Planning for integrated solid waste management at the industrial Park level: A case of Tianjin, China

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Abstract

Industrial parks play a significant role in the production and use of goods and services. The proper management of solid waste is a major challenge for industrial parks due to the large quantity of wastes and the variability of waste characteristics from these types of developments. Therefore, integrated solid waste management has become very crucial to the industrial park managers. Such an approach requires industrial park managers to assess the overall use of resources, and to seek waste reduction, reuse and recycling opportunities both at the individual company level and among different tenant companies. The adoption of this method can bring both economic and environmental benefits. This paper introduces the planning efforts of a real case in China. It first presents the basic information on Tianjin Economic Development Area (TEDA), and then introduces its current practices on solid waste management. The main focus of this paper is to describe how to plan an integrated solid waste management system at TEDA. Benefits and challenges are all identified and analyzed. The experiences and methods from this case study should be applied in other industrial parks so as to improve the overall eco-efficiency of the whole industrial park.

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1. Introduction

China has experienced a very rapid increase in its economy during the last two decades and has moved quickly to encourage local industrialization by attracting foreign investment. However, in the absence of a comprehensive sustainable development scheme, this increase has brought severe environmental issues, such as water resources depletion and pollution, soil erosion, desertification, acid rain, sandstorms, forest depletion, and solid waste pollution (SEPA, 2003). This trend is most pronounced in the Chinese industrial parks, where most manufacturers locate and operate. Among these environmental issues, solid waste is becoming a critical issue, not only in terms of the impacts being created but also in terms of resources being consumed. It has been estimated that the amounts of industrial waste increased by 10% while at the same time municipal waste has increased by 15% per year in China (Zhu and Zhao, 2004). If not properly managed, the accumulation of industrial wastes within an industrial park can give rise to serious environmental damage, as well as increased safety problems and health-care costs. One of the significant challenges facing industrial park managers is how to minimize the negative impacts of solid wastes while still attempting to promote rapid industrial development. One solution has been to adopt principles of integrated solid waste management by encouraging government and industries to integrate sustainable practices, comply with environmental regulations, and select and apply suitable technologies and management programs to achieve realistic waste management goals and objectives.

This paper examines the planning and application of integrated solid waste management at the industrial park level by employing a case study of Tianjin Economic Development Area (TEDA), which is recognized as the largest
industrial park in China (Geng, 2005). The paper explores how this approach provides valuable information that can benefit an industrial park by strengthening the current practices and developing linkages. This paper commences with an introduction of TEDA. Suggestions are presented on how to plan an integrated waste management (IWM) system, followed by a study on potential benefits and the challenges of implementation within an industrial area. Finally, we draw our own conclusions.

2. Current situation of solid waste management in TEDA

2.1. A brief introduction of TEDA

The Tianjin Economic Development Area (TEDA) is a special development zone located on Bohai Bay in North China (Fig. 1). TEDA is in the eastern portion of Tianjin Municipality (China’s third largest city), which is approximately 50 km from the city center of Tianjin (Fig. 2). TEDA was founded in 1984 and provides essentially the same preferential policies, incentives, and flexible measures as other special economic zones in China. It has a planned area of nearly 36 km$^2$, including separate sections for industrial development, mixed residential, financial and commercial uses. In many ways, TEDA functions in a manner that is similar to a small municipality. At the end of 2003, the population living in the industrial estate was 53,893. Approximately, 152,000 workers or managers travel every day between the city of Tianjin and the zone (TEDA, 2004).

TEDA can be classified as an outer suburban estate with comprehensive functions, given its varied companies and industries. Businesses in the estate cover a range of ownership-types, including joint ventures, private companies, state-owned enterprises, and wholly foreign owned enterprises. Numerous tenant sites, especially companies with a staff of more than 400 employees, have both manufacturing and residential buildings within their compounds. This is in keeping with Chinese government policy whereby businesses are expected to provide social benefits to employees, such as food and accommodation (Geng, 2005).

TEDA reflects the trend of most Asian industrial estates as it has a large number of tenants of diverse nationalities, many of whom tend to be competitive with one another. Within TEDA there are over 3300 foreign-invested enterprises, including 28 companies that are ranked among the Fortune 500 group. Total investment in the park has reached close to US$12.6 billion (TEDA, 2004). Through almost two decades of development, TEDA has established four pillars of manufacturing: electronic communications, foodstuffs, bio-medicine, and machinery manufacturing. Examples of famous multinational companies include Motorola, Toyota, Hyundai, Samsung electronics, Hartwell Textile, Coca-Cola, General Electric, Dingyi Food, Novozymes and Glaxo-SmithKline (TEDA, 2003).

The Tianjin Municipal government has the responsibility for managing TEDA and set up an administrative agency to oversee the daily administration of the park. This agency is called the TEDA Administrative Commission; it is comprised of a chairman and a large number of departments and bureau branches. This administrative commission is the city’s legal representative at TEDA and functions as the local government. Its main administrative functions include enforcing national laws and regional regulations, monitoring environmental protection, levying tax, stipulating economic and social development policies, and managing public financial resources. Under this system, the main bureau responsible for environmental protection is the TEDA Environmental Protection Bureau (EPB). This bureau’s portfolio includes the Comprehensive Administration Department (in charge of environmental enforcement, including solid waste issues), General Engineer’s Office (in charge of research and development), and the Environmental Protection Monitoring Station (in charge of environmental quality monitoring) (TEDA, 2003). When a park tenant is found to be non-compliant with respect to the environmental regulations, the comprehensive administration department will impose fines or bring court actions,
therefore ensuring that environmental enforcement can function effectively.

2.2. A brief introduction of solid waste management in TEDA

Solid waste management is one of TEDA’s priority issues as it relates to the protection of the environment and conservation of natural resources. Challenges are expected to minimize total solid waste generation while maintaining rapid development, especially since the industrial park managers want to develop TEDA into an international center for manufacturing. Rao (2002) indicated that with most manufacturing firms locating in East Asia in the near future, opportunities will be created, along with the creation of substantial environmental burdens. Consequently, TEDA will have to cope with managing increasing quantities of industrial and domestic solid wastes within its territory. This section introduces TEDA’s current practices on managing their solid waste. Issues and challenges are also identified.

A solid waste survey conducted by a research team of the Dalian University of Technology shows that the total amount of solid waste produced in TEDA in 2003 was 132,000 tons, including 99,800 tons of industrial waste and 32,000 tons of municipal waste (Zhu and Zhao, 2004). Table 1 presents the quantity of solid waste generated in TEDA in 2003. Fig. 3 shows the solid waste flow within TEDA in 2003, where we can see that 60,000 tons of industrial waste is reused or recycled, 35,000 tons is collected and sent to a landfill by a professional government-owned company, the Environment and Sanitation Company (E&S), and 4000 tons is collected by the local scavengers. Of the 60,000 tons of reused/recycled industrial wastes, 42,000 tons are reused or recycled within one company or among different tenant companies, and 18,000 tons are collected, treated and sent out of the park for reuse and recycle by licensed recycling companies. Of the 35,000 tons waste sent to the landfill, 800 tons are hazardous waste, 67,000 tons are partly mixed, and 4000 tons are used batteries.

### Table 1
Solid waste quantity generated in TEDA in 2003 (TEDA, 2004)

<table>
<thead>
<tr>
<th>Type of solid waste</th>
<th>Production amount (10^3 tons)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sent to landfill</td>
<td>35</td>
<td>26.5</td>
</tr>
<tr>
<td>Collected by scavengers</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Reused/recycled</td>
<td>60</td>
<td>45.5</td>
</tr>
<tr>
<td>Hazardous</td>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>Municipal waste</td>
<td>32</td>
<td>24</td>
</tr>
<tr>
<td>Medical waste</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>132</td>
<td>100</td>
</tr>
</tbody>
</table>
landfill, a further analysis indicates that 20,000 tons still have potential value for reuse or recycle, while the remain-
der is suitable for disposal. All municipal wastes in TEDA are collected in bags by the Environment and Sanitation Company with no source sorting and sent to the local land-
dill. Among these municipal wastes sent to the landfill, about 18,000 tons still have potential value, including, 13,000 tons organic waste suitable for composting and 5000 tons reusable or recyclable waste, accounting for 40% and 15% of the total amount of municipal waste, respec-
tively, which corresponds to 9.7% and 3.7% of the total amount of solid wastes produced in TEDA (Zhu and Zhao, 2004).

With regard to the composition of those wastes in TEDA, the survey indicated that the majority of solid wastes in TEDA are waste paper, waste plastics, waste metal, and organic wastes (see Table 2).

Although TEDA is still in the early stage of managing their solid wastes, several solid waste treatment facilities have been established, including a new hazardous waste treatment center, an energy-recovery incinerator and a landfill.

Locating in the territory of TEDA, the Tianjin New Hazardous Waste Treatment Center (TNHWC) is one of the main facilities and formally began operation on September 1, 2003. This center can treat over 600 types of wastes, with an annual treatment capacity of 37,000 tons. It is equipped with an incinerator for disposing of 13,500 tons of toxic and hazardous waste per year, a landfill for depositing of 6200 tons of toxic and hazardous waste per year, a recycling facility for recycling 10,000 tons of waste liquid containing heavy metal and chemical solvent per year; and a medical waste treatment facility for disposing of 7300 tons medical wastes per year (TEDA, 2004). This center passed an international audit by Motorola, GM and Intel in 2003, in order to meet with their hazardous waste treatment requirements. Currently over 80 companies in TEDA have discussed the potential cooperation with the center, but the barrier is that the treatment fee is higher than what they expect. Therefore, most of those companies still contract with those licensed waste treatment companies employing old and low technologies, and charging cheaper treatment fees.

The Shuanggang Municipal Solid Waste Incinerator was built in 2002, a facility located within the TEDA’s territory. It employs Japanese technology and can meet the EU emissions standard. One indicator is that the dioxin concentra-
tion of its emissions is less than $10^{-7}$ g/m$^3$, while the current Chinese standard is $10^{-8}$ g/m$^3$ (Zhang, 2003). Currently, this facility is fully being operated, with a daily treatment capacity of 1200 tons solid waste, while producing 18 MW of power per day. The ash from this facility is being sent to the local landfill, but the facility managers are considering making bricks with the ash. The operation of this facility has the potential to save 480,000 tons coal per year for heating, which makes a lot of sense in the Tianjin region where coal is the main energy source and the main air pollution comes from coal-burning.

The local landfill, namely, Hangu Landfill, was established in 2003 and can accept up to 700 tons of solid wastes per day. This facility locates outside Teda, but can provide services to tenants in Teda. The total area of this landfill is about 27.7 ha, and the landfill is expected to be used for 10 years. This landfill employs bioreactor landfill technology and implements many of the practices, such as leachate and gas collection. It can accelerate the biological decomposition of organic wastes by promoting conditions necessary for the microorganisms that degrade the waste (TEDA, 2004). However, the higher fee charged by the landfill managers and longer distance between TEDA and the landfill (30 km) have impeded tenant companies from sending their wastes to the landfill.

With regard to solid waste management at the individual company level, some have already established their own management systems, especially the international firms, such as Motorola, Samsung and Novozymes. Programs on managing solid waste include eco-design, ISO 14001 certification, cleaner production and waste minimization initia-
tives. For instance, the Danish pharmaceutical giant, Novozymes, has successfully refined their residue from the fermentation process into a new kind of artificial fertilizer, NovoGro. This fertilizer contains a higher content of cal-
cium and other nutrients and, therefore, can help improve the quality of the local saline soil. Currently, Novozymes provides this new product to the local farmers at no charge. This new initiative has reduced their total solid waste and improved the local ecosystem, resulting in a win–win situation for both the company and the local community. However, such practices are still few and most tenant companies have not recognized the significance of minimizing their solid wastes.

The TEDA industrial park managers also tried to reduce the total solid waste within the park. They established their environmental management system (EMS) and passed the ISO 14001 certification in 2002 (TEDA, 2003). One of their EMS objectives is to reduce solid wastes volume within their management building. Training activities on minimizing solid wastes have been conducted for all the management

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**Table 2**

<table>
<thead>
<tr>
<th>Waste types</th>
<th>Total quantity in 2003 (10$^3$ ton/year)</th>
<th>Percentage of the total wastes (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic waste</td>
<td>32.12</td>
<td>24.3</td>
</tr>
<tr>
<td>Waste wood</td>
<td>10.68</td>
<td>8.1</td>
</tr>
<tr>
<td>Sludge</td>
<td>9.60</td>
<td>7.3</td>
</tr>
<tr>
<td>Waste metal</td>
<td>6.69</td>
<td>4.6</td>
</tr>
<tr>
<td>Waste paper</td>
<td>5.77</td>
<td>4.4</td>
</tr>
<tr>
<td>Waste plastics</td>
<td>1.68</td>
<td>1.3</td>
</tr>
<tr>
<td>Leather</td>
<td>1.05</td>
<td>0.8</td>
</tr>
<tr>
<td>Textile</td>
<td>0.98</td>
<td>0.7</td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>0.80</td>
<td>0.6</td>
</tr>
<tr>
<td>Waste oil</td>
<td>22.96</td>
<td>17.4</td>
</tr>
<tr>
<td>Waste solvent</td>
<td>16.45</td>
<td>12.5</td>
</tr>
<tr>
<td>Construction waste</td>
<td>18.79</td>
<td>14.2</td>
</tr>
<tr>
<td>Others</td>
<td>5.03</td>
<td>3.8</td>
</tr>
</tbody>
</table>
staff and some tenant companies. Efforts on helping companies reduce their solid wastes have also been carried out, such as providing subsidies and technical assistance. However, those activities were mainly for those large companies and there are no efforts to promote the exchange of byproducts among different companies. Consequently, the efficiency of the solid waste management system is still very low.

Generally, the basic solid waste recycling and treatment facilities have been established and operated in TEDA. However, from a system point of view, these facilities are still fragmented as there is little to no inter-cooperation. None of these facilities are subordinate to one another, nor can any of them play a leading role on waste reduction, reuse and recycling. Challenges include how to sort out reusable/recyclable waste from material sent to the landfill, how to improve management performance for hazardous wastes, how to better superintend those scavengers and decomposers, how to improve the local peoples’ awareness and capacity on managing solid wastes, and how to promote byproduct exchanges at the inter-firm level.

3. Methodologies on integrated solid waste management planning

3.1. Objectives and goals

Integrated solid waste management is an approach that can be used to develop a sustainable solid waste management system that is environmentally effective, economically affordable and socially acceptable for a particular region and its individual circumstances (McDougall, 2001). It can be adopted by larger systems, such as industrial parks, where environmental management is needed for activities such as legislation, planning and design, and supply of services. Within an industrial park, this means that industrial park management should adopt a systematic method to assess the overall use of resources; seek waste reduction, reuse and recycling opportunities both at the individual company level and among different tenant companies; consider the full range of waste streams to be managed; and view the available waste management practices as a menu of options from which waste managers can evaluate waste management options based on site-specific environmental, economic and social considerations.

Such an approach is suitable in TEDA as TEDA is eager to apply innovation to its resource and environmental management processes. In 2000, TEDA was designated as an ISO 14001 national demonstration district by China’s State Environmental Protection Administration (SEPA) and in 2002, TEDA initiated a eco-industrial park (EIP) project in order to achieve greater efficiency through “economies of systems integration”, where partnerships between businesses meet common service, transportation, and infrastructure needs (Geng, 2005). Also, because most of TEDA’s tenants are wholly foreign owned enterprises and joint ventures, they tend to have a higher level of environmental awareness and would like to collaborate with each other in terms of resource and environmental management. Finally, given their environmental challenges, especially their increasing solid waste volume, they regard integrated solid waste management as one of the key elements of their sustainable development plan.

Under such a circumstance, the TEDA management decided to initiate integrated solid waste management planning in 2003 (TEDA, 2003). The main objective is to maximize resource efficiency and minimize the amount of waste production and disposal so that the total site can realize sustainable industrial development. Detail measures include (1) developing an integrated solid waste management system in order to serve TEDA’s long-term development strategy for becoming an international manufacturing and processing center; (2) establishing an environmental management information system in order to promote waste reduction, reuse, recycling, and exchange; (3) encouraging tenant enterprises to adopt new environmental management strategies, such as cleaner production, life cycle management that tries to reduce environmental impacts for a product through its whole life cycle, ISO14001 certification, and eco-design; (4) constructing new environmental facilities for municipal and industrial waste sorting; and (5) conducting capacity building programs to improve the local people’s environmental awareness in managing solid waste issues.

In order to reach its goals, the TEDA management set up several indicators by considering its own realities. Such indicators include the amount of solid waste production per GDP value, the amount of solid waste disposal per GDP value; the rate of solid waste reclamation, the recycling rate of waste paper and waste plastic, and the rate of safe disposal for hazardous wastes. Details are shown in Table 3.

### Table 3

<table>
<thead>
<tr>
<th>Indicators</th>
<th>2003 (Benchmarking year)</th>
<th>2008 (Short term)</th>
<th>2013 (Middle term)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of solid waste production per GDP (kg/10^4 RMB)</td>
<td>59.5</td>
<td>42.7</td>
<td>36.2</td>
</tr>
<tr>
<td>Amount of solid waste disposal per GDP (kg/10^4 RMB)</td>
<td>30.3</td>
<td>19.2</td>
<td>14.5</td>
</tr>
<tr>
<td>Rate of industrial solid waste reclamation (%)</td>
<td>60</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>Recycling rate of waste paper and waste plastic (%)</td>
<td>50</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>Rate of safe disposal for hazardous wastes (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

a RMB is China’s official currency. According to recent exchange rate, 1 US$ = 8.1 RMB.
Hierarchy” strategy, namely, reduction, reuse and recycle, incineration, and land disposal. From the perspective of planning, such an approach requires the characterization of solid waste flows at a combination of individual company, industrial park and regional scales. In each level, different planning measures should be adopted. The following sections will introduce these in detail.

At the individual company level, cleaner production has been widely promoted among the tenant companies. In 2002, China’s people’s congress passed the Cleaner Production Law. The text of this law provides language encouraging pollution prevention, recycling, treatment and disposal as a hierarchy for management. With this legal framework, TEDA management adopted new measures to promote cleaner production. Planning efforts involve issues about technical assistance, fees, incentives and training. For instance, 17 pioneering companies (including Motorola, Samsung, Coco-Cola, Novozymes, etc.) signed the “International Cleaner Production Declaration” on April 22, 2003 (Earth Day), with presentation of United Nations Environmental Programme (UNEP)’s officers (TEDA, 2004). Such an event established a solid foundation for the whole park to promote cleaner production in their tenant companies due to its demonstration effect. From the local government point of view, the TEDA management will establish a specific website for disseminating cleaner production information and providing technical help through their expert database. A special fund for cleaner production will be established by TEDA management to subsidize small and medium sized companies, as they usually lack money to carry out such an innovative activity. The source of this fund will come from the local emission charge, which was used to subsidize the traditional end-of-pipe treatment in the past (TEDA, 2004). With the leadership of TEDA management, at least 178 companies have initiated their cleaner production programs, including cleaner production audits, technical updating, and related training programs (TEDA, 2004). Other tools, such as eco-design, source sorting, life cycle assessment, and end-of-pipe treatment, are also fully combined with cleaner production in order to minimize the total volume of solid waste.

For instance, demonstration projects on source sorting will take place in the key polluting industries. The aim is to develop the local standards for source sorting, which can reflect the local situation. At the initial stage, main tasks include establishing the incentive and control mechanism and fostering markets through various propaganda and training activities. Valuable wastes, such as waste paper, wood, metal, and plastic, are asked to be collected and sold to those certified scavenger companies. Such companies are to hold special licenses and operate according to local regulations. Hazardous wastes, such as waste adhesives, flammable solvents, and toxic materials, are required to be collected and sent to the Tianjin New Hazardous Waste Treatment Center, where there are specialized transportation tools, treatment facilities and experienced staff members. Other inert wastes are asked to be sent to the local landfills.

At the industrial park level, the main planning effort is to pursue waste reduction, reuse and recycling to the maximum extent possible, primarily through system optimization, material management, byproducts exchange and economic recovery of residues. Detailed measures include the following:

- to create a cooperative industrial ecosystem by encouraging byproducts exchange among firms;
- to make feasible policies for maximizing the eco-efficiency of the whole park; and
- to provide technical assistance and training for tenant companies.

The encouragement of industrial symbiosis activities is the main focus among these measures. Just like the natural ecosystem, the industrial park firms take in energy and materials and transform them into products. Each firm has its own niche or functional role, which can be defined in a similar fashion to those found in an ecosystem, namely, producers, consumers, scavengers and decomposers (Geng and Cote, 2002). Most firms within TEDA should be defined as producers and consumers as they extract, refine or process raw materials and then process them into finished materials or products. Such a scenario creates the problem of having a linear industrial process when resources are limited and consumption levels are high; thus, the whole industrial system is not sustainable. Consequently, companies that can feed off the waste resources of other companies in the system (scavengers) and use the waste resources from both producers and consumers and then transform or recycle them back into the system (decomposers) should be encouraged in order to mimic the natural ecosystem. Therefore, the planning efforts focus on creating byproducts exchange network among tenant companies and recruiting new scavengers and decomposers.

Scavengers are typically companies that collect the waste materials either on-site or at several points along the disposal route. These companies then sell the wastes to secondary companies referred to as decomposers who in turn transform or recycle the wastes into useful products to be sold as resources.

In order to promote byproducts exchange, an Internet-based information sharing website will be established by the TEDA management. This platform will allow tenant companies to upload their waste information (both quantity and quality) to the public database. Every company has access to such information, but without detailed information on the waste providers. The TEDA management will be responsible for facilitating waste transactions, with a reasonable agent fee being added to help recover costs of running the website. A special feature of the operation is that all the transactions will be done confidentially. This is very important as some waste producers do not like to release such information. Adopting this approach can facil-
itate the creation of industrial symbiosis clusters. For instance, by employing the system analysis method and the current wastewater data, an information system can help identify the potential wastewater reuse opportunity among large water users at TEDA, which could reduce the total freshwater amount by 16.9% and total wastewater emission by 45.58% (Geng, 2005). Another example is that an industrial symbiosis cluster will be developed at TEDA, based upon the existing sludge reuse of the Danish pharmaceutical company Novozymes. The core company of this cluster is the local landscaping company (LC), providing landscape service to the park, such as greening the land and watering the local gardens. Fig. 4 shows the details of this cluster. This company will blend industrial wastes such as alkali slag from a local alkali company, bottom ash from power plants to produce a “new” landscaping soil. The landscaping company will utilize biological sludge from the Novozymes, organic wastes from local food producers and local communities to produce organic fertilizer for landscaping purpose. A 5-year agreement will be signed between Novozymes and the landscape company, indicating that 80% of the biological sludge from Novozymes will be blended with other organic fertilizer for local soil quality improvement. The other 20% sludge will still be provided to the local farmer free of charge.

In terms of managing municipal wastes, the source sorting approach has been selected as it can bring both environmental and economic benefits. Since TEDA will be further developed, it is predicted that the population in TEDA will reach 300,000 by 2020. This means that the municipal waste will be increased by 15% each year (Zhu and Zhao, 2004). Therefore, to reduce the total amount of municipal wastes by source sorting is very crucial to TEDA. Source sorting focuses on two types of municipal wastes. The first type includes those organic wastes such as food residues and landscape wastes. Such wastes are required to be composted. The second type is hazardous wastes such as used paints, used batteries, which should be collected and treated by specialized companies. The rest of the municipal wastes is to be sent to the local landfills.

With regard to recruiting scavengers and decomposers, in order to attract them, the TEDA management set up preferable policies, such as providing waste-related information, reducing their tax and subsidizing their operation. The TEDA Administrative Committee will also invest to build a new resource recycling company (RRC) at TEDA. The purpose is to maximize the eco-efficiency of the whole area. This new company will implement the central sorting and recycling for both non-hazardous industrial and municipal solid waste. Main functions include:

- Operating as a transfer station. The transfer station sorts and recycles industrial and municipal waste such as waste glass, waste plastic and waste paper. The transfer station can get not only economic benefit from resource recovery and decrease the amount of waste for transportation, but also can gain environmental benefit by reducing the amount of solid waste sent to the landfill. However, if not managed well, this station may be a potential source of pollution to the local surrounding, such as dust. Consequently, the transfer station will be designed as a closed facility.
- Treating wastes and turning them into new resources.
- Selling new products reclaimed from wastes.
- Providing storage facilities for those wastes with large amounts and potential value but unreclaimable currently, such as waste batteries.

All of the staff members of this facility will be strictly trained and have the capacity to ensure safe operation. In addition, due to its environmental sensitivity, the local environmental protection bureau will set up a very strict monitoring program on its operation.

With regard to the policies, new regulations are being made by the TEDA management in order to facilitate waste reduction, reuse and recycling. There is little eco-
economic incentive to reduce, reuse or recycle or find alternative uses when the disposal cost is too cheap. Consequently, applying the concept of the polluter pays principle is essential. This concept provides a legal basis for attributing the financial responsibility for pollution. It offers an incentive for manufacturers to reduce the environmental impacts of their products and promotes the application of eco-design. TEDA management will enact a new solid waste management regulation, in order to better superintend solid waste treatment, encourage research and development ventures related to solid waste management. It also provides economic and tax incentives, and creates a demand to utilize reclaimed products (TEDA, 2004). For instance, the new regulation stipulates that the landfill fee will be gradually increased in order to encourage tenant companies to reduce the total amount to the landfill. With regard to possible hazardous wastes and the corresponding precautions, the new regulations are stipulated by the TEDA management, requiring all tenant companies to fully inform the TEDA management about the potential hazard or risks. These new regulations also include site contingency plans, designed to cope with emergencies and accidents. In addition, in order to further improve the overall eco-efficiency of the area, the TEDA management will implement green purchasing as a demonstration of the practice to others. The essence of the green purchasing policy is to purchase those products or services that have a reduced or lesser effect on human health and the environment, even in some cases paying a premium; thus, saving money, cutting waste, and boosting recycling effort.

Capacity building is always important for developing countries, such as China, as they lack technology and environmental awareness. In particular, human resources development in solid waste management is a critical need in China. Environmental management programs and facilities at academic institutions are limited. Most government officials lack an understanding of environmental principles. Enterprise managers, schooled in production/output activities, lack an appreciation of the benefits of introducing an effective solid waste management system and collaborating with others (Li, 2002). Under such a circumstance, the TEDA management has set capacity building as one of the main targets when planning the solid waste management system. Proposed activities include the design and delivery of training modules, with a particular emphasis on solid waste management policies and programs, for those involved in industrial park management, as well as industrial training and certification programs to assist industry managers in implementing effective integrated solid waste management at the firm level. According to the plan, training for industrial park management and industrial managers will occur at two levels. Senior park managers and enterprise managers (CEOs) will be sensitized to general concepts and the social, environmental and economic benefits of integrated solid waste management while junior park managers and industry middle managers will receive more.
in-depth training on tools and techniques of integrated solid waste management. Another important measure is that the TEDA management plans to develop a waste minimization club for their tenant companies. The main purpose of this club is to create a platform for their tenant companies to share their solid waste management experiences, identify potential opportunities for byproduct exchanges and strengthen the solid waste management capacity of individual enterprises. The key benefit of the proposed capacity building programs will be enhanced networking/partnership among tenant companies, industrial park management and academic institutions by establishing linkages among these institutions in the delivery of programs and activities.

The regional scale may be important because the major waste treatment facilities are found outside the boundary of TEDA. Due to many limits (such as land and functions), the participating entities of industrial symbiosis do not need to locate within the same industrial park boundary. Therefore, it is necessary to create a virtual eco-industrial network at TEDA. Such a network is composed of related regional companies that are not physically located in the same park. Companies in such a virtual network can create economies of scale for cooperative solid waste management or sharing employees’ services. Firms participating in waste exchanges may pay lower prices for secondary raw materials and may realize savings in hazardous waste disposal charges. Networked businesses can also enjoy reduced transportation costs, whether the firms are industrial, commercial or retail establishments. Consequently, TEDA is planning to develop a regional network for solid waste management, based upon their current linkages with local treatment facilities. Fig. 5 shows the potential industrial solid waste management network between TEDA and the local communities. Fig. 6 shows the potential municipal solid waste management network between TEDA and the local communities. Such a regional approach can enhance regional progress towards sustainability while identifying and targeting opportunities for socio-economic benefits.

Generally speaking, given its size, innovation, data availability, and the solid waste problem, the TEDA case study provided an opportunity to test the availability of integrated solid waste management at the industrial park level. The planning efforts demonstrate a feasible solution for both the park managers and the tenant companies.

4. Potential benefits and challenges

4.1. Benefits

The above introduction and discussions indicate that the application of an integrated solid waste management framework within an industrial park, such as the case of TEDA, would bring added values to both the industrial communities and to the industrial park managers. This new approach could provide comprehensive economic, environmental, and societal benefits. The following sections detail some of these benefits.

Since this framework encourages waste reduction, reuse and recycle both at the individual and the inter-firm levels, conservation of financial resources relative to solid waste management can be realized. For instance, resource costs, solid waste treatment costs, and environmental liability and insurance costs relative to solid waste issues could be reduced through more efficient materials use, potentially lower insurance costs, and lower waste treatment requirements. Also, additional financial benefits of developing such an integrated system include increased revenues from the sale of wastes; increased sales due to ‘green’ and niche marketing and more competitive production methods; and the avoidance of regulatory penalties that were paid due to waste discharges in the past.

Second, integrated solid waste management systemically considers the various types of solid waste, including industrial and municipal waste, as well as all stakeholders’ concerns; therefore, this approach could gain various environmental benefits, such as conserving natural resources, reducing solid waste volume, and reducing the burden of the local landfills. Moreover, byproduct exchanges based on sorting and treatment together with composting can further reduce the amount of waste sent to the landfill or the incinerator.

Finally, the case of TEDA indicates that some societal benefits of applying this system could be achieved, such as improved public awareness by carrying out capacity building programs and improved public health by reducing solid and hazardous wastes. By restructuring the management of solid waste, this system can encourage more collaboration among tenant companies and between tenants and industrial park management, as well as between industrial park and local communities, therefore, strengthening friendship and coordinating community relations. In addition, the recruitment of scavengers and decomposers can create job opportunities for the local residents.

4.2. Challenges

The integrated solid waste management in TEDA can help improve the environmental image while gaining economic and social benefits at the same time. However, TEDA is meeting challenges during the implementation and development of such an integrated solid waste management approach.

It would be ideal for the generators of industrial wastes to manage their wastes themselves or contract qualified industrial treatment companies to dispose of their wastes. However, over 90% of the companies in TEDA are small or medium-sized enterprises (SMEs). Many of them lack skills, manpower, economic ability, technology and equipment, and pioneering vision for solid waste management. Consequently, how to facilitate them to adopt such an
integrated approach has been a big challenge although some subsides will be provided by the TEDA management.

The second challenge is the increasing solid waste volume due to the rapid increase of the industrial economy and population. Even by promoting eco-management practices in enterprises, the amount of industrial waste generated by TEDA is estimated to increase by 10% per year until 2010 (Zhu and Zhao, 2004). At the same time, the population has also increased rapidly since more companies are recruited. Therefore, even with measures such as sorting and reclamation, TEDA will still have to meet the challenge of an increasing amount of solid waste.

To attract more investment, industrial zones in China, including TEDA, provide subsidies for enterprises to cover solid waste disposal costs (Zhu and Sarkis, 2004), which means that an industrial zone levies less money from enterprises than the cost for the solid waste disposal while the zone uses its financial resources as a subsidy to cover the gap. However, with the increasing quantity of waste sent to landfills and increasing environmental awareness of the public, solid waste disposal will have increased demands. In addition, the landfill cost will be highly increased as the result of more strict environmental standards and the increasing price of land.

The last, but not the least important, challenge is the harmony with local facilities such as the Hangu landfill, the Tianjin New Hazardous Waste Center and the Shuanggang waste recovery incinerator. All of these facilities want to have more business, charge more and compete with each other. To coordinate the relations among them will be a tough mission for the TEDA management.

5. Conclusions

With the rapid development of industrial parks, the effective and efficient management of solid waste generated from these complexes has become an increasing environmental concern. Integrated solid waste management is one of the holistic approaches to environmental and resource management, which are emerging from applying the concept of sustainable development (Wei and Huang, 2002). It takes an overall approach to solid waste management, and combines a range of collection and treatment methods to handle all materials in the waste stream in an environmentally effective, economically affordable and socially acceptable way; therefore, it should be advocated by the industrial park management facing increasingly severe solid waste challenges.

In this context, the case study performed in the Tianjin Economic Development Area demonstrated that integrated solid waste management system is a useful tool for the strategic planning of different wastes at the industrial park level. Just as in natural ecosystems, interconnected entities form symbiotic relationships to assure survival and resource efficiency within an industrial park when implementing such an approach (Zhu and Geng, 2003). For business, value is added as its waste byproducts are cycled back into the overall production stream of an industrial park or region. This closing of the loop results in the conservation of natural resources and lower disposal and production costs. In addition, potential income through sale of reclaimed solid waste could be gained. It can also be a powerful economic tool to attract foreign investment, which is a cornerstone to Chinese industrial parks relying on foreign capital for growth. Consequently, such an approach should be adopted by more Chinese industrial parks.

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