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Worldwide solid waste recycling strategies: A review

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Abstract

This study seeks to compile data on the worldwide established technologies and systems for waste recycling. Waste recycling is currently seriously considered as an integral part of solid waste management in many parts of the world. A vast number of options ranging from small scale decentralized to larger scale centralized plants may be adopted. The identifiable waste reuse schemes worldwide have been critically analyzed in this paper. Peer-reviewed journal papers, conference papers and information gathered from the internet formed the basis of this review paper. The available cost data were also furnished. This paper, therefore, as a whole adds to both technological and economical aspects of the knowledge-base of waste recycling schemes. Besides the technical aspect, issues like public acceptance, economic and hygienic risks etc. should be taken into account to counter the obstacles facing implementation of waste recycling.

Keywords: Review; reuse; recycling; solid waste; technology

Introduction

The management of solid waste represents a major economic and environmental issue throughout the world (Demirbas, 2010). Recycling involves the reprocessing of materials into new products. It prevents useful material resources being wasted, reduces the consumption of raw materials and energy usage, and hence greenhouse gas emissions, compared to virgin production. Recycling is a key concept of modern waste management and is the third component of the waste hierarchy. The purpose of recycling is to take waste products that would be landfilled, or otherwise disposed, out of the waste stream and place them back into use as feedstocks or raw materials for new or useful products (Dyson & Chang, 2005).

The rising costs of waste disposal are creating cost competitive opportunities for recycling. Recycling, therefore, may cost less than disposal. In cases where there is strong public support for recycling, citizens are paying for recycling services as a normal part of their solid waste collection and disposal fees (Fu *et al*., 2010).

There are a variety of options for developing a recycling system which best meet the needs of a community. While several developed countries have efficiently adopted waste recycling strategies, many of the developing countries are yet to adopt a sustainable waste management strategy. The goals for a recycling program must be carefully matched to capital and operating costs to ensure that the program is successful and sustainable. Complete business planning analysis helps to create a sustainable program. Community leaders and citizens need to work together to develop a recycling system that best suits their needs and attitudes (Jørgensen & Madsen, 2000).

The aim of this article is to provide a comprehensive review of the solid waste recycling options established in the leading countries which have successfully implemented waste recycling as an integral part of the solid waste management system. While separate studies highlighting the waste management strategies at particular locations are available in the literature, such comprehensive compilation and critical assessment is not available. Therefore this article addresses an important knowledge gap in the literature.

Types of recycling

There are two kinds of solid waste recycling (Jørgensen & Madsen, 2000):

Product recycling: considered a necessary solution and an alternative for new production and could be a played to the complete production or to the component as following:

- Product recycling maintaining its shape, texture and its high value after maintains or development and reuse for the same purposes or otherwise.
- Product recycling after disassembly and assigning its components and parts for the production and collection process and this kind is considered less valuable than pervious one.

Material recycling

Recyclable materials, also called "recyclables" may originate from a wide range of sources including the home and industry. They include glass, paper, aluminum, asphalt, iron, textiles and plastics. Biodegradable waste, such as food waste or garden waste, is also recyclable with the assistance of microorganisms through composting or anaerobic digestion (Khoo, 2009).

Benefiting from materials that are involved in manufacturing any product in a different or similar industries after sorting out the materials that are involved in its manufacturing in a cordons with environmental conditions as following;

- Recycling materials by remanufacturing and its use as operating materials.
- Recycling materials by chemical or thermal treatment to manufacture new row materials.

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A very relevant concept is waste reduction. What's intended here is reduction in the use of raw materials , thereby reduction in the waste through (Kollikkathara *et al*., 2010): either by less use of raw materials; by using row materials that produces less waste; or by limiting the usage of materials involved in the packaging and process, i.e. plastic, paper and metals; and that require environmental consciousness from the pare of the investor and the producer; for example in the united state of America many liquid sop producers adhered to concentrating it, so it could be packed in smaller packages, or producing toothpaste without its the usual cardboard packaging, and that what is called waste minimization.

Reuse is collecting waste such as food and drink containers to be cleaned, refilled and resold. That means -for example- reusing the plastic bottles of mineral water after sterilization, and refilling bottles and jars after usage, this method minimize the amount of waste, but it requires environmental consciousness on the part of the general public in the method of waste disposal, and the process of the simple sorting to all plastic, paper, glass and metallic waste before discarding it (Louis & Shih, 2007).

Environmental benefits of recycling

Recycling basic materials in order to make new products has several environmental benefits (Matsuto & Ham, 1990): It reduces the demand for raw materials by extending their life and maximizing the value extracted from them; It reduces the habitat damage, pollution and waste associated with the extraction of raw materials. For example each tonne of glass recycled saves about 315 kg of carbon dioxide from entering the atmosphere from refining operations; It reduces transport costs and pollution from transporting raw materials and manufacturing new products; It reduces emissions to air and water in the production process; It reduces disposal impact (if more waste is recycled, less waste goes to landfill or incinerators); It promotes personal responsibility for the waste we create.

Economical benefits of recycling

Recycling basic materials in order to make new products has several economical benefits (McCarty & Shrum, 1994): Reduce the cost of waste disposal; It saves energy in the production process when compared with the energy consumed in using raw materials. For example recycled paper takes between 28-70% less energy than making new paper; It offers enormous potential for job creation. A recent study suggested that up to 45,000 jobs could be created in recycling and composting in UK if the Government were just to meet its recycling target of 30% by 2010; Long lifespan of landfill; Reduce importation of raw material.

Worldwide recycling case studies

Although there are many areas around the world where recycling has not yet materialized, there are many other countries that are just as active recyclers as the United States and a few, like Germany, The Netherlands, and Japan, that are more aggressive.

Presently, Europe Union (EU) produces approximately 306 million tons of solid waste annually (2.5 pounds per person), 57% of which is land filled. The European Union (EU) has spearheaded efforts across Europe to improve waste minimization through issuing a number of waste specific directives and suggesting a hierarchy for waste management: prevent, reuse, recycle, recover as energy, and landfill. Some positive gains have been observed (Slater & Frederickson, 2001) such as: Recycling has risen in the EU from 11% between 1985 - 1990 to 29% in 2000; The percent landfilled decreased from 67% in 1995 to 57% in 1999.

United States

The total resident population in united states in 1980 was 226,545,805 capital, and they arising in 2003 to 290,342,554 capita (Chang & Davila, 2008). The total annual MSW generation in the U.S. has increased more than 50% since 1980 to the current level 236.2 millions tons per year 2003. Fig.1 show the composition of this wastes. Between 1960 and 1990 per capita MSW generation in the U.S. increased 67% including an increase of more than 20% in the 1980's, but per capita generation has been relatively constant for the past decade. The current per capita rate is 2.02 Kg/captia/day (Clarke *et al*., 1999).

In 2002, 55.9% of MSW generated in the U.S. was disposed of in 1,767 landfills. While the total number of landfills in the U.S. has been declining steadily, total capacity has remained relatively constant. Current available U.S. landfill capacity is 3,600 million tons; at the current rate this would provide 28 years of disposal. Disposal fees for landfills in the U.S currently average $25 per ton with a high of more than $72 per ton in Massachusetts. Currently, 14% of MSW generated in the U.S. is disposed of through waste incineration. Combustion reduces waste to ash (a 75% reduction in weight) for disposal in a landfill (Hristovski *et al*., 2007).

Waste-to-energy programs that convert MSW into useable energy generated 289 trillion BTU of energy in 2001 (approximately 0.3% of total U.S. demand). In 2003, 107 waste-to-energy facilities were in operation in the U.S with average disposal fees of $52 per ton (Reddy *et al*., 2009).

Currently, 31% of MSW generated in the U.S. is recovered for recycling or compost diverting more than 72 million tons of material from landfills and incinerators (Fig.2). This is more than double the value from only a decade earlier. Recovery of material for composting represents 23% of all material recovery. Currently 8,875 curbside recycling programs serve 139 million people in the U.S. The number of curbside programs in the U.S. has increased threefold since 1990. Over 71% of corrugated boxes are recovered for recycling; other commonly recycled products include newspapers (82%), office papers (56%), and aluminum beverage cans (44%) (Hristovski *et al*., 2007).

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Fig.1 .US municipal solid waste composition, 2001

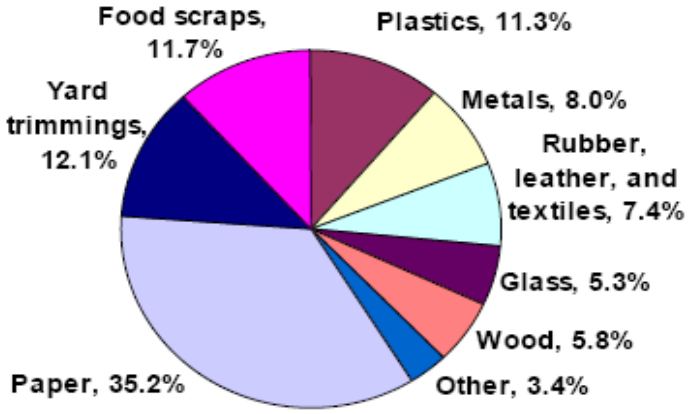


Fig. 2. US ways of solid waste disposal, 2003

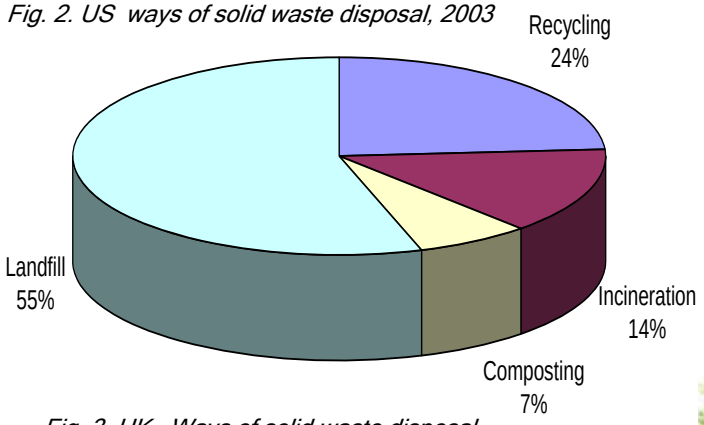


Fig. 3. UK , Ways of solid waste disposal, 2003

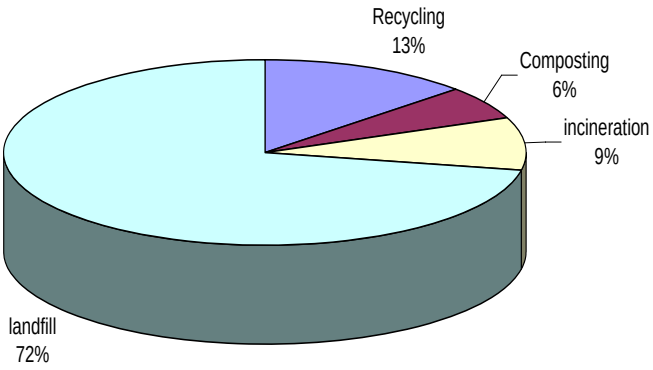


Fig. 4. Recycle bins in UK

Fig. 5. Korea, ways of solid waste disposal, 2003

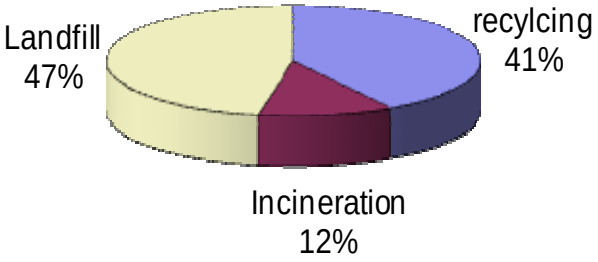


Fig. 6. Denmark, ways of solid waste disposal, 2003

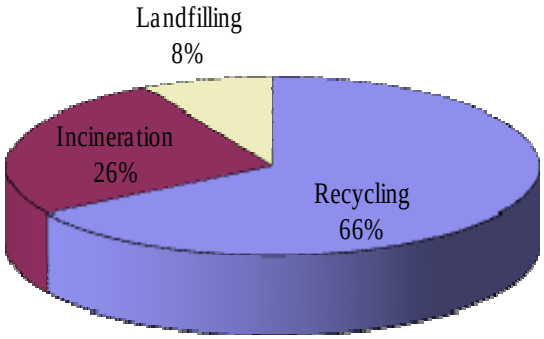
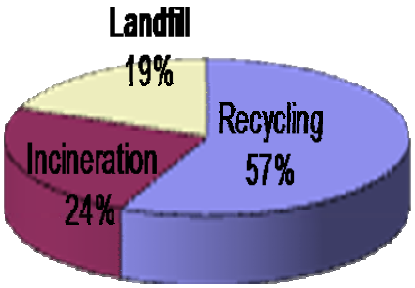


Fig.7. Recycling bins in Germany

Fig. 8. Germany, ways of solid



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The Resource Conservation & Recovery Act (RCRA) assigns primary responsibility for recycling and all non-hazardous waste policy decisions to state governments. Consequently, recycling initiatives and recycling programs in the US are not uniform, since they are designed and implemented at the state and local levels. This in turn means that any economic analysis of recycling must rely on local observations and, to assure that the results can be generalized, must control for community and region-specific influences and factors (Reddy *et al*., 2009).

United Kingdom

Total municipal waste raisings in England in 2003/04 were 29.1 million ton, down from 29.4 million ton in 2002/03, a 1% reduction. This was the first time, in recent years, to show any reduction in municipal waste raisings (Garg *et al*., 2009). The total waste generated daily by capita was 1.33 Kg/capita/day with total populations of 60,094,648 capita.

The proportion of municipal waste being disposed of at landfill fell from 75% in 2002/03 to 72% in 2003/04. For the second year in a row the actual tonnage of waste being disposed of in this way has also decreased from 22.1 million ton to 20.9 million tones (Karousakis & Birol, 2008).

About 8.1 million ton 28.0% of municipal waste had some sort of value (recycling, composting, energy recovery, RDF manufacture) recovered from it in 2003/04 up from 7.3 million ton 24.7% in 2002/03. The proportion of municipal waste being recycled or composted has increased from 15.6% in 2002/03 to 19.0% in 2003/04. The proportion of waste incinerated with energy recovery has remained roughly constant at 9% while there has been a steady decrease in both incinerated waste without energy recovery and the manufacture of refuse derived fuels. Waste for composting remained the most commonly collected material for recycling with 1.4 million ton collected (30% of the total recycling) in 2003/04 (Fig.3). Paper and cardboard was the next most commonly collected (28%, 1.3 million ton) followed by glass (0.6 million ton, 13%).

In the UK, the household and commercial sectors have relatively low recycling rates. This is in comparison to some other wastes, such as construction and demolition waste and sewage sludge. The Government is hoping to increase the amount of household waste that we recycle to 33% by 2015. Some of the materials that they can recycle include paper, plastics, metals (such as aluminium cans) and tyres (Sarkar *et al*., 2003).

A large majority, some 85%, of residents in Allerdale now have a recycling service from their door for paper/card and garden waste. These properties are provided with a small green bin for paper/card and a larger green bin for garden waste. These bins are collected on alternate weeks. These properties are also provided with a small black bin for their residual waste (waste disposed of at landfill). This service will become the standard method of collection within the borough as shown in Fig. 4 (Karousakis & Birol, 2008).

There is a large network of recycling banks in supermarket car parks and other convenient locations within the Borough where residents can take items for recycling. The larger recycling sites have a wide range of facilities, such as paper and cardboard, glass, textiles, cans and plastic bottles. Smaller sites such as those in rural villages have facilities for glass and cans. There are currently in excess of 160 community recycling sites open to the public (Garg *et al*., 2009).

South Korea

With high population density which raise to 490% per km^2 with total population of 47,925,000 capita in 2003 with Annual population growth rate 0.57%, the Korean government has difficulty in finding suitable sites for waste disposal (Lee & Paik, 2011). Hence, the government has tried to strengthen its effort to reduce waste generation as well as increase recycling. In the past, the amount of waste treatment cost levied on each household was proportional to the residence size and the amount of property tax. The current Volume-based Waste Fee System imposes a differentiated treatment cost as determined by the amount of waste generated by each resident. The System is significant in that it provides for an economic incentive that actualized the Polluter Pays Principle, the User Pays Principle and the principle of prevention in the field of waste.

Under the Volume-based Waste Fee System, enforced nationwide in January 1995, wastes are collected in synthetic resin volume-based waste bags that are purchased at the price of waste treatment cost. Recyclable wastes are sorted and put out in separate bins without paying any charge. The System played a significant role in reducing the amount of waste generated and fostering recycling. It also helps cut down on the waste processing cost and institute an environment-friendly processing method, paving the way for a society with minimal waste generation (Kim *et al*., 2001).

As a result of the Volume-based Waste Fee System, per capita waste amount fell from 1.33kg in 1994 to 1.04 Kg (the volume observed in advanced nations in 2003), with total waste generation of 98,385,020 ton (Shim *et al*., 2005).

The amount of waste being landfilled or incinerated also fell by 45% of the previous figure while the collection of recyclable goods rose by staggering 115%. The recycling rate also jumped from 15.4% to 41.3%, while the landfill rate dropped from 81.1% to 47% (Fig.5). During the 6-year period from 1995 to 2000, Koreans generated a total of 37.72 million tons (6.29 million tons per year) less than before and separated 13.46 million more tons of recyclable goods. This figure is equivalent to a total of 5.2 trillion won in social and economic savings (3.45 trillion won from waste reduction and 1.75 trillion

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won from increased recycled goods), or 866.6 billion won per year (Jang *et al*., 2006).

With an expedited supply of recyclable goods, such as paper, cans and plastics, recycling-related industrial sector saw a rise in the number of recycling businesses and a sharpened competitiveness of re-producing companies in the market.

Manufacturing and distribution industries also converted their production and sales procedures to curb excessive packaging and waste generation. Furthermore, notable changes have been witnessed in people's lifestyle as well. It is now common to see people swapping or purchasing second-hand goods, buying refillable goods that tend to produce less waste, and carrying reusable shopping bags, all of which demonstrate an elevated commitment of environmental preservation (Kwak *et al*., 2006).

Denmark

Danish waste policy comprises both prevention and handling of waste. Supreme authority in waste matters is the Danish EPA. Municipal and regional councils are in charge of the practical administration of waste management. All municipal councils survey waste amounts and draw up waste management plans. Also, it is the responsibility of municipal and regional councils that sufficient incineration and landfill capacity is available (Manscher *et al*., 1990; Jensen *et al*., 2010).

The most important objective of Danish waste management policy is to reduce waste amounts. Prevention has top priority. By environmental management and cleaner technology it is possible to reduce the generation of waste, for example by taking waste treatment into consideration already at the design of products and by using less environmentally harmful products. In 2003, total reported waste generated amounted to 12,835,000 ton, which is 270,000 ton, or 2% less than in 2002. In Denmark, the total population in 2003 was 5,384,384 capita, and every one of them generate around 2.4 kg of waste per capita every day of the year. The task of ensuring collection, correct treatment and largest possible rate of recycling of this waste is heavy, but not impossible (Birgisdóttir *et al*., 2007).

Another aim is to recycle as much waste as possible. Some 66% of the total amount of waste is recycled in 2003. The Danish waste hierarchy is the basis for our prioritization of waste management options: recycling ranks higher than incineration with energy recovery, and land filling ranks lowest. Recycling is the highest ranking waste treatment form - it ensures better exploitation of resources in waste (Eriksson *et al*., 2008).

In Denmark incineration does not count as recycling. Waste is incinerated when it cannot be recycled, and when residues from incineration do not cause environmental problems. Energy is recovered for generation of power and heating. The total waste led to incineration in 2003 amounted to 3,287,000 ton. This is actually a 57,000-tonne drop in waste amounts compared to the previous year, and it corresponds to 25% of total waste generated, plus an additional 1% left in temporary storage to be incinerated at a later time.

Land filling is the lowest ranking treatment form - it does not exploit resources in waste. Also, landfilling may lead to soil and groundwater pollution. Waste led to landfill in 2003 amounted to 981,000 ton, which is a decrease of 213,000 ton from 2002. The rate of waste land filled amounts to 8% of total waste generated (Fig.6). In Denmark, landfilling of waste suitable for incineration is banned (Jensen *et al*., 2010).

Germany

Waste management is an important economic factor in Germany with more than 200.000 employees and a turnover of about 50 Billion Euro. The total volume of waste in Germany amounts to about 366 million ton in 2003. About 58 % of the municipal and 42 % of the industrial waste is recycled in 2003 (Zhang *et al*., 2010).

Until the 1970's the only kind of eliminating waste was the dispose. All sorts of waste were simply disposed. This type of waste elimination occurred to grave contaminations of the soil and water resources, to ecological- and human-toxicological damages and to a big damage to the national economy as well. At this time people were afraid to be choked by the surmounting waste, because of capacity shortfalls in disposal and the scale of ecological damages became alarming (Johnke, 1992; Tritt & Schuchardt, 1992).

At the beginning, there was the idea to improve the security of landfills and to make the combustion cleaner. But nevertheless, people began to realize that landfills not guaranteeing a long-term environmental security and therefore developed the demand for a sustainable waste management. This meant to integrate the "waste" economy in a sustainable way of production and consumption (introducing producer responsibility and the emergence of a health and environment orientated consumer), and the creation of a material-circulation-paradigm of the waste management industry (Vehlow, 1996).

The objectives were the following: firstly, preventing the generation of waste. Only if this is impossible one had to recycle the waste. And given the case that even recycling is not feasible, it became mandatory to dispose the waste in an adequate way.

In 1986 the German parliament passed the law of Avoidance and Elimination of Waste with the goal to minimize the waste production and to recycle waste. The law concerns about the legislative authority which means that the government has the right to pass detailed instructions, orders or directives for waste management and handling. Consequently, the legislative authority was enlarged to lawful stipulations regarding packing, the treatment of used oil and cars, etc.

In 1996 the second stage was initiated with the introduction of the law of Economy of Cycle. This law

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defined producer responsibility. The objective is firstly to reprocess complementary resources of production into an inner production cycle or into a co-operation between different companies (clean production). Secondly, it was demanded to design products in a kind that toxicological threats to the environment and people are not occurring and in a way which makes the reuse the materials of disposed products possible. As a result, the separation of production and waste elimination was solved. Now producers have the ultimate responsibility of an adequate waste elimination. They are left to choose between avoidance, minimization and recycling or the costly deposition in landfills. Regarding recycling, it is important to choose a high reutilization quality and to avoid down cycling. The success of this law is demonstrated by the stable number of landfills and the growth in consumption at the same time (Wittmaier *et al*., 2009).

The development of the German waste industry into an integrated economy of cycle has created the effects (Zhang *et al*., 2010): A web of laws and orders; A web of control and authorizing administrative bodies; Self commitments by producers (product responsibility); Environmentally sensitive citizens (waste separation and partly avoiding); Economization of waste treatment (at least cost equalization); Considerable saving of natural resources; A radical minimization of health and environmental dangers; Creation of qualified jobs; Creation of waste management sectors in logistics, controlling and monitoring, R&D, etc.

The total level of municipal solid waste (MSW) generated in Germany has changed little since 1990. Of the total waste arising, about 340 million t/a, generated of municipal solid wastes made up approximately 45.5 million t, of which about 43 million t were domestic wastes (including commercial wastes similar to domestic waste). MSW recovery and recycling have increased significantly, however, especially as regards separately collected domestic waste fractions (Vehlow, 1996).

According to data from the Federal Environment Agency, the proportion of recoverable MSW, which was less than 15% in 1990, had risen to more than 50% by 2001. In 2004, MWS recovery rates rose still further, to approximately 57%. Particularly high recovery rates, ranging from 60 to over 90%, were achieved through the separate collection of glass, paper, cardboard, organic wastes and lightweight packaging (Winkler & Bilitewski, 2007).

In 2004 the total quantity of waste was 48,433,000 ton, and it is composed largely of the following waste types: domestic waste, domestic-type industrial waste, bulky waste, market waste, garden and park waste, road sweepings, and separately collected reusable/recyclable waste such as organic waste, paper, board, glass, plastics etc. The total generated waste per capita was 1.61 kg/capita/day with total population of 82,424,609 capita (Eriksson et al., 2008).

Recycling was the dominant waste disposal method in Germany in 2004 with total quantity of 27,710,000 ton making up 57% of the total quantity of waste. Recycling is considered very important in Germany. Besides paper, glass, cans, and plastic, each homeowner also recycles batteries, milk and juice containers, and garden compost. Recycling is picked up from the front of each home for a fee. In addition, there are recycling bins virtually everywhere. Certain containers have a special green circle indicating they need to go in the 'yellow sack' as shown in Fig. 7 (Wittmaier *et al.,* 2009).

About 11,521,000 ton of waste which represents 24% of the total quantity of waste had incinerated to produce energy. The rest of waste goes to landfill with total quantity of 9,203,000 ton which represent 19% of the total quantity of waste (Fig.8).

1 June 2005 saw the end of the landfilling of untreated biodegradable wastes, ushering in a new era of MSW management in Germany. That date, however, while a turning point, did not mark the end of all development in waste management. The sector is far from exhausting its potential for change. In particular there is scope for further developing such potential at the interfaces with other areas such as product and production policy, chemicals policy, and resource and climate protection policy (Zhang *et al*., 2010).

Netherlands

The Netherlands is a densely populated country with 15,981,472 capita in 2001 with an average density of about 450 capita/km^2, with a strong international orientation and an open economy. Economic growth and a growing population keep the country in a permanent state of reconstruction and alteration (Dornburg & Faaij, 2006).

Waste management in Netherlands at the end of the 1980s was not what it should have been. Many activities in the field of waste management were still characterized by smallness of scale and inadequate environmental protection. For example, nearly all landfill sites in use lacked soil protection facilities, while flue gas scrubbing in waste incineration plants was inadequate. Waste incinerators were even permanently shut down for this reason. And despite the fact that the reuse and recycling of waste was increasing, too much waste was still being incinerated and landfilled. The planning and construction of processing plants was carried out at regional or provincial level (provincial waste plans), but coordination and harmonization between the authorities was lacking (Born *et al*., 1994; Scholtens, 2001).

In political and social terms, there was considerable resistance to the construction of new landfill sites and incineration plants, which led to a shortage of such capacity. As a result of this shortage and the steadily growing supply of waste, waste even had to be stored temporarily in inland barges in 1991.

In the late eighties, early nineties, this situation provided a major incentive for the formulation of

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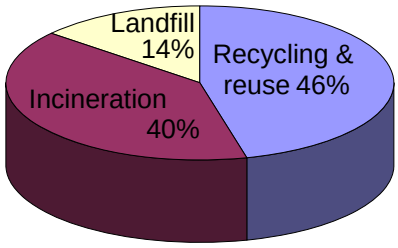
ambitious programs and activities. These were geared to limiting the supply of waste via waste prevention, promoting the reuse and recycling of waste, reducing the unwanted environmental impact of waste management, developing planning at national level and promoting cooperation between the authorities. These programs and initiatives have been quite fruitful (Dornburg & Faaij, 2006).

Fig. 9. Netherlands, ways of solid waste disposal, 2001



The annual quantity of waste produced in the Netherlands rose between 1985 and 2000 from over 46,000,000 ton to over 57,000,000 ton, an increase of around 24%,and the total municipal solid waste generated in 2001 was 8,675,000 ton and . In same period, waste reuse and recycling increased from around 50% to upwards of 77%, and the total municipal solid waste recycled and reused in 2001 was 46% with total quantity of 3,975,000 ton. The land filling of waste fell from 35% to around 8%, and the total municipal solid waste landfilling in 2001 was 14% with total quantity of 1,230,000 ton (Fig.9). The municipal solid waste incinerated reach to 40% in 2001 with total quantity of 3,470,000 ton of the total municipal solid waste supply

Fig. 10. Recycling bins in Netherlands

(Fu *et al*., 2010).

Household waste accounts for about 10% OF all waste generated in the Netherlands. Local authorities are responsible for the collection of this type of waste, and must collect compostable kitchen and garden waste glass, paper/cardboard, textiles and small scale chemical waste separately. Approximately 43% of household waste was collected separately for recycling. The remaining waste that is the waste which remains after household have kept specific streams separate and offered them separately to the collector. Provincial environmental ordinances require local authorities to arrange for the collection of glass, paper/cardboard, textiles and small scale chemical waste separated at source as shown in Fig.10 (Dornburg & Faaij, 2006). At present plastics are not separated from household waste at source. Two incinerators do however separate out plastic waste from the waste before incineration. Plastic is used as a fuel.

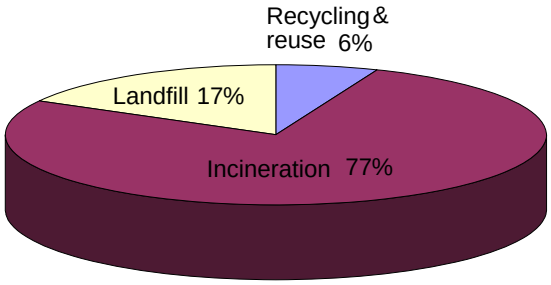
Japan

In June 2000, the Government of Japan began implementing "*The Basic Plan for Establishing a Recycling-Based Society*", providing a 10-year program to promote comprehensive and systematic policies aimed at changing unsustainable patterns of production and consumption: "to reduce the amount of resources that are removed from nature as much as possible, and to reduce the amount of things that are finally discarded in nature as much as possible by inputting things once used in society as recycled resources (Kleiss & Imura, 2006).

Wastes are classified into two categories in Japan: municipal and industrial waste. The disposal of municipal wastes is the responsibility of the municipalities. The disposal of industrial wastes is the responsibility of the entities that generate the wastes. Waste treatment in Japan is performed based on the "Waste Disposal and Public Cleansing Law." The Environment Agency is responsible for setting up the standards for landfill waste, landfill site structure, and landfill site operation and maintenance (Miyazaki *et al*., 2007).

In fiscal 2000 the total quantity of solid waste generated in Japan was 52.36 million ton slightly more than the previous year (Geng *et al*., 2010). The total waste generated per capita was 1.13 kg/capita/day with total population of 126,549,976 capita. By source, there were 34.37 million ton of household waste and 17.99 million ton of business waste. Of all waste that was treated, 46.78 million ton went through intermediate treatment whether incineration, crushing or sorting, while 2.22 million ton were directly transported to recyclers, together accounting for 94.1% of all treated waste. Of the 46.78 million ton of intermediate treatment waste, 2.87 million ton were recycled and reused. Of the intermediate treatment waste, 40.35 million ton or 77.4% of the whole were incinerated (Fig.11). The amount of final disposal

Fig. 11 Japan, ways of solid waste disposal, 2000



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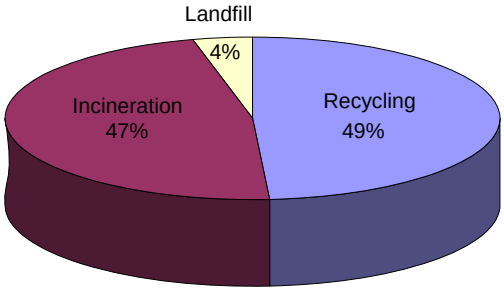
waste has shown a tendency to decrease at 10.51 million ton in fiscal 2000. The biggest problem of general waste treatment is that it is difficult to find new landfill sites. Because of this, attitudes are moving away from the end-of-the-pipe approach of before and have recently started heading towards emissions control, sophisticated treatment and recycling. Also, because of issues regarding the management of chemical substances such as dioxins and the need to prevent global warming as well as stiffen regulations, constructive efforts, such as the voluntary acquisition of ISO14001, are needed (Hwang & Kawamoto, 2010).

Fig.12. Singapore, ways of solid waste disposal, 2005



One of the most distinctive features of Japan's municipal solid waste treatment is the comparatively high rate of incineration, now around 77 percent. Waste incinerators can be roughly classified into mechanical stoker types and fluidized bed types, both of which are nearly established technologies. Countermeasures against dioxins - the major problem in waste incineration - are also nearly complete, with the suppression of dioxin generation by high-temperature and efficient combustion and the collection and decomposition of dioxins using decomposing catalyst and bag filters. Regarding the issues of dioxin decomposition, prolonging final disposal sites (detoxifying ashes, recycling) and improving heat recovery, a shift is expected from incineration technologies to new technologies. These will include stoker type incinerators combined with ash solidification technologies, and gasification and ash melting technologies (Sakai *et al*., 2008).

Technologies for sorting the bottles and cans that are discharged are nearly complete. At present, the main topic is automatic sorting of bottles by color to save labor. Manufacturers have produced a variety of methods on a commercial basis, which are working. But destinations for the recycled glass must still be developed. Also, passage of the Low for Promotion of Sorting and Recycling of Containers and Packaging has stimulated recovery of an increasing amount of PET bottles Technology that provides simple and convenient blowing, pressing and packing for them is expected.

All of these systems, which use waste incineration and gas turbines to generate electric power, are already in operation in the cities of Takasaki, Sakai, Kitakyushu and Chiba, Japan. By taking advantage of the resulting increase in power generating efficiency (from around 15 percent to around 35 percent), the surplus electric power can be sold (Miyazaki *et al*., 2007).

Singapore

Strategies adopted by Singapore to manage solid waste (Zhang *et al*., 2010) are: Incineration to reduce the volume of waste landfilled; Recycling to reduce the volume of waste disposed of at the incineration plants; Reduction the amount of waste going to landfill; Promoting waste minimization to avoid the generation of waste.

In 2005 the total quantity of solid waste generated in Singapore was 5,018,200 ton. Total of 2,548,800 ton (51%) of waste was disposed of in 2005. About 2,330,000 ton or 91% of the total waste disposed was incinerated while the remaining quantity was land filled (Fig.12).

Of the amount disposed of, 57% was generated from residential premises, food centers and markets. Commercial and industrial premises accounted for the remaining 43%. The average amount of domestic waste generated per capita daily in 2005 was 0.89 kg/capita/day, with total population of 4,425,720 capita (Khoo *et al*., 2010).

Between 2000 and 2005 waste growth has been contained as Singapore's overall recycling rate rose from 40% to 49% with total quantity of 2,469,400 ton in 2005. The projected lifespan of Semakau Landfill has risen from 25-30 years to 35-40 years, while the need for additional incineration plants has been reduced from one in every 5-7 years to one in every 7-10 years. The National Environmental Agency in Singapore has initiated several recycling programs to promote waste minimization and recycling in the homes, condominiums, private apartment estates, schools, industrial estates, offices, hotels, etc (Khoo, 2009).

The National Recycling Program was launched in April 2001. Under this program, the public waste collectors licensed by The National Environmental Agency NEA are required to tie up with recycling companies to implement door-to-door collection of recyclable material in both HDB estates and landed properties within their servicing sectors (Bai & Sutanto, 2002). Residents are given recycling bags for HDB dwellers and trays or bins for landed properties, where

Fig.13. Collecting solid waste in Singapore

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Table 1. Summary of recycling cause study

Country	Year	Population million capita	Municipal solid waste generation 1000ton	Generation of waste Kg/capita/day	Ways of disposal	
					Way	Rate %
United States	2003	290.34	236,200	2.02	Landfill	55
					Recycling	24
					Incineration	14
					Composting	7
United Kingdom	2003	60.1	29,100	1.33	Landfill	72
					Recycling	13
					Incineration	9
					Composting	6
Korea	2003	47.93	98,385	1.04	Landfill	47
					Recycling	41
					Incineration	12
Denmark	2003	5.4	12,835	2.4	Recycling	66
					Incineration	26
					Landfilling	8
Germany	2004	82.42	48,433	1.61	Recycling	57
					Incineration	24
					Landfilling	19
Netherlands	2001	15.98	8,675	1.48	Recycling	46
					Incineration	40
					Landfilling	14
Japan	2000	126.6	52,360	1.13	Incineration	77
					Landfill	17
					Recycling & Reuse	6
Singapore	2005	4.43	5,018	0.89	Recycling	49
					Incineration	47
					Landfilling	4

Table 2. Recycling rate in some countries

Country	*Rates %*
Netherlands (2001)	46
Germany (2004)	57
Denmark (2003)	66
Austria(2001)	63
Belgium (1998)	52
Finland (1997)	33
Sweden (1998)	33
Spain (1999)	27
Italy (1997)	16
France (1998)	14
U. Kingdom (2003)	13
Portugal (1999)	9
Greece (1997)	8
Hungary (2000)	3
Korea (2003)	41
Singapore (2005)	49
Singapore (2001)	44
United States (2003)	24
Canada (2000)	24
Russia (2001)	15
Japan (2000)	6
Malaysia (2006)	5

they can put in paper, plastic and glass bottles, old clothing, metal cans, drink cartons etc. The recycling companies will collect them from their doorsteps fortnightly on a predetermined collection date, as shown in Fig.13 (Khoo *et al*., 2010).

Comparative recycling and final waste processing scenarios

Table 1 and 2 summarizes the waste recycling and final waste disposition scenarios in different countries. It is interesting to note that the developed countries tend to divert waste from the landfill either through intensive recycling program or through other final processing options (e.g., incineration). Among the listed countries, except UK and USA, other countries keep the land filled portion as low as possible, for instance, in case of Singapore, the land filled waste comprises only 4% of the total waste generated. Comparatively higher ratio of land filling in UK and USA may be attributed to their abundance of land area. Nevertheless owing to the increasing public concern, those countries too will have to resort to other options in the near future. Some of the listed European and Asian countries have significant recycling ratio, for instance, Denmark recycles 66% of its waste. Countries such as Japan or Singapore do not have any alternative but to divert waste from the landfill, either through intensive incineration (Japan) or intensive recycling (Singapore), because of the scarce land area. Taking all the data in Table 1 and 2 into consideration it may be asserted that recycling, along with other options of final waste processing, is becoming an effective means to do away with the environmental hazards and low public

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acceptance of waste landfills. This is one of the important aspects that this comprehensive review has revealed.

Conclusion

Waste recycling presents a promising solution to the growing pressure on natural resources. The review furnished here underscores the importance of waste reuse and highlights the technologies and the associated costs. Several developed countries appear to have been successful to integrate waste recycling into the main stream waste management system. With new innovations, the technologies are expected to be more cost-effective day by day, which will endow the opportunity of their widespread application. However, waste reuse implementation faces obstacles that include insufficient public acceptance, technical, economic and hygienic risks and further uncertainties caused by lack of awareness, accepted standards, uniform guidelines and legislation. This issues also have to be given due consideration.

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