Inter-industry Analysis of the Demand for Landfill Capacity

June 2000 No. 2002

NAKAMURA Shinichiro

NAKAMURA, Shinichiro
Professor
School of Political Science & Economics
Waseda University
Tokyo 169-8050
e-mail: nakashin@mn.waseda.ac.jp
http://faculty.web.waseda.ac.jp/nakashin/

INTER-INDUSTRY ANALYSIS OF THE DEMAND FOR LANDFILL CAPACITY

Shinichiro Nakamura
School of Political Science and Economics
Waseda University
Tokyo

ABSTRACT

The emission of waste including landfill consumption of an economy is to a large extent determined by its pattern of technology, institution, and life-style. A mathematical model (the Waste Input Output model, WIO for short) is presented that gives a simple analytical representation of this interdependence. The WIO was used to evaluate the effects of alternative waste disposal and recycling options on the levels of industrial production, landfill consumption, and the emission of carbon dioxide, and also to analyze the overall dependence on landfill of individual industries. It was found that a systematic combination of the options could be effective in reducing the overall landfill consumption and carbon dioxide emission.

INTRODUCTION

Japan is the country characterized by the most intensive economic activity and waste emission per inhabitable area. It is said that the currently available landfill capacity will be used up within several years. The opening of a new landfill site has become increasingly difficult, and the landfill cost has been steadily rising.

The emission of waste, including landfill consumption, of an economy is to a large extent determined by its pattern of technology, institution, and life-style. Any change in the pattern would affect the level of economic activity and waste emission in a mutually interrelated way. It is quite possible that a policy, which is effective in reducing landfill consumption in one sector of the economy, leads to an increase in landfill consumption in other sectors. Consider, for instance, the case of melting and solidification of incinerator ash. While this means is effective in reducing landfill consumption originating from the incinerator, the additive demand for power induced by its operation increases the emission of waste such as flyash (coal dust) in the electric power industry.

For reducing the overall level of landfill consumption in particular and waste emission in general, we need to take account of the interdependence between goods production, waste emission, and waste management (disposal and recycling). With this motivation in mind, Nakamura (1999a) developed a mathematical model, the waste Input-Output model (the WIO for short), which gives a simple analytical representation of this interdependence in the form of an extended input-output model.

The author actually estimated a WIO model for the Japanese economy, which consists of fifty-two industrial sectors, three waste disposal sectors, and twenty-four types of waste, ranging from garbage, sludge, to molten slag. This paper is concerned with its application to evaluating the effects of alternative waste disposal and recycling options on the levels of overall economic activity, landfill consumption, and the emission of carbon dioxide. The options considered include regional disposal with power generation from waste heat, the melting of incinerator residue, the separation of waste according to flammability, the recycling of construction debris as s substitute for gravels, the recycling of dust as a substitute for clay in cement production, and the injection of waste plastics into blast furnaces as a substitute for pulverized coal. Furthermore, the model was used to analyze the degree of overall (including both direct and indirect) dependence on landfill capacity of individual industries under alternative combinations of waste disposal and recycling options.

THE WASTE INPUT-OUTPUT MODEL

The Waste IO Table

TABLE 1 gives a prototype of the Waste Input Output (WIO) table. It describes the flow of goods and waste among industrial (arteriole) sectors and waste treatment (venous) sectors in the form of an extended IO table. X_o (n times n matrix with n equal to the number of industrial sectors) and X_t (n times k matrix with k equal to the number of waste treatment sectors) respectively refer to the conventional IO transaction matrix of the arteriole and venous sectors. For instance, the i-th row and j-th column element of X_o, say $x_{o:ij}$, refers to the amount of the output of the i-th sector that was used by the j-th sector as input. Similarly, the i-th row and k-th column element of X_z, say $x_{z:ik}$, refers to the amount of the output of the i-th industrial sector that was used by the k-th waste treatment sector.

TABLE 1
THE WASTE INPUT-OUTPUT TABLE

	Industry (input)	*Waste treatment*	*final demand*	*Sum*
Industry (output)	X_o	X_z	X_f	X
Waste (net emission)	W_o	W_z	W_f	W
Primary inputs	V_o	V_z		V
Effluents	E_o	E_z	E_f	E

Waste in a broad sense is divided into "waste in a narrow sense" and "effluents". The former refers to that part of waste that still remains within economic activity to undergo treatment or recycling. Effluents refer to the rest of the waste that is removed from economic activity and emitted into the environment. W_o (m times n matrix with m equal to the number of types of waste) and E_o (m' times n matrix with m' equal to the number of effluents) respectively refer to the net emission of "waste" and "effluents" associated with the activity of the arteriole sectors. The k-th row and j-th column element of W_o, say $w_{o:kj}$, refers to the amount of the k-th waste net of recycling that was emitted by the j-th industrial sector. The fact that W_o refers to the emission of waste net of that recycled implies that the activity of the arteriole sector subsumes recycling activities. Recycling of a waste material reveals itself as a negative entry of W_o.

Waste and effluents are measured in physical units such as ton or ton-carbon in the case of carbon dioxide. Corresponding to this, the activity level of waste treatment sectors is also measured by physical units.

The waste treatment sector transforms a given set of wastes into different types of waste and effluents to meet regulatory requirements. The matrices W_z (m times k matrix) and E_z (m' times k matrix) represent this transformation of waste. For instance, let the h-th waste be ash, and the k-th sector be incineration. Then, the h-th row and the k-th column element of W_z refers to the amount of ash generated by incineration. The final demand sector demands X_f of the output of arteriole sectors, and emits W_f of waste and E_f of effluents.

In general, the number of types of waste is much larger than that of waste treatment processes, and there is no one-to one correspondence between the former and the latter (flammable waste such as plastics can be incinerated and/or landfilled). Therefore, the matrix W_z in TABLE 1 is generally not square because waste occurs in a row but waste treatment occurs in a column. Following Nakamura (1999a) this can be transformed into a square matrix by using the distribution matrix S that maps individual items of waste into the corresponding treatment(s). TABLE 2 shows the square WIO table obtained by multiplying the waste row of TABLE 1 from the left by S. Note that waste treatment now occurs as both column and row elements. $Z:=SW$ gives a vector with k elements the i-th element of which refers to the activity level of the i-th treatment sector.

TABLE 2
THE SYMMETRIC WASTE IO TABLE WITH TECHNICAL COEFFICIENTS

	Industry	*Waste treatment*	*Final demand*	*sum*
Industry	A_oX	A_zX	X_f	X
Waste treatment	Sg_oZ	SG_zZ	SW_f	Z
Primary inputs	V_o	V_z		V
Effluents	e_oX	e_zZ	E_f	E

A_o and A_z refer to the matrices of conventional input coefficients, which are obtained by dividing the column elements of X_o and X_z by the corresponding production and treatment levels. For instance, the i-th row and j-th column element of A_o, say $a_{o:ij}$, gives the input from the i-th sector per activity of the j-th sector. Division of the column elements of X_z by the corresponding levels of activity yields the emission coefficients matrix G_z, the i-th row and j-th column element of which refers to the emission of the i-th waste per activity of the j-th treatment sector.

On the other hand, the i-th row and j-th column element of the k times k matrix SG_z gives the input of the i-th waste treatment activity per activity of the j-th treatment sector. G_0 is a k times n matrix obtained by dividing each element of the matrix W_0 by the corresponding level of sectoral production. Its i-th row and j-th column element gives the emission of the i-th waste per output of the j-th industrial sector. e_o and e_z give the emission of effluents per unit of activity, which are defined in an analogous manner. Note that in TABLE 2 an increased recycling of waste takes the form of reducing the input of waste treatment, while in TABLE 1 it took the form of reducing waste emission.

The WIO Model

Using the matrix notations of TABLE 2 we can represent the balancing equation between input and output for arteriole and venous sectors as follows

$$\begin{pmatrix} A_o & A_z \\ SG_o & SG_z \end{pmatrix}\begin{pmatrix} X \\ Z \end{pmatrix}+\begin{pmatrix} X_f \\ S_f \end{pmatrix}=\begin{pmatrix} X \\ Z \end{pmatrix}.$$

Following the practice of conventional input-output analysis, this system of equations could be solved for X and Z

$$\begin{pmatrix} X \\ Z \end{pmatrix}=\begin{pmatrix} B_{oo} & B_{oz} \\ B_{zo} & B_{zz} \end{pmatrix}\begin{pmatrix} X_f \\ SW_f \end{pmatrix}. \quad (1)$$

The Leontief inverse matrices B's inside the first brackets of the right hand side of (1) depend on A, S and G, and hence can be seen as a representation of technology and institutions. On the other hand, the elements inside the second brackets refer to final demand, and can be seen as a representation of lifestyle.

The emission of effluents associated with a given set of technology, institutions, and lifestyle can then be given by

$$E=(e_oB_{oo}+e_zB_{zo})X_f+(B_{oz}+B_{zz})SW_f+E_f. \quad (2)$$

The first term on the right hand side of (2) refers to the emission of effluents induced by the final demand for goods and services, the second term refers to that induced by the final demand for waste disposal, and the last term refers to that directly emitted by final demand. In the following, equations (1) and (2) are used to evaluate the economic and emission effects of the introduction of alternative waste treatment- and recycling options. These options were formulated in terms of alternative combinations of a set of matrices A, G, e, and S.

The Waste IO Table for Japan

A WIO table in the form of TABEL 1 was estimated using published data and other sources. The main data sources were the Japanese IO table for 1990 with 411 industrial (column) sectors, and the statistics on industrial and municipal waste published by the Ministry of Welfare. Detailed information on municipal waste (composition, calorific value, bulk density etc) and waste treatment technologies was taken from Tanaka and Matsuto (1998). For further details of the estimation of Japanese WIO table, see Nakamura (1999b).

The estimated WIO table consists of fifty-four ordinary industrial sectors, three waste treatment sectors (shredding- and separation, incineration, and landfill), and twenty-four types of waste involving both municipal and industrial waste. In addition, five types of bulky waste are identified, which consist of bulky textile products, wooden furniture, bikes and other non-electrical home appliances, electrical home appliances, and automobiles. It was assumed that each of the bulky wastes undergoes the shredding- and separation process in order to be decomposed into a subset of the twenty-four types of waste.

TABLE 3
PROPERTIES OF INCINERATOR

Properties of incinerator			
Continuous Firing	Yes	Yes	No
Capacity t/d	500	180	26
Heat utilization	Power	Heat supply	None
Melting of residue	All	Flyash	Flyash
Scenario setups by share of incineration capacity			
Control	0.343	0.144	0.513
i *Regional disposal*	0.647	0.000	0.353
vii *Unified disposal*	1	0	0

ANALYSIS

Waste Management Options and Scenarios

We consider seven types of waste management options, which consist of (i) regional disposal with power generation and the melting of incinerator residue with molten slag being utilized in public construction as a substitute for gravel, (ii) the melting of sewage sludge with molten slag being utilized in public construction as a substitute for gravel, (iii) the utilization of 3 million tons of coal ash as material for cement production, (iv) the separation of waste according to its flammability, (v) the utilization of 10 million tons of construction debris as a substitute for gravel in public construction, (vi) the injection of 2 million tons of waste plastics into blast furnaces as a substitute for pulverized coal, and (vii) the unified disposal of municipal and industrial waste. Henceforth, each of the seven options is indicated by Roman numerals. Alternative combinations of these options yielded seven scenarios, the economic and emission effects of which were then compared with those of the solution for 1990 of the estimated model that served as *Control*.

TABLE 3 shows the composition of different types of incinerator for *Control*, (i) regional disposal, and (vii) unified disposal. Under (i), all municipal waste is incinerated by continuous firing plants with a capacity of 500 tons per day. Under (vii), this is further extended to all waste, including both municipal and industrial waste. While the efficiency of incinerator in terms of the utilization of waste heat increases under (i) and (vii), they require transportation of waste over longer distances. To accommodate for this, the input of road transport per ton of incineration was set at two times the level of *Control* for (i) and at four times that of it for (vii).

In general, the operation of a recycling activity incurs additional demands for energy and other inputs, including transportation costs as above. For instance, the recycling of construction debris (v) requires power for crushing and sorting processes to make debris usable as a substitute for gravels. The injection of plastics into blast furnaces (vi) also requires a series of pretreatments such as sorting and crushing. The melting of sludge (iii) is known to be quite a power intensive process. The power and material requirements associated with these recycling activities were taken into account in the model. As for the introduction of complete separation (iv), however, we could not take account of the associated power requirements due to a lack of information.

Currently, waste is not completely separated according to its flammability. This is shown in the columns indicated "Incomplete" of TABLE 4, which gives two examples of the allocation matrix *S*. For instance, about 40% of waste plastics and 45% of waste rubber are landfilled, while a portion of inflammables such as ceramics finds its way into the incinerator. The columns indicated "Complete" give the allocation of waste under (iv). Under complete separation, any inflammable waste is landfilled, and any flammable waste is incinerated *if* they are not recycled.

Effects on Industrial Activity and Emissions

The Single Recycling Process: TABLE 5 shows major results of the effects on economic activity and emissions of the seven scenarios. The figures refer to the rate of change relative to *Control*. Scenario *B* refers to the introduction of option (ii) (recycling of sewage sludge) under the incineration pattern of *Control*. This reduces landfill consumption by 3.4% in weight, but increases the emission of carbon dioxide by 0.1%. The latter result is mainly due to the fact that the melting of sludge is an energy- and equipment intensive process.

TABLE 4
WASTE AND TREATMENT

Separation	Incomplete		Complete	
	Incineration	landfill	Incineration	Landfill
Garbage	0.900	0.100	1.000	0.000
Waste paper	0.931	0.069	1.000	0.000
Waste textiles	0.929	0.071	1.000	0.000
Waste plastics	0.590	0.410	1.000	0.000
Iron scraps	0.007	0.993	0.000	1.000
NF metal scarps	0.003	0.997	0.000	1.000
Glass bottles	0.000	1.000	0.000	1.000
Glass cullet	0.035	0.965	0.000	1.000
Waste ceramics	0.095	0.905	0.000	1.000
Waste rubber	0.554	0.446	1.000	0.000
Animal & plant residue	0.978	0.022	1.000	0.000
Flyash	0	1	0	1
Incineration ash	0	1	0	1
Slag	0	1	0	1
Wood waste	1	0	1	0
Organic sludge	0	1	0	1
Inorganic sludge	0	1	0	1
Waste oil	1	0	1	0
Waste acid	1	0	1	0
Waste alkali	1	0	1	0
Construction debris	0	1	0	1
Animal waste	1	0	1	0
Carcass	1	0	1	0
Molten Slag	0	1	0	1

TABLE 5
RESULTS OF SCENARIO ANALYSIS

Properties	A	B	C	D	E	F	G
	Scenarios						
Regional disposal a	*1*	*0*	*1*	*1*	*1*	*1*	*0*
Unified disposal b	*0*	*0*	*0*	*0*	*0*	*0*	*1*
Separation by flammability c	*0*	*0*	*0*	*1*	*1*	*1*	*1*
Recycling options							
Flyash d	*0*	*0*	*1*	*1*	*1*	*1*	*1*
Molten slag: incinerator ash e	*1*	*0*	*1*	*1*	*1*	*1*	*1*
Molten slag: sewage sludge f	*0*	*1*	*1*	*1*	*1*	*1*	*1*
Construction debris g	*0*	*0*	*0*	*0*	*1*	*1*	*1*
Plastic injection h	*0*	*0*	*0*	*0*	*0*	*1*	*1*
Economic Activity							
Employment	-0.007	0.213	0.205	0.197	0.191	0.190	0.205
Other mining	-0.343	0.165	-0.180	-0.330	-0.335	-0.455	-0.843
Gravel & crushed stones	-0.449	-0.063	-0.515	-0.541	-2.748	-2.754	-2.760
Petroleum & coal products	-0.093	0.124	0.029	-0.019	-0.033	-0.332	-0.363
Iron & steel	-0.001	0.598	0.595	0.589	0.609	0.607	0.624
General machinery	0.014	2.644	2.657	2.688	2.810	2.802	2.876
Electric power	-1.595	0.152	-1.449	-2.121	-2.113	-1.806	-3.863
Rail transport	0.057	0.059	0.113	0.122	0.111	0.105	0.357
Road transport	0.093	0.078	0.168	0.179	0.124	0.117	0.568
Waste disposal and waste emission							
Carbon dioxide	-0.426	0.101	-0.393	-1.206	-2.854	-3.235	-3.730
Incineration	-0.001	0.022	0.020	10.954	10.953	7.318	7.318
Landfill weight	-2.336	-3.392	-8.888	-15.057	-25.874	-26.087	-26.272
Landfill volume	-1.548	-3.325	-7.525	-27.333	-35.122	-35.245	-35.652
Dust	-1.127	0.408	-90.531	-90.979	-90.966	-90.756	-92.192
Ash	-18.719	0.054	-18.663	-19.100	-19.124	-19.925	-40.545
Slag	-0.109	1.652	1.536	1.534	1.094	1.083	1.123
Organic sludge	-0.003	-46.859	-46.862	-46.861	-46.862	-46.865	-46.862
Waste plastics	-0.002	0.052	0.049	0.046	0.045	-22.653	-22.651
Construction waste	-0.028	0.029	-0.009	-0.097	-41.423	-41.421	-41.444
Molten slag	-89.364	-0.049	-89.418	-75.830	-75.830	-86.817	-52.009

1: the option holds, *0*: the option does not hold.
a, b: See TABLE 3.
c: See TABLE 4.
d: 3 million tons of coal flyash is additionally used in cement production.
e: 2.3 million tons of molten slag from incinerator residua is used in public works.
f: 0.425 million tons of molten slag from swage sludge is used in public works.
g: 10 million tons of construction debris is additionally used in public works.
h: 2 million tons of waste plastics injected into blast furnaces.

The power demand increases by .15%, and this further increases the emission of dust by 0.4%. The repair and maintenance of equipment increases the output of the machinery industry by 2.6%, steel production by 0.6%, and the emission of slag by 1.7%. Of the industrial sectors listed in TABLE 5, gravel and crushed stones is the only one that shows a decline of its output level. This decline is due to the substitution of molten slag for gravels. Reflecting this positive overall effect on industrial production, the level of employment increases by 0.21%, the highest rate among the scenarios considered.

Scenario *B* gives a typical example of the introduction of a single energy-intensive recycling process. The process does save the emission of a particular waste, sewage sludge in the present case, but increases at the same time the emission of waste in other sectors such as power generation, and equipment- and materials production. The very operation of the recycling process can induce counteractive indirect effects, which work to reduce its direct effect on the reduction of environmental loads. For the purpose of reducing the overall environmental loads of an economy, we need to devise a proper combination of a set of recycling- and disposal measures that works not to strengthen but to weaken these counteractive indirect effects.

Regional Disposal : Scenario *A* refers to (i). This decreases "commercial" power generation (power generation henceforth) by 1.6%, landfill consumption by 2.3% in weight, demand for gravel by 0.4%, and the emission of carbon dioxide by 0.4%. The reduction in landfill consumption is due mainly to the recycling of incinerator residue in the form of molten slag and to the reduction of flyash from "commercial" power plants. Of the scenarios considered, *A* is the only case where the level of employment decreases relative to *Control*.

Scenario *C* combines regional treatment (i) with the recycling of sewage sludge (ii) and the recycling of dust (iii). This scenario reduces landfill consumption by 8.9% in weight and carbon dioxide emission by 0.4%, while increasing the level of employment by 0.2%. This combination of several options thus works to reduce the overall emissions without reducing the level of economic activity.

Separation: Scenario *D* is the case where separation option (iv) is added to *C*. This raises the calorific value of waste entering into the incinerator, while lowering its ash content. Furthermore, the removal from the landfill site of waste with low bulk density (weight/cubic meter) such as plastics and rubber reduces the landfill volume.

Under *D*, the volume of incineration increases by 11%, but landfill consumption decreases by 15% in weight and by 27% in volume! Compared with *C*, both power demand and the emission of carbon dioxide decreased by 0.8%. The separate treatment of waste based on flammability thus strengthens the landfill and carbon dioxide saving effects of *C*. The level of employment slightly decreases relative to *C*, but still represents an increase relative to ***Control***.

Construction Debris: Scenario *E* adds the recycling of construction debris (v) to *D*. This decreases landfill consumption by 26% in weight and by 35% in volume relative to ***Control***. Notwithstanding the intensive recycling activity, the emission of carbon dioxide decreases by 3%, while the level of employment increases by 0.19% relative to ***Control***. This combination of recycling and disposal options can significantly reduce both landfill consumption and the emission of carbon dioxide without reducing economic activity.

Plastics in Steel Making: *F* adds (vi) to *E*. Other things being equal, this way of utilizing waste plastics is more efficient than power generation from waste heat because it substitutes coal directly, whereas with power generation the substitution proceeds indirectly and involves a considerable loss of energy transformation. The result is a 0.38% decrease in carbon dioxide emission relative to *E*, while keeping the level of employment at almost the same level.

Unified Treatment: We finally consider the case *G* where (vii) is added to *F*. Any waste heat originating from the incineration of waste is now utilized for power generation. Of the scenarios considered, this is the one with the largest reduction in landfill consumption (26.3% in weight and 36% in volume) and carbon dioxide emission (3.7%) relative to ***Control***. Furthermore, the level of employment increases by 0.21%! It thus appears that a significant reduction in landfill consumption and in carbon dioxide emission cane be achieved with a slight increase in the level of economic activity. What is important is to combine a set of waste management options in a systematic way taking into account the mutual interdependence among arteriole and venous sectors.

Final Demand and Landfill Consumption

Landfill Capacity: According to the Japanese Ministry of Welfare, the available landfill capacity in Japan (municipal solid waste and industrial waste combined) is about 350 million cubic meters. The above calculations showed that if the current emission and disposal patterns represented by ***Control*** were maintained, the capacity would be used up within 3.9 years even with zero economic growth. If the pattern were replaced by that represented by *C*, the remaining years of the current landfill capacity could be prolonged to 4.2 years. If we further introduced the unified treatment and the set of recycling options as represented by *G*, this could be further prolonged to 6 years.

Within the framework of the IO model, any production in the industrial sector is ultimately induced by the final demand, and so is the emission of waste. For instance, the emission of slag in the steel industry is, among others, induced by the final demand for construction and machinery. Given the input- and emission coefficients matrices and the distribution matrix *S*, the composition of final demand determines the pattern of emission as indicated by (1) and (2).

Induced Demand for Landfill: We now turn to the analysis of induced demand for landfill at the level of individual expenditure items of the final demand. Of the scenarios considered above, *G* turned out to be the one that minimizes the demand for landfill consumption and emission of carbon dioxide without reducing economic activity. TABLE 6 shows the demand for landfill induced by major expenditure items of the final demand under ***Control*** and *G* (the results are not shown for items whose induced demand was less than 800 thousand tons).

With ***Control*** the final demand for construction (in the private sector) and landfill together induce 83 million tons of the demand for landfill consumption. The latter refers to the portion of waste emitted by the final demand that is directly landfilled. The final demand for construction (in the private sector) and machinery (transport, general, and electrical) account for 52% of the positive induced demand for landfill. If we combine the production of machinery together with the disposal of automobiles and electrical appliances, the total landfill demand induced by the final demand for the combined machinery industry becomes 20 million tons. Another significant generator of the demand for landfill consumption is the service industry (trade, medical service, public administration, and other services), which account for 8.3% (11 million tons) of the positive demand.

TABLE 6
SECTORAL INDUCED DEMAND FOR LANDFILL CONSUMPTION

	Control		***G***	
	Mill. t	share	Mill. t	Share
Construction	55.6	0.415	53.9	0.439
Landfill	27.4	0.21	22.9	0.186
Transportation machinery	5.9	0.044	5.7	0.047
General machinery	5.0	0.037	4.8	0.039
Electric machinery	3.5	0.026	3.3	0.027
MACHINERY PRODUCITON	14.4	0.107	14.2	0.115
Discarded automobiles	4.4	0.033	4.2	0.034
Discarded electrical appliances	0.8	0.006	0.7	0.006
MACHINERY DISPOSAL	5.2	0.039	4.9	0.040
MACHINERY TOTAL	19.6	0.146	19.1	0.155
Other services	4.1	0.030	3.8	0.031
Retail trade & restaurants	3.5	0.026	3.0	0.024
Wholesale trade	1.1	0.008	1.0	0.008
Public administration	1.0	0.007	0.9	0.008
Medical services	1.6	0.012	1.5	0.012
SERVICE TOTAL	11.5	0.083	8.7	0.083
Foods	2.8	0.021	2.5	0.020
Incineration	1.3	0.014	1.8	0.015
Water supply	1.6	0.010	1.6	0.013
Electric power	1.4	0.010	1.4	0.011
Iron & steel	1.2	0.009	1.1	0.009
Chemical industry	1.0	0.008	1.0	0.008
Sewage disposal	2.2	0.012	1.4	0.004
TOTAL POSITIVE DEMAND	133.9	1.000	122.7	1.000
Agriculture (exc.. livestock)	-1.0	0.025	-0.8	0.016
Cement	-1.2	0.030	-1.3	0.024
Misc. stone & clay products	-1.4	0.035	-1.6	0.030
Beverage, feeds & tobacco	-2.7	0.069	-2.6	0.050
Public utility construction	-32.3	0.834	-46.0	0.874
TOTAL NEGATIVE DEMAND	-38.8	1.000	-52.6	1.000
TOTAL	95.1		70.1	

The bottom part of TABLE 6 gives the negative induced demand for landfill, which refers to the reduction of landfill consumption resulting from the recycling of waste. The final demand for public utility construction accounts for 83% of the negative demand for landfill consumption. If we combine public- and private construction together, it follows that the final demand for the combined construction industry induces net demand for landfill of 23.3 million tons. This volume is smaller than that of direct landfill (27 million tons) and is rather close to that of combined machinery industry (20 million tons). It follows that in terms of the net consumption of landfill, the construction sector is *not* the largest consumer in the Japanese economy.

Under scenario *G* the negative demand for landfill consumption induced by the final demand for public construction increases by 36% from 32 million to 46 million tons. The net landfill consumption of the combined construction sector shrinks from 23 million to mere 8 million tons. In contrast to this, with its 19 million tons, machinery industry (including both production and disposal) turns out to be the largest consumer of landfill among the Japanese industrial sectors.

CONCLUDING REMARKS

In Japan the treatment cost of waste originating from industry has to be carried by the industry that emits it. Due to the increased difficulty of opening new landfill sites, the treatment cost has been rising. According to our calculations, the machinery industry appears to be the one that will be most severely affected by this development.

The construction industry, on the other hand, could become a leading recycling industry because it could absorb the mass of molten slag, construction debris, and lower grade steel products.

For the machinery industry, however, the extent to which this end of pipe (EOP) type strategy applies is quite limited because of its high quality demand for components and materials. It is thus imperative for the Japanese machinery industry to devise another strategy for reducing its dependence on landfill capacity.

Inverse Manufacturing (IM) is regarded as a new paradigm of product design that could fundamentally change the way manufacturing products are designed manufactured, and even owned. It is hoped that IM will help the Japanese machinery industry absorb or at least soften up the constraints imposed by landfill capacity.

ACKNOWLEDGEMENTS

I would like to thank Dr. Yasushi Kondo (Toyama University) for writing MATLAB programs and Professor Anthony Newell (Waseda University) for editorial support. Any remaining errors are solely mine. This research was supported by the Kashima Foundation for Promotion of Research, and by a Waseda University Grant for Special Research Projects No. 98A-008.

REFERENCES

Nakamura, S., 1999a, "Input-Output Analysis of Waste Cycles," *First International Symposium on Environmentally Conscious Design and Inverse Manufacturing*, Proceedings, IEEE Computer Society, Los Alamitos, pp.475-480, 1999.

Nakamura, S., 1999b, "The Waste Input-Output Table: On its Estimation for Japan," IRCPEA Working Paper 9903, Waseda University, in Japanese.

Tanaka, K., and T., Matsuto, 1998. "Development of a Computational Support System for the Total Control of Municipal Solid Waste," Graduate School of Engineering, Hokkaido University, in Japanese.