Benefit/Cost Analysis of RDF Process in Taiwan

Ni-Bin Chang* and Y. H. Chang**

presented to

Fifth North American Waste-to-Energy Conference

Research Triangle Park, NC

April 21-25, 1997

---

* Associate Professor, Department of Environmental Engineering, National Cheng-Kung Unicversity, Tainan, Taiwan, R.O.C.

**Graduate Student, Department of Environmental Engineering, National Cheng-Kung Unicversity, Tainan, Taiwan, R.O.C.

Benefit/Cost Analysis of RDF Process in Taiwan

Ni-Bin Chang and Y. H. Chang

Department of Environmental Engineering
National Cheng-Kung University
Tainan, Taiwan, Republic of China

ABSTRACT

Reducing the waste stream through incineration is very important to minimize the use of landfills and to maximize the recovery of energy. The technology of mass burn waterwall incineration was widely used in the past two decades for solving the problems of solid waste disposal. In recent years, the sorting process is considered as an essential pretreatment unit prior to the incineration process. However, many engineering and economic disciplines are involved in the integration of refuse-derived fuel and waste-to-energy processes. This paper illustrates the related benefit/cost analysis issues during selecting an appropriate sorting process for Pa-Li municipal incinerator in Taipei metropolitan region of Taiwan.

INTRODUCTION

RDF (Refuse-derived Fuel) technology was developed in the US in the early 1970's. The first RDF facilities were based on firing RDF in coal-fired utility boilers. The initial reason for processing municipal solid waste prior to incineration was to remove a large fraction of the non-combustibles and to size the RDF so that some of it could more readily burn in suspension. The coupling of RDF preparation with new incineration systems designed exclusively for firing RDF is not an easy work. There were many technical and economic problems that had to be overcome. However, the RDF technology evolved slowly to where it is today has been a proven and reliable technology.

The original economic trade-off of RDF technology was primarily based on the capital and O&M cost savings of smaller boiler and air pollution control systems versus the added capital and O&M cost of the processing equipment. Also, RDF offered potential benefits for recycling part of the secondary materials, providing lower pollutant emissions, resulting in environmentally secure disposal of residues, and increasing energy recovery efficiency. Hence, cost-benefit or cost-effectiveness analysis is therefore an important indicator for the application of such a technology. The current focus of economic aspects using RDF technology as an auxiliary component in the solid waste management system is how to fully identify the related benefits while traditional costs become more apparent. These benefits may relate to the resale income from secondary material market, the improvment of recycling potential, the achievment of lower pollutant emissions, and the production of a clean bottom ash amenable to reuse. However, economics does not always adequately reflect direct benefits from waste sorting. The saving of management expenditure from a regional sense and the scarcity of physical resources from a national sense should be considered to a reasonable extent in order to justify the investment of large scale sorting and recycling programs. Hence, this analysis also tries to cover the intangible benefits and indirect costs associated with waste sorting and recycling activities.

Overall, the purpose of this paper is to present an integrated evaluation framework and summarize the profile of both tangible and intangible benefits as well as direct and indirect costs. Such information would facilitate a thorough evaluation of economic viability of burning RDF as fuels in the future. The case study conducts a series of description of the general situation of solid waste management in Taipei metropolitan region. A typical refuse-derived fuel system, developed by a local engineering firm in Taiwan, which consists of standard unit operations of shredding, magnetic separation, trommel screening, and air classifying is fully described. The benefit/cost analysis to characterize the economic feasibility of adding such a sorting process to Pa-Li incinerator is then discussed as the related management issues become more clear. Final integrated evaluation of MRF and RDF based on the entire Taipei metropolitan region is proposed as well.

LITERATURE REVIEW

The engineering efficiency using RDF process prior to incineration has been well known. While sorting process prior to incinerators has won public concern over the years, its economic viability has not developed as quickly due to the lack of front-end planning information of related benefit/cost. In recent years, Derks and Hadfield [1] presented an innovative method to figure out the price of RDF according to the discounted cost of fuel displaced by burning RDF and the discounted revenue received for excess energy recovery by allocating the boiler output energy to steam and electrical generation. Zach [2] developed a computer model for examing recycling system life cycle economic costs. Gershman [3] further discussed the factors affecting the costs of solid waste management from a broader sense. Hartman and Smith [4] emphasized the beneficial use of RDF technology with recycling and environmental protection goals. Lea and Kowalewski [5] tried to apply a computer model to evaluate the cost structure of an integrated solid waste management system in south Louisiana. The model has been used to predict the future cost of twelve waste management options available to local government. The articles written by Porter and Robert [6] in the book "Energy Savings from Waste Recycling" presented a thorough survey of the indirect benefit of recycling which further characterizes many intangible issues in solid waste management.

ANALYTICAL BACKGROUND OF CASE STUDY

Taipei City, located at the central part of Taipei County, is the largest city in Taiwan. The geographical location of this region is illustrated in Figure 1. The City of Taipei is divided into 12 administrative districts where each has its own garbage collection team in charge of individual clean-up work. However, 29 administrative districts are organized in Taipei County, and a single garbage collection team is also organized within each district in charge of waste shipping and disposal. The Taipei City and County Government handle their solid waste streams independently, although the resident's activities in both areas have amalgamated to form a unique metropolitan region. The 1995 population of Taipei City and County were about 2,600,000 and 3,500,000, respectively. This large metropolitan region with a total population over 6 million and an area of over 2,000 sq.km., requires solid waste management on a regional basis.

The Taipei metropolitan region currently generates over 6,500 tonnes of solid waste which is collected daily using a labor force of 6,741 and 1,008 collection vehicles. Six administrative districts have promoted their household recycling programs in Taipei City. Shan-Chu-Ku regional sanitary landfill is the only existing landfill, located at the eastern boundary of the city. In addition, two municipal incinerators (Nei-Hu and Mu-Cha) are currently in operation with the design capacity 900 TPD and 1,500 TPD, respectively, and the construction of a third (Pei-Tou) with the design capacity 1,800 TPD is in progress. Municipal solid waste streams in Taipei County are transported to two existing incinerators -- Shu-Lin and Hsin-Tein with the design capacity 1,350 TPD and 900 TPD, respectively -- or to the only regional sanitary landfill (San-Hsia) for waste treatment and disposal. The shaded areas indicated in Figure 1 represent the service region originally assigned for Shu-Lin and Hsin-Tein incinerators. Although a number of small landfills are operated by local public or private agencies in several administrative districts of Taipei County, they will be out of capacity very soon. New incinerator and landfill, both located at the Pa-Li area, are being constructed now. The design capacity of Pa-Li incinerator is 1,350 TPD, that is to be started up in the year 2000. No MRF or RDF facilities exists in the current solid waste management system.

Some observations about an apparently significant trend in the solid waste management system has developed due to rapid economic development in this region and the uncertain need for waste treatment and disposal in the long run. Tables 1 and 2 describe the quantity and quality information of MSW in Taipei County. It is estimated that about 40% of the waste streams can be recovered as the secondary materials. While the source separation programs was not so successful in the last few years, the need of MRFs or IPCs, and/or RDF plants in the existing system configuration is phenonmenal. The RDF technology would help make recycling compatible with waste incineration. Figure 4 illustrates the current and future solid waste management system configuration using RDF and MRF as new components.

In addition, the increase of heat values of waste streams results in a lower throughput in Shu-Lin and Hsin-Tein incinerators, which is almost one-third below the original design capacity. However, the heat value of MSW used to design Pa-Li incinerator is 8,000 KJ/Kg that is almost 50% higher than the existing average heat value of MSW in Taipei County. This will result in a possibility of siting RDF as a pretreatment unit in Pa-Li incinerator in the future. The first benefit in favor of the use of a sorting process in Pa-Li incinerator may be the increase of heat value of RDF destined for incineration. This would indirectly achieve higher energy recovery efficiency from a local sense and handle higher amount of waste flow at Pa-Li incinerator than originally planned level from a regional sense. Concurrent with attempts to impose a sorting process prior to Pa-Li incinerator, the Environmental Protection Bureau began effort to think about the idea of redistribution of waste flow according to the heat value of waste flow generated in different administrative districts so that the design capacity of these incinerators can be fully utilized.

Several economic-oriented issues encountered in this system include: (a) Is it necessary to build RDF process in this system to meet the growing demand of solid waste generation? (b) What are the impacts from the economic aspects through the use of such a RDF process? (c) Would the considerations of benefit/cost profile become different with respect to the scale of planning area? and (d) What is the possible incentives for the private sectors to perform BOT (Build, Operation and Transfer) or BOO (Build, Operation and Own) projects? These questions can be analyzed using the benefit/cost analytical framework in this paper.

RDF PROCESS DESCRIPTION

Various equipment are available for processing mixed or source-separated solid waste feedstocks for the recovery of secondary materials. The selection of the appropriate unit operations in a RDF or MRF system is a function of the characteristics of the feedstock, the specifications for the recovered products. The designed process of the first refuse-derived fuel process in Taiwan, as described in Figure 2, consists of three major subsystems: shredding, air classification, and screening. The impacts from the engineering aspects through the use of such a RDF process has been fully characterized by Chang, et al. ([7]-[10]). These engineering factors include throughput capacity, composition of the feedstocks, product specifications, and available technologies. Mass balance diagram can be made as illustrated in Figure 3. Table 3 lists the average energy requirements in this RDF process during two test runs in 1996.

BENEFIT/COST ANALYSIS

Benefits of Sorting prior to Incinerator

System economic benefits can accrue from the sale of recovered materials, which is itself a function of market demand, processing efficiency and separation efficiency. Revenues from the sale of materials can be estimated using information derived in a formal market investigation, as indicated in Table 4. Other funding sources may include tipping fees, subsidy, and even landfill diversion credits (or avoided cost). Direct avoided costs are calculated using the procedure corresponding to the saved shipping cost from incinerator to landfill and the disposal cost in landfill. But the indirect avoided cost might involve the calculation of the social value of nonrenewable resource (i.e., landfill space) conservation. The other indirect benefits might relate to improving the processing of waste prior to combustion so that greater amounts of energy are conserved during the reuse of those recyclables, achieving lower pollutant emissions, increasing the energy recovery efficiency, and producing a clean bottom ash amenable to reuse. Hence, they are summarized as below:

♦ Direct Benefits:
  - Revenues from the sale of materials
  - Revenues from tipping fees
  - Revenues from governmental subsidy
  - Revenues from the sale of compostables
  - Revenues from the sale of RDF as fuels to boiler utility or incinerator
  - Avoided costs from the saving of shipping and disposal expenditure

♦ Indirect Benefits:
  - Social value of nonrenewable resource (landfill space) conservation
  - Energy conservation due to the reuse of those recyclables
  - Lower pollutant emissions during incineration
  - Clean bottom ash amenable to reuse
  - Increase of energy recovery efficiency in boiler utility or incinerator

Costs of Sorting prior to Incinerator

Costs associated with RDF process include siting, building, and operation, process residue disposal, and material storage and shipping. The information of cost data, using the first pilot RDF process in Taiwan, becomes available in this study that is the first test run in this country. The essential items of cost analysis are summarized as below:

♦ Direct Costs:
  - Costs for siting
  - Costs for construction
  - Costs for operation and maintenance
  - Costs for process residue disposal
  - Costs for material storage and shipping

♦ Indirect Costs:
  - Costs for possible subsidy to the residents due to environmental impacts
  - Costs for possible payment for waste inflow due to unexpected flow control

- Costs for shipping the recyclables for disposal due to instability of secondary material market

THE DIFFERENCE BASED ON PLANNING SCALE

From Private Sector Point of View

The evaluation of using sorting plant as a pretreatment unit associated with incinerator might not be based on too broad profile of benefits and costs terms in engineering analysis. Direct benefit/cost with limited extent might be more helpful for the alternative selection. Since the stability of secondary material market is quite unstable, the designer of such a sorting system must fully grasp the characteristics of the waste feedstock and the end product property required by the recycling sectors. The unit cost of processing solid waste may include debt service, taxes, insurance, labor, fringes, administrative, parts, supplies, utilities, and other costs incurred for the operation and maintenance of the system. The debt service is basically the amortization of the initial capital investment. These costs are conveniently divided into fixed costs (debt service, taxes, insurance, etc.) and operating and maintenance costs. On the other hand, the benefit terms could be characterized by the resale income of recyclables from secondary material market as well as tipping fees charged for those users.

In this analysis, the determination of the level of debt service is based on a uniform interest rate of 7% within operational period of 20 years that would result in a yearly capital recovery factor of 0.09439. The value of 0.9 is assumed as the system availability rate and a yearly throughput of 78,000 tons is chosen as a operational basis. According to the power consumption profile and other information, the long-term operating cost can be estimated as approximately 800 NT$/ton (29 US$/ton) in average, including the amortization of the initial capital investment. On the other hand, the income by selling the ferrous metals in the secondary material market is about 125 NT$/ton (4.5 US$/ton). Therefore, the tipping fee required for a profitable operation is equal to 675 NT$/ton (25 US$/ton). However, the true benefit of such a sorting plant could be further justified from its indirect contribution (i.e., avoided cost) in a solid waste management system.

From Regional Point of View

Cost and benefit redistributions through the use of sorting or recycling process are the major concerns in system planning of solid waste management in the metropolitan region. It obviously shows that the income from electricity sale is the largest direct benefit and the cost spent for waste transportation is the major expenditure in many cases. Hence, an optimization analysis to reorganize the waste flow to those three incinerators such that the average heat value of waste inflow destined for each incinerator might be consistent with its original design level. To clearly understand such a methodology, Chang, and et al. have delineated the comparative structure of cost and benefit distributions for many different planning scenarios ([11]-[12]). The program calculates avoided labor, equipment and overhead costs, then integrates these values to produce an overall value for avoided cost. A simulated run was initialized by Chang, et al. to estimate the avoided cost by recycling according to the net benefit difference, recycling cost, and the corresponding electricity loss. It shows that the avoided cost per unit of material recycled is 963NT$/tonne (36US$/tonne). Hence, the indirect benefit of waste recycling might include such an avoided cost as well. Overall, the systematic evaluation methodology used for the regional analysis can be presented in Figure 5 for the purpose of demonstration. Costs and benefits which are directly or indirectly associated with either collection or processing must be considered in any economic life cycle analysis.

From National Point of View

Advanced considerations in the development of benefit/cost scheme might rest upon the possible extent to which the energy saving from waste recycling can be estimated from a broader point of view. Consumer motivation of waste recycling probably not only based on the direct income but also from resources conservation. The contribution which resource recovery from waste streams makes to the conservation of energy and materials may be measured conveniently by its implications for primary energy use. Hence, the appreciation of the environmental and conservation benefits which accrue should be emphasized. Direct energy recovery from MSW can be achieved through direct incineration methods. However, energy savings result from waste recycling if the energy used in collecting, separating and treating reclaimed wastes, and subsequent processing, is less than the energy used in originating and processing primary materials and disposing of wastes. There are considerable variations in material production processes both within and between countries. Also the age of plant and purity and form of the primary and secondary materials affects the energy consumption of manufacturing processes. Comparison of unit energy savings by appropriate recycling of secondary material were summarized as follow [6]: 1) aluminum: 222×10^9 Joules/ton; 2) waste paper: 7×10^9 Joules/ton; 3) glass: 17×10^9 Joules/ton; and 4) rubber: 44×10^9 Joules/ton. These values can be used as representative indicators when assessing a national policy related to the waste recycling or sorting actions.

INTEGRATED EVALUATION

Taipei metropolitan region is a highly populated area in Taiwan. Various non-hazardous types of waste disposal issues, such as the construction debris and scrape tire, can be handled together as part of the MSW streams. However, the need of material recovery facilities (MRFs) or intermediate processing centers (IPCs) to facilitate all types of recycling activities becomes at least equally important in the integrated solid waste management programs today. How to manage such an adapting change in the system become more and more critical. Since the Solid Waste Clean-up Law in Taiwan was just amended by the members of Legislative Yen in 1996. Multi-channel recycling programs are emerging in this country such that the MRFs would be an innovative technology to be used in the solid waste management alternatives. A new system configuration, as described in Figure 6, can be proposed, in which the MRFs and RDF plants are incorporated together to achieve a higher value of partnership. While RDF technology assisits in the incineration process, the MRFs consolidate and improve the purity materials collected from all possible waste streams before they are sent to markets.

CONCLUSIONS

Mixed waste processing, though apparently well established in Europe and USA, has a much less well established track record in Taiwan. Benefit/cost profile is an effective indicator for the justification of waste sorting or recycling programs. However, only part of those benefits and costs can be easily characterized and quantified for comparative analysis. The objective of this study was designed to assess the scope of acquired benefits and costs from waste sorting by a more broader point of view although some of them are difficult to be quantified for detailed assessment. It shows that additional benefits, such as avoided costs and energy savings, resulting from sorting and recycling program must be finally attractive. Compared to alternative disposal options, the tax reduction or subsidy from the governmental agencies would be an essential policy to encourage the privatization for solid waste management in the metropolitan region.

REFERENCES

1. Derks, E. V. and Hadfield, J. S.,"Determination of the Price of RDF for Billing Purposes," in Proceedings of 1988 National Waste Processing Conference, Nov., 1988, Philedephia, PA, USA, pp. 65-72.
2. Zach, P.,"A Computer Model for Examing Recycling System Life Cycle Economic Costs," in Proceedings of Second United States Conference on Municipal Solid Waste Management, June, 1992, Arlington, Virginia, USA pp. 1-11.
3. Gershman, H. W.,"Costs of Solid Waste Management -- 1986, 1991, and 1996," in Proceedings of Second United States Conference on Municipal Solid Waste Management, June, 1992, Arlington, Virginia, USA, pp. 113-131.
4. Hartman, R. M. and Smith, M. L.,"The Beneficial Co-existence of Refuse Derived Fuel Technology with Recycling and Environmental Protection Goals," in Proceedings of Second United States Conference on Municipal Solid Waste Management, June, 1992, Arlington, Virginia, USA, pp. 457-467.
5. Lea, R. W. and Kowalewski, R.,"Cost Analysis and Optimization of Local and Regional Solid Waste Management," in Proceedings of The Tenth International Conference on Solid Waste Management, Nov., 1994, Philedephia, PA, USA, pp. 1B.
6. Porter, R. and Robert, T.,"Energy Savings from Waste Recycling," Elsevier, New York, 1985.
7. Chang, N. B. and Chang, Y. H., "Performance Testing of Solid Waste Sorting Plants," in Proceedings of 1996 National Waste Processing Conference, April, 1996, Boston, MA, USA, pp. 309-316.
8. Chang, N. B., Chang, Y. H., and Chen, W. C.,"Evaluation of Heat Values and its Prediction for Refuse-derived Fuel," The Science of the Total Environment, 197:139-148 (1997).
9. Chang, N. B., Chen, W. C., and Chang, Y. H.,"Integrated Evaluation of Refuse-derived Fuel Incineration," Journal of Hazardous Materials, to appear, Oct., 1997.
10. Chang, N. B. and Chen, W. C., "Systematic Evaluation of Solid Waste Presorting Process in Taiwan," Journal of Air & Waste Management Association, in review, 1997.
11. Chang, N. B. and Wang, S. F., "Comparative Risk Analysis of Solid Waste Management Alternatives in a Metropolitan Region," Environmental Management, 20(1):65-80 (1996).
12. Chang, N. B. and Wang, S. F., "Managerial Fuzzy Optimal Planning for Solid Waste Management Systems," Journal of Environmental Engineering, ASCE, 122(7): 649-658 (1996).

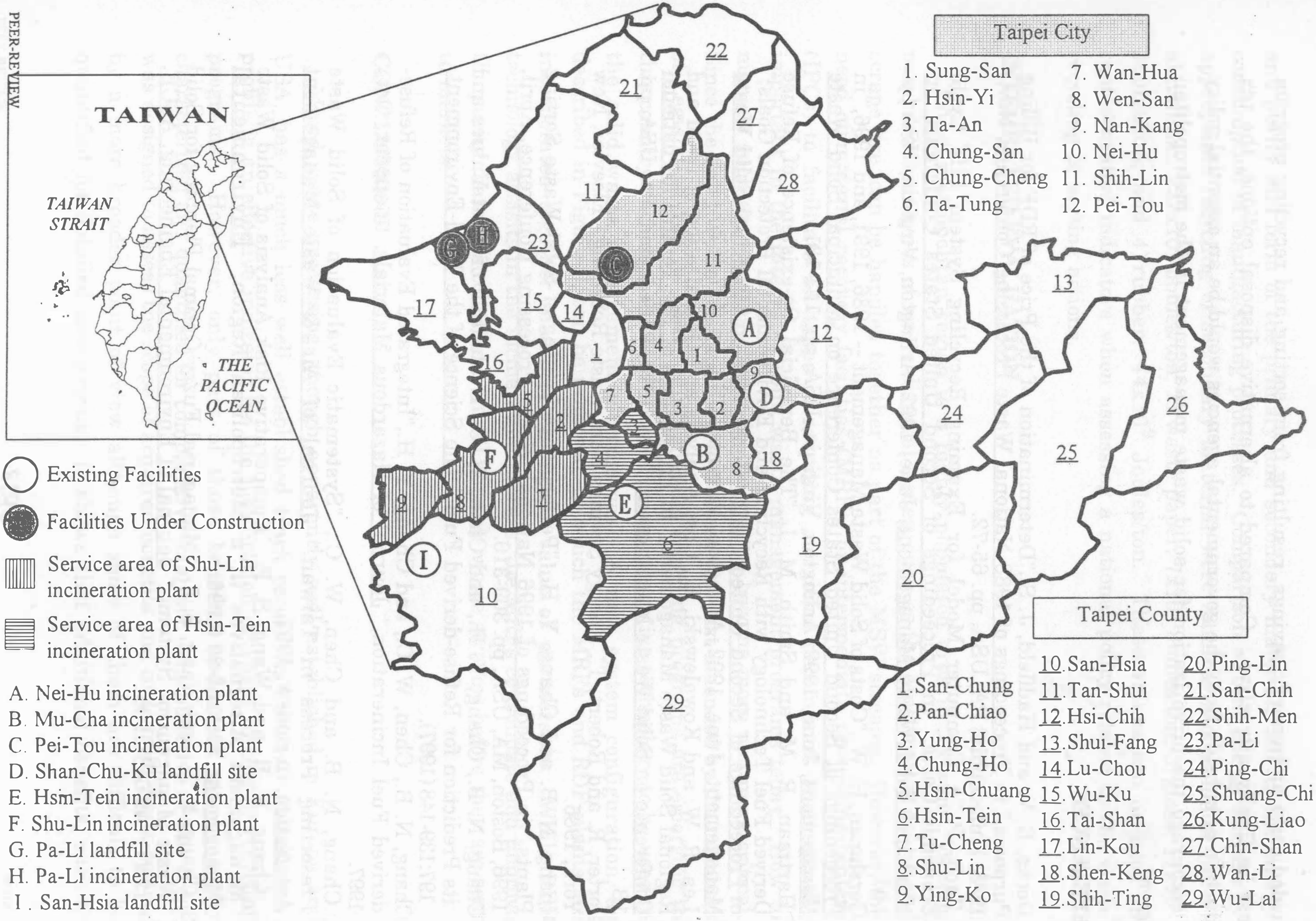


Figure. 1. The Planning Area, Incineration Plants and Landfill Sites

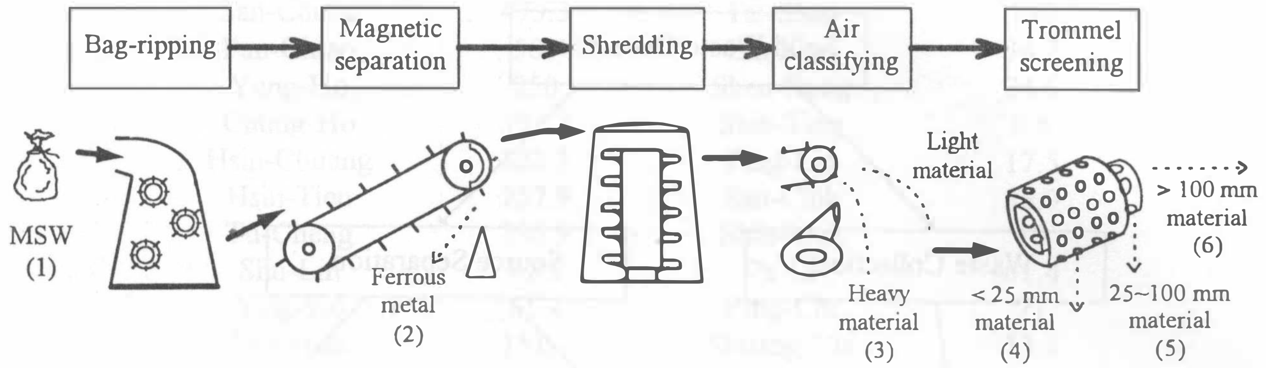
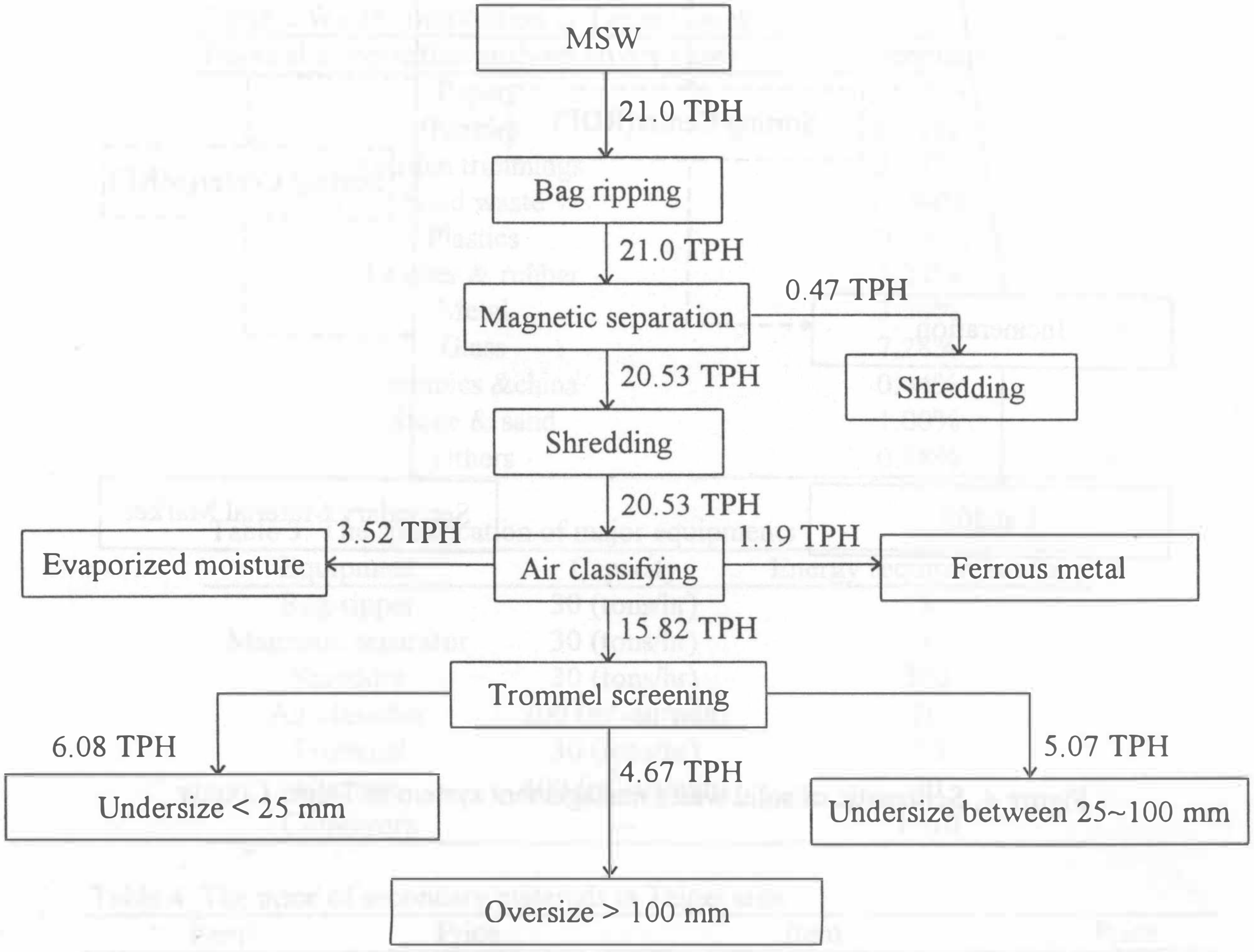


Figure 2. The system configuration of solid waste sorting process



TPH : tons/hour

Figure 3. Mass flow diagram of sorting process

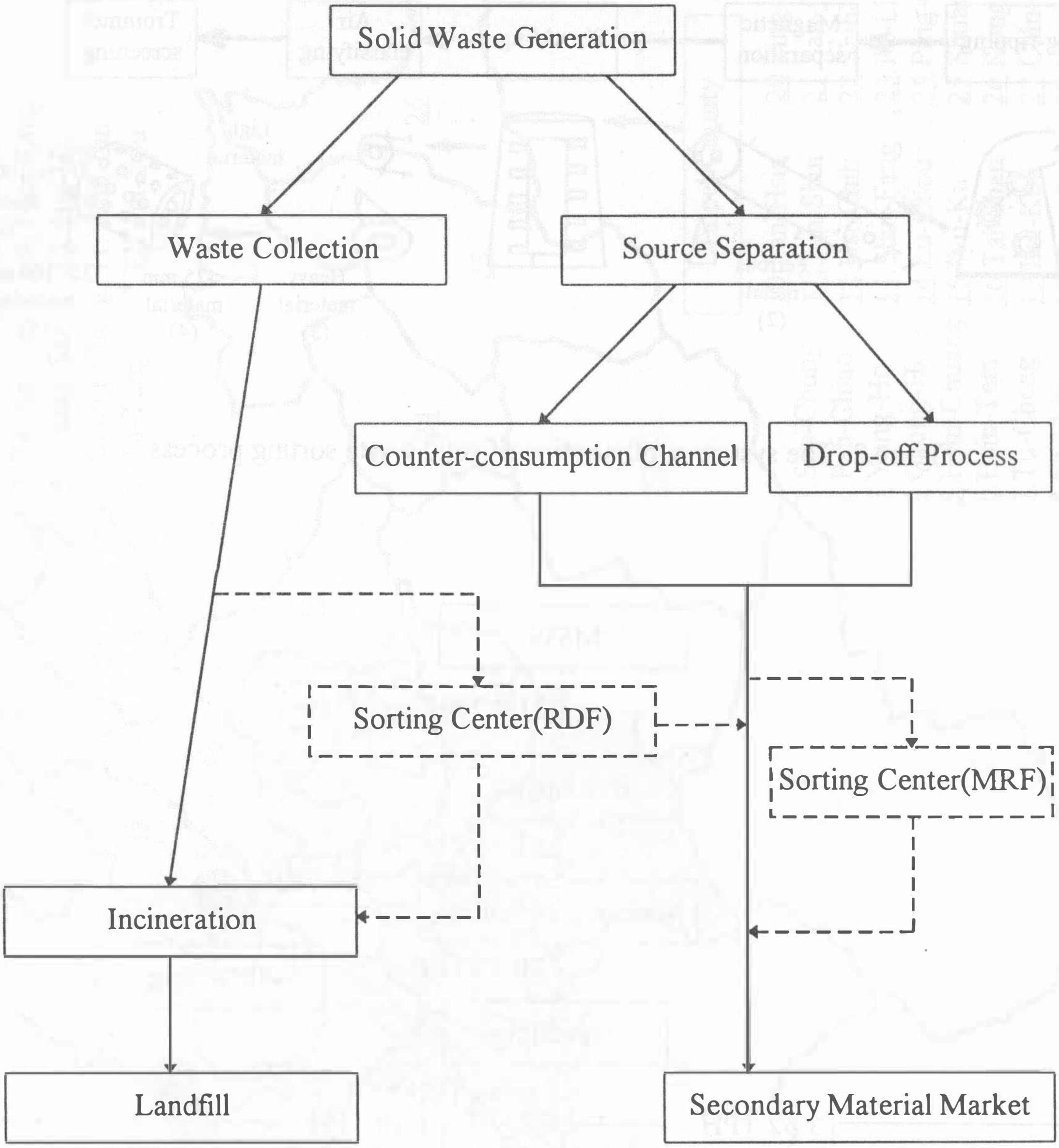


Figure 4. Schematic of solid waste management system in Taipei County

Table 1. The waste generation of areas in Taipei county

Area	Amount(tons/day)	Area	Amount(tons/day)
San-Chung	473.3	Tai-Shan	130
Pan-Chiao	565	Lin-Kou	34.2
Yung-Ho	250	Shen-Keng	24.6
Chung-Ho	391.7	Shih-Ting	9.8
Hsin-Chuang	323.3	Ping-Lin	17.5
Hsin-Tien	257.9	San-Chih	38.9
Tu-Cheng	235.9	Shih-Men	10
Shu-Lin	82.5	Pa-Li	61.4
Ying-Ko	65.4	Ping-Chi	21
San-Hsia	151.7	Shuang-Chi	13.1
Tan-Shui	162.5	Kung-Liao	21
Hsi-Chih	60	Chin-Shan	22.7
Shui-Fang	350.7	Wan-Li	42.5
Lu-Chou	150	Wu-Lai	9.8
Wu-Ku	82.9		

Total waste amount in Taipei county : 4059.2 tons/day

Table 2.Waste composition in Taipei County

Physical composition analysis(on dry base)	Percentage
Paper	37.99%
Textiles	6.11%
Garden trimmings	2.57%
Food waste	18.94%
Plastics	19.86%
Leather & rubber	1.24%
Metal	3.68%
Glass	7.28%
Ceramics &china	0.44%
Stone & sand	1.00%
Others	0.88%

Table 3. The specification of major equipments

Equipment	Capacity	Energy requirement (hp)
Bag-ripper	30 (tons/hr)	5
Magnetic separator	30 (tons/hr)	3
Shredder	30 (tons/hr)	500
Air classifier	200 (m^3-air/min)	20
Trommel	30 (tons/hr)	7.5
Cyclone	400 (m^3-air/min)	40
Conveyors	--	1~10

Table 4. The price of secondary materials in Taipei area

Item	Price	Item	Price
Waste paper	7.5 NT$/kg	Waste green glass	1.87 NT$/kg
Ferrous metal	3.9 NT$/kg	Waste dark glass	1.3 NT$/kg
Aluminar can	2.8 NT$/kg	Coke plastic bottle	2.8 NT$/item
Waste textile	25.3 NT$/kg	Plastic bottle for mineral water	0.5 NT$/item
Waste white glass	4.1 NT$/kg		

*The currency ratio is 27.5 NT$/1US$ in 1997

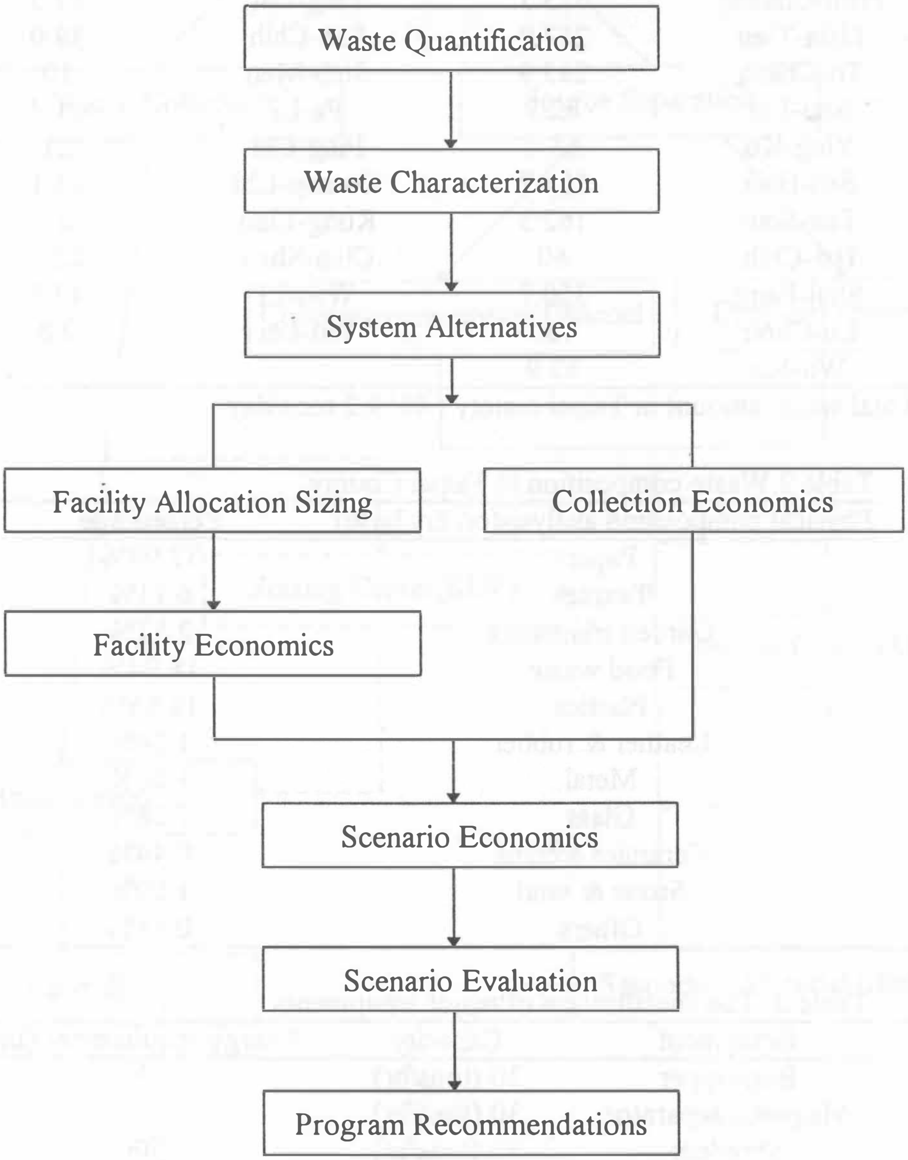


Figure 5. Integrated evaluation model for benefit/cost characterization

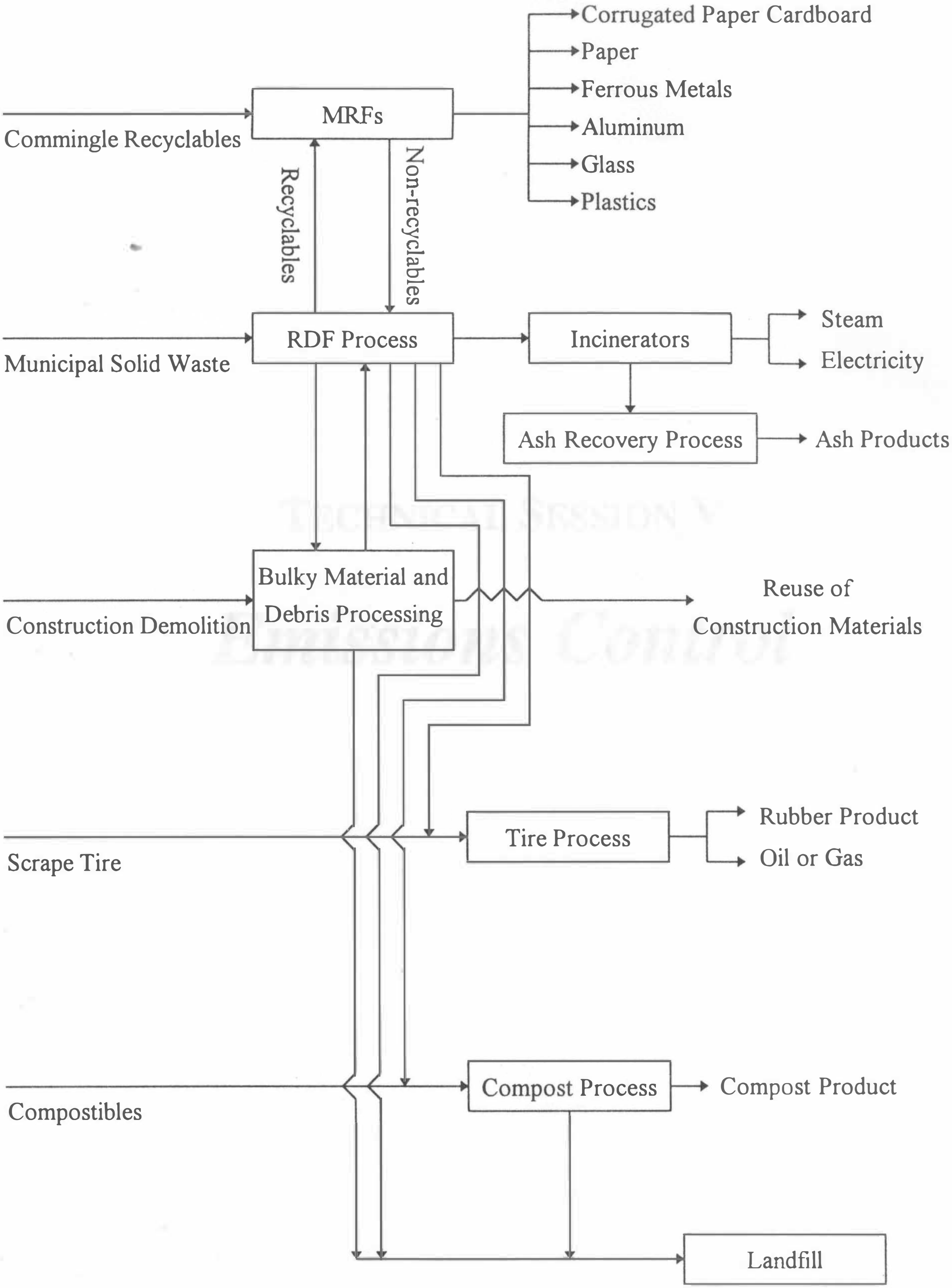


Figure 6. Future integrated system of MRF and RDF