EVALUATION SYSTEM OF ENVIRONMENTAL IMPACTS FOR POLICY SCENERIOS OF MUNICIPAL SOLID WASTE RECYCLING IN KAWASAKI CITY

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This paper focuses on an evaluation system for municipal solid waste recycling strategies with the consideration of local environmental policy options and the industrial collaborations for conversion technologies. MSW recycling strategies in Kawasaki City are planned based on the options on the types of wastes to be circulated especially by local manufacturing industries and the numbers of incineration plants. It is identified that paper, steel and cement industries located in Kawasaki Eco-town can recycle mix papers, waste container and packaging plastics, methane fermentation residues and incineration ashes. Eight future policy scenarios in 2015 are planned, and environmental impacts of local recycling ratio, quantity of landfilled incineration ashes and CO_2 emissions are evaluated. The results showed that, in maximum, local recycling ratio can increase by 10%, landfilled incineration ashes can have a reduction of 13 thousand ton, and 53 thousand ton of CO_2 emissions can be reduced annually.

Key Words: *waste recycling, industrial symbiotic technology, scenario planning, renovation schedule of incineration plant, GIS*

1. INTRODUCTION

In 2004, Japanese government proposed a 3R Initiative, namely Reduce, Reuse and Recycle, in G8 summit to globally promote a sound material-cycle society. It was endorsed by other leaders and officially launched in 2005. Japan is ready to take the leadership of global 3R movement by disseminating own experiences and technologies to the international society, which would also strengthen domestic efforts for realizing a zero-waste society[1)].

In order to achieve the sustainable future, national and municipal governments are working together to reform municipal solid waste management systems by promoting waste recycling to achieve domestic 3R targets. Separation and recycling of waste resources are expected to mitigate financial burden on waste treatment and environmental burdens such as fossil fuel energy consumption and pollutant emissions, and to expand life periods of garbage landfill sites. Recovery of solid wastes can also reduce the dependency on the consumption of imported natural resources and provide local renewable energy supplies.

To promote municipal recycling activities, this paper focuses on a scenario planning and integrated evaluation process for municipal solid waste (MSW) recycling policy strategies. Recycling practices with the application of a variety of conversion technologies are considered by clarifying possible collaborations with local recycle oriented manufacturing and heavy industries, and then quantitative inventory data are surveyed and utilized for the simulations. Policy scenarios are designed based on the applications of a single technology as well as a combination of multiple technologies for waste recycling. A spatial database of waste emissions and transportation network is developed to determine collection boundaries and transportation distances to treatment or recycling facilities.

In this paper, alternative scenarios for future solid waste recycle strategies in Kawasaki City are planned and evaluated. Kawasaki City started re-

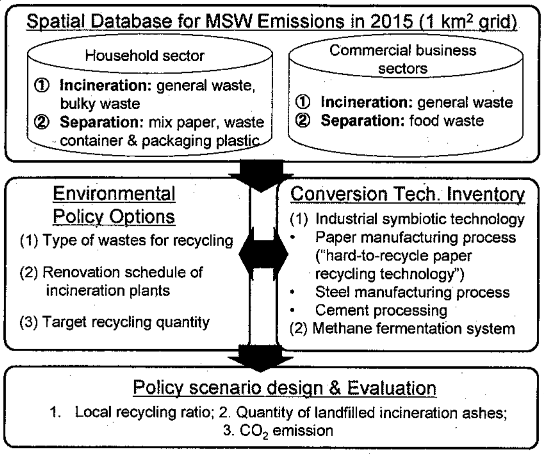

Fig. 1 Research framework

cycle activities on PET, glass bottles and cans as early as 1997 after national Container and Packaging Recycling Law was implemented. The quantity of resources recovered from MSW boosted since then, while improvement of recycling ratio and reduction of solid wastes to landfill are critical because landfill were expected to exceed capacity in about two decades[2)].

After first four national eco-towns, including Kawasaki Eco-town, were designated in 1997, the utilization of separated solid wastes as substitution inputs into heavy industries or manufacturing factories have been considered as an effective option which economically and environmentally realizes sustainable regional recycling system. This industrial symbiotic approach is expected to be effective under growing constraints of global warming prevention and resource scarcity as well as financial constraint for MSWM.

In this paper, by using the methodology, hypothetical simulations on future recycling scenarios targeting household mix papers, waste container & packaging plastics (simplified as waste C&P plastics), and food wastes from commercial business sectors are performed (Fig. 1). Local manufacturing industries including paper, steel and cement industries are identified to be equipped with industrial symbiotic technologies to accept solid wastes into the production processes. Due to the difficulty to separate and collect household food waste, it is excluded as an option for recycling. Commercial business sectors are assumed to be responsible for own paper and plastic waste recycling activities.

The impacts on local recycling ratio, quantity of incineration ashes and CO_2 emissions are evaluated based on an estimated spatial waste distribution database in 2015. Transportation network and industrial accumulation are presumed to be identical to current situation. Social factors such as employee retrenchment due to the change of MSWM and reactions from neighborhood residents upon the construction and operation of new recycling facilities, and economic factors such as additional costs for the collection process and construction of recycling facilities are not considered in this paper.

2. PAPER REVIEWS

The summary of reference research papers are shown in Table 1. Introducing new conversion technology to the typical treatment system for waste recycling was found common, for instance, Matsumoto et al.[3)] evaluated the environmental impacts by introducing conversion technologies for circulating household food wastes. He first evaluated the $LCCO_2$ of five household food waste recycling systems by considering a combination of conversion technologies such as methane fermentation system, compost and biodegradable plastics (PLA) using different types of food grinder for food waste separation. Three future scenarios (from 2000 to 2050 years), which included the social changes such as the increase of popularity for food grinders in newly constructed housing complexes, and the predominance of particular type of system, were designed and evaluated for energy

Table 1 Summary of reference research papers

Author (year)	Research objective
Matsumoto et al. (2003)	To evaluate the environmental impacts of three future scenarios which consist of five household food waste recycling systems using different types of food grinder.
Matsuto et al. (2001)	To develop a computer model which supports the evaluation of life-cycle energy consumption, CO_2 emission and cost as a decision making tool for municipal solid waste management.
Matsui et al. (2007)	To study the relationship of citizen's behaviors on waste separation and the consequent environmental impact.
Kurisu & Fujita et al. (2003)	To evaluate CO_2 emission reduction impacts in Muko River Basin by recovering organic wastes using multiple conversion technologies..
Ohnishi & Fujita et al. (2005, 2006)	To examine CO_2 emission reduction impacts in cement and steel manufacturing industries by recycling industrial and municipal plastic wastes as raw materials and fuels.

consumption and CO_2 emission reduction effects.

The efficiencies of different MSW treatment systems were studied by Matsuto et al.[4]. He developed a computer model which supports the evaluation of life-cycle energy consumption, life-cycle emission of CO_2, and cost as a decision making tool for municipal solid waste management. Eight subsystems were designed based on a typical solid waste treatment system, in which waste recycling intermediate treatment facility, composting facility, RDF facility, incombustible waste treatment facility, bulky waste treatment facility, incineration facility, landfill, and collection and transportation process were included. In total, 28 municipal solid waste material flows were incorporated in this system.

Matsui et al.[5] studied the relationship of citizen's behaviors on waste separation and the consequent environmental impact. He examined the effect of political measures on the citizen participation rate for waste separation and on the environmental load reduction. Political measures include the raising of awareness, the provision of information, and the conditions of collection services. A questionnaire survey was conducted and logistic regression analyses were performed to create predictive models for recycling behaviors, and sensitivity analyses of the models were carried out to estimate the increase in citizen participation rate achievable through the implementation of various political measures. The reduction of environmental load by improving the participant rate was evaluated.

For integrated waste recycling strategies, Kurisu and Fujita et al.[6] evaluated CO_2 emission reductions in Muko River Basin by recovering sewage sludge, food wastes, livestock manures, crop residues and wooden wastes. The suitability of technology applications are decided by three indicators considering the quality and quantity of waste inputs, and neighborhood thermal demands. The study focused on evaluating the efficiency of technologies on waste recycling strategies but the consideration of environmental policy options such as changes in MSWM infrastructure including the reduction of existing treatment facilities were not considered.

This paper aims to promote the recycling of MSW in local heavy manufacturing industries as raw materials for production. The environmental impact of CO_2 emission reductions in cement and steel industries by recycling industrial and municipal plastic wastes as raw materials and fuels were examined by Ohnishi and Fujita et al.[7,8]. In this paper, multiple MSW circulation using existing industrial symbiotic technologies is focused, and the renovation schedule of incineration plants is included in the planning of circulation policy scenarios. The termination of old incineration plants becomes possible alternative due to the reduction of general wastes for incineration after recycling practices.

By recycling solid wastes as raw materials in industries and the reduction of incineration plants, positive environmental and economic impacts could be expected for both industry sector and municipal government. Due to the uncertainty in financial aspect, the evaluation of economic impact is excluded. The environmental impacts on local MSW treatment system and industrial substitution effects are evaluated in this paper.

3. MUNICIPAL SOLID WASTE MANAGEMENT IN KAWASAKI CITY

Kawasaki City has a population of 1.3 million in 2005, the ninth-largest city in Japan. It is highly accumulated with industrial activities in which heavy manufacturing industries are located at coastal industrial zone, most of the zone is designated as Kawasaki Eco-town. Kawasaki is geographically long and narrow, which greatly affects the locations of MSWM infrastructure to minimize the cost of waste transportation.

(1) Solid waste treatments

Five city-operated waste collecting offices are responsible for the collection and transportation of household wastes; whereas business sector is responsible for own recycling activities and is required to carry the wastes into treatment facilities. General and bulky wastes from household and business sectors are incinerated and landfilled. Wastes, such as cans, glass bottles, PETs, used papers and metals are collected, stored and recycled by municipal government. More than 60% of the incinerated general wastes in dry weight are paper and plastic wastes (Table 2).

Table 2 The composition and separation condition of general wastes in 2004[9]

		2004 (actual data)
Composition of general waste (dry-based)		
Paper waste		44%
Plastic waste		18%
Food waste		13%
Others		25%
Recycling condition of general waste		
Household	General waste	307,754
	Mix paper	402
	Waste C&P plastic	-
Commercial business	General waste	155,311
	Food waste	-

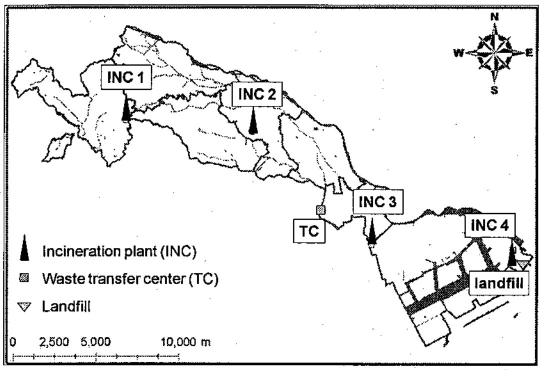

Fig. 2 Major infrastructure of MSWM

(2) Infrastructure

Fig. 2 shows the distribution of major infrastructure of MSWM for general wastes.

a) Incineration plants

There are four incineration plants in operation. Two incinerations plants are equipped with the facility to recover metals from dismantling bulky wastes. The incineration plants have been operated for 11, 20, 27 and 32 years. Renovation will be necessary in the near future.

b) Waste transfer center and landfill

Because of geographically long and narrow shape of Kawasaki City, incineration plants are located at four parts of the city, from north to south. Incineration ashes generated from northern incineration plants are transferred to the coastal landfill site by railway transportation. Since population is low in the southern region, wastes from high density areas are collected in transfer center and transferred to south by compact containers.

(3) Waste recycling targets in 2015

The city has brought out waste management policies to reduce waste emissions, improve recycling activities, and reduce incineration ashes to prolong the life of landfill site from the period of 2005 to 2015[2]. The population in Kawasaki City is estimated to reach maximum in 2015. The trends on emission reduction in household general wastes and slightly increment for business general wastes are observed[10]. With the consideration of efforts on promoting waste reduction and improving recycling rate, an overall emission reduction for incinerated wastes is expected in 2015.

Kawasaki City has estimated target quantities for the recovery of paper, plastic and food wastes from general wastes in 2015. The target values of mix papers, namely newspapers, magazines, cardboards and milk cartons, waste C&P plastics, including white color trays, and food waste from commercial business sectors are obtained from the report of Kawasaki City Waste Treatment Target Value in 2015[11].

4. POLICY SCENARIO DESIGN

Alternative future scenarios are designed for MSW circulation strategies based on optional factors including the renovation schedule of incineration plants and waste acceptance capacity of coastal industrial plants. Older incineration plants need renovation and the scenarios studied two situations in 2015 including four incineration plants are assumed continuously operated and one plant is abolished with three plants in operation. Collection boundaries should be reconsidered based on the capacity of incineration plants.

(1) Waste recycling technologies and policy options

Paper, steel and cement factories are identified to be equipped with industrial symbiotic technologies to utilize solid wastes as substitutions of nature resources. Methane fermentation system is considered as another conversion technology in this study to recover food wastes.

a) Mix paper recycling

Mix papers, namely newspapers, magazines, cardboards and milk cartons, are input as raw materials for paper manufacturing industry, which is equipped with "Hard-to-Recycle Paper Recycling" technology. No limitation on acceptable quantity is imposed because the priority to circulate local paper wastes is assumed.

b) Waste container and packaging (C&P) plastic recycling

Waste C&P plastics, including white color trays, can be fed into steel blast furnace to substitute the consumption of cokes. Plastic wastes need to be pretreated in the facility of "Waste Plastics as Raw Material for Blast Furnace". Based on the capacity of pretreatment facility, an annual limitation of 50,000 ton of municipal plastic wastes is imposed. The priority of recycling local plastic wastes is assumed.

c) Food waste recycling

Food wastes with high moisture content result in lower calorie in general wastes. They can be recovered by methane fermentation system to produce biogas. Due to the difficulty of separation and it is costly to collect food wastes from household sector, commercial businesses such as retail shops and restaurants are targeted for recycling. Biogas plant is a new treatment facility and the capacity is decided by the quantity of collectable food wastes from target business activit-

Policy scenarios	Environmental policy options						Convention technology inventory			
	(1) Renovation schedule of incinerator		(2) Target waste options				(1) Industrial symbiotic tech.			(2) Methane fermentation
	4 incinerators (current)	3 incinerators	Household mix paper	Household C&P plastic	Business food waste	Incinerati on ash	Paper manufactur'g process	Steel manufactur'g process	Cement manufactur'g process	Thermophilic digestion condition
Scenario 1-0	○		Baseline, no recycling							
Scenario 1-1	○		○				○			
Scenario 1-2	○			○				○		
Scenario 1-3	○		○	○			○	○		
Scenario 1-4	○		○	○	○		○	○		○
Scenario 2-1		○	○	○			○	○		
Scenario 2-2		○	○	○	○		○	○		○
Scenario 2-3		○	○	○	○	○	○	○	○	○

Fig. 3 Policy scenarios for evaluation

ies with the assumption of 30% recovery rate. Fermentation residues are circulated into cement factory and no limit is assumed because the quantity of residues is insignificant.

d) Incineration ash recycling

Incineration ashes are used as raw materials in cement factory to substitute clays. An annual limitation of 5,000 ton is imposed because municipal incineration ashes with high chlorine content will affect the quality of cement.

(2) Summary of scenarios

Eight scenarios are designed and summarized in Fig. 3. In Scenario 1-, the present four incineration plants are assumed continuing in service in 2015.

- Scenario 1-1 & 1-2
  The impacts of single waste recycling strategies are examined in Scenario 1-1 for mix papers and Scenario 1-2 for waste C&P plastics because introducing these two recycling practices are identified as having higher priority in Kawasaki City.
- Scenario 1-3 & 1-4
  Because paper and plastic wastes are major components in general wastes, the integrated impacts of separating these two wastes are determined in Scenario 1-3. In Scenario 1-4, additional effect for the recycling of food waste is examined.

For Scenario 2-, incineration plants are reduced to three, in which one incineration plant is industrial symbiotic technologies in manufacturing industries. Due to the limitation of incineration capacity for three-incineration-plant system, multiple waste recycling strategies are required to reduce the quantity of incinerated wastes.

- Scenario 2-1, corresponding to Scenario 1-3, mix paper and waste C&P plastic recycling are introduced.
- Scenario 2-2, corresponding to Scenario 1-4, in which food waste recycling is also implemented.
- Scenario 2-3, besides introducing three recycling practices, this scenario also examines the impact of circulating incineration ashes into cement manufacturing industry.

The environmental impacts of designed scenarios are compared to a baseline of Scenario 1-0, in which no recycling strategy is introduced in 2015.

5. EVALUATION OF CO_2 EMISSIONS

Scenarios are evaluated using a disaggregated spatial database (1 km^2 grid) of waste distributions from household and commercial business sectors in 2015). The distribution of household wastes is estimated from population (Fig. 4). Based on the estimated demographics obtained from Kawasaki City, the alteration of population in each ward in 2015 is considered. For commercial business sector, the distribution of wastes is estimated based on current building usage polygon database. Detailed estimation process is illustrated in Yanagi and Fujita et al.[12].

CO_2 emissions are determined from the waste transportation process, the operation of existing MSW treatment infrastructure including incinerat-

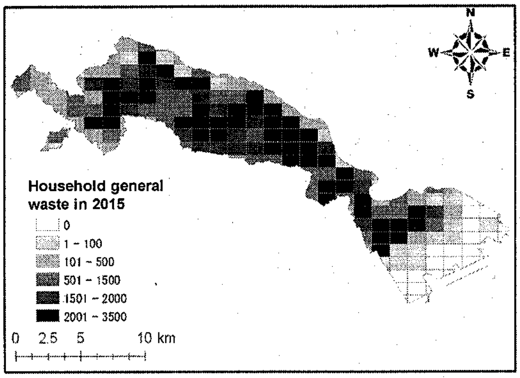

Fig.4 Household general waste distribution in 2015

ion plants, waste transfer center and landfill, the operation of new facilities, and emission reductions from the substitution effects in symbiotic industries. CO_2 emissions from the renovation and construction of facilities are excluded because the logic of distributing these emissions to annual scale is not well discussed with local stakeholders.

(1) CO_2 emissions from transportation process

CO_2 emissions from the transportation of wastes to treatment facilities, incineration ashes to landfill, and wastes/ashes to recycling facilities are calculated. Waste emissions in each grid are assumed to be transported to closest facility or transfer center from the center point of grid. A GIS-based collection and transportation model to determine of the shortest transportation routes is developed in Yanagi and Fujita et al.[12]. Traffic condition is not considered in this model.

(2) CO_2 emissions from the operation of exiting MSW treatment infrastructure

The existing infrastructure includes four incineration plants, one waste transfer center and one landfill site. CO_2 emissions from waste transfer center and landfill are calculated based on the electricity consumptions. For incineration plants, CO_2 emissions are calculated based on the net electricity generation, heat supply, supplementary fuel (town gas) consumption, emissions from general waste burning, and emissions from plastic burning.

The operation data for each facility is acquired from Kawasaki City and is included in the report of National Institute of Environmental Studies (NIES)[13].

a) Incineration plants

Each of the incineration plants has different patterns of electricity generation and heat recovery levels with varied efficiencies. For the incineration of general wastes, CO_2 and N_2O emissions are concerned. CO_2 emission is calculated only for

Table 3 Moisture content & composition of general waste (dry-based) in different scenarios

Scenario	M.C (%)	Compositions of general wastes			
		Paper	Plastic	Food	Other
1-0	48.0	44.0	18.0	13.0	25.0
1-1	48.6	40.3	19.2	13.9	26.7
1-2	49.8	47.6	11.2	14.1	27.1
1-3, 2-1	50.6	43.9	12.1	15.1	29.0
1-4, 2-2, 2-3	49.8	44.9	12.4	13.0	29.7

Table 4 Parameters for CO_2 emissions in incineration plant

Parameter	CO_2 emission factor
Electricity	0.555 kg/kWh
Heat supply	0.057 kg/MJ
Town gas (supplementary fuel)	2.08 kg/m3
Plastic waste incineration (dry-based)	2,690 kg/ton
General waste incineration (dry-based)	0.0565 kg-N_2O/ton 17.52 kg/ton (GWP=310)

* source: 「特定排出者の事業活動に伴う温室効果ガスの排出量の算定に関する省令（平成１８年３月経済産業省、環境省令３号）」

plastic burning because plastics are petrochemical products, and papers and food wastes are considered as carbon neutral. N_2O emission is counted for the incineration of general wastes.

The quantity of general wastes in dry-based and composition of plastic wastes are altered depending on the moisture contents and waste compositions in each scenario. The composition of general waste in 2004 is used for the determination of composition changes after mix papers, waste C&P plastics and food wastes are recycled. Table 3 shows a summary of the moisture content and the composition of general wastes in different scenarios. In this paper, calorie variation caused by the separation of plastic wastes is not considered.

Parameters for the calculation of CO_2 emissions in incineration plant are listed in Table 4.

(3) CO_2 emissions from the operation of new facilities

All of the new facilities are assumed to be constructed within the area of existing waste treatment facilities in order to avoid the conflict with local neighborhoods. Two intermediate treatment facilities for mix papers and two for waste C & P plastics are assumed to be located at the existing incineration plants, cargo station and transfer center which are located at northern and southern parts of Kawasaki City. One biogas plant is assumed to be located at sewage treatment plant which is neighboring to Kawasaki Eco-town district so the fermentation residues and generated electricity can be recycled and reutilized by the coastal industrial accumulation.

Table 5 Parameters for biogas plant

Parameter	Value
Biogas productivity	115 Nm^3/ton
Heating value	5,001 $Kcal/Nm^3$
Elect. generation eff.	30%
Elect. self-consumption	80%
Fermentation residue rate	25%
Chemical consumption	
Caustic soda	0.008 t/t
Coagulating agent	0.006 t/t

* data was acquired from plant maker

Through interview surveys with the makers of facilities, the results showed that intermediate treatment facility of mix paper consumes electricity, and that of waste C&P plastic consumes electricity and diesel. Detailed operation data for each intermediate facility can be obtained from the report of NIES [13].

a) Biogas plant

Food wastes generated from commercial business sectors are recovered by methane fermentation system where biogas is converted into electricity, and surplus electricity is presumed to be sold to electricity network system. Waste heat is used for digestion heating but thermal recovery by neighborhood demand is not considered. Supernatant is treated and discharged to sewage system, and fermentation residues are assumed as 25% of the input food wastes. The parameters for calculation are summarized in Table 5.

(4) CO_2 emission reduction from industrial substitution effect

Paper, steel and cement factories are assumed to circulate mix papers, waste C&P plastics and incineration ashes from MSW treatment system. The paper manufacturing industry is currently using 100% of paper wastes as raw materials so the substitution effect from circulating mix papers is excluded. For cement factory, the substitution effect from incineration ash circulation is also excluded because 100% of clay is currently substituted by industrial sludge; however the company shows interest to collaborate with local government for accepting municipal incineration ashes.

a) Waste plastic recycling as substitution inputs for blast furnace

Waste C&P plastics can be used as raw materials in iron making process to substitute cokes as reducing agents. The substitution effect of CO_2 emission reduction is evaluated using life cycle analysis (LCA), where mining and transportation of virgin materials, pretreatment stage, manufacturing stage, product processing stage and private power generator are considered. Pretreatment stage includes coke oven for the preprocessing of virgin materials, fracturing facility, and plastic waste pretreatment facility of "Waste Plastic as Reducing Agent for Blast Furnace". Manufacturing stage includes the operation of blast furnace.

By substituting cokes for plastic wastes, the electricity consumption of coke oven and the emission of coke oven gases (COG) that contain CO_2 can be reduced. The utilization of plastic wastes in blast furnace can also achieve an overall CO_2 emission reduction from because CO_2 content of blast furnace gases (BFG) with plastic waste feed is less than that of cokes. However, addition electricity will be required for plastic waste pretreatment process. Detailed calculation process is explained in Onishi et al.[8].

6. RESULTS & DISCUSSION

(1) Local waste recycling quantity and ratio

The evaluation results of eight scenarios showed that introducing waste recycling practices can increase the quantity of recovered waste resources from 18 to 59 thousand ton per year (Fig. 5). The recycling of mix papers, waste C&P plastics and food wastes can improve local recycling ratio from 27% to 37% in 2015, a maximum 10% increment can be achieved.

(2) Quantity of landfilled incineration ashes

Fig. 6 shows that depending on the scenarios, 3 to 13 thousand ton of incineration ashes are reduced. The combination of three waste recycling activities of mix papers, waste C&P plastics and food wastes (Scenario 1-4 & 2-2) reduces 8 thousand ton of incineration ashes. By circulating the ashes to cement manufacturing company (Scenario 2-3), about 20% of total reduction can be achieved comparing to non-recycling situation.

(3) CO_2 emissions

The results in Fig. 7 show that the operation of incineration plant is the major factor for CO_2 emissions. In Scenario 1-1, the separation of mix papers results in additional CO_2 emissions because of the increase of general waste input to incineration plants with low efficiency in energy recovery. It is due to the change of general waste collection boundary after the separation of mix papers. Recycling of waste C&P plastics contributes to significant CO_2 emission reduction, in which 45 thousand ton of CO_2 emissions can be avoided annually. It is because plastics are petroleum products and burning plastic releases fossil CO_2 back to atmosphere; whereas incineration of mix

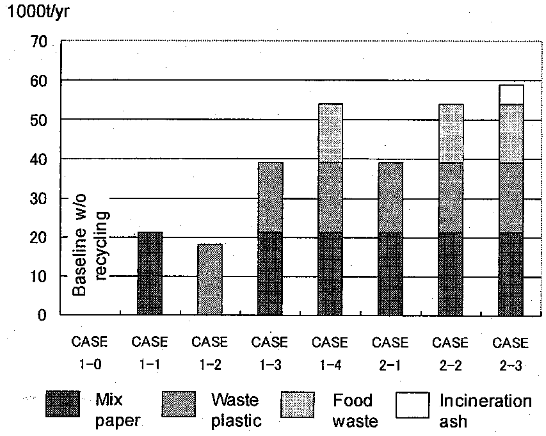

Fig. 5 Quantity of recycled wastes

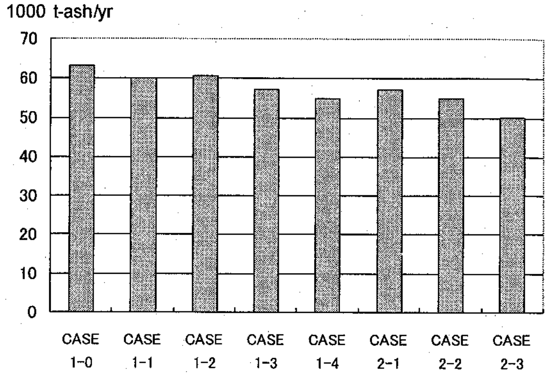

Fig. 6 Quantity of landfilled incineration ashes

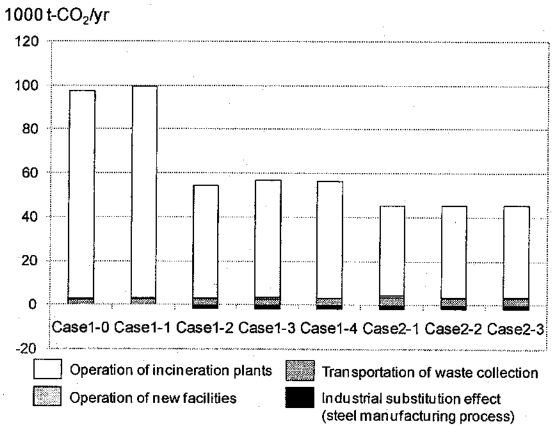

Fig. 7 CO_2 emissions

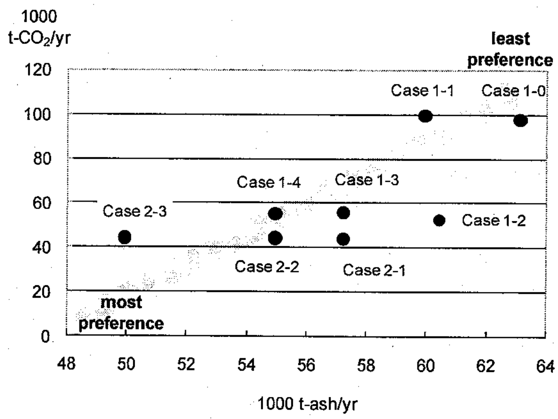

Fig. 8 Case comparisons for CO_2 emissions and landfilled incineration ashes

papers and food wastes are considered as carbon neutral. CO_2 emissions from the operation of intermediate treatment facilities and the additional transportation process for separated waste collection are insignificant comparing to overall impact. Food waste recycling with electricity production is also found to be minor impact (Scenario 1-4).

The coke substitution effect by plastic wastes in steel factory is relatively small compared to the emission prevention in incineration process because there is a limit for accepting municipal waste C&P plastics, and the factory is currently operated close to the limit by accepting municipal plastic wastes from other cities. The reduction of plastic waste transportation distance due to the priority of accepting local wastes is the major factor in substitution effect.

In the cases of three incineration plants in operation (Scenario 2-), an additional 11 thousand ton of CO_2 emission reduction can be expected annually. It is due to different patterns and efficiencies of electricity generation and heat recovery in incineration plants. The termination of old plant with no or low energy recovery increases general waste inputs to other plants with better energy recovery efficiency. Comparing to non recycling situation, about 53 thousand ton or 57% of CO_2 emission reduction in maximum can be achieved.

Fig. 8 shows the comparison of different recycling strategies from the view point of CO_2 emissions and the quantity of incineration ashes. The situation of non-recycling is discouraged for achieving the targets of CO_2 emission reduction and extension of the life period of landfill site. Introducing single recycling practice, especially mix paper recycling (Scenario 1-1), is a less preferable option. Multiple recycling technology applications and the termination of old incineration plant with low energy recovery efficiency are found as better strategies aiming for both reduction targets.

7. CONCLUSIONS

In this paper, policy scenarios in 2015 for municipal solid waste recycling strategy in Kawasaki City by the application of conversion technologies, especially industrial symbiotic technologies, are designed, and the impacts on local recycling ratio, quantity of landfilled incineration ashes and CO_2 emissions are evaluated. The scenarios are planned with the consideration of single and a combination of conversion technology application to recycle mix papers, waste C&P plastics, food wastes and incineration ashes. Renovation schedule of incineration plants are also considered in the scenarios because old incineration plant can be abolished if multiple recycling practices are introduced.

The evaluation results showed that separating mix paper alone is not encouraging because it will result in slight increase of CO_2 emissions. It is due to the increase of general waste inputs to incineration plants with low energy recovery efficiency because collection boundaries change after the separation of mix papers. Waste C&P plastic recycling is recommended because CO_2 emission reduction is significant by avoiding plastic wastes to be incinerated. Non fossil fuel energy recovery from biogases is not effective for electricity production only, and further investigation is required to examine the impact from thermal recovery. The reduction of incineration plants to three can contribute to further CO_2 emission reduction because the incineration plant with low energy recovery efficiency is abolished and general wastes can be treated in incineration plants with better electricity generation and heat recovery efficiencies. Recycling of incineration ashes to cement industry is an encouraged option to extend the life of landfill.

As a result, solid waste recycling in local manufacturing industries can reduce the quantity of general wastes for incineration, results in the termination of old incineration plant, and consequently achieves significant reductions in landfilled incineration ashes and CO_2 emissions. However, industrial substitution effects are insignificant compared to current situation because waste utilization policy is well employed by recycling-oriented manufacturing industries in Kawasaki Eco-town.

Because the evaluation is performed based on the assumptions that transportation network, technology efficiency and industrial accumulation in Kawasaki City are identical in 2015, dynamic simulation is required for further work. Although this paper did not focus on financial evaluation, the impact on financial affair due to the change of MSWM should be further investigated.

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川崎エコタウン産業共生技術を中核とする資源循環政策シナリオ評価システム

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本研究では川崎エコタウンに立地する循環型の生産施設の循環型転換技術を中核とする，一般廃棄物の政策シナリオを設計して評価するシステムを開発した．川崎市の廃棄物計画に基づいて,廃棄物の焼却施設の更新や臨海部に立地する循環型の生産施設への分別された事業系ゴミの搬入の環境改善効果を算定するプロセスを開発した．製紙工場，高炉製鉄工場，セメント工場を対象として分別可能な廃棄物量の分布を算定して，2015年に向けて8つの将来シナリオを評価した．その結果，廃棄物の再資源化利用率を10%改善して，最終処分量を13000t削減できるとともに，53000tの二酸化炭素の発生量削減が可能になることを明らかにした．