No. 868

Environmental and Economic Evaluation of Refuse Derived Fuels: With a Special Focus on the Application of Japanese Technology in Canada

by

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June 2000

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Abstract

In this research paper, the actual situation of refuse derived fuel (RDF) in the world, with a special emphasis on Japan, was studied. Focus was placed on describing both the environmental and economic evaluation of RDF. Actual data for the production of RDF was obtained in the case of Japan. This data was used in a theoretical model to carry out a simulation analysis on the possibility of applying technology, that was partly developed in Japan, for the production of RDF plants and RDF itself, to the Canadian situation, using the Greater Vancouver Regional District (GVRD) as a Canadian representative city. As a result of the calculations for the simulation, it was determined that at least two types of social benefit may arise if RDF plants were constructed in Canada for the purpose of producing RDF. First, it was determined that by the construction of RDF plants and subsequent production of RDF, there could be a drastic reduction in the amount of CO_2 that is released to the atmosphere and thereby partially mitigate the greenhouse effect. Second, there may be a social benefit due to the reduction in the amount of waste that goes to the landfills thus lengthening the life of those landfills. In addition, it is expected, as show by calculations, that the expenses related to overall waste treatment for GVRD can be greatly reduced by the construction of an RDF plant and the subsequent production of RDF itself.

Keywords: RDF, GVRD, Social Benefit, CO_2 reduction

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1. Introduction:

The amount of municipal solid waste generated in Canada will most certainly continue to grow, and will require new and innovative ways of management. There are several MSW management approaches currently used including direct landfill, 3R programs (recycling, reducing, reusing), and incineration. Decisions on what type of management approach (whether mutually inclusive or exclusive) to be used is usually reduced to economic reasoning. Ultimately, the volume of garbage produced and the amount of environmentally safe land available for landfill become major competing economic forces for the inclusion of recycling and incineration in MSW management. The best example of this case can be found in Japan.

Due to these directive forces, the need to reduce the volume of MSW in Japan is achieved through thermal incineration. Municipal waste incineration has been an accepted part of the Japanese, American and European waste management practice for several decades.

It is now well understood that MSW has economic value as an energy resource. Throughout the world, incinerators which recover energy from burning MSW are in operation. In many countries, including Japan, the United States of America, and throughout Europe, an alternative MSW management technology harnessing this energy resource is currently being used.

Given that the incineration of MSW is now an accepted practice, there is much effort now being paid into the improvement of MSW as a fuel source. Municipal solid waste, proven as an energy source, can be processed into a fuel which is higher in energy value, contains less hazardous compounds, and can be used as a merchant fuel in most thermal power plants (Haneda, 1995; Duckett, 1991). This fuel, known as ‘refuse-derived fuel’ (RDF), has been used minimally in North America and Europe for the past 20 years, and has recently shown great promise in Japan (Duckett, 1991; Haneda, 1995).

Given the current rise in the production of RDF in Japan and throughout the world and its apparent economic and environmental benefits, it is important to study the production and combustion of RDF as an alternative MSW management approach and to determine if it could be an effective management tool for the Canadian situation.

2: RDF PRODUCTION SIMULATION FOR THE GREATER VANCOUVER REGIONAL DISTRICT (GVRD), CANADA: The Situation of Waste Management in the Greater Vancouver Regional District (GVRD)

GVRD Waste Situation

Currently, between 2.3 and 3 million tons of solid waste is produced in the Greater Vancouver area per year while the amount that is generated is ever increasing with the rise in population. In the residential sector about 931.67 g of waste was thrown out per person in 1991. About 24 % comes from residential sources, 37% from industrial, commercial and institutional (ICI), and 39% from demolition, land clearing and construction (DLC) materials. With respect to these numbers and referring to the figures for 1991 of table 2.2, it can be deduced that about 574,364 tons is produced in the residential area, while about 885,636 tons is generated in the ICI region. In addition, about 860,000 tons of waste was produced in the DLC area in 1991. This gives a total of approximately 2,320,000 tons of waste being generated in 1991 for all sources. Currently 30% of all solid waste is recycled, 61% is landfilled and 9% is incinerated.

With respect to the cost of waste disposal, it was reduced from $68 to $64 per ton on July 1, 1996. Waste in the Greater Vancouver Regional District (GVRD) goes to one of four disposal sites- Vancouver Landfill (Burns Bog), Port Mann Landfill,, Cache Creek Landfill or the Burnaby Incinerator.

Vancouver Landfill (Burns Bog)

This landfill has been designed to accept about 480,000 tons of waste per year and is still in operation.

Port Mann landfill

This landfill was designed to handle about 180,000 tons of waste per year, but it will be closed in 1997.

Cache Creek Landfill

The Cache Creek Landfill which is located about 300 kilometers from Vancouver is a 48 hectare site that is located in an industrial area south of the Village of Cache Creek. This landfill was developed for the GVRD and the local residents of Cache Creek by the village of Cache Creek and Wastech Services Ltd. Every year since 1989, about 300,000 tons of GVRD waste has been shipped to Cache Creek.

Burnaby Incinerator

The Burnaby Incinerator is located in the commercial/industrial area of South Burnaby. This incinerator is owned by the GVRD and it is maintained and operated by an independent contractor.

Since 1988, when operation of the incinerator began, about 240,000 tons of waste have been incinerated each year, producing about 700,000 tons of steam per year of which 67% is used by a neighboring paper recycling facility.

Composition of Waste

The composition of waste from homes and businesses (not including large-scale demolition, landclearing and construction wastes) is given as follows:

Table 2.1 Vancouver Waste Stream

Category	*Waste Stream*
Paper	35.0%
Organic	35.0%
Plastic	8.0%
Fine material (less than 1.26 cm)	7.0%
Metals	4.0%
Glass	3.0%
Inorganic	1.5%
Household Hazardous	1.5%
Small Appliances	0.5%
Other	4.5%
Total	100.0%

Taken from T. Guest, Mercury Control in Canada, Air & Waste Management Association, June 1993.

Anticipated Waste Flows

The following table, which represents a model developed by Montenay, Inc., gives the anticipated flows of waste in GVRD.

Table 2.2 Residential and Industrial, Commercial and Institutional Data (ICI)

Unit: 1000's tons

Year	Population[1]	Generation[2]	Reduction[3]	Recycle	Composted	Residual
1991	1689	1460	-	319	13	1128
1992	1727	1500	-	339	16	1133
1993	1766	1580	-	360	20	1138
1994	1806	1616	16	416	43	1141
1995	1847	1669	33	425	53	1158
1996	1889	1724	52	434	64	1174
1997	1932	1781	71	444	83	1183

Total 3R's = 3.38%

[1&2] are based upon the Report by CH_2M

[3] is based upon a 1% per year (max. 10%) increase in reduction

Adapted from T. Guest, Montenay 20 Year Analysis of Solid Waste, December 1993

Table 2.3 Residual in Demolition, Landclearing and Construction (DLC)

Unit: 1000's tons

Year	Generation[1]	Reduction[2]	Recycle	Residual
1991	830		406	424
1992	856		418	438
1993	884		430	454
1994	912	1%=9	443	460
1995	941	2%=19	456	466
1996	971	3%=29	470	472
1997	1002	4%=40	484	478

*Net effect of 3R's will be 57% in the DLC area.

[1] 3.2% annually

[2] Rising to 10% by the year 2003

Adapted from T. L. Guest, Montenay 20 Year Analysis of Solid Waste, December 1993

Table 2.4 System Capacity **Unit:1000's tons**

Year	Port Mann	Cache Creek	Burns Bog	Incinerator	Total Capacity	Disposal	Excess + Shortage -	Size of Facility
1991	170	270	480	240	1160	**1128**	+32	
1992	175	180	480	240	1175	**1133**	+42	
1993	180	300	480	250	1210	**1138**	+72	
1994	180	300	480	250	1210	**1141**	+69	
1995	180	300	480	250	1210	**1158**	+52	
1996	180	300	480	250	1210	**1174**	+36	
1997	Closed	300	480	250	1030	**1183**	-153	180

Note: Data (for 1991) taken from 'Montenay 20 Year Analysis of Solid Waste, December 1, 1993 (T.L. Guest).

Montenay 20 Year Analysis of Solid Waste

As the Port Mann landfill will close in 1997, it has been suggested that the Burnaby incinerator be expanded so that it can handle an additional 180,000 tons per year. Through a recent study, it was also found that incineration would be markedly cheaper that landfilling at Cache Creek which could lead to a savings of 85 million Canadian dollars over the next 20 years (T. Guest, 1993).

Interesting Cost Comparison

The Vancouver landfill which is designed to handle 460,000 tons of waste per year, results in the use of about 8 hectares per year, where it is estimated that this will cost about 247 million dollars over 20 years considering that 1 acre costs 500,000 dollars. However, an incinerator can be constructed for only 3 million dollars while needing only a little more than 2 hectors (T. Guest, 1993).

On the point of considering whether to expand the Burnaby incinerator or Cache Creek landfill for the disposal of an addition 180,000 tons of waste, it has been found that although the initial capital for expanding the Burnaby incinerator is more than twice that of what is needed to expand the Cache Creek landfill. The net costs for 1993 would be about 2.7 million dollars less as a result, in part, due to the revenue generated from the sale of steam. In addition, the annual costs for 1997 would be about 3 million dollars less (16.60 less a ton) for the Burnaby incinerator (T. Guest, 1993).

Environmental Analysis

Methane is 25 times stronger than carbon dioxide as a greenhouse gas. It has been estimated by the Ministry of Lands and Parks that more than 50% of methane emissions come from landfills.

Table 2.5 Anthropogenic Methane Emission in British Columbia[1] Unit: tons

Source	Methane Emissions	Carbon Dioxide Equivalents
Year	1990	
Landfills	290,500	7,262,500
Incineration	6800	170,000
Totals	532,400	13,310,000

Taken from M.O.E. publication ‘Greenhouse Gas Inventory and Management Options’, June 1993 (T. Guest)

To handle another 180,000 tons of waste by shipping it to Cache Creek will require an additional 5625 trips per year using a 400 hp diesel truck. As a result of this, another 1900 tons of carbon dioxide and 135 tons of carbon monoxide (2.5 times stronger than carbon dioxide) will be released to the atmosphere.

It is estimated that landfills contain 79% garbage, 17% wood waste and 4% pulp mill sludge. It is estimated that if both wood waste and garbage, which comprise 96% of landfills, were used as fuel and incinerated to produce power, there would be a reduction of about 6.5 million tons of greenhouse gases (T. Guest, 1993).

3: RDF Production Simulation

Evaluation of the Policy Concerning the Recycling of Waste

Simulation Analysis of the Produced RDF

(1) Setting of Model for Simulation Analysis

Using the data of the physical composition of waste from the GVRD, a simulation analysis of RDF production will be carried out.

The following table gives the moisture ratio in paper, plastics, kitchen waste, fibers, grass and wood.

Table 3.1 Water Ratio, Calorific Value Data for Nogi and Haibara Town

	Paper	Plastics	Kitchen Waste	Fibers	Grass and Wood
Moisture Content (Nogi)	24.70	18.70	61.40	21.70	41.80
Moisture Content (Haibara)	49.20	33.30	78.30	54.00	54.00
Moisture Content (Average)	36.95	26.00	69.85	37.85	47.90
High level Calorific Value (kcal/kg)	3900	8000	4200	4100	4000

* Calorific Value: Dry base

* From Yasuda and Yamanaka (2000)

In this paragraph five policies will be considered as follows:

Policy 1: Producing RDF from all combustibles.

Policy 2: Producing RDF from combustibles while excluding all paper.

Policy 3: Producing RDF from combustibles while excluding all plastics.

Policy 4: Producing RDF from combustibles while excluding all kitchen waste.

Policy 5:Producing RDF from combustibles while excluding 50% paper and 50% organics.

With respect to each of these policies, as given below, an analysis from the standpoint of the calorific value and moisture content of RDF will be carried out.

The composition of the waste is divided into paper, plastic, kitchen waste, fibers, yard waste, and non-combustible waste. The amount for each is given by $X^0{}_k$, $X^0{}_p$, $X^0{}_c$, $X^0{}_s$, $X^0{}_m$, $X^0{}_f$. If the total amount of waste produced is $X^0{}_t$, then $X^0{}_t = X^0{}_k + X^0{}_p + X^0{}_c + X^0{}_s + X^0{}_m + X^0{}_f$. In addition, in order to produce RDF, the ratio of each is given by r_k , r_p , r_c , r_s , r_m , r_f (in the case of policy 1, $r_k = r_p = r_c = r_s = r_m = r_f = 1$),

$$X_t = r_k X^0{}_k + r_p X^0{}_p + r_c X^0{}_c + r_s X^0{}_s + r_m X^0{}_m + r_f X^0{}_f \quad = X_k + X_p + X_c + X_s + X_m + X_f$$

The basic process for producing RDF is given as follows:

Q_2 Q_4 Q_6

Q_1 ↑ Q_3 ↑ Q_5 ↑ Q_7

Raw waste➔separation➔drying➔shaping➔RDF

W_1 W_3 W_5 W_7

H_1

Q: Material flow, W: Moisture ratio, H: Low level calorific value

If the waste used for raw material has a low level calorific value H_1, a moisture content W_1, and a high level calorific value $H_1{}^h$, they are given as follows:

$$H_1 = 1/ X_t[\{ H_k(1- W_k)-600 W_k\}X_k + \{ H_p(1- W_p)-600 W_p\}X_p + \{H_c(1- W_c)-600 W_c\}X_c + \{ H_s(1- W_s)-600 W_s\} X_s + \{ H_m(1- W_m)-600 W_m\} X_m]$$

$$W_1 = (W_k X_k + W_p X_p + W_c X_c + W_s X_s + W_m X_m) / X_t$$

$$H_1{}^h = (H_1+600W_1)/(1- W_1)$$

In the separation process for Nogi Town, Tochigi Prefecture about 10% of the waste used for raw material which is non-suitable is removed. Similarly, about 20% is removed at Haibara Town, Nara Prefecture. The average of these two values is used for the waste from GVRD due to the lack of data.

Q_2=0.1 Q_1 (Nogi) Q_2=0.2 Q_1 (Haibara) Q_2=0.15 Q_1 (GVRD)

Assuming that there is no change in the moisture content before and after the separation, $W_1=W_2$. Also, since the amount of moisture contained in the non-suitable items is not considered to have a large effect on the water balance, for the purpose of simplification, $W_1=W_2=W_3$.

It is necessary to reduce the moisture contained in RDF, to below 10%, in order to limit rotting and unpleasant odors. The actual results at Nogi Town, Tochigi Prefecture show that the moisture content after the drying process is about 4% and similarly it is about 6% at Haibara Town, Nara Prefecture. Again, due to the lack of data, the average for Nogi Town and Haibara Town will be used for GVRD which is 5%.

W_5=0.04 (Nogi), W_5=0.06 (Haibara), W_5=0.05 (GVRD) $Q_5 = Q_3 \{(1- W_3)/ (1- W_5)\}$ $Q_4=Q_3-Q_5$

In Nogi Town, Tochigi Prefecture the moisture content after the shaping process is about 3% and similarly about 4% for Haibara Town, Nara Prefecture. In the shaping process, assuming that about 20% of the moisture remaining is evaporated,

$W_7=0.8Q_5W_5/ Q_7$, $Q_7= (1- W_5)Q_5 +0.8 Q_5W_5$

Also, the low level calorific value of RDF is given by $H_7= H_1^h(1- W_7) – 600 W_7$.

Table 3.2 Results of Simulation for GVRD **Unit: 1000's**

	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
	GVRD				
W_1 (moisture content, %)	50.37	59.76	52.90	36.73	48.25
W_5 (moisture content, %)	5.00	5.00	5.00	5.00	5.00
W_7 (moisture content, %)	4.00	4.00	4.00	4.00	4.00
Q_1 (material flow, t)	1,241.00	730.00	1124.2	730.00	730.00
Q_2 (material flow, t)	186.15	109.50	168.63	109.50	109.50
Q_3 (material flow, t)	1054.85	620.50	955.57	620.50	620.50
Q_4 (material flow, t)	503.77	357.67	481.81	207.25	282.49
Q_5 (material flow, t)	551.08	262.83	473.76	413.25	338.01
Q_7 (material flow, t)	545.57	260.20	469.02	409.12	334.63
Q_7/Q_1 (%)	43.96	35.64	41.72	56.04	45.84
Low level calorific value	4353.04	5046.44	3813.68	4467.82	4693.11

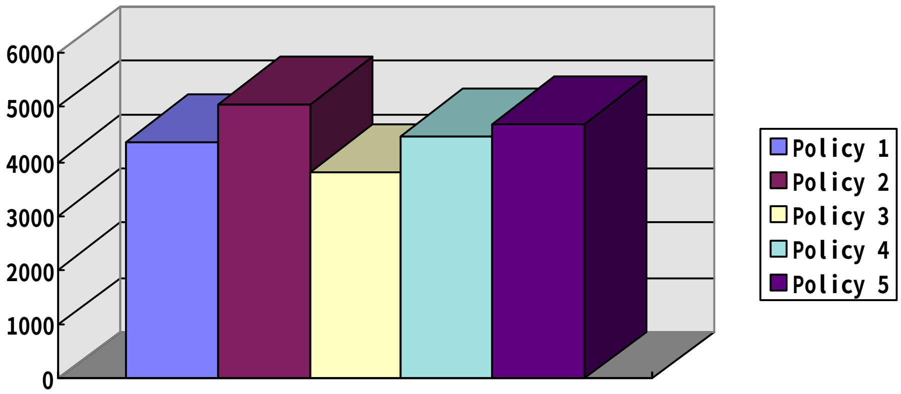

Figure 3.1 Calorific Value, Kcal/Kg

With respect to the above table it can be seen that for Policy 3, in which all the plastic is removed, the calorific value is the lowest of all policies at 3813.68 kcal/kg. This shows that plastic is a necessary component in giving RDF a high calorific value. Oppositely, the calorific value is the highest, at 5046.44 kcal/kg, for Policy 2, in which RDF is made after removing all the paper. Policy 1, where all combustible waste is used to make RDF and Policy 4, in which the organic component has been removed, show a very similar calorific value, 4353.04 kcal/kg and 4467.82 kcal/kg, respectively.

Considering the situation in the GVRD, in which there is a lot of material being recycled, and where plans exist to increase the rate of recycling from 25% to 50%, Policy 5, which represents the production of RDF, where 50% of paper and organics are removed seems to be the best policy. The reason for this is that the calorific value of 4693.11 kcal/kg and a production rate of 45.84% are both relatively high when compared with the other policies. In addition, it would be better to recycle paper through material recycling and organic matter could be made into compost, both of which could be used by the community.

3.1 Social Benefits of RDF System

It is estimated that every ton of newspaper that is recycled saves three cubic meters of landfill space (source: Recycling Council of Ontario). Therefore, if 50% of paper alone, or 255,500 tons, is recycled and not put into a landfill, that means that about 766,500 cubic meters of landfill space will be saved each year. In addition, if half of the organic material is used for making compost instead of being disposed of in landfills, that means that another 255,500 tons is being diverted from landfills. Assuming that one ton of organic waste takes up as much space as one ton of paper, that means that another 766,500 cubic meters of landfill space will be saved each year. There is also an additional 216,000 tons or 657,000 cubic meters of waste that would be diverted from the landfill with the production of RDF. Therefore, a total of approximately 2,161,749 cubic meters (considering that 12.90% of ash produced must be landfilled) of landfill space per year can be saved. This is equivalent to a block about 129 meters long by 129 meters wide and 129 meters deep.

Due to the above policy, about 720,583.00 tons (assuming 87.10% of the ash can be recycled) of waste are diverted from landfills. Noting that the present cost of disposal is about $64.00 per ton of waste, this translates into a reduction in tipping fees (ignoring the cost of shipping for the RDF facility) of $46,117,312.00. There is also the added benefit since the 334, 630.00 tons of RDF can be sold (assuming a market can be secured).

With respect to carbon dioxide equivalent emissions, in British Columbia, about 0.035 tons, 0.56 tons, 1.50 tons and 6.03 tons of CO_2 equivalents are given off for every ton of waste that is recycled, incinerated, composted and landfilled respectively. Therefore, if 50% of waste paper is recycled and the other 50% is used to make RDF, this translates into a reduction in CO_2 equivalents of about 2,929,307.50 (3,081,330.00 - 152,022.50) tons per year. Likewise, if 50% or organic waste is made into compost and the other 50% is used to make RDF there would be a reduction in CO_2 equivalents of about 2,689,137.50 (3,081,330.00 – 392,192.50) tons per year. In addition, there is also a reduction in CO_2 equivalents of 1,312,905.00 (1,320,570.00 – 7665.00) tons per year due to other materials. This gives a total reduction in CO_2 equivalents of about 6,931,350.00 tons. Also, if RDF is used in an energy recovery system instead of fossil fuels, there is an additional social benefit resulting in the conservation of non-renewable fuels and the reduction of NO_x, SO_x and CO_2 that results upon its combustion.

Table 3.3 Expected Savings/Reductions with Implementation of Policy 5

Item	Numerical Value
Amount of Waste Diverted from landfills	720,583.00 Tons
Amount of landfill Space Conserved	2,161,749 m^3
Savings in Handling Costs[*1]	$46,117,312.00 (Canadian)
Reduction in CO_2 Emissions	6,931,350 Tons

[*1]Assuming that the tipping fee is $64.00 (Canadian)

In a paper by Yu (1996), it was shown that there was a substantial social benefit arising as shown in a simulation of two systems that produce RDF which results in a reduction in NO_x, SO_x and CO_2 emissions. It was suggested that there would be a positive economic benefit of about 1068 yen (the average between the two simulations) for every ton of waste that is processed into RDF. NO_x, SO_x and CO_2 accounted for 28.81% (308.50 yen), 16.98% (182.00 yen) and 54.21% (577.50

yen) respectively. Therefore, if 730,000 tons of waste in the GVRD were processed into RDF, the social benefit that would arise due to the fact that there would be a large avoidance of NO_x, SO_x and CO_2 emissions with the production and use of RDF instead of the use other fossil fuels, would be very significant.

The question of whether it is better to bury waste in landfills, burn it in incinerators and recover the heat, or to transform the waste into a fuel with a stable energy value and then burn it and recover the heat, is one that must be answered in order to determine what waste management method is the most appropriate for a particular area. As landfills become full, the distance that must be travelled from the city center, in order to dispose of waste, is ever increasing. By implementing material and thermal recycling, the life of the present landfills is extended. In addition, it is expected that there will be a marked decrease in greenhouse gases that escape from landfills.

At present the only incinerator in operation, in the GVRD, is the one located in Burnaby. This incinerator effectively reduces the volume of waste and also produces steam which is used by a nearby paper manufacturing company. It has been proposed that the Burnaby incinerator be expanded to handle another 180,000 tons of waste per year with studies even showing that this is cheaper than expanding the Cache Creek landfill, not to mention the added benefit from a reduction in greenhouse gases. However, this proposition is flawed in at least three ways. First of all, the expansion of the incinerator by one line will require the purchase of more land. Second, for the steam produced, upon combustion of waste to be useful, it has to be sent to nearby facilities that are willing to purchase it. At present there is only one such facility near enough to the incinerator that can actually effectively use the steam for its operation. The additional production of steam that will result with the construction of an additional line will be wasted as there will be no demand unless a new company decides to construct a plant near the incinerator. Finally, there is still much opposition to the incineration of waste as an effective waste management method due mostly to the fear of dioxins.

Here it is proposed that an RDF production facility be built instead of either expanding the Cache Creek landfill or the Burnaby incinerator. The production of RDF from waste can lead to an extension of the lifetime of landfills and a reduction in CO_2 gases as mentioned above. Although the same is true for incineration, the production of RDF has many merits when compared to the former. For example, an RDF production plant requires far less space than an incinerator with underground operation also possible. Thus this will reduce the cost of land that must be purchased. In addition, the calorific value of the produced RDF is quite fixed and it can be stored for an extended period of time and be used when needed. Just like steam, the RDF can be sold which is an added merit. Another major merit is that there is no direct burning of waste in the production of

RDF. Therefore, it is not expected that there will be great opposition to the building of an RDF production plant. One important thing to note is that a supply must be found for RDF prior to its production. This may be quite difficult and will require further research.

On the cost side, as was shown in the report by Yasuda, et al. (1992), the construction of an incinerator is markedly more expensive than that of an RDF production plant. In addition, in a paper by Yasuda, (1994), it was shown that the overall treatment expenses were slightly cheaper for an RDF Plant than an incinerator, without considering the social benefit. However, on the other hand, when the social benefit was considered, the treatment expenses for the RDF Plant were more than 26% cheaper than for that of an Incinerator.

With respect to the actual results obtained in Japan, it is expected that the building of an RDF production plant would be cheaper than expanding the Burnaby incinerator, and considerably cheaper than an expansion of the Cache Creek landfill, in terms of both direct expenses and those that consider the social benefits derived. Relatively speaking, the overall expenses for an RDF plant are expected to be cheaper than for an incinerator and the construction of the latter should be seriously considered as an effective waste management system option.

As actual results involving the construction and operation of both RDF plant and incinerators exist in Japan, comparative analysis can be made. However, the former have not been constructed in Canada and it is therefore not possible to make a direct comparison in terms of costs at this time. As a result, it is important to adapt the data obtained in Japan and construct a model for making a simulation analysis in consideration of the Canadian case. Further research is needed in constructing such a model and conducting a social cost-benefit analysis. Such a preliminary model is shown in figure 3.2. The numbers accompanying the diagram, 1 to 4 are explained as follows:

①: Transport of waste from the site of origin to the respective system that handles it.

②: Either the direct transport of waste to the landfill or the transport of waste from the system to the landfill.

③: Transport of RDF from the RDF System to the Energy Recovery Plant.

④: Transport of ash to an ash processing plant.

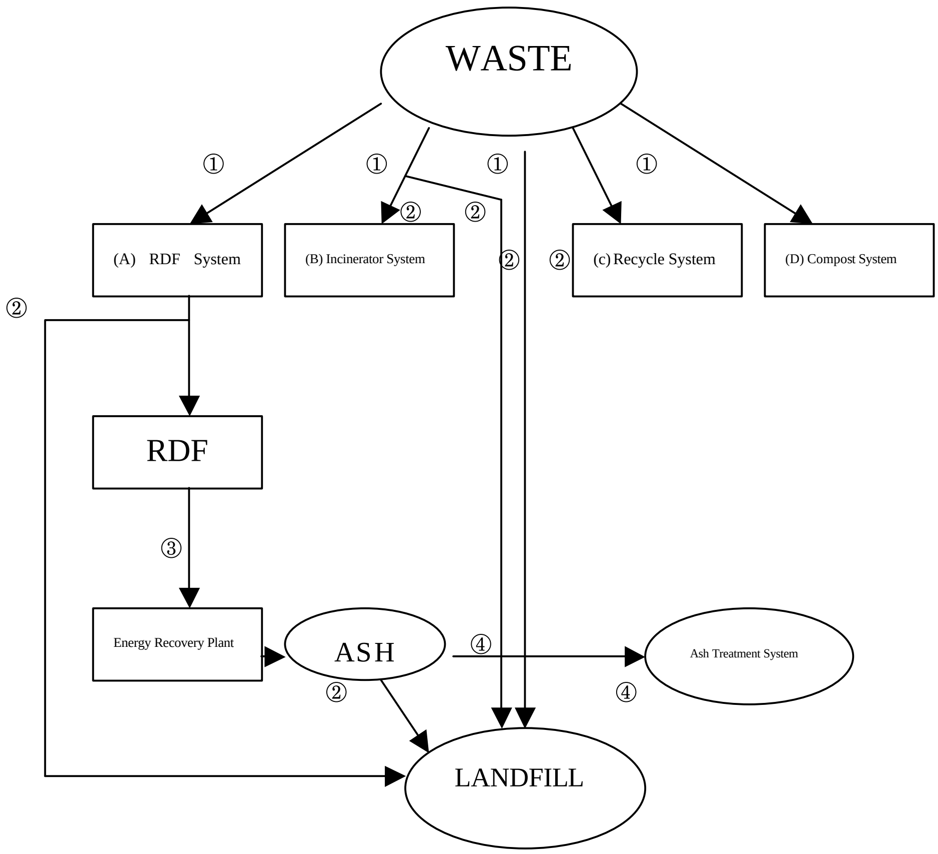

Figure 3.2 Complex Waste Management System

With respect to this figure four systems are available for managing waste which include: a compost system, recycling system, energy recovery incinerator system and an RDF system in combination with an energy recovery system. It will be important to determine which systems should be used in a particular area.

With respect to cost, there are both direct costs and social costs that must be considered for each individual system. For system (A), which is the RDF system, the direct costs include: cost to ship waste to the RDF production facility, cost of producing RDF (including such things as construction, maintenance and personnel expenses), cost of disposing material that is not suitable for making RDF, cost of shipping RDF to the energy recovery plant, and the cost to ship the ash residue to a disposal location (which includes the landfill tipping fee). On the social side there are costs to the environment such as those associated with the discharge of greenhouse and toxic gases upon the combustion of fossil fuels used to make RDF and the combustion of RDF itself. Compared with the incinerator system and direct landfilling, there are social benefits such as the reduction in greenhouse gases for example. Further study will be necessary to determine the overall social cost of the production and use of RDF, as well as that of other methods of waste management.

4. Conclusion:

There are many advantages to using RDF. Using densified RDF which has been processed with CaO, the fuel has an excellent storage ability and will not putrefy while the facility is down. Using densified RDF, the production of RDF can be performed at one facility and the combustion at another. Another advantage to using RDF is that it can be burned in conventional coal burning boiler systems. However, it is important that there be a market for the RDF and for that market to be near the RDF production facility which is necessary for reducing the costs of shipping. The use of municipal solid waste as a fuel is far superior to the direct landfilling of that waste as energy can be recovered. Research results also show that the combustion and energy recovery of RDF is superior to that of unprocessed municipal solid waste due to the fact of the calorific value homogeneity that is associated with RDF. From now on it will be important to determine in what the results obtained for RDF in Japan can be applied to the Canadian situation to find a better way of handling waste in Canada.

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