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Recommending the Use of Blast Furnace Cement to Reduce CO₂ Emission*

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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 CO₂ 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 CO₂ emission¹. It is found that inputs with relatively high levels of CO₂ 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 CO₂ 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 CO₂ conversion ton) of CO₂ is emitted². Cement has the highest level of CO₂ emission other than energy related goods. The emission of CO₂ from iron ranked second, amounting to 32 ton. Moreover, within the total CO₂ emission of 1000 million ton in Japan in 1985 (in CO₂ conversion unit), 55 million ton or 5.5% of the total are contributed by the cement sector and a further 100 million ton

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¹Yoshioka et al.(1992b)[9]

²Yoshioka et al.(1992a) [8].

or 11% are emitted from the iron and steel sector, and hence the CO₂ 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 CO₂ emission in the respective industry through the improvement in production facilities, may be extremely difficult to achieve as compared to other countries³. Therefore we question if it is possible to further reduce the emission of CO₂ 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 extent CO₂ 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 CO₂ 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 material⁴. Although the initial strength of blast furnace cement is weaker than that of Portland cement, its strength increases above Portland cement 3 months after production. As 64% of the CO₂ emission from the cement industry is contributed by limestone, the use of blast furnace slag has thus the effect of reducing CO₂ emission.

Japan has a long history in the production of blast furnace cement⁵. However, this arises not from the purpose of reducing CO₂ emission but from the common economic rationality in both the iron and steel and the cement industries. Hence, if the CO₂ 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 CO₂ 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.

³Fujiwara [4].

⁴The 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 CO₂ emission reduction through the use of blast furnace slag in cement production, we assumed that blast furnace cement composed of 100% slag.

⁵In 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 CO₂ Emission

In this section, we introduce the production process of Portland cement and the sources of CO₂ emission⁶. 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 → (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°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 CO₂ emission in the production of cement. The source of CO₂ emission in the production of Portland cement can be attributed to the following 2 reasons

- (1) CO₂ emission from limestone; and
- (2) CO₂ emission from the combustion of fossil fuels.

In (1), CO₂ is emitted from the decomposition of calcium carbonate, the major component in limestone, to calcium oxide and carbon dioxide at approximately 825°C.

For (2), CO₂ is emitted from the combustion of fossil fuels, which is used as the energy source needed in the chemical reactions.

Table 1 shows the CO₂ 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 CO₂ emission from the cement sector amounted to 55.4 million ton, within which the CO₂ emission from limestone amounted to 35.6 million ton, constituting 64% of the total CO₂ emission from the cement sector. Therefore, it is clear that limestone is the major source of CO₂ emission. On the other hand, CO₂ emission from the combustion of coal amounted to 16.1 million ton, constituting 29% of the total CO₂ emission from the cement sector. Hence, CO₂ emission originating from limestone and coal constituted 93% of the CO₂ 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 CO₂ emission in the cement industry, and CO₂ emission are mainly originated from limestone and chemical fuels.

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

Table 1: CO₂ emission by sources in the cement sector(CO₂ton)

Sources	CO ₂ Emission	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
Hydrocarbon Oil	78,420	0.14
Hydrocarbon 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: Annual energy consumption by the cement production processes(10⁹kcal/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 composition 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 ₂ O ₃	Fe ₂ O 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

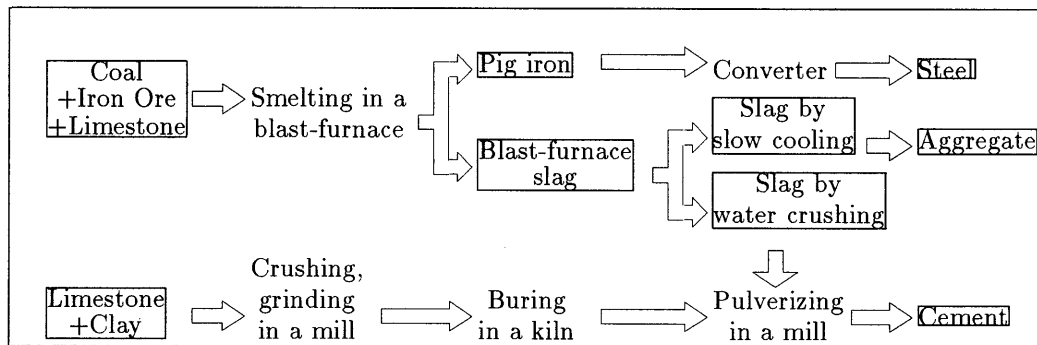


Figure 1: Production Process of Cement

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 it⁷. 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 slag⁸. 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 CO₂ emission could be achieved.

⁷Slag 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.

⁸However, 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)	Portland cement	Slag cement	Fuel inputs per cement(t)	Portland 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 (CO₂ ton) of CO₂ is emitted according to our estimation⁹. 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 CO₂ 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 respectively 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 CO₂ emission when 1 million yen of goods and services are demanded and the CO₂ 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 obtained¹¹.

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

⁹Yoshioka et al.(1992b) [9].

¹⁰Final demand sector is defined as the household consumption sector and the non-household consumption sector. CO₂ emissions related to energy consumption in special trade, such as army, embassies, foreign vessels are not included.

¹¹The 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

$$X_{ij} = Xp_{ij} + Xs_{ij} \quad (1)$$

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,

$$ap_{ij} = \frac{Xp_{ij}}{xp_j} \quad (2)$$

$$as_{ij} = \frac{Xs_{ij}}{xs_j} \quad (3)$$

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 CO₂ 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 cement¹².

In this paper, the reduction in the emission of CO₂ refers to the difference in the CO₂ 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 CO₂ 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 CO₂ reduction effect is 74.5 ton. This is because in the case of blast furnace cement, there is no emission of CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emission from the final demand of the construction sectors could be largely reduced.

Next, the CO₂ 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%, respectively¹³. The results of the estimation are summarized in Table 6. Here, the reduction in CO₂ emission is defined as the difference in

¹²The simulation is based on the following formula,

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

where c is the vector for CO₂ emission, A is input coefficient matrix, e is the emission coefficient vector of CO₂, \hat{M} is the import coefficient matrix (diagonal matrix), and I is the unit matrix. The input coefficient matrix A and the vector for CO₂ emission coefficient e is derived by the following equations,

$$A = \lambda Ap + (1 - \lambda)As \quad (5)$$

$$e = \lambda ep + (1 - \lambda)es \quad (6)$$

$$0 \leq \lambda \leq 1 \quad (7)$$

where Ap and ep are the input coefficient matrix and the vector for CO₂ emission coefficient, respectively, when cement production consisted of 100% Portland cement, and As and es are the input coefficient matrix and the vector for CO₂ emission coefficient, respectively, when cement production consisted of 100% blast furnace cement.

¹³The simulation is based on the following

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

where C is the CO₂ emission, Ch is the CO₂ 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 CO₂ emission from each final demand of 1 million yen(CO₂ton)

		CO ₂ t/1million yen production in 1985 producer prices			
	Code of IO table	Sector	CO ₂ emission		CO ₂ Reduction
			Pottland	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	Agricultural 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	Miscellaneous ceramic, stone and clay	27,940.4	27,808.4	132.0
19	2599-01	Clay refractories	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

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

Table 6: Reduction of CO₂ by utilizing Blust Furnace Cement(CO₂ton/year)

Utilization ratio of slag cement	CO ₂ t per annum	
	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

- CO₂ reduction is the deviation from the slag 0% utilizing.

CO₂ emission when the ratio of blast furnace cement is increased from 0% to other ratios. The CO₂ 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 CO₂ 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 cement¹⁴. Further, in 1985, the output of cement amounted to 72.2 million ton, and 1012.5 million ton of CO₂ is emitted.

Further, point B indicates the annual CO₂ emission when all the 24.65 million ton of blast furnace slag is used in the production of cement. Hence, the annual reduction in CO₂ 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 CO₂ 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 CO₂ emission will amount to about 20 million ton (CO₂ 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 CO₂ reduction. Therefore, the use of blast furnace slag in the cement industry will be very important in the reduction of CO₂ emission in the future.

¹⁴The 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.

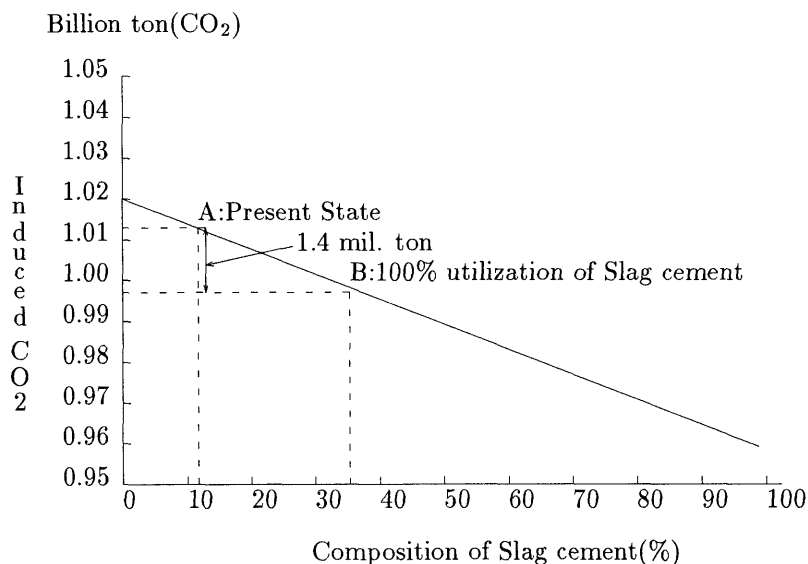


Figure 2: Simulation results of CO₂ reduction by slag cement utilization

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