefficient vector of CO_2, $\hat{M}$ is the import coefficient matrix (diagonal matrix), and I is the unit matrix. The input coefficient matrix A and the vector for CO_2 emission coefficient e is derived by the following equations,

$$A = \lambda Ap + (1 - \lambda)As \tag{5}$$

$$e = \lambda ep + (1 - \lambda)es \tag{6}$$

$$0 \leq \lambda \leq 1 \tag{7}$$

where Ap and ep are the input coefficient matrix and the vector for CO_2 emission coefficient, respectively, when cement production consisted of 100% Portland cement, and As and es are the input coefficient matrix and the vector for CO_2 emission coefficient, respectively, when cement production consisted of 100% blast furnace cement.

[13] The simulation is based on the following

$$C = e \cdot [I - (I - \hat{M})A]^{-1}[(I - \hat{M})Fd + E] + Ch \tag{8}$$

where C is the CO_2 emission, Ch is the CO_2 emission vector of the household consumption sector and the non-household consumption sector, Fd is vector for domestic final demand and E is the export vector.

Table 5: Induced CO_2 emission from each final demand of 1 million yen(CO_2ton)

CO_2t/1milion yen production in 1985 producer prices

	Code of IO table	Sector	CO_2 emission		CO_2 Reduction
			Poltland	Slag	
1	2521-01	Cement	85,277.4	10,704.6	74,572.8
2	2522-01	Ready mixed concrete	20,888.6	4,884.0	16,044.6
3	2523-01	Cement products	16,272.9	8,111.6	8,161.3
4	4131-03	Agricultual public utility construction	5,354.8	3,206.1	2,148.7
5	4132-01	Railway construction	5,619.3	4,044.7	1,574.6
6	4131-01	Public utility construction of roads	4,377.4	2,921.8	1,455.6
7	4131-02	Public utility construction of rivers	4,445.2	2,989.9	1,455.3
8	4132-09	Other civil engineering and construction	4,672.8	3,367.2	1,305.6
9	4121-01	Repair of construction	4,195.1	3,077.4	1,117.7
10	4132-02	Electric utility facilities construction	3,740.6	2,891.2	849.4
11	4111-02	New residential construction(non-wooden)	3,634.4	2,897.0	737.4
12	4112-02	New non-residential construction(non-wooden)	3,510.8	2,782.8	728.0
13	4111-01	New residential construction(wooden)	2,689.3	2,161.3	528.0
14	4112-01	New non-residential construction(wooden)	2,541.4	2,127.6	413.8
15	4132-03	Telecommunication utility facilities	3,069.3	2,775.4	293.9
16	2631-02	Cast iron pipes and tubes	13,200.4	12,917.7	282.7
17	7179-02	Service relating to water transport(public)	1,991.6	1,767.1	224.5
18	2599-09	Miscellananeous ceramic, stone and clay	27,940.4	27,808.4	132.0
19	2599-01	Clay refactories	7,560.8	7,453.8	107.0
20	9000-00	Activities not elsewhere classified	4,764.9	4,673.3	91.6
21	6421-01	House rent	408.1	321.0	87.1
22	7113-01	Local railway and tramway transport	2,330.8	2,251.6	79.2
23	5211-01	Water supply	3,694.7	3,626.3	68.4
24	0711-01	Coal mining	6,087.0	6,029.1	57.9
25	7179-01	Road transport facility service	1,335.2	1,281.3	53.9
26	5211-02	Industrial water supply	2,781.1	2,727.9	53.2
27	2599-02	Other structural clay products	10,325.9	10,276.7	49.2
28	7111-01	National railway transport	4,332.4	4,289.9	42.5
29	5211-03	Sewage disposal	5,302.1	5,260.7	41.4
30	3421-04	Electric bulbs	3,030.7	2,991.9	38.8

- 'Poltland' is the case that all cement is assumed to be made of poltland cement.
- 'Slag' is the case that all cement is assumed to be made of slag cement.
- 'Reduction' is the difference between the emission of poltland 100% case and slag 100% case.

Table 6: Reduction of CO_2 by utilizing Blust Furnace Cement(CO_2ton/year)

CO_2t per annum

Utilization ratio of slag cement	Induced CO_2 emission	CO_2 reduction
0	1,019,398,857	0
10	1,013,557,274	6,841,583
30	1,001,874,273	17,524,584
50	990,191,478	29,207,380
70	978,508,919	40,889,939
90	966,826,571	52,572,286
100	960,985,482	58,413,375

- CO_2 reduction is the deviation from the slag 0% utilizing.

CO_2 emission when the ratio of blast furnace cement is increased from 0% to other ratios. The CO_2 reduction effect is found to be close to a linear relationship. In addition, for every 10% increase in the ratio of blast furnace cement used, the reduction effect amounted to about 6.8 million ton.

The results of Table 6 are plotted in Figure 2. Point A indicates the total CO_2 emission in 1985 and the ratio of blast furnace cement used. In 1985, out of the 24.7 million ton of blast furnace produced, about 8 million ton of it is used as raw material input in the production of cement[14]. Further, in 1985, the output of cement amounted to 72.2 million ton, and 1012.5 million ton of CO_2 is emitted.

Further, point B indicates the annual CO_2 emission when all the 24.65 million ton of blast furnace slag is used in the production of cement. Hence, the annual reduction in CO_2 emission in Japan will amount to less than 1 billion ton if all the blast furnace slag produced in 1985 is used in cement production.

6. Conclusion

The combustion efficiency of kiln in the calcination process and the rate of utilization of blast furnace in the Japanese cement industry could be considered to have reached a high level in international comparison. The ratio of Portland cement is 100% in Taiwan, 99% in the US, Canada and Portugal, and 98.3% in South Korea. Hence, the overall potential of reducing CO_2 emission by using blast furnace slag cement production still remain very high.

In 1985, 25 million ton of blast furnace slag are produced in Japan. If all the blast furnace slag are used in the production of cement, the reduction effect on CO_2 emission will amount to about 20 million ton (CO_2 conversion ton), as compared to the case when blast furnace slag is not used at all. However, the present utilization rate of blast furnace slag in the Japanese cement industry, only contributed to 6 million ton of CO_2 reduction. Therefore, the use of blast furnace slag in the cement industry will be very important in the reduction of CO_2 emission in the future.

[14] The sales of slag in the cement industry was 10.3 million ton in 1985. Within which, granulated blast furnace slag (the raw materials for blast furnace cement) amounted to 8.6 million ton and the remaining 1.7 million ton consisted of air-cooled blast furnace slag.

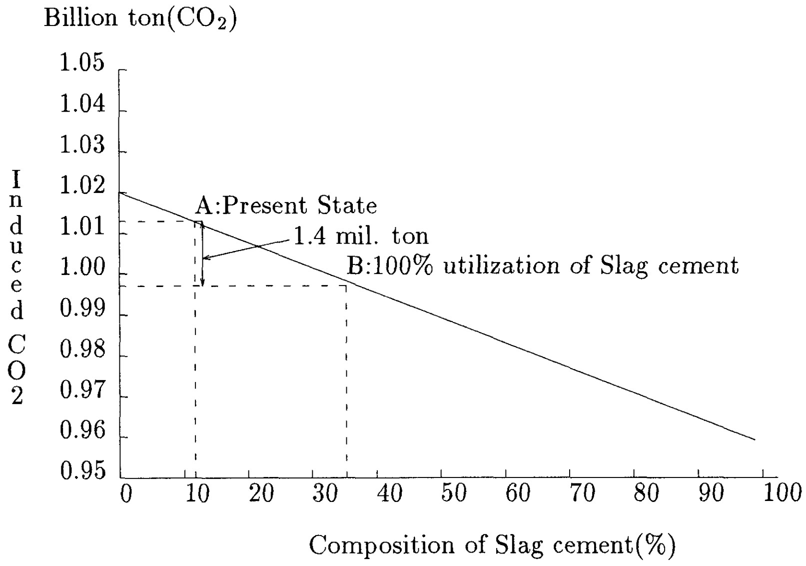

Figure 2: Simulation results of CO_2 reducion by slag cement utilization

References

[1] Cement Association (ed.)(1992), *Semento no joushiki*, Cement Association[15].

[2] Cement Association (ed.) (1992), *Semento Handobukku*, (Cement Handbook), Cement Association.

[3] Daimon, S (ed.) (1993), *Semento no kakaku — porurando semento no seizou to konka.*

[4] Fujiwara, K., "The Possibility of Reducing CO_2 Emission in the Cement Industry: An Estimate Using the Input-output Table for Environmental Analysis," *Keio Economic Observatory Occasional Paper* to be appeared.

[5] Iron and Steel Slag Association (ed.) (1992), *Tekkou sulagu no kourou semento no riyou nitsuite heisei 3 nendo ban*, Iron and Steel Slag Association.

[6] Iron and Steel Slag Association (ed.)(1992), *Tekkou sulagu toukei nenppo heisei 3 nen*, Iron and Steel Slag Association.

[7] Onozaki, T. (1989), "Semento sangyou niokeru enerugi shouhi doukou", *Enerugi Keizai*, 15(8).

[8] Yoshioka, K., Tonooka, Y., Hayami, H., Ikeda, A. and Suga, M.(1992a), "The Compilation of Input–Output Table for Environmental Analysis," *Keio Economic Observatory Occasional Paper*, no.26.

[9] Yoshioka, K., Hayami, H., Ikeda, A. and Suga, M.(1992b), "Application of the input–output approach in environmental analysis: the emission of CO_2 in production activities and their Causes," *Innovation & I-O Technique*, vol.3, no.4.

[10] Yoshioka, K., Hayami, H., Ikeda, A., and Suga, M.(1992c), "A simulation analysis of the environmental effects of energy saving housing : an application of input-output approach in environmental analysis," *Keio Economic Observatory Occasional Paper*, no.32.

[11] Yamada, K, Ichigawa, S. and Ohashi, K. (ed.), *Wakariyasui semento to konkuri-to no chishiki*, Kashima shuppankai.

[15] The cited references are all in Japanese.