

**MANAGEMENT OF MUNICIPAL SOLID WASTES IN ATTICA  
REGION OF GREECE, AND POTENTIAL FOR WASTE-TO-ENERGY**

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# **MANAGEMENT OF MUNICIPAL SOLID WASTES IN ATTICA REGION OF GREECE, AND POTENTIAL FOR WASTE-TO-ENERGY**

## **EXECUTIVE SUMMARY**

The objectives of this study were to examine the current Municipal Solid Waste (MSW) management in the Attica Region of Greece, the environmental issues that arise, and the potential integration of one or more Waste-to-Energy (WTE) facilities in the current Regional Plan for Solid Waste Management (SWM).

The study began with an examination of Attica Region in terms of its demographics, generation and characterization of MSW, as well as its morphological and geologic features, land uses and existent transportation infrastructure. Finally, alternatives for the amelioration of waste transportation are suggested.

The problem of waste management in Greece has reached a critical point, because of lack of environmental awareness and deficient national plans of the past. As of February 2006, there were 1,300 operating Uncontrolled (non-regulated) Waste Disposal Sites (UWDS) that often result in soil, surface and groundwater contamination. Furthermore, intentional or spontaneous fires at many of these locations result in major air pollution since they are the largest source of dioxins and other toxic emissions in Greece and in the long-term may affect tourism, especially during the summer.

The waste management problem is most acute in the Region of Attica that houses approximately 45% of the population of Greece and generates over 58% of the national MSW. A survey conducted in this study of the MSW generation by the 122 municipalities and communities of the Region showed that the daily generation of MSW is about 7,735 metric tons, corresponding to 1.6 kilograms daily per capita. This value is very high in comparison to the generation of MSW in other parts of Greece that ranges between 0.6 and 1.4 kilograms per capita per day.

Most of the MSW collected in Attica is transferred to a single sanitary landfill, which has reached its full capacity and should have ceased operation in February 2006. To alleviate this situation, the Greek Government has planned a new SWM system for the Region, including the construction of three new sanitary landfills in Attica, at the Organizations of Local Administration (OLAs) of Phyli, Grammatico and Keratea. However, there is strong opposition against these landfills by the neighboring communities and environmental organizations. Furthermore, the European Union (EU), to which Greece belongs, has issued the Landfill Directive that requires curtailing the amounts of compostable and combustible wastes landfilled in sanitary landfills. For all

these reasons, it is clear that major changes need to be made to the current waste management plan for Attica Region.

A promising long-term solution practiced in many countries throughout Europe is the controlled combustion of MSW with generation of electrical and thermal energy in specially designed and operated Waste-to-Energy (WTE) facilities. In addition to other environmental advantages, these facilities save valuable landfill space and can be used in perpetuity with proper maintenance.

This study includes a preliminary assessment of implementing a WTE facility of a daily capacity of 3,000 metric tons of MSW, to be located at the municipality of Phylli in western Attica. This area was selected as the most suitable of the three new sanitary landfill sites proposed at the Regional Plan for SWM. The construction costs were estimated to reach approximately \$535 million (€420 million). Approximately, 2 gigawatt-hours of net electricity and 1.5 gigawatt-hours of net thermal energy will be produced daily. Also, the facility will result in the recovery of an estimated 20,000 tons of metals and potential beneficial use of 175,000 tons of bottom ash annually. These numbers correspond to a potential increase of materials recycled in Attica by 5-54%, in reference to the rate of recycling that will result from the implementation of the Regional Plan for SWM. Also, the amount of MSW to be landfilled in Attica will decrease by 48-56%, in reference to that proposed by the Regional Plan.

In addition, the potential of further implementation of WTE in the Region of Attica was examined. More particularly, siting WTE facilities of total daily capacity 6,000 tons would result in the recovery of at least 40,000 tons of metals and potential beneficial use of 350,000 tons of bottom ash maximum annually. These numbers correspond to a potential increase of materials recycled in the Region by 10-108%, in reference to the rate of recycling that will result from the implementation of the Regional Plan for SWM. Also, the amount of MSW to be landfilled would be reduced by 73-89%, in comparison to the rates proposed by the Regional Plan. Additionally, the net generated energy would reach 3.9 gigawatt-hours of electrical and 3 gigawatt-hours of thermal energy daily. Implementation of this potential would require the construction of at least one Marine Transfer Station (MTS).

Finally, waste transportation by water and railroads, as well as the usage of alternative truck fuels should be preferred to the current dependence on diesel trucks, in order to reduce air pollution and traffic congestion.

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## INTRODUCTION

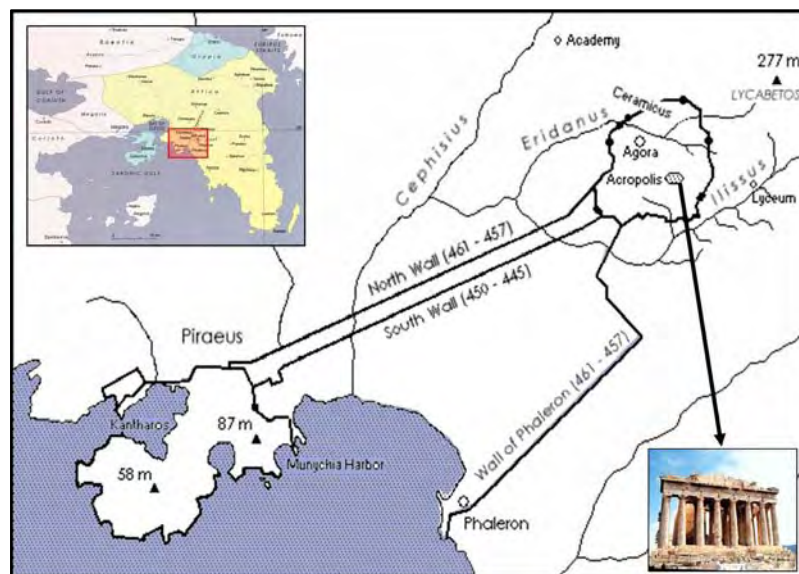
Solid wastes have been an issue for humans from the moment that people began to live together in permanent settlements. When humans abandoned nomadic life at around 10,000 B.C., they began to live in communities, resulting in the production of solid wastes.

At about 3,500 B.C., in the city of Ur (northwest of the Persian Gulf), the sweepings from house floors and the contents of rubbish bins were flung into the street. Such a great amount accumulated that the street levels were gradually raised and from time to time new doors were cut to maintain access to houses<sup>(82)</sup>.

By 2,100 B.C., the cities on the island of Crete, which is located in southern Greece, had trunk sewers connecting homes<sup>(71)</sup>. Also, the first known composting operation is dated at about 1,500 B.C. in Crete.

In 1,300 B.C., the Mosaic Law referred specifically to public sanitary practices. Everyone was expected to act as his or her own scavenger, removing refuse and burying it in the earth.

Moreover, in 500 B.C., the people of Athens (capital of Greece) developed the first municipal dumpsite in the western world and required waste disposal to be at least 1.6 kilometers from the city walls<sup>(2)</sup>. The figure on the right shows a map of the ancient city of Athens and the location of the city walls<sup>(9)</sup>.



By 200 B.C., the cities in China had “sanitary police”, whose job was to enforce waste disposal laws.

Collection of solid wastes at the Roman Empire (14 A.D.) was probably better organized than that of any other civilization of the time. Yet, the Romans were not able to overcome the problem of dealing with the large accumulation of waste.



Regarding USA, the conditions in many of the cities were appalling in the past. Waste was disposed by the throwing it into streets, where rag pickers would try to salvage what had secondary value. Not so very long ago, as the coastal cities of young USA grew to metropolitan regions, the disposal of Municipal Solid Wastes (MSW) was achieved by simply loading up large barges, transporting them some distance from the shore and shoveling the garbage into the water. One such barge, operated out of New York City during the turn of the twentieth century, is pictured on the left<sup>(71)</sup>.

Throughout history and throughout the world, cities have struggled to manage the waste produced by their citizens. As the population and urbanization increased, waste disposal also became a more serious problem. In today's cities, MSW are either reprocessed for subsequent reuse or directly sent for disposal after their collection.

This global problem is characterized by numerous negative consequences, which not only affect the environment, but also create enormous problems in public health. Therefore, a rational waste management system, including organized collection, effective treatment and proper disposal of waste, is of great importance.

The significance of waste management in contemporary society is confirmed by the fact that the "industry" engaged with waste management comes fourth in concern after other global issues, such as weapons, chemical and pharmaceutical industries. More particularly, in Greece Solid Waste Management (SWM) holds the second position concerning the priorities set by the National Plan for the period of 2000 – 2006 towards Sustainable Development.

From an economic point of view, 40% of the money spent in the European Union (EU) for waste management is granted for solid wastes. The EU offered a total of \$372 billion (€92.2 billion) for the improvement of the quality of life and the environment in Greece in terms of the Operational Program "Environment" (2000 – 2006)<sup>(41)</sup>.

Presently, the problem of waste management in Greece has reached a critical point, because of the lack of environmental consciousness and the deficient national plans of the past. In 2001, the Uncontrolled Waste Disposal Sites (UWDSs) reached the number of 2,180<sup>(12)</sup> and received 45% of the generated waste. By February 2006, there were 1,300 active illegal landfills, which should cease operation by 2008 according to the EU regulations<sup>(11)</sup>. The arbitrary and unrestrained operation of the UWDSs has often led to soil, surface and groundwater contamination. Besides, the uncontrolled combustion of MSW, in some cases caused by spontaneous ignition, results in major air pollution. Also,

often it has led to destruction of extended areas of land and may be the cause of declination of tourism in the country, especially during summer.

This study focuses on the Region of Attica, which faces a great challenge concerning SWM. The majority of the MSW generated in the Region is disposed at one sanitary landfill, which should have ceased operation a long time ago.

Moreover, very few locations satisfy the criteria for creating new landfills. The geomorphologic structures; hydrologic, geologic and seismic features, numerous archeological sites; as well as the high-density population of the area render the land too scarce to provide space for new landfills. Finally, there is strong public opposition to landfills by local residents and environmental organizations.

For all the aforementioned reasons, it is clear that several alterations must be made in the MSW management system in order to increase material recovery, reduce the waste landfilled and minimize its negative consequences.

A promising long-term technique that may be practiced as a treatment process is the incineration of waste with generation of thermal and electrical energy (Waste-to-Energy; WTE). WTE facilities save valuable landfill space, as they reduce the waste volume by 90% and can be used in perpetuity with proper maintenance. About 140 million tons of MSW are combusted annually in over 640 WTE facilities worldwide that produce steam and electricity and also, recover metals for recycling<sup>(56)</sup>. For this reason, a study for the implementation of WTE as a possible solution to the waste problem in the Region of Attica was considered as crucial.

Essential definitions and parameters regarding solid wastes and MSW are referred in Chapter 1, while Chapter 2 analyzes the WTE concept. Chapter 3 portrays Attica Region by providing basic information in terms of geography, morphology, climatology, geology, land uses and transportation infrastructure. Moreover, a detailed description of the MSW management system of the Region is provided in Chapter 4. Chapter 5 includes a WTE assessment for the Region of Attica, as part of the proposal of methods for the improvement of the current SWM system and Chapter 6 presents alternative solutions to the methods currently employed for waste transportation. Finally, Chapter 7 comprises an overview of the proposal and refers to future work that must be performed.

It must be noted that for the conversion of the monetary values from euros (€) to dollars (\$) and vice-versa, the equivalence of May 7, 2006 (€ = \$1.27312)<sup>(163)</sup> was used.

## **CHAPTER 4: MUNICIPAL SOLID WASTES IN ATTICA REGION**

### **4.1 INTRODUCTION**

This section provides information on the generation and characterization of the Municipal Solid Wastes (MSW), and the Solid Waste Management (SWM) practice in the Region of Attica. Relevant studies and past investigations were examined. In addition, information was acquired by visits to Attica's SWM facilities sites; and by discussions with experts in the field, and local and central authorities.

Furthermore, an appropriate questionnaire was developed and distributed to the Organizations of Local Administration (OLAs) of Attica Region. The questionnaire included questions regarding the current actual population; the generation and composition of MSW; the collection and disposal methods; the recycling habits; and the costs of the current SWM system. The data for the completion of this questionnaire were collected via interviews of people responsible for the SWM system of each OLA. Out of 122 questionnaires that were distributed, there were 105 municipalities and communities that responded – a success ratio of 86%. The database was completed by estimates of the missing data based on the collected data.

The information accumulated by the aforementioned methods led to identification of the assets and liabilities of Attica Region's SWM system and the determination of the basic parameters. These were integrated by means of Geographic Information Systems (GIS) technology to provide a better description of the current waste situation.

### **4.2 REGULATORY FRAMEWORK**

Waste management systems in Greece must comply with the regulations of the European Union (EU) and Greece, the most important of which are presented in this section.

The international community, recognizing the importance of the issue of waste, has set in Agenda 21 a framework for integrated waste management. In addition to safe disposal, the framework puts emphasis on a three-level approach aiming primarily at the Reduction, the Reuse and the Recycling of waste as part of the ideal SWM system described in the previous chapter.

The EU regulations are partially determined by the European Environment Agency (EEA), as mentioned earlier. However, the legislation of each country in EU may vary depending on the domestic situation. As a result, additional laws regarding, for example treatment permits or the taxing of waste management activities, may apply.

The following paragraphs offer information on the European and Greek regulations, while a complete list can be found in Appendix B.

#### **4.2.1 European Regulations**

EU adopted the philosophy of integrated waste management in its Fifth Action Program for the Environment (1993 – 2000). In the Sixth Action Program (2002 – 2012), EU set a 20% reduction target of the total waste quantity to be disposed by 2010 and 50% reduction by 2050, in relation to 2000 levels<sup>(40)</sup>.

Furthermore, EU has adopted a set of Directives in order to deal efficiently with certain critical aspects of the issue. Directive 94/62/EC on “Packaging and Packaging Wastes” set a 50% recovery target (including composting and energy recovery) and a 25% recycling target by weight of all packaging materials by 2001. The Directive was amended in 2004, setting more ambitious targets for 2008: A minimum of 60% by weight to be recovered or combusted in Waste-to-Energy (WTE) plants; and between 55 – 80% by weight to be recycled, with a minimum of 60% for glass, 60% for paper, 50% for metals, 22.5% for plastics and 15% for wood. It must be noted that Greece, Ireland and Portugal are allowed to reach these limits by 2011. The amended Directive also presents new definitions to include new technologies and indicative guidelines on interpretation of the term “packaging”.

Furthermore, Directive 99/31/EC sets the target of reducing the biodegradable wastes discharged in landfills by 75% of the 1995 level by the year 2006, 50% by 2009 and 35% by 2016. It also establishes strict specifications for large landfills. States-members that landfilled over 80% of their MSW in 1995, such as Greece and the United Kingdom, may postpone each of the targets by a maximum of four years.

Finally, new targets have been set regarding renewable energy: 20.1% of electricity should be generated as renewable energy by 2010 and 29% by 2020.

#### **4.2.2 Greek Legislation**

Since the Rio Convention in 1992, Greece has started to adopt a strategic policy framework towards Sustainable Development. Since then, Greece has promoted the extension and the reorganization of its relevant infrastructures and adopted a National Plan for Integrated and Alternative SWM, based on the principles and guidelines of the European policy. At the same time, provisions have been adopted for delegating the

responsibility for planning and waste management to the Regional Authorities and the local Prefectures; this measure is expected to facilitate an integrated approach of the issue.

In Greece, the Ministry of Environment, Physical Planning, and Public Works (MEPPPW; ΥΠΕΧΩΔΕ in Greek) is charged with environmental protection and provides co-ordination and advice on the main environmental policy areas. Also, the Ministry of the Interior has particularly important responsibilities regarding solid wastes and local waste treatment, as part of its role in supervising local authorities (OLAs).

The structure of the SWM system includes methods of SWM, such as temporary storage, collection, transport, processing and disposal; the necessary number of Waste Transfer Stations (WTSs); the responsibilities of the SWM carriers, meaning both private companies and OLAs; the goals posed in order to achieve Reduction, Reuse and Recycling of waste; and the conditions regarding the funding, foundation and operation of the management system.

The first Waste Framework Directive (75/442/EEC) was adopted in 1975 and established general rules for the management of waste. It was amended in 1991 by Directive 91/156/EEC, and has been incorporated into Greek Legislation, through three Joint Ministerial Decisions (JMDs):

- JMD 69728/824 defined the terms and measures for SWM;
- JMD 114218/97 provided detailed technical specifications for SWM facilities, equipment and procedures;
- JMD 113944/97 outlined the general directions of SWM policy in Greece.

In 2000, the National Plan for SWM became a legal text, as a JMD, which sets the priorities and gives directions for the sustainable management of solid wastes of the country.

In 2002, MEPPPW initiated the update of the National Plan, aiming at the evaluation of the Prefectural Schemes according to the Regional Schemes that were elaborated for promoting integrated SWM; the elaboration of integrated SWM systems for the 13 Regions of Greece; the management of Uncontrolled Waste Disposal Sites (UWDSs) and their gradual elimination; and the development of modern sanitary landfills, covering the entire country by the end of 2008<sup>(158)</sup>.

During the period of 2002 – 2003, MEPPPW focused also on the transposition of the EU Legislation on waste management into the National Legal System and, thus, issued new JMDs, including JMD 29407/3508/2002 on measures and terms for sanitary disposal (harmonization with the EU Directive 99/31/EC) and JMD 50910/2727/2003 on measures and terms for SWM.

The application field of Law 2939/2001 (harmonization with the EU Directive 94/62/EEC) on “Packaging and the Alternative Management of Packaging and other Materials” extends to packaging wastes, end-of-life vehicles, waste batteries and accumulators, catalysts, used tyres, wastes from electrical and electronic equipment, oils and waste oils, and demolition and construction wastes. This law obligates the economic actors to organize or participate in systems of alternative waste management in order to achieve specific quantitative targets. Pursuant to Law 2939/2001, the JMD 106453/2003 and 105857/2003 approved the operation of two nationwide systems for the collective alternative management of packaging wastes.

Most recently, MEPPPW issued JMD 22912/1117/2005, by which the EU Directive 2000/76/EC on waste incineration is integrated in the Greek Legislation.

### 4.3 MUNICIPAL SOLID WASTES IN GREECE

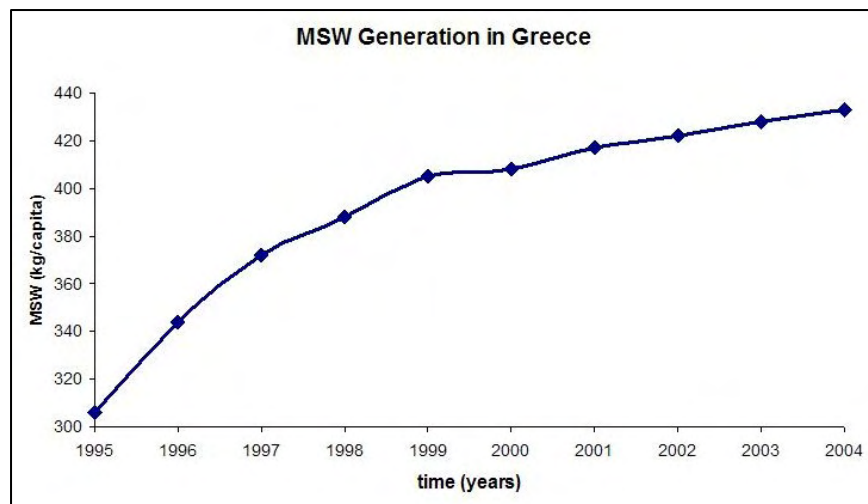
#### 4.3.1 Generation Rates

Greece is considered as the third-fastest-growing producer of waste in EU, after Malta and Ireland. For the period of 1987 – 1994, the MSW generated increased by an average of 650,000 tons per year. In 2004, the quantity was estimated to reach 4.8 million tons<sup>(84)</sup>, corresponding to an increase by 56% since 1990. Experts estimate that Greece now generates 5.5 million tons of waste. Unless some action is taken, generation of MSW is expected to increase by 35% within the next 15 years.

Figure 4.1 shows the change of MSW generation per capita through the years 1995 to 2004, while Figure 4.2 illustrates the per capita generation in the EU countries in 2003. It can be seen that the country generating the highest amounts of MSW is Norway,

followed by Denmark. Greece is below the average value despite the significant increase of the MSW quantity since the eighties.

**Figure 4.1** Generation rates of MSW per capita in Greece (based on Reference 84).



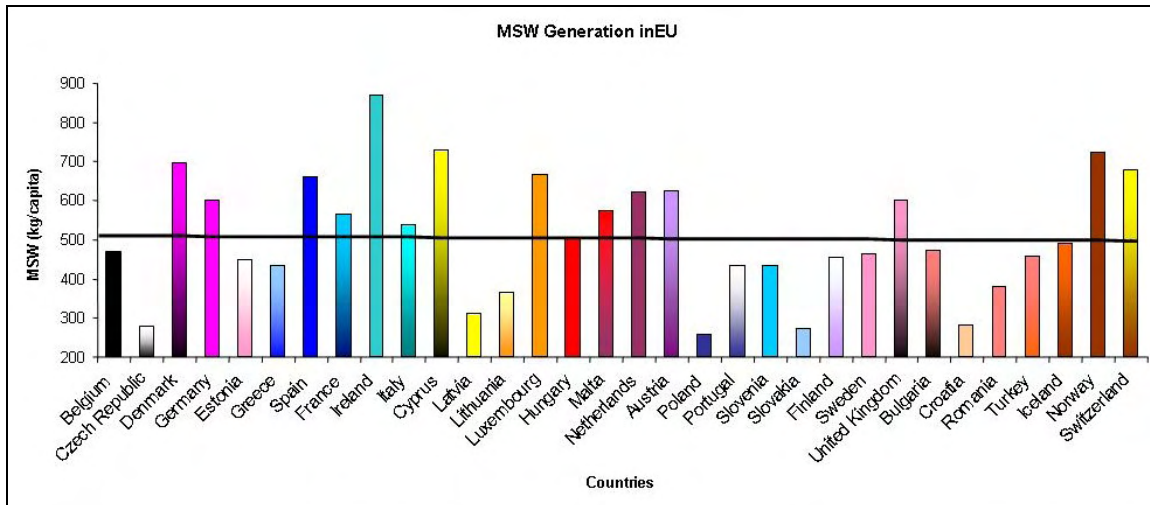


Figure 4.2 Generation rates of MSW per capita in EU for 2003 (based on Reference 84).

Finally, Figure 4.3 compares the quantities of MSW produced in the 13 Regions of Greece in 1997. It shows that Attica and Central Macedonia, where the two largest cities of Greece are located, were the highest in MSW production.

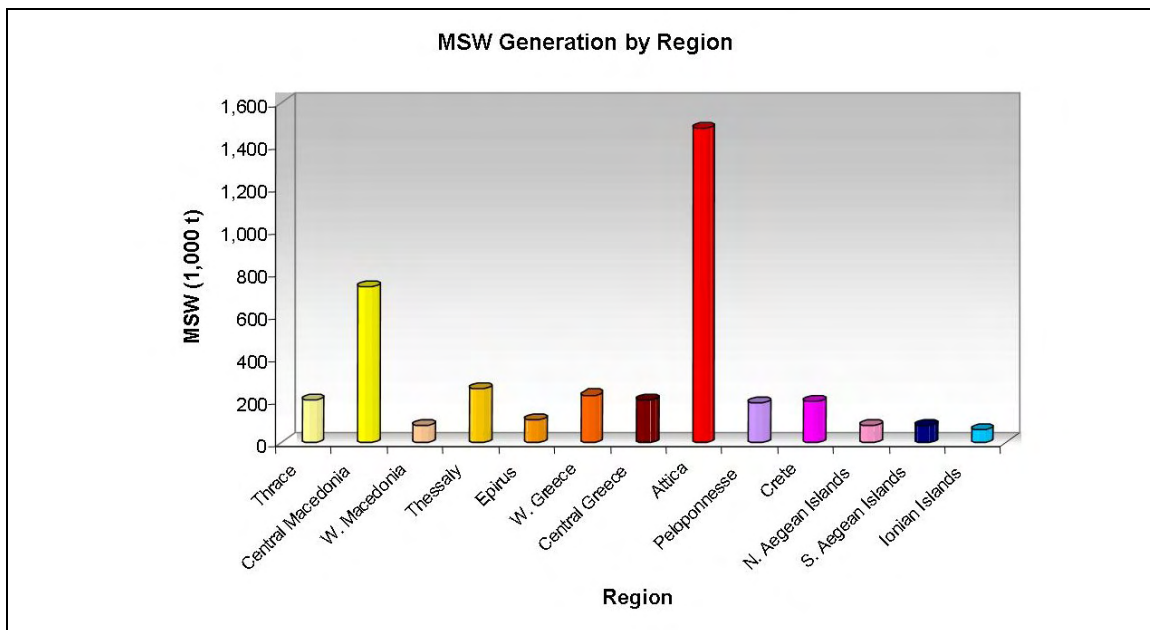


Figure 4.3 MSW generation in the Greek Regions in 1997<sup>(62)</sup>.

### 4.3.2 Composition

In general, the MSW composition cannot be precisely determined, because of their heterogeneity and variations; nevertheless, mean values have been established since it plays an essential role in the design of MSW management systems.

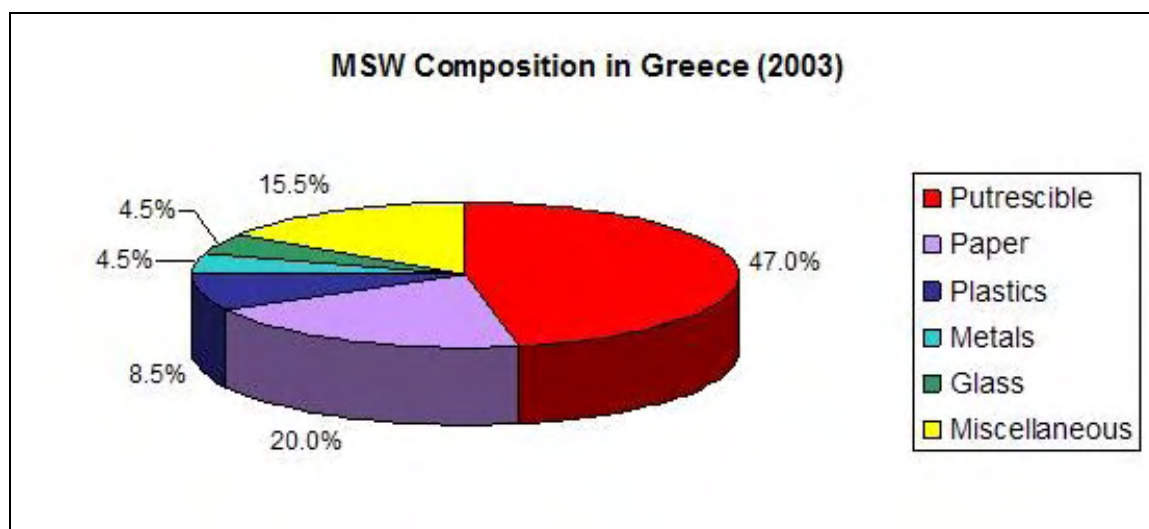
Table 4.1 shows the changes in MSW composition over the years, while Figure 4.4 illustrates the composition of MSW in Greece in 2003, which is considered to remain

unchanged until today. MSW consisted of 47% putrescibles, 20% paper, 8.5% plastics, 4.5% metals, 4.5% glass and 15.5% miscellaneous.

**Table 4.1 Change in Greek MSW composition over the years.**

Types of wastes	1985 <sup>(29)</sup>	1990 <sup>(29)</sup>	1995 <sup>(29)</sup>	1996 <sup>(29)</sup>	1997 <sup>(51)</sup>	2003 <sup>(45)</sup>
Putrescibles (%)	58	49	49	51	49	47
Paper (%)	19	22	20	18	20	20
Plastics (%)	7	11	8.5	10	8.5	8.5
Metals (%)	4	4	4.5	3	4.5	4.5
Glass (%)	3	4	4.5	3	4.5	4.5
Textiles, Rubber, Wood, e.t.c. (%)	4	4	n/a*	4	3	n/a
Miscellaneous (%)	5	6	13.5	11	10.5	15.5

\* n/a: not available



**Figure 4.4 Greek MSW composition in 2003.**

Table 4.2 compares the composition of waste generated at several cities of Greece and Table 4.3 is an example of the variation of MSW composition based on the seasons. As one can observe, MSW are characterized by the maximum percentage of putrescibles and minimum of paper during the summer months.

**Table 4.2 MSW composition of selected Greek cities.**

Cities	Putrescibles (%)	Paper (%)	Plastics (%)	Metals (%)	Glass (%)	Textiles, Rubber, Wood, e.t.c. (%)	Miscellaneous (%)
Athens <sup>(29)</sup>	56.0	20.0	7.0	3.0	2.5	4.0	7.5
Thessaloniki <sup>(43)</sup>	52.0	18.0	7.0	5.0	4.0	8.0	6.0
Patras <sup>(36)</sup>	56.3	19.3	12.2	3.3	3.0	n/a*	5.9
Rhodes <sup>(43)</sup>	41.0	15.0	12.0	10.0	16.0	4.0	2.0

Cities	Putrescibles (%)	Paper (%)	Plastics (%)	Metals (%)	Glass (%)	Textiles, Rubber, Wood, e.t.c. (%)	Miscellaneous (%)
Chania <sup>(43)</sup> (Crete)	55.0	19.0	8.0	4.0	4.0	4.0	6.0
Kos <sup>(43)</sup>	37.0	25.0	11.0	5.0	12.0	5.0	5.0
Calamata <sup>(43)</sup>	47.0	25.0	7.5	3.5	3.0	6.0	8.0
Naxos <sup>(43)</sup>	48.0	22.0	9.0	3.0	6.0	5.0	7.0
Xanthi <sup>(74)</sup>	61.2	15.1	7.1	3.2	2.1	n/a	11.3
Comotini <sup>(17)</sup>	67.0	9.0	6.0	3.0	2.0	n/a	13.0
Carpenisi <sup>(139)</sup>	55.0	18.0	10.0	3.0	3.0	n/a	11.0

\* n/a: not available

**Table 4.3 Seasonal variation of Thessaloniki's MSW composition<sup>(69)</sup>.**

Types of wastes	Spring	Summer	Autumn	Winter
Putrescibles	54.7	57.3	49.2	45.9
Paper	17.2	15.0	20.4	18.1
Plastics	6.9	6.5	6.4	9.5
Metals	6.2	5.7	6.0	5.0
Glass	3.8	3.7	4.7	4.8
Textiles, Rubber, Wood, e.t.c.	7.7	7.3	10.2	12.5
Miscellaneous	3.5	4.3	3.1	4.2

Finally, a comparison of MSW composition for selected countries is shown in Table 4.4. It can be seen that the Greek waste composition differs from that of other countries, due to a higher content in putrescibles and a relatively lower content in packaging materials.

**Table 4.4 MSW composition of selected countries<sup>(84)</sup>.**

Countries	Putrescibles (%)	Paper (%)	Plastics (%)	Metal (%)	Glass (%)	Textiles, Rubber, Wood, e.t.c. (%)	Miscellaneous (%)
Austria	29.20	24.00	15.50	7.20	9.40	2.80	11.90
Belgium	27.00	18.00	6.00	4.00	4.00	3.00	38.00
Bulgaria	35.00	11.00	6.00	4.00	6.00	3.00	35.00
Cyprus	38.53	27.43	11.36	7.57	1.47	6.21	7.43
Czech Republic	18.00	8.00	4.00	2.00	4.00	2.00	62.00
<b>Greece</b>	<b>51.00</b>	<b>18.00</b>	<b>10.00</b>	<b>3.00</b>	<b>3.00</b>	<b>4.00</b>	<b>11.00</b>
Hungary	32.00	19.00	5.00	4.00	3.00	3.00	34.00
Israel	44.00	26.00	14.00	4.00	3.00	n/a*	9.00
Netherlands	n/a	27.00	5.00	2.00	6.00	2.00	58.00
Norway	30.00	36.00	9.00	4.00	3.00	4.00	14.00
Romania	51.00	14.00	7.00	6.00	6.00	6.00	10.00
Slovak Republic	26.00	13.00	9.00	8.00	6.00	3.00	35.00

\* n/a: not available

### 4.3.3 Heating Value

The amount of energy generated at a WTE facility depends primarily on the calorific value of the fuel. Table 4.5 shows the estimated values of the chemical composition of waste materials that can be used to calculate the calorific values of the MSW.

**Table 4.5 Ultimate analysis of waste<sup>(51)</sup>.**

Types of wastes	C (%)	H (%)	O (%)	N (%)	Cl (%)	S (%)	H <sub>2</sub> O (%)	Ash (%)
Household Food Wastes	17.93	2.55	12.85	1.13	0.38	0.06	60.00	5.10
Yard Wastes	23.29	2.93	17.54	0.89	0.13	0.15	45.00	10.07
Newspapers	36.62	4.66	31.76	0.11	0.11	0.19	25.00	1.55
Books, Magazines	32.93	4.64	32.85	0.11	0.13	0.21	16.00	13.13
Other types of paper	32.41	4.51	29.91	0.31	0.61	0.19	23.00	9.06
Plastics	56.43	7.79	8.05	0.85	3.00	0.29	15.00	8.59
Metals	4.31	0.60	3.94	0.05	0.07	0.01	5.00	85.97
Glass	0.50	0.07	0.35	0.03	0.01	0.00	2.00	97.04
Textiles	37.23	5.02	27.11	3.11	0.27	0.28	25.00	1.98
Rubbers, Leather	43.09	5.37	11.57	1.34	4.97	1.17	10.00	22.49
Wood	41.20	5.03	34.55	0.24	0.09	0.07	16.00	2.82

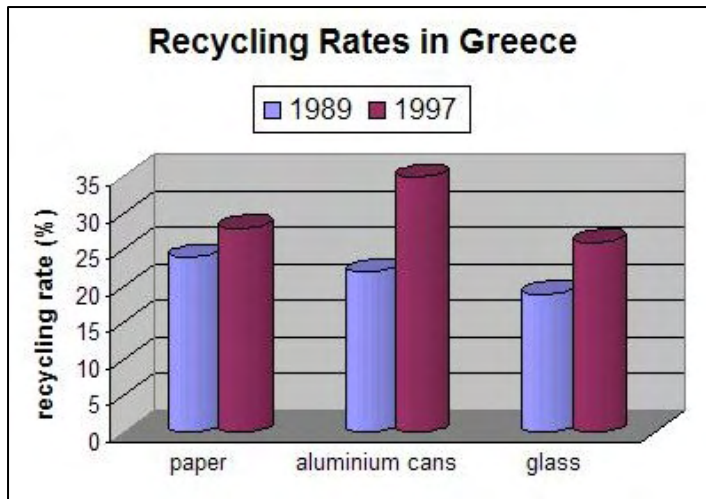
Table 4.6 shows the Lower Heating Values (LHVs) for various types of wastes in USA and Greece. Accordingly, the average LHVs of the MSW for USA and Greece are about 10,469 kilojoule per kilogram and 11,995 kilojoule per kilogram, respectively. However, it has been determined that the average calorific values of both USA and Greek MSW are approximately 13,000 kilojoule per kilogram. The difference of the aforementioned values is owed to the generalization made in order to form a broad view of each country's MSW composition.

**Table 4.6 Lower Heating Values of MSW in USA and Greece.**

Types of wastes	Lowest Heating Value (kJ/kg)	
	USA <sup>(42)</sup>	Greece <sup>(51)</sup>
Putrescibles	2,000	4,602
Paper	12,000	16,569
Plastics	30,000	32,217
Metals	0	690
Glass	100	138
Textiles, Rubber, Wood, e.t.c.	17,500	18,410
Miscellaneous	2,000	24,142

#### 4.3.4 Management System

Until 1994, the proportion of the population of Greece served by regular collection systems was around 70%. In small islands and isolated villages collection was poorly organized. Waste was disposed at 4,850<sup>(20)</sup> recorded waste disposal sites all over Greece, of which only 30% were controlled in some way.



Since 1994, many improvements have been attained in the MSW management system in Greece. For example, recycling activities were developed with remarkable results, due mainly to private sector efforts. Figure 4.5 shows the increase of recycling rates from 1989 to 1997.

Figure 4.5 Recycling rates in Greece in 1989 and 1997<sup>(62)</sup>.

During the period of 1994 – 2000, priority was given to the reduction of UWDSs and to the establishment of properly designed and operated sanitary landfills. Having achieved to a great extent these first two goals, as will be described below, Greece proceeded to the planning and implementation of an integrated infrastructure for the effective management of MSW.

More particularly, the National Plan for integrated SWM in the period of 2000 – 2006 was developed in accordance to the European and Greek regulations with the following objectives<sup>(134)</sup>:

- Establishment of improved waste collection systems, effective transportation and temporary storage of waste;
- Construction and operation of new sanitary landfills, upgrading of existing ones in order to ensure the safe disposal of waste, and the reclamation of all open UWDSs;
- Maximization of material recovery rate by promoting waste separation at the source in all major OLAs of the country and by providing for the construction of modern Material Recovery Facilities (MRFs);
- Materialization of complete substructures of waste management, such as facing the pollution of touristic coasts, constructing facilities for management of hazardous wastes, and restoring old UWDSs;

- Increase of the awareness of the administration, citizens, private and public sectors regarding the need for waste management; and
- Successful collaboration of private industries with the public sector (Public-Private Partnership; PPP) in waste management projects.

The implementation of the National Plan was successful. By 2001, 85% of the Greek population was served by a regular collection system. From the total amount of MSW, approximately 7.1% was recycled at the source in 2001, a value that is slightly higher than that of 2000 (7%).

The material recovery could have been much higher, as the recyclable materials reached approximately 37.5% of the generated MSW. Table 4.7 presents values of the packaging wastes that were produced and recycled in 2000 and 2001 in Greece. The packaging wastes recycled in 2000 and 2001 corresponded to approximately 33.3% and 33.4% of the produced packaging wastes (7% and 7.1% of the annual produced quantity of MSW), respectively.

**Table 4.7 Recycling of packaging wastes in Greece for 2000 – 2001<sup>(37)</sup>.**

Types of wastes	2000			2001		
	Produced	Recycled	%	Produced	Recycled	%
Paper	356,000	240,000	67.40	374,000	253,000	67.60
Plastics	260,000	8,000	3.10	270,000	8,000	3.00
Aluminum	15,500	5,100	32.90	15,500	5,300	34.20
Other Metals	78,000	5,000	6.40	90,000	5,000	5.60
Glass	180,000	43,000	23.90	180,000	44,000	24.40
Wood	45,000	10,000	22.00	45,000	10,000	22.20
<b>TOTAL</b>	<b>934,500</b>	<b>311,100</b>	<b>33.29</b>	<b>974,500</b>	<b>325,300</b>	<b>33.38</b>

Moreover, the percentage of waste discarded at sanitary landfills increased to 51% and many UWDSs were closed, reaching the number of 2,180<sup>(40)</sup> in 2003.

By 2004, 15 WTSs had been constructed for the improvement of the transportation and final disposal of 23.4% of the generated MSW. Additionally, five MRFs and one Mechanical Recycling and Composting Facility (MRCF) had initiated operation, resulting in a small increase of recycling rates. Furthermore, 43 sanitary landfills were constructed and 15 UWDSs were retrofitted.

Today, organized collection and transportation of MSW is applied throughout the country. It is estimated that 8.2% of the produced MSW is recycled, 0.7% is composted and 91.1% is landfilled<sup>(79)</sup>. The number of UWDSs has been reduced to 1,300<sup>(111)</sup>. Moreover, numerous projects, including the construction of WTSs, MRFs, MRCFs and

sanitary landfills, as well as rehabilitation projects and recycling programs, have been approved and are under implementation throughout Greece.

During the period of 1993 – 1999, over \$411 million (€322.8 million) were invested in waste management studies; construction of sanitary landfills, WTSs and waste processing facilities; restoration and rehabilitation of waste disposal sites; and collection and recycling equipment programs.

Early studies estimated that funds of about \$1.4 billion (€1.1 billion) would be required for the implementation of the National Plan for 2000 – 2006. During 2000 – 2003, \$297 million (€233 million) were allocated to SWM projects, including approved and in-progress studies. For addressing the remaining needs, MEPPPW had also bound over \$891 million (€700 million) from national and community resources (Cohesion Fund, Structural Funds, e.t.c.) for additional waste management projects<sup>(18)</sup>.

With a view to achieving Sustainable Development, the Operational Environmental Program (OEP) of Greece for the period of 2000 – 2006, focused on investments in infrastructure needed to guarantee rational management of environmental resources, as in the waste management sectors. It included projects on SWM with an overall budget of approximately \$10.4 million (€8.2 million), as shown in the following Table<sup>(134)</sup>.

**Table 4.8 Budget for SWM – OEP<sup>(134)</sup>.**

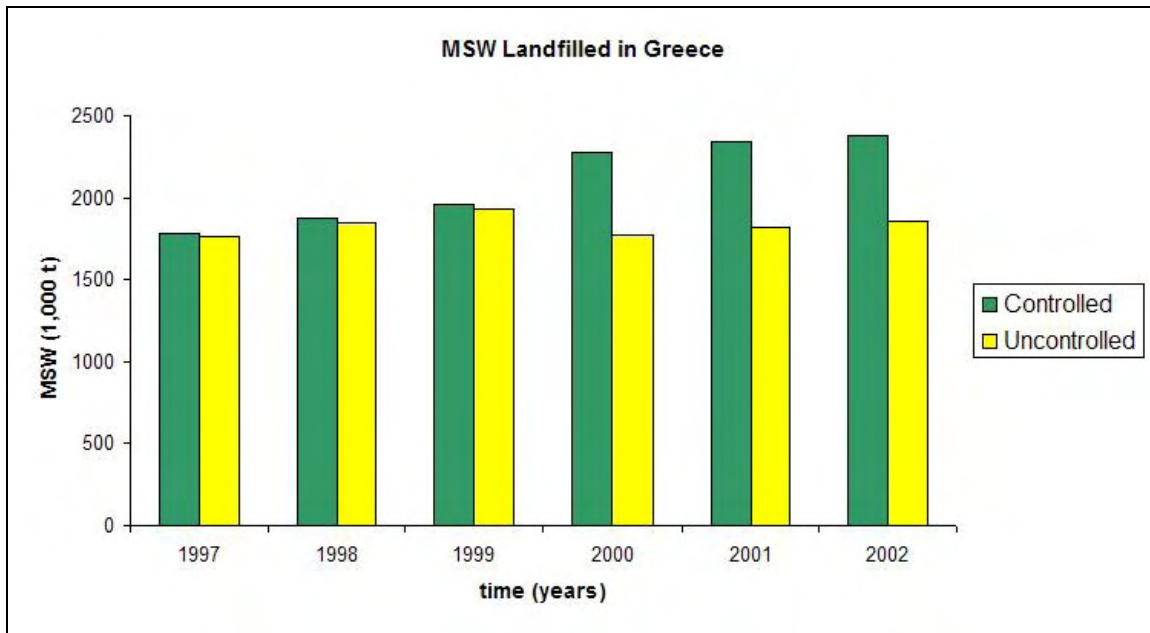
Years	Total Funds		EU Funds		Government Funds	
	(\$)	(€)	(\$)	(€)	(\$)	(€)
2000	0	0	0	0	0	0
2001	2,557,055	1,966,965	1,806,435	1,389,565	750,620	577,400
2002	1,502,528	1,155,791	1,043,522	802,709	459,007	353,082
2003	1,502,527	1,155,790	1,043,522	802,709	459,005	353,081
2004	1,293,899	995,307	905,728	696,714	388,171	298,593
2005	1,725,088	1,326,991	1,207,562	928,894	517,526	398,097
2006	2,033,403	1,564,156	1,423,382	1,094,909	610,021	469,247
<b>TOTAL</b>	<b>10,614,500</b>	<b>8,165,000</b>	<b>7,430,150</b>	<b>5,715,500</b>	<b>3,184,350</b>	<b>2,449,500</b>

Other OEPs, such as OPCOM 2000 – 2006, also include relative measures with respective budget lines related to waste management. At a Regional level, financial support for SWM is provided by the Regional OEPs, for each Region of Greece, under the framework of the Third Community Support Framework.

Despite the efforts towards Sustainable Development, Greece has been repeatedly fined by EU, because it failed to accomplish the posed targets on time. The high number of open UWDSs constitutes the most negative element, while the percentage of useful material recovery is still very low.

#### 4.3.4.1 Waste Disposal

As discussed earlier, land disposal is the predominant method of SWM in Greece. Figure 4.6 shows the amounts of MSW disposed at UWDSs and sanitary landfills for the period of 1997 – 2002. It can be seen that the quantities of MSW disposed at sanitary landfills increased with time, while those discharged at UWDSs remained almost the same, which is another evidence of the increase of MSW generation in country.



**Figure 4.6 Quantities of waste landfilled** (based on Reference 84).

The UWDSs lack lining, leachate and Landfill Gas (LFG) control management systems. In addition, the provision against floods or fires is inexistent and, in fact, fires are set deliberately in landfills to increase their storage capacity. These deficiencies render the operation of such sites hazardous for the environment and public health.

The most important environmental consequences deriving from the operation of UWDSs are underground leachate and LFG leakages; LFG emissions to the atmosphere and stench; dioxin and furan emissions from landfill fires; landslides, due to the fact that waste is improperly or not at all compacted; explosions and fires, due to LFG accumulation or other factors; short- and/or long-term health issues; and aesthetic degradation of the landscape. Also, the presence of UWDSs may have negative impacts on a social (e.g. demotion of areas where UWDSs are located) and developmental (e.g. tourism, recreational areas, e.t.c.) level.

Figures 4.7 and 4.8 show the estimated methane ( $\text{CH}_4$ ) and greenhouse-gas emissions from waste landfilled in the period 1997 – 2002.

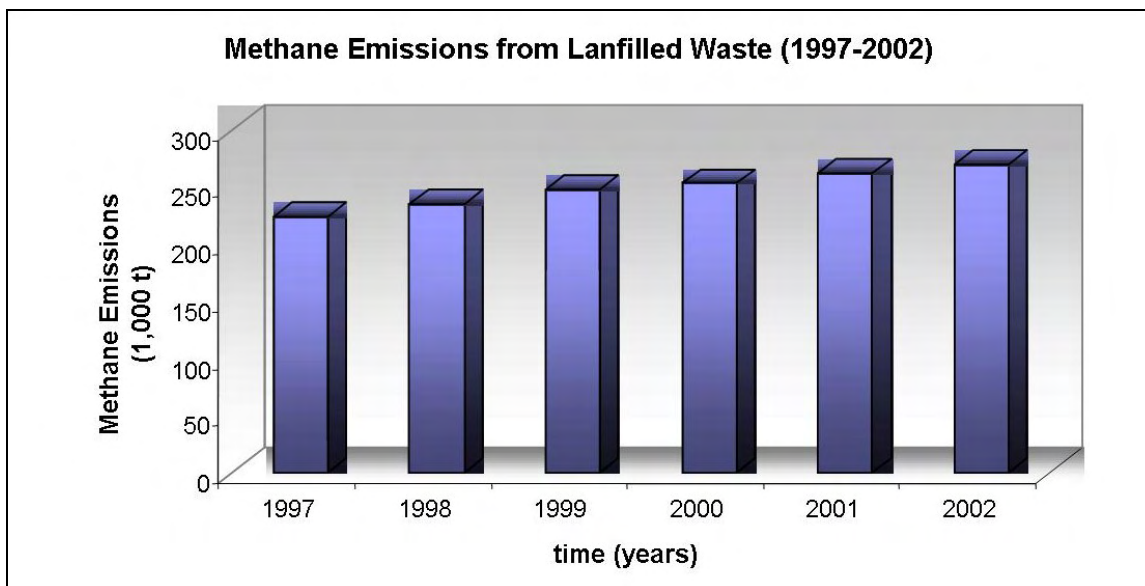


Figure 4.7 Methane emissions from waste disposal sites (based on Reference 84).

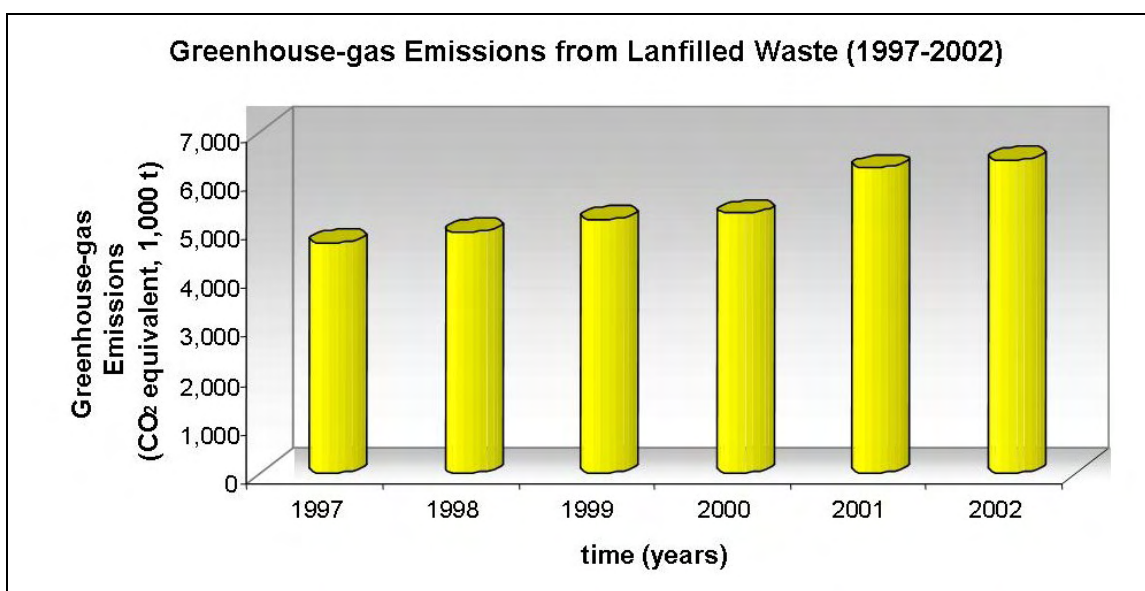


Figure 4.8 Greenhouse-gas emissions from waste disposal sites (based on Reference 84).

Table 4.9 presents the number of fires that were initiated at UWDSs during the period 2000 – 2005 and the area of the land that was destroyed, which reached approximately 15.8 square kilometers. As one can see, the general trend is the decrease of occurrences of such fires with time, in part because of the restoration of many UWDSs.

Table 4.9 Catastrophic fires at UWDSs during 2000 – 2005 (based on Reference 33).

Years	Number of fires	Area destroyed (1,000 m <sup>2</sup> )
2000	735	5,291
2001	703	5,098

Years	Number of fires	Area destroyed (1,000 m <sup>2</sup> )
2002	452	2,064
2003	591	933
2004	562	1,825
2005	399	554
<b>TOTAL</b>	<b>3,442</b>	<b>15,765</b>

Today, 19 sanitary landfills are in the implementation phase, estimated to serve another 19% of the Greek population combined with the expansion of existing facilities, such as sanitary landfills in Larissa and Kefallonia. Proposals for the construction of 32 new sanitary landfills in the Regions of South Aegean Islands, Crete and Thessaly have been submitted, and some of them have already been approved. The implementation of the proposed facilities could serve an additional 21% of the Greek population.

#### 4.4 MUNICIPAL SOLID WASTES IN ATTICA

##### 4.4.1 Generation Rates

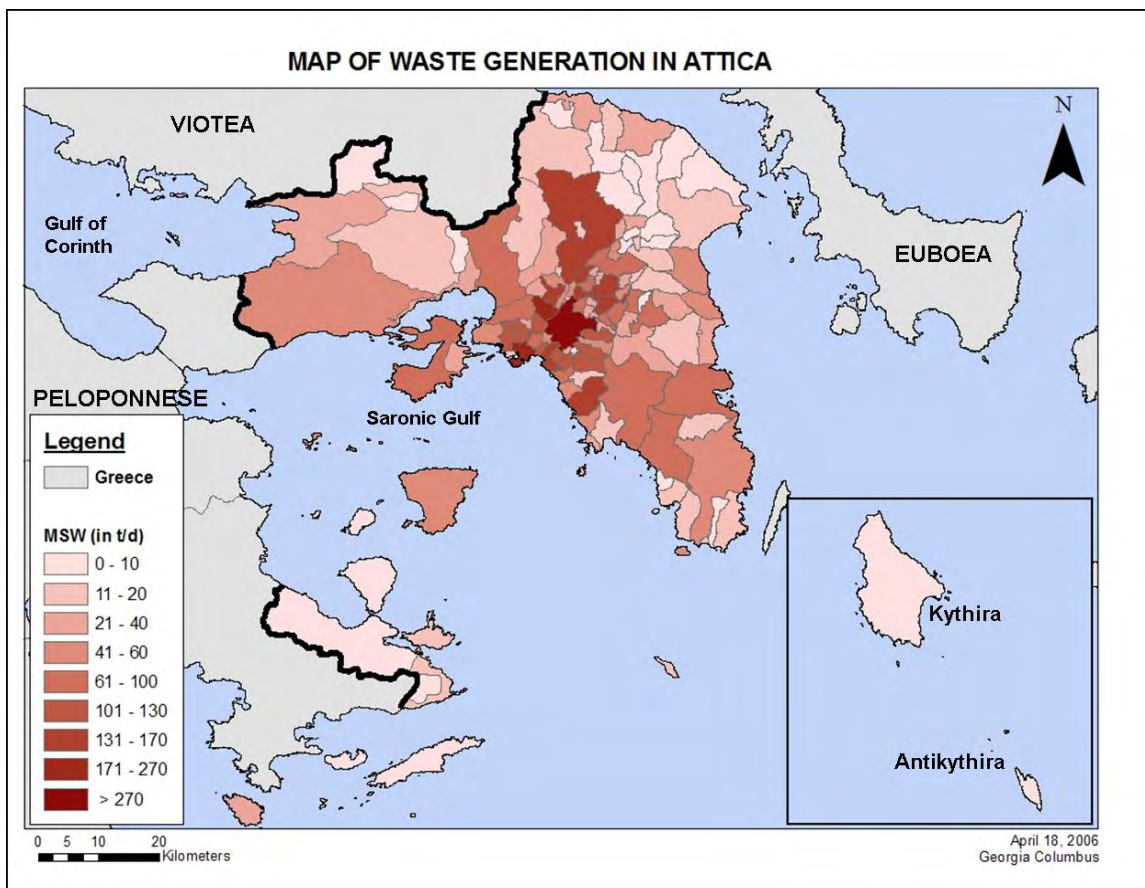
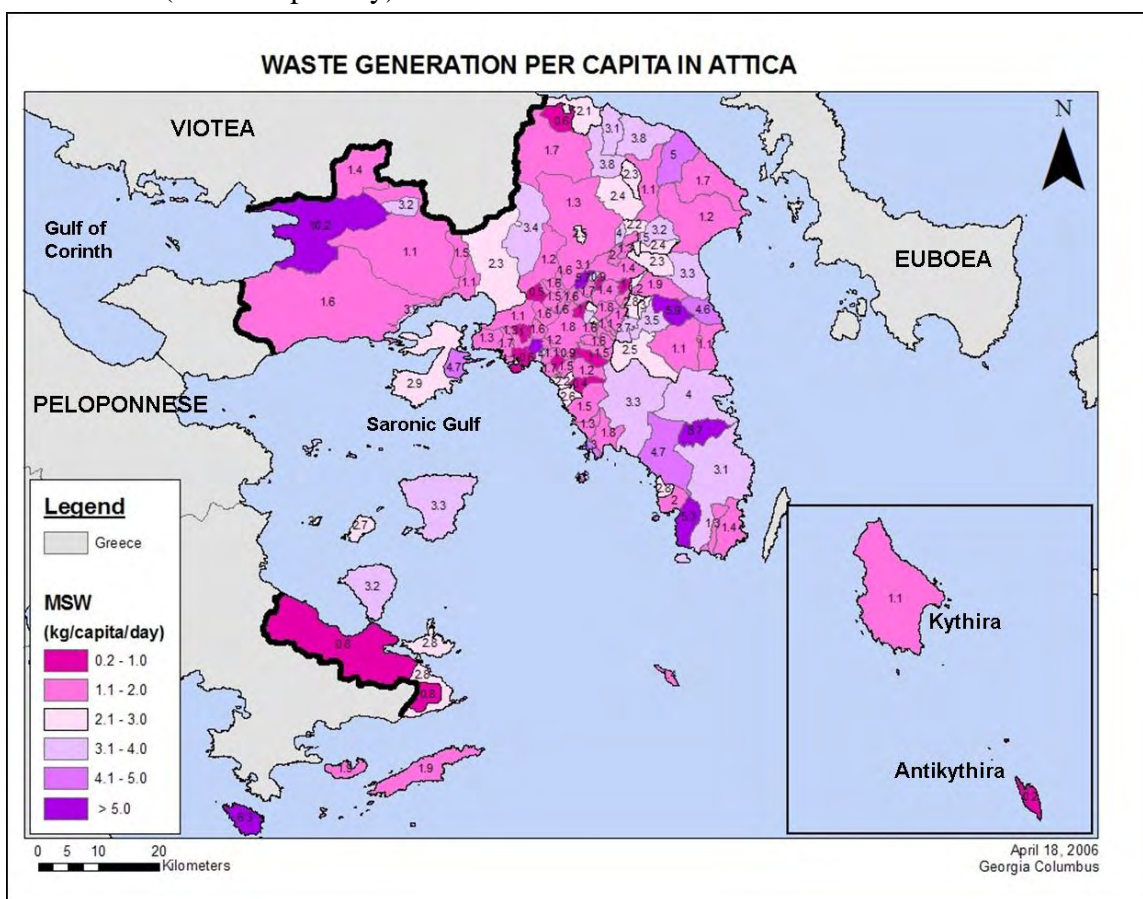


Figure 4.9 Distribution of daily waste generation in Attica Region.

The Region of Attica generates over 58% of the annual MSW produced at a national level. The generation of MSW is estimated to reach about 7,735 tons daily (2.8 tons annually), which corresponds to 1.6 kilograms of MSW daily per capita. This value is very high in comparison to the generation of MSW in other areas of Greece, which range between 0.6 and 1.4 kilograms per capita per day. A complete list of the generation rates of MSW by OLA of Attica Region is listed in Appendix C.

The map of Figure 4.9 shows the distribution of the generated quantities of MSW by OLA in Attica. The highest MSW quantities are produced at the continental part of Athens-Piraeus Prefecture. The maximum values are observed at the most populated municipalities of the Region: Athens (1,400 tons per day), Peristeri (270 tons per day) and Piraeus (250 tons per day).



**Figure 4.10** Waste generation rates per capita in Attica Region.

Figure 4.10 illustrates the range of MSW produced daily per capita for each OLA. The MSW generation rates range from 1 to 2 kilograms per capita per day in most OLAs. The OLAs of Aghios Ioannis Rendis, Couvaras, Metamorphosi, Pikermi and Vilia are characterized by higher than the average generation rate per capita. These OLAs are partly in or near industrial and/or commercial zones. It is possible that part of the

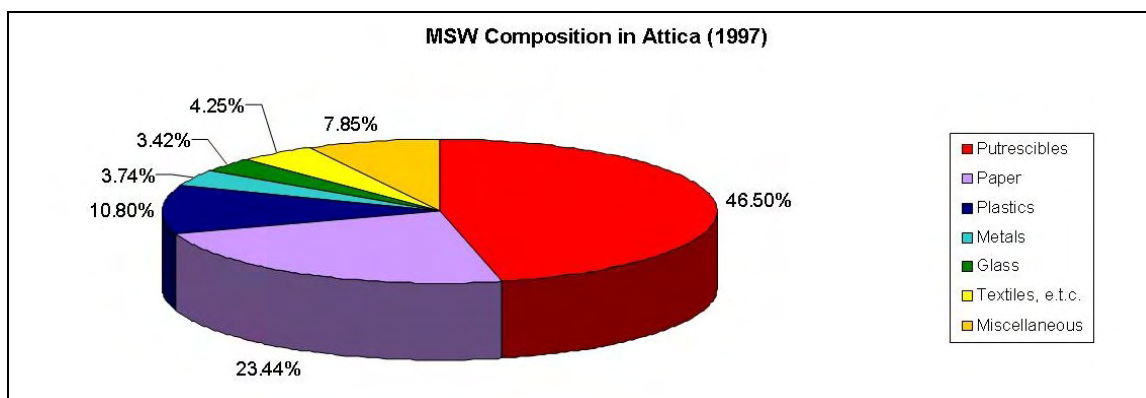
generated non-hazardous industrial and/or commercial wastes were taken into consideration when determining the quantities of MSW produced in each OLA.

#### 4.4.2 Composition

The following Table shows the changes in MSW composition over time and the projected composition for 2005, which was based on information provided by the Association of Communities and Municipalities of Attica Region (ACMAR; ΕΣΔΚΝΑ in Greek). In 1997, it consisted of 46.5% organic wastes, 23.4% paper, 10.8% plastics, 3.7% metals, 3.4% glass, 4.3% textiles, rubber and wood, and 7.9% other types of wastes. According to ACMAR, it was expected that by 2005 the percentage of paper and plastics would increase, while that of the remaining types of MSW would decrease. Figure 4.11 shows the composition of MSW in Attica in 1997.

**Table 4.10 Change in MSW composition of Attica over the years<sup>(52)</sup>.**

Types of wastes	1982	1985	1991	1997	2005
Putrescibles (%)	55.76	56.50	48.50	46.50	40.00
Paper (%)	23.28	20.00	22.00	23.44	32.00
Plastics (%)	9.20	7.00	10.50	10.80	13.00
Metals (%)	4.22	4.00	4.20	3.74	3.50
Glass (%)	2.79	2.70	3.50	3.42	2.50
Textiles, Rubber, Wood, e.t.c. (%)	n/a	4.30	3.50	4.25	3.20
Miscellaneous (%)	4.75	5.50	7.80	7.85	5.80
* n/a: not available					



**Figure 4.11 MSW composition in Attica in 1997<sup>(52)</sup>.**

Table 4.11 presents the composition of MSW at certain representative OLAs of Attica, their weighing coefficients ( $\varphi$ ) with regard to population and the resultant total composition of MSW of Attica in 2006. Figure 4.12 shows the average composition of Attica MSW in 2006, as it was determined by this study.

**Table 4.11 Composition of MSW in municipalities of Attica.**

OLA	Putrescibles (%)	Paper (%)	Plastics (%)	Metals (%)	Glass (%)	Textiles, Rubber, Wood, e.t.c. (%)	Miscellaneous (%)
Acharnae*	48.38	22.29	9.68	4.15	3.67	4.33	7.5
$\varphi = 8.85$	4.279	1.972	0.856	0.367	0.325	0.383	0.663
Aghios Ioannis Rendis	60	15	5	n/a <sup>#</sup>	1	10	9
$\varphi = 1.11$	0.666	0.167	0.056	-	0.011	0.111	0.100
Alimos	40	20	15	5	5	5	10
$\varphi = 3.41$	1.362	0.681	0.511	0.170	0.170	0.170	0.341
Ambelakia	50	10	20	5	5	5	5
$\varphi = 0.63$	0.314	0.063	0.125	0.031	0.031	0.031	0.031
Anavyssos	97	1	n/a	1	n/a	n/a	1
$\varphi = 0.43$	0.415	0.004	-	0.004	-	-	0.004
Anixi	48.5	22	10.5	4.2	3.5	n/a	11.3
$\varphi = 0.50$	0.241	0.109	0.052	0.021	0.017	-	0.056
Athens	40	32	13	3.5	2.5	n/a	9
$\varphi = 56.91$	22.764	18.212	7.398	1.992	1.423	-	5.122
Cryoneri	60	20	n/a	n/a	n/a	5	15
$\varphi = 0.44$	0.265	0.088	-	-	-	0.022	0.066
Galatsi	80	5	n/a	5	n/a	n/a	10
$\varphi = 5.90$	4.718	0.295	-	0.295	-	-	0.590
Hydra	25	20	20	20	10	5	0
$\varphi = 0.19$	0.048	0.038	0.038	0.038	0.019	0.010	0
Ilion	30	15	10	5	5	30	5
$\varphi = 7.24$	2.172	1.086	0.724	0.362	0.362	2.172	0.362
Kifissia*	45.52	25.12	11.61	4.46	3.78	3.79	5.72
$\varphi = 4.42$	2.013	1.111	0.514	0.197	0.167	0.168	0.253
Marcopoulo Oropou	50	10	20	5	5	10	0
$\varphi = 0.29$	0.144	0.029	0.057	0.014	0.014	0.029	0
Metamorphosi	50	10	5	5	2	20	8
$\varphi = 1.95$	0.975	0.195	0.098	0.098	0.039	0.390	0.156
Nea Chalkidona*	46.91	23.20	11.07	4.59	3.42	4.11	6.70
$\varphi = 0.75$	0.349	0.173	0.082	0.034	0.025	0.031	0.050
Nickaia	47	21	12	12	4	3.5	0.5
$\varphi = 6.86$	3.222	1.440	0.823	0.823	0.274	0.240	0.034
Varnava	80	2	2	2	2	2	10
$\varphi = 0.15$	0.118	0.003	0.003	0.003	0.003	0.003	0.015
<b>ATTICA</b>	<b>44.06</b>	<b>25.66</b>	<b>11.34</b>	<b>4.45</b>	<b>2.88</b>	<b>3.76</b>	<b>7.84</b>
* Reference 178							
# n/a: not answered							

By comparing the composition of Attica's MSW in 1997 (Table 4.10) and 2006 (Table 4.11) one can observe increase of the percentage of paper, plastics and metals; and reduction of putrescibles, glass, textiles, rubber, and wood. Generally, the trend of change

of the MSW composition is in accordance with the projections for 2005 by ACMAR (Table 4.10); nevertheless, the actual values diverge slightly from the projected.

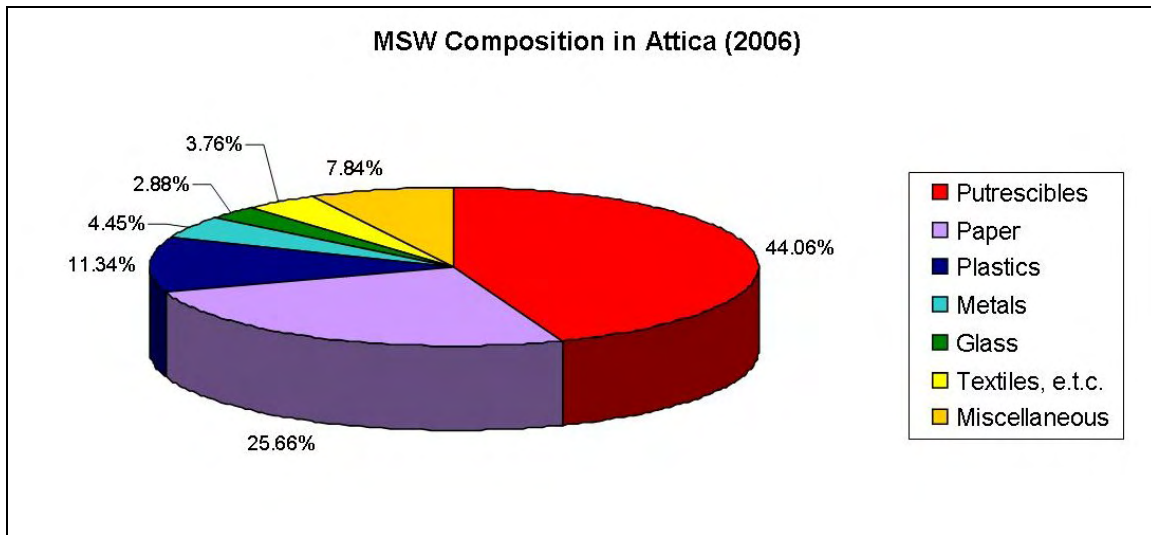
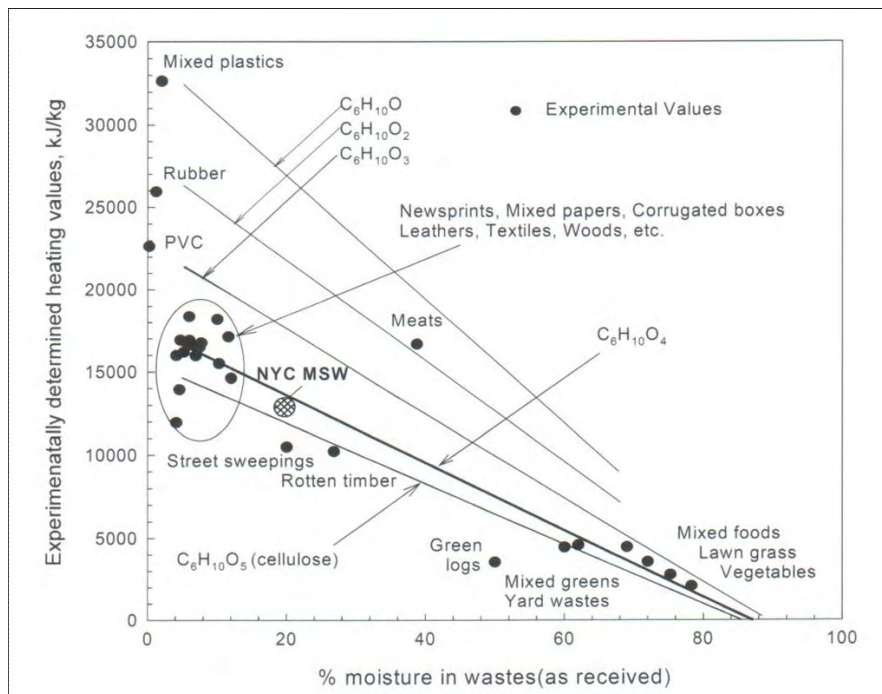


Figure 4.12 MSW composition in Attica in 2006.

#### 4.4.3 Lower Heating Value

Based on the MSW composition (Table 4.11) and on the LHV of Greek MSW (Table 4.6), the average LHV of Attica's MSW was calculated to be 12,670 kilojoule per kilogram, a value higher than that determined for the MSW of the entire country.



Compared to the experimental data shown at Figure 4.13, the LHV of Attica's MSW is lower than that of New York City. This is due to the fact that it contains large amounts of putrescibles and, thus, is characterized by higher moisture.

Figure 4.13 Comparison of experimental heating values of various waste materials (Hollander, Tchobanoglous, 1980). Lines show thermochemical values for respective  $C_6H_{10}O_x$  materials<sup>(60)</sup>.

#### 4.4.4 Management System

Developments that took place during the period of 1990 – 1999, including the implementation of the “Ioannis Kapodistrias” Program (merging of Local Authorities) in Greece and the construction of waste management facilities in the Prefecture of Western Attica, played an essential role in establishing organized SWM systems in Attica.

In 1970, ACMAR was established to manage the collection, recycling and disposal of solid wastes in Attica. Since then, it undertook all the activities required to implement a successful SWM system, including MRFs, WTSs and suitable locations for sanitary landfills. Currently, ACMAR handles the MSW generated at 87 OLA-members (73 municipalities and 14 communities), which are shown in Figure 4.14 and are listed in Appendix C. In average, ACMAR collects 6% of the income of each OLA-member in order to manage its MSW. The OLAs that are not served by ACMAR have organized autonomous SWM systems or have assigned the relevant activities to private companies.

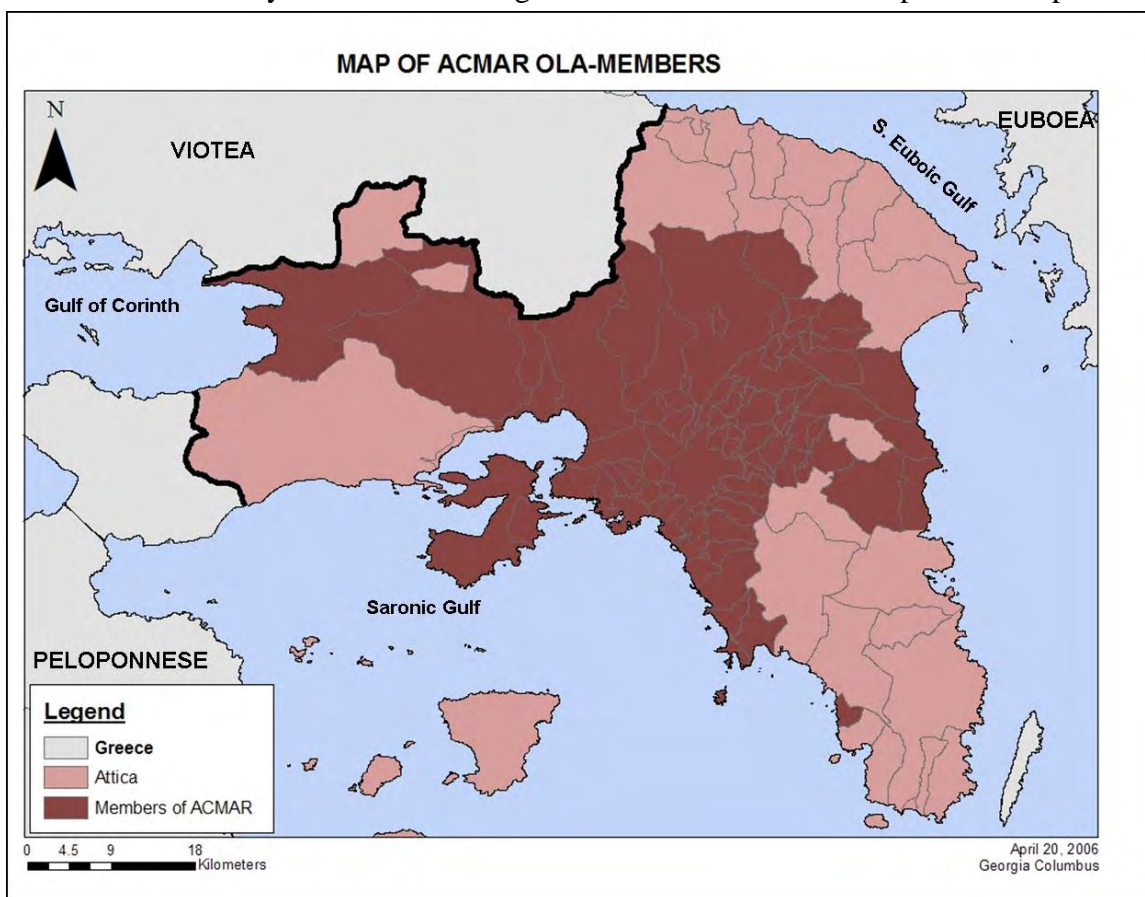


Figure 4.14 OLA-Members of ACMAR.

The Regional Plan for SWM for the period of 2000 – 2006, focused on the application of a rational management system that embodies archiving data; organized collection; safe transportation; appropriate processing; efficient recycling; high material

recovery; and proper disposal of solid wastes. Attention was given also to the remediation of the land that had been subjected to uncontrolled waste disposal and pollution.

The expenditure for SWM in the Region of Attica amounted to \$123.9 million (€7.3 million) for the period of 1994 – 1999. According to MEPPPW, \$1.5 million (€1.2 million) and to \$2.8 million (€2.2 million) were spent on the management of non-hazardous solid wastes in 2002 and 2005, respectively. The respective expenses for 2006 are estimated to reach the amount of \$3.2 million (€2.5 million)<sup>(134)</sup>. It must be noted that these values refer to projects included in the National Plan, as well as the Regional OEP.

#### 4.4.4.1 Temporary Storage

Generally, the MSW generated in households are deposited by citizens into bins or containers placed throughout the Region for their short-term storage. The bins are



Figure 4.15 Metallic bin.

metallic or plastic and have a capacity ranging from 0.66 to 1.10 cubic meters.



Figure 4.16 Plastic bin<sup>(147)</sup>.

Another less commonly used system for temporary storage of MSW consists of fixed containers, which are partially (65%) underground, as shown in Figure 4.17. The containers are placed at an average depth of 1.6 meters and have a height of 1.1 meters from the surface of the earth. Their shape is cylindrical with a diameter of 1.4 meters. These containers hold reusable sacks, in which recyclable bags are contained. The waste is thrown into the recyclable bags and is compressed due to gravity.

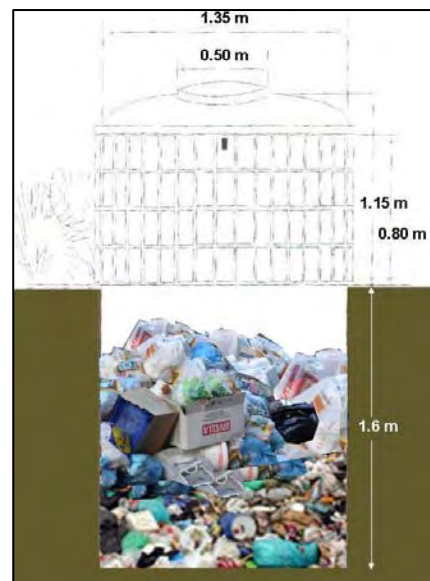


Figure 4.17 Underground Container (based on Reference 55).

After the bags are filled, cranes remove the sacks, place the recyclable bags into open trucks for their transportation and reinstall the sacks with new empty recyclable bags in the container<sup>(55)</sup>.

This system has been applied at the municipality of Aghii Anargyri since 1996. Currently, the municipality is served by 261 containers of capacity 3 cubic meters. Also, two containers of this type with a capacity of 20 cubic meters have been placed at the municipality of Lavreotiki.

#### 4.4.4.2 Collection, Transfer and Transport

The temporarily stored MSW of Attica Region are collected by more than 780 collection trucks of various types. The typical types used are rear-loader trucks, equipped with rotating drums or compactors. Their capacity ranges from 2 – 22 cubic meters, depending on the amount of MSW that they collect. Other types of collection trucks less commonly used are side-loaders and open trucks.

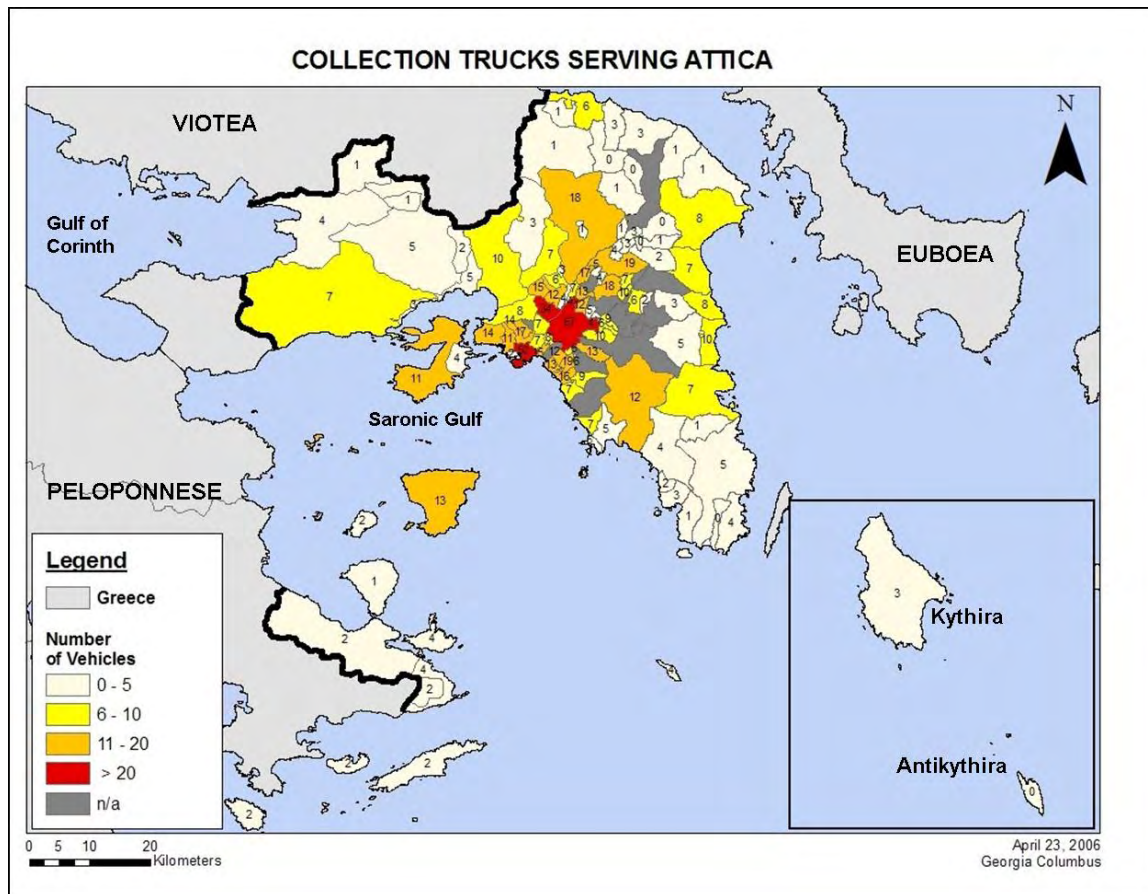


**Figure 4.18 Typical waste collection trucks.**

Most of the OLAs of Attica's Region own MSW collection trucks. Other OLAs, such as the communities of Stamata and Drossia, have assigned the collection and transportation of their MSW to private companies. Figure 4.19 shows the number of collection trucks serving each OLA.

The trucks usually collect MSW during the night or early in the morning. Depending on the quantity of MSW generated in each OLA, the frequency of waste collection ranges from 1 to 3 routes per day and 1 to 7 days per week. After the collection

is completed, the waste is transferred to WTSs, sorting plants, recycling facilities or waste disposal sites.



**Figure 4.19** Number of collection trucks serving each OLA.

#### 4.4.4.3 Processing and Resource Recovery

In general, numerous attempts towards recycling have been made by local authorities, public institutions and private companies.

Occasionally, recycling projects have been implemented at several OLAs. For example, the municipality of Athens launched a pilot recycling project in 2005, which included using three different companies to collect recyclable wastes in different ways and the establishment of automated recycling machines, also known as “recycling centers”. These machines gather pure material only, as they are programmed to reject unsuitable wastes<sup>(111)</sup>.

Figure 4.20 illustrates a recycling machine that operates in the municipality of Athens, while Figure 4.21 shows the OLAs that participate in recycling projects today. These endeavors, however, are usually ineffective, mainly due to their small size, lack of organization and/or insufficient advertisement.



Figure 4.20 Recycling Machine.

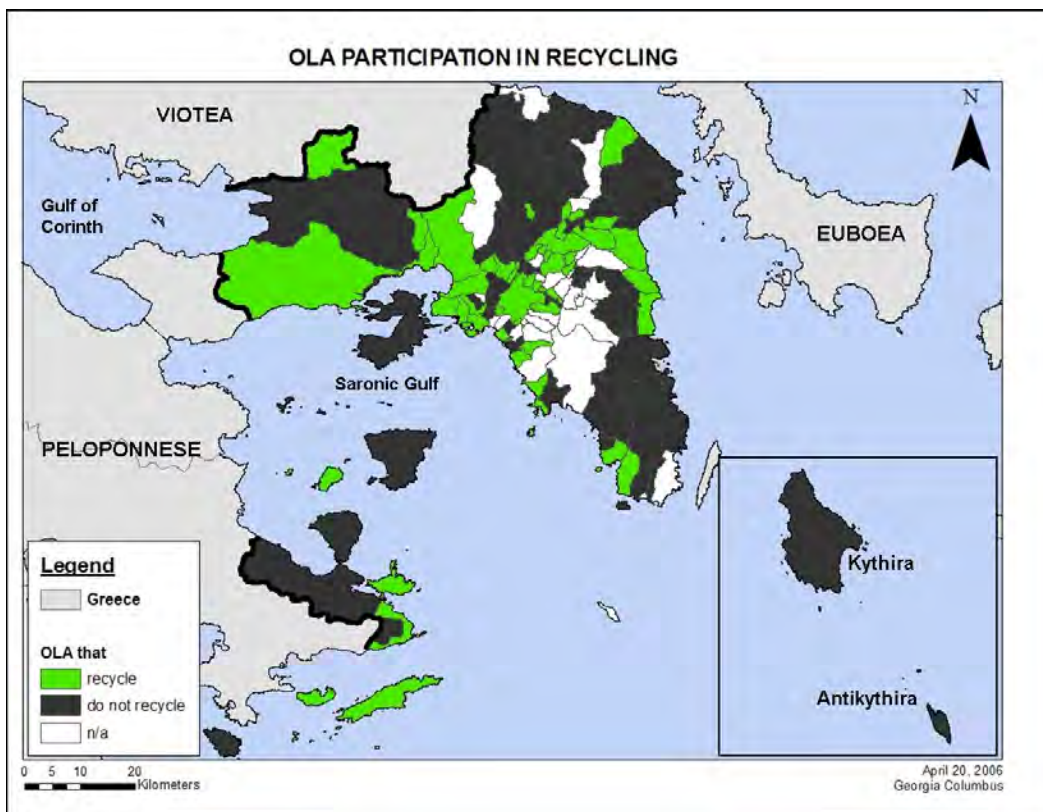


Figure 4.21 Map of OLAs that participate in recycling.

Furthermore, special bins for recyclable materials, such as paper, batteries and aluminum cans, have been placed on the streets and at numerous schools. This plays an essential role not only in recycling as an action, but also in teaching children the importance of recycling to Sustainable Development.

An illustration of the encouragement towards recycling in the private sector is that made by the supermarket chain “AB Vassilopoulos” that operates 53 stores in Attica Region. Since 2004, it has initiated the installation of recycling machines, similar to those shown in Figure 4.20. In addition, AB Vassilopoulos offers discounts to shoppers who recycle.



Figure 4.22 Paper-collection truck of ACMAR<sup>(136)</sup>.

A more systematic recycling practice is employed by ACMAR, which runs a paper-recycling program since 1994 and has placed 3,400 special containers at its OLA-members. This effort results in the collection of about 10,000 tons of paper annually<sup>(154)</sup>. ACMAR also manages the biggest recycling facility in Europe, located at the municipality of Ano Liossia, about 20 kilometers northwest from the center of Athens.

Finally, an organized two-stream recycling program was initiated by the Hellenic Recovery and Recycling Corporation (HERRCo; EEAA in Greek) in December 2001. Recycling bins for the storage of packaging wastes have been placed beside regular bins for the temporary storage of MSW, at the participating OLAs. After collection, the recyclables are transferred to sorting facilities. Currently, there are two such plants operating under HERRCo. One is located at the municipality of Maroussi and will be described in more detail below. The other facility is located at the municipality of Aspropyrgos and is now under works for its expansion.



Figure 4.23 Bins for recyclables of HERRCo.



Regarding composting, since 2003 only three OLAs out of the 122 of the Region have encouraged and are practicing successfully home-composting pilot projects in cooperation with Ecological Company of Recycling: Maroussi, where 11 composting bins were installed; Elefsina, where the municipality funded the installation of 60 bins; and Anixi that funded 50% of the program. The bins used for composting by these OLAs are shown in Figure 4.24.

**Figure 4.24 Bin for home-composting –Ecological Company of Recycling<sup>(154)</sup>.**

Moreover, the National Technical University of Athens (NTUA) ran another pilot project, “LIFE – Environment COMWASTE”, in cooperation with the OLAs of Acharnae, Kifissia and Nea Chalkidona during the period of 2003 – 2005. The prototype home-composting system that was designed by NTUA for this project is shown in Figure 4.25. It consists of a reactor vessel isolated from the feeding system; an agitation system; a structure allowing the continuous collection of the compost and leachate; and an odor control system.



**Figure 4.25 Bin for home-composting designed by NTUA<sup>(178)</sup>.**

Finally, a Composting Facility, more information on which will be further provided, is operated at Ano Liossia by ACMAR.

#### 4.4.4.4 Waste Disposal

All the MSW generated in Attica Region were discarded at UWDSs until the construction of the largest sanitary landfill in Europe, which is located at the municipality of Ano Liossia in Western Attica Prefecture.

According to data acquired in this study, approximately 89.55% of the total MSW generated in the Region is disposed at the sanitary landfill of Ano Liossia that serves 91 OLAs (Figure 4.26). The remaining 10.45%, collected at 33 OLAs, is transferred to 24 recorded UWDSs (March 2006). Figure 4.27 shows the location of all the waste disposal sites of the Region of Attica.

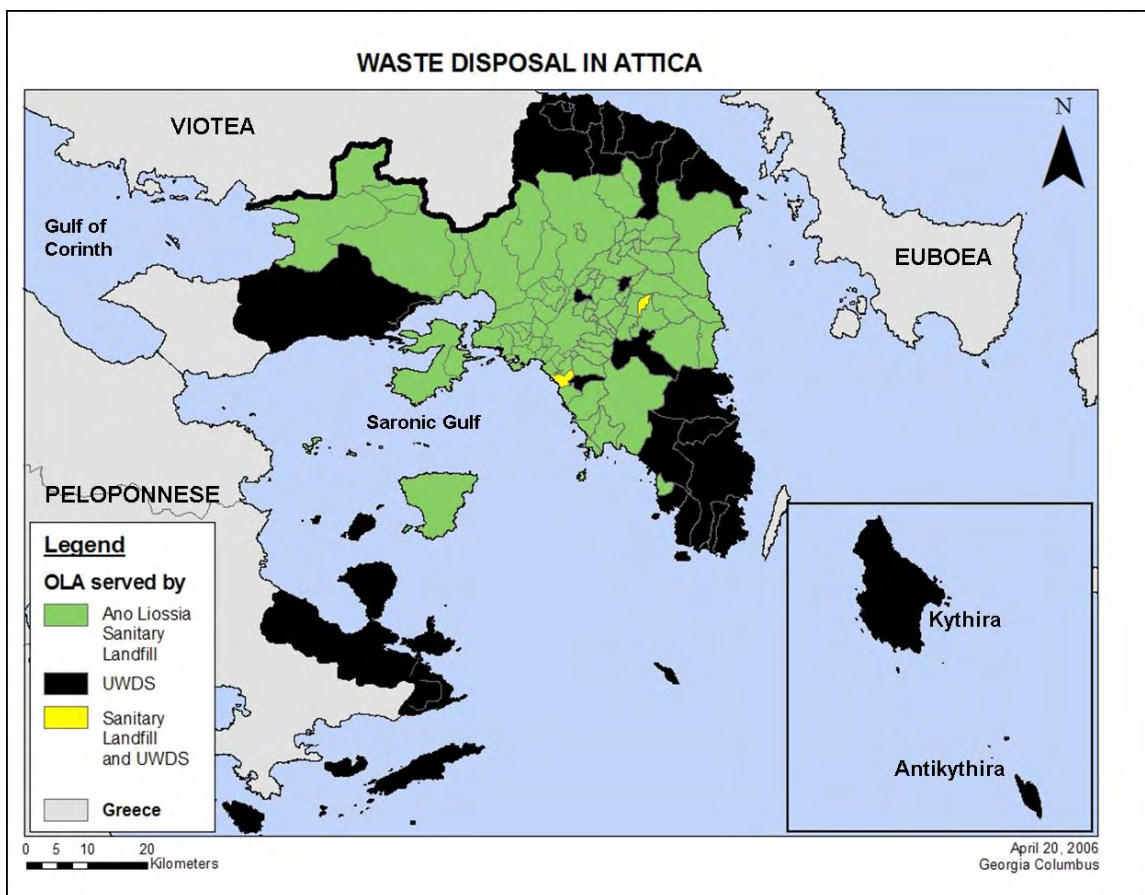


Figure 4.26 Map of OLAs served by waste disposal sites.

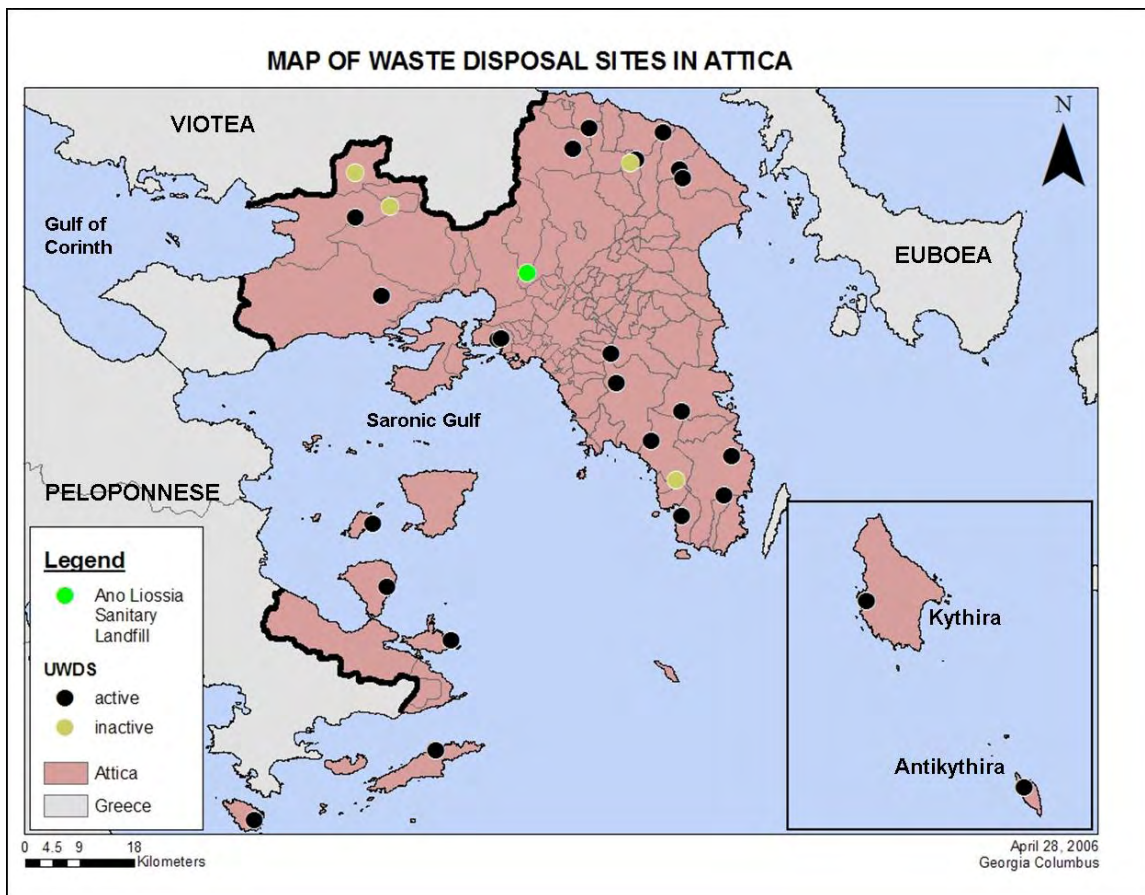


Figure 4.27 Map of waste disposal sites in Attica Region (based on Reference 45).

The most important waste management facilities of Attica Region are described analytically in the following section.

## 4.5 EXISTING WASTE MANAGEMENT FACILITIES IN ATTICA

### 4.5.1 HERRCo Sorting Facility at Maroussi

#### 4.5.1.1 General Information

HERRCo is a non-profit organization that was established in 2001 by industrial and commercial companies that are distributors of packaged products to the Greek market or manufacturers of various types of packaging. The equity capital is owned 35% by the Central Association of Municipalities and Communities of Greece (CAMCG; ΚΕΔΚΕ in Greek). Some of the other large shareholders are<sup>(28)</sup>:

- CHIPITA S.A.
- COCA-COLA 3E S.A.
- COLGATE PALMOLIVE S.A.
- FRIESLAND S.A.
- CROWN HELLAS CAN S.A.
- PEPSICO - IVI S.A.

- TETRA - PAK S.A.
- UNILEVER S.A.
- VPI S.A.
- ATHENIAN BREWERY  
(ATHINAIKI ZYTHOPIIA) S.A.
- YOULA S.A.
- DELTA S.A.
- ELAIS S.A.
- ELVAL S.A.
- ION S.A.
- KLIAFAS S.A.
- MEVGAL S.A.
- NESTLE S.A.
- PAPASTRATOS S.A.
- PROCTER & GAMBLE S.A.
- FAGE S.A.

HERRCo's mission is to promote recovery of packaging wastes by coordinating and reinforcing the participation of the responsible institutions, OLAs and citizens. Its objectives are to reduce the volume of waste sent to landfills, and to save energy and raw materials. More particularly, it aims to accomplish the recovery of energy at a minimum percentage of 60% by weight of packaging wastes, as well as the recycling of 55-80% by 2011, as required by the European Directives.

In order to achieve its goals, HERRCo organized the Collective Alternative Management System – “RECYCLING” (CAMS – RECYCLING), which is approved by MEPPPW and relates to the collection, transfer, reuse and recovery of packaging wastes. With this program, the OLAs can obtain the support required to develop and operate effectively financially feasible recycling programs.

HERRCo uses money from contributions made by the 826 companies-members and allocates it appropriately for the carrying out of target-projects of its collective system. The budget of the CAMS is approximately \$50.9 million (€40 million), provides for the recovery of 268,000 tons of recyclable material in the entire country and serves 4.5 million inhabitants.

In the framework of the implementation of its operational plan, HERRCo has developed 10 recycling projects that operate in various parts of Greece, such as Attica, Patras and Zakynthos, which were the first facilities to be constructed. Furthermore, it has undertaken six more projects in other parts of Greece, such as Aspropyrgos, Eastern Salonica, Corfu and Crete that are expected to be completed in 2006.

#### 4.5.1.2 Maroussi Sorting Plant

The specific recycling program of HERRCo started as “The Project of eight Municipalities”, but the number of OLAs that are involved continues to grow. In February 2006, the participants were 13 OLAs: Maroussi, Vrillissia, Melissia, Pefki,

Philothei, Chalandri, Kifissia, Lykovryssi, Nea Erythraea, Neo Psychiko, Anixi, Dionyssos and Nea Pendeli.

Maroussi HERRCo facility (Figure 4.28) was constructed in 1996 and currently serves approximately 398,000 inhabitants. It occupies an area of about 10,000 square meters and employs 25 people, 10 of whom are working on the manual separation of the incoming packaging wastes.



**Figure 4.28** Entrance of Maroussi HERRCo facility.

The facility accepts materials 18 hours per day, 6 days per week from the OLAs with which it has contracts. According to the Project Engineer, Mr. Ioannis Kolokythas, it receives currently approximately 50 tons of packaging wastes per day, i.e. 15,600 tons annually.

The materials are collected from the special bins placed at each OLA-member by regular collection trucks of capacity 16 cubic meters, two or three times weekly, and are delivered to the sorting facility. After the trucks enter the facility, they are weighed on an electronic scale (Figure 4.29) and are automatically directed to the tipping floor, where the waste is discharged. The reception and sorting areas are housed in a single closed building.



**Figure 4.29** Weighing scale at HERRCo Facility.

After the withdrawal of cardboards from the incoming wastes, the waste is fed to a conveyor belt in order to be manually sorted in metals, plastics, paper, glass and non-recyclables, which are put in different storage containers (Figures 4.30 – 4.32). The

plastics are separated to polyethylene, film, and mixed plastics; while paper is separated to cardboards, white paper, and mixed paper, consisting of magazines, newspapers and packaging cartons (i.e. milk cartons). The metals, plastics and paper are then carried to a baling machine, where they are compressed into bales that are sold to recyclers in Greece and abroad.



Figure 4.30 Container for mixed plastic.



Figure 4.31 Container for mixed paper.

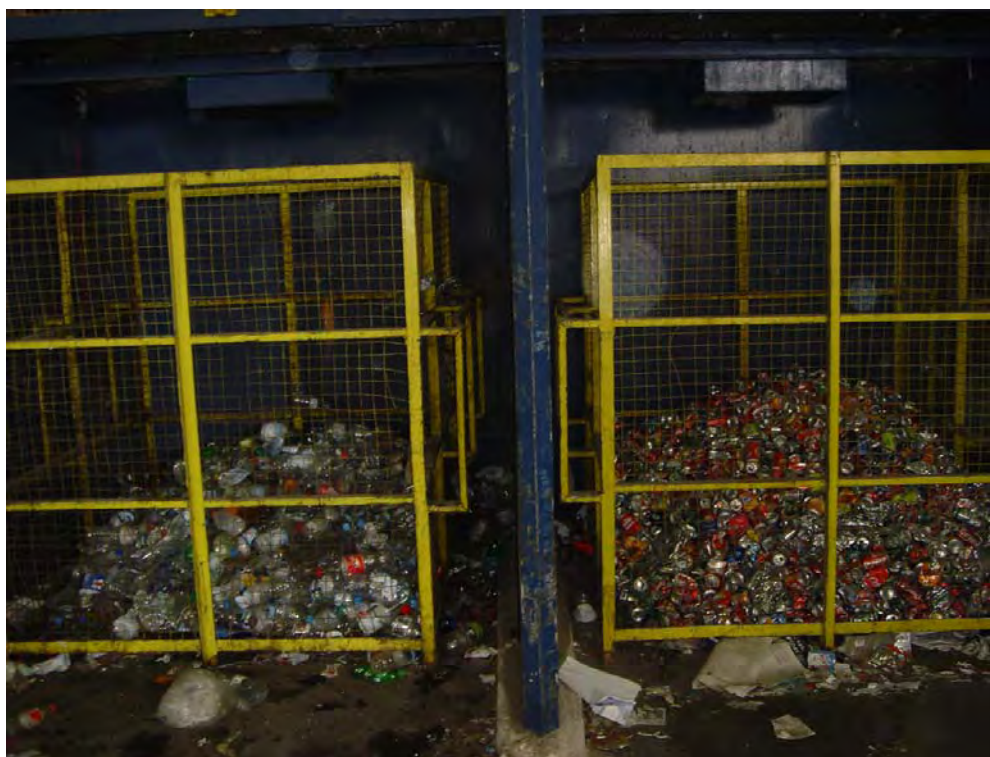


Figure 4.32 Containers for plastic bottles and aluminum cans.

Figure 4.33 shows the baling machine, on the right part of which one can see bales of white paper that have a relevantly high market value, because of the paper's high quality. Figure 4.34 shows bales of plastic bottles as they exit the baling machine.



**Figure 4.33** Bailing machine.



**Figure 4.34** Bales of plastic bottles.

Figure 4.35 shows the interior of the facility as seen from the entrance. From the left to the right, one can see the tipping floor, the conveyor belt and people manually sorting the incoming wastes.



**Figure 4.35 Interior of Maroussi HERRCo facility.**

The aluminum cans are transferred for further processing to the nearby Recycling Center for Aluminum Cans since it started operation in January 2004<sup>(128)</sup>. The products of



the recycling center are bales of 100% aluminum cans (Figure 4.37) and bales of cans made of mixed metals (Figure 4.38). The specific recycling center buys the aluminum cans at \$1.27 (€1) per kilogram, while it sells it at \$1.66 (€1.3) per kilogram.

**Figure 4.36 The Recycling Center for Aluminum Cans at Maroussi<sup>(128)</sup>.**



**Figure 4.37 Bales of aluminum cans.**



**Figure 4.38 Bales of cans made of mixed metals.**

The sorted glass is stored in large containers (Figure 4.39) and then, delivered to other facilities for further sorting depending on its specific gravity. Finally, the non-recyclables, which are estimated to represent 30% of the incoming materials by weight, are transferred to the sanitary landfill at Ano Liossia.



**Figure 4.39** Container for mixed glass.

## **4.5.2 Mechanical Recycling and Composting Facility**

### **4.5.2.1 General Information**

In 1997, ACMAR initiated the construction of the MRCF next to the existing at that time uncontrolled landfill at Ano Liossia. The joint-venture of EMPEDOS S.A., KRUGER A.S., KORONIS S.A., ENVITEC S.A. and A. ZACHAROPOULOS S.A. undertook the design and construction of the facility.

KRUGER International Consult A.S. (Denmark) is an international consulting company specializing in environmental engineering, providing consulting services with regard to management and development of water resources, water supply (including water treatment), sewerage and wastewater treatment, and industrial environment (including cleaner technologies). The parent company, KRUGER A.S., was founded in 1903, and is one of the largest environmental engineering companies in Denmark with broad international experience.

KORONIS S.A. is part of ENVI LTD, a company that provides services for the study/design, special construction and trade of systems for environmental protection.

ENVITEC S.A. is a company that undertakes construction and installation of building, hydraulic engineering, harbor, electromechanical, industrial/power, road building works, landscape works and wastewater and solid waste treatment. Also, ENVITEC S.A. is a pioneer in the construction of recycling plants in Greece.

A. ZACHAROPOULOS S.A. is a company that has been recognized in the construction industry as the “business associate for difficult tasks” and its name has been associated with the achievement of pioneering feats in special technical works in Greece.

The construction of the MRCF lasted approximately 6 years (1997 – 2003), and the costs of the entire project reached the amount of \$71.3 million (€6 million), exceeding the initial estimate of \$57.3 million (€45 million).

The MRCF is one of the biggest and most modern plants of its kind worldwide, having a “nameplate” capacity of 500,000 tons of commingled MSW per year. On an annual basis, it is designed to accept 375,000 tons of MSW; 40,000 tons of yard wastes or similar material for the control of the porosity of the organic fraction; and 85,000 tons of processed sludge from Psyttalia Wastewater Treatment Plant.



Figure 4.40 The recycling and composting plant (top view)<sup>(29)</sup>.

#### 4.5.2.2 Mechanical Recycling Plant

The collected MSW are brought into the facility by waste collection and transfer trucks, and are fed to three parallel lines, each consisting of a trommel drum, where the compostable portion is separated from the recyclable solids, followed by mechanical sorting equipment. The compostable products of the three lines are fed into a single composting unit.

According to the initial planning, the recycling plant would operate 10 hours per day, 6 days per week and process about 1,200 tons of waste daily. Its process philosophy is determined by the combination of ecological principles of recycling natural organic matter back to the soil and the need to take full advantage of the non-organic recycling products, either through thermal utilization with negligible environmental impact or through the re-introduction of materials back to the market and the production cycle. The projected<sup>(136)</sup> final marketable products of the waste processing were approximately:

- 360 tons per day of compost products, to be derived from processing of the compostable fraction of MSW, yard wastes, and processed sludge. Compost can be utilized for a variety of land uses, e.g. landscaping as soil conditioner in parks, in restoration of quarries and other similar uses.
- 350 tons per day of Refuse Derived Fuel (RDF) of 8% moisture with a calorific value of 10 megajoules per kilogram. RDF represents the most refined fuel form that can be obtained from mixed MSW. This fuel justified the investment of recycling plant and was projected to be financially advantageous to the conventional approach of mass-burning of solid wastes.
- 33 – 40 tons per day of ferrous and 5 tons per day of aluminum products were projected to be recovered for recycling. The compacted bales of ferrous and aluminum metals are to be used as raw materials in foundries and secondary smelters of the respective metals.

The useless side-products, estimated to exceed 330 tons daily, were to be directed to the adjacent sanitary landfill after their mechanical compaction, thus saving valuable space and increasing the landfill's life.

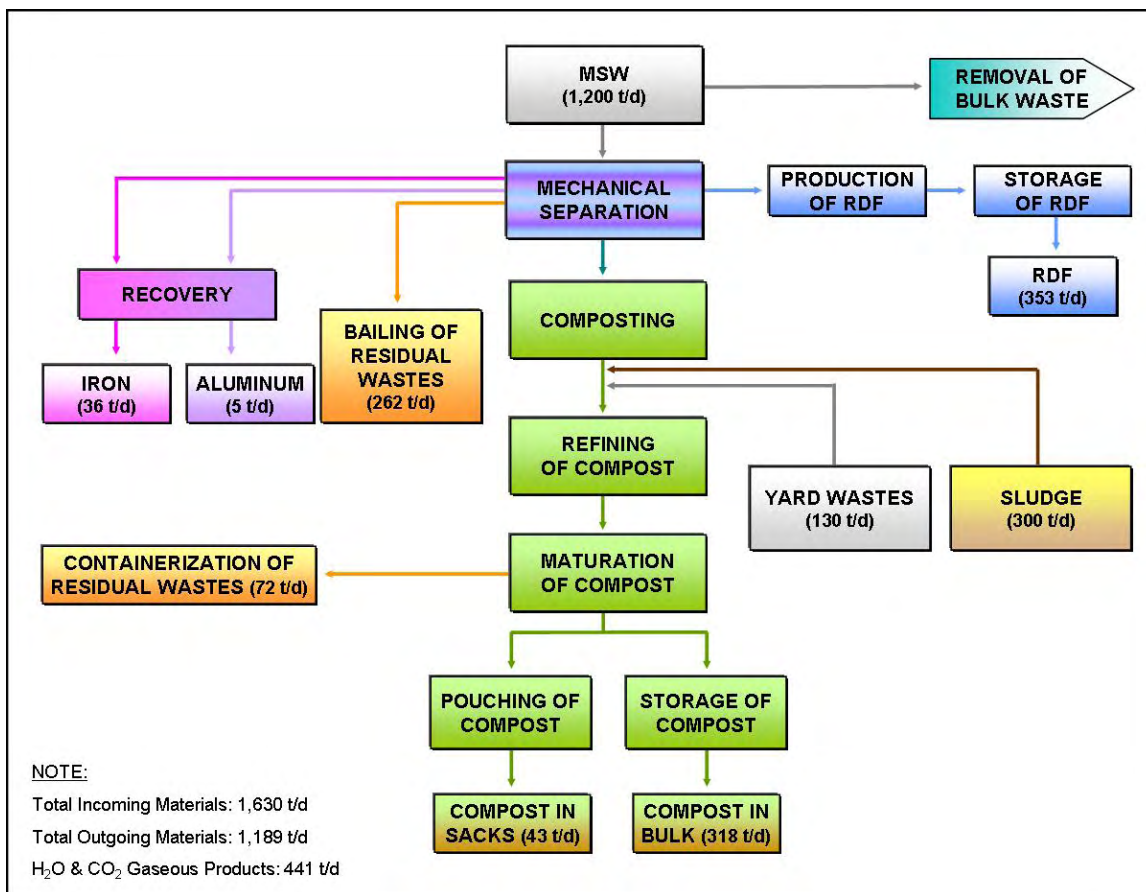


Figure 4.41 Schematic process diagram of MRCF (based on Reference 52).

The plant started operating the last week of July 2004. Until January 2005, only two of the three modules of mechanical sorting operated. The total amount of waste processed was 200 tons daily (16.7% of the planned capacity), resulting in the production of approximately 38 tons of compost, 30 tons of RDF, 750 kilograms of ferrous metals and 375 kilograms of aluminum. At that time, 100 tons of waste and 30 tons of RDF ended to Ano Liossia sanitary landfill daily. The only recyclable products were the ferrous and aluminum metals. In addition, five compost turners, as well as the refining unit at the plant were in operation. By March 2006, the facility did not reach its targets towards recycling. According to some experts, this is due to the installation of defective equipment. The situation is aggravated by landslides of the nearby landfill that occurred in the past (2003, 2005) and impeded normal operation of the facility.

#### 4.5.2.2.1 *Reception of Waste*

After the waste collection trucks enter the facility, they are weighed and automatically directed to the tipping floor. The waste is unloaded in large refuse bunkers (Figure 4.42), which are housed in a covered area and have sufficient capacity for peak loads. Then, it is fed by cranes into hoppers, from where it is dosed to the mechanical



sorting section. The reception and subsequent mechanical sorting processes are divided into parallel lines, which are housed in a single closed building equipped with the appropriate deodorization and dust-collection systems.

**Figure 4.42 Tipping Floor of MRCF<sup>(21)</sup>.**

The reception and feeding area of the sludge, yard wastes and other materials used for control of the porosity of the wet waste fraction (organic fraction, from which the compost is produced) is the same as that of the MSW. The sludge feeding line is divided into parallel dosing lines as well.

#### 4.5.2.2.2 *Mechanical Sorting of Waste*

As mentioned earlier, separation of solids from liquids; separation of ferrous and aluminum metals from the rest of the wastes; and baling of metals, RDF and residual wastes take place inside the mechanical sorting building, which occupies an area of 200,000 square meters.

For the separation of solids from the liquid fraction, the waste dose undergoes initial screening, which is followed by enrichment of solids with materials of high heating value. After this process, the product, which contains 20% water (half of the initial content), is compressed and baled for its future distribution as a fuel. The wastewater is further treated until it reaches the required criteria for blending with the sludge and subsequent feeding to the composting unit.

Along the dry fraction processing lines, ferrous and aluminum metals are extracted by magnetic and eddy-current separation, and are conveyed to the baling machines. Figure 4.43 illustrates the aluminum products that are compacted into bales, which are ready for distribution to the market.



Figure 4.43 Aluminum bales<sup>(21)</sup>.

The rejects produced at the intermediate stages of mechanical sorting are also collected and transferred on conveyor belts for pressing and baling, before their disposal to the adjacent sanitary landfill.

Figure 4.44 shows the residual wastes coming out of the baling machines. At the other end, loading trucks stand by to receive the bales in order to transfer them to the disposal site.



**Figure 4.44 Baling machines<sup>(21)</sup>.**

#### 4.5.2.3 Composting Plant

Composting, which is the aerobic degradation process induced by bacteria and fungi, takes place in parallel-process lines inside an enclosed and deodorized building. The homogenized fraction of organic wastes (of diameter smaller than 40 millimeters), sludge and porosity controlling materials are fed to the composting unit, and are spread in layers by a composting mixer (Figure 4.45) in aerating elongated channels (Figure 4.46), where they remain for several weeks for their stabilization.

The parameters that control the efficiency of the process are: (a) the initial composition of organic fraction; (b) the aeration; (c) the temperature and moisture; (d) the control of acidity – pH; and (e) the carbon-nitrogen (C:N) ratio.

It must be noted that the gases exhausted from the aerobic degradation are treated with chemical methods (scrubbing with  $H_2SO_4$ , NaOCl and NaOH). Also, the composting unit is equipped with a system suitable for collection of leachate deriving from the composted material that may be used either in remediation of old landfills or as a marketable product.



Figure 4.45 Composting mixer<sup>(21)</sup>.



Figure 4.46 Channels in the composting unit<sup>(21)</sup>.

#### 4.5.2.3.1 *Refining – Maturation*

The produced compost material undergoes refining, which is developed in parallel-process lines, until the desired quality is achieved. Refining is a process that removes foreign admixtures (glass, plastics, organic material), which reduce the commercial value of the compost.

After refining, the compost is led to the maturation area, where it remains in windrows for 4 weeks until the humification process is complete. During this period, the windrows are gradually mixed by front-loaders. Part of the mature compost is packaged and distributed for sale.

#### 4.5.2.4 Environmental Protection Measures

A wastewater treatment plant operates on site, where the treatment of sewage and the leachate produced in the facility takes place. Depending on the load and volumetric rates of air stream either biofilters or scrubbers are used for their purification. In addition, bag filters are used for the removal of dust.

#### 4.5.2.5 Other Facilities

The systematic maintenance of the facility's vehicles and machinery takes place in the maintenance building, which is provided with all the necessary equipment. There is also a special storage area, where spare parts of the equipment are stored. The administration building houses the chemistry laboratory, the control room and the personnel offices.

### 4.5.3 Medical Waste Incinerator

#### 4.5.3.1 General Information

The study for the construction of the Medical Waste Incinerator (MWI) was conducted during the period of 1999 – 2001 from the joint-venture of the companies TOMI S.A. and ANSALDO ENERGIA, which is headquartered in Genoa, northern Italy.

TOMI S.A. is an engineering office established in Athens in 1987. It undertakes infrastructure design works and consultant services for the public or the private sector in Greece and other foreign countries. Since July 1999, the company has a system of assured quality ISO 9001, which is certified by ELOT (EN ISO 9001) and the international quality network.

ANSALDO ENERGIA is a company with more than 100 years experience (since 1853) in power generation from projects accomplished in 90 countries all over the world. It covers the entire power generation spectrum with a combination of plant engineering, manufacturing and service activities. The company is involved with the design, construction and supply of plant solutions on different types of packages, such as turnkey, engineered and individual components.



**Figure 4.47 View of the MWI.**

The construction of MWI was completed in 2002 and the costs of the entire project were estimated to reach the amount of \$11.8 million (€3 million)<sup>(132)</sup>. In June 2002, it started operating in a trial mode, but it fully operates (24 hours per day, 7 days per week) since June 2004. The MWI has the capacity to process 30 tons of medical wastes daily, but it currently receives only 6 tons (from 63 hospitals) out of the 20 tons that are estimated to be produced at the Region's 127 hospitals. The remaining 14 tons are either

sterilized and then, disposed at Ano Liossia sanitary landfill; or are transferred to UWDSs<sup>(6)</sup>.

According to an article of the Greek newspaper “KYRIAKATIKI”, the tipping fee at the MWI is about \$2.6 (€2) per kilogram of incoming wastes, amount that includes the transportation costs. On the other hand, the sterilization of medical wastes costs approximately \$0.51 (€0.4) per kilogram of waste and therefore, is preferred by almost half of the hospitals in Attica. However, according to Mr. Mastorakos, head of ACMAR, the tipping fee will be much lower when the incoming wastes reach the plant’s capacity.

#### 4.5.3.2 Process Description

At the generation source, medical wastes are put into bags and then into cartons of capacity 5.4 cubic meters. Then, these cartons are transferred by special vehicles operated by ACMAR to the MWI, where they are weighed and stored at a temperature of 4 – 6°C for 2 – 3 days maximum.

The waste is then fed in two combustion lines of capacity 15 tons each, which can independently run in case of emergency. Then, hydraulic ram feeders push the waste into a single 6-meter long rotary kiln, which has a diameter equal to 2 meters and an inclination of 2°. The kiln has a smooth (non-perforated) interior fire-resistant surface to avoid any potential problems during the combustion, and turns at a relevantly slow speed (7.5 rotations per hour). Theoretically, the residence time of medical wastes in the kiln is 40 minutes.

Figures 4.48 and 4.49 show the stored containers and the rotary kiln of the MWI, respectively. Figure 4.50 presents the flow diagram of the processes that take place at the MWI.



Figure 4.48 Medical wastes in containers<sup>(6)</sup>.



Figure 4.49 Rotary kiln of the MWI<sup>(21)</sup>.

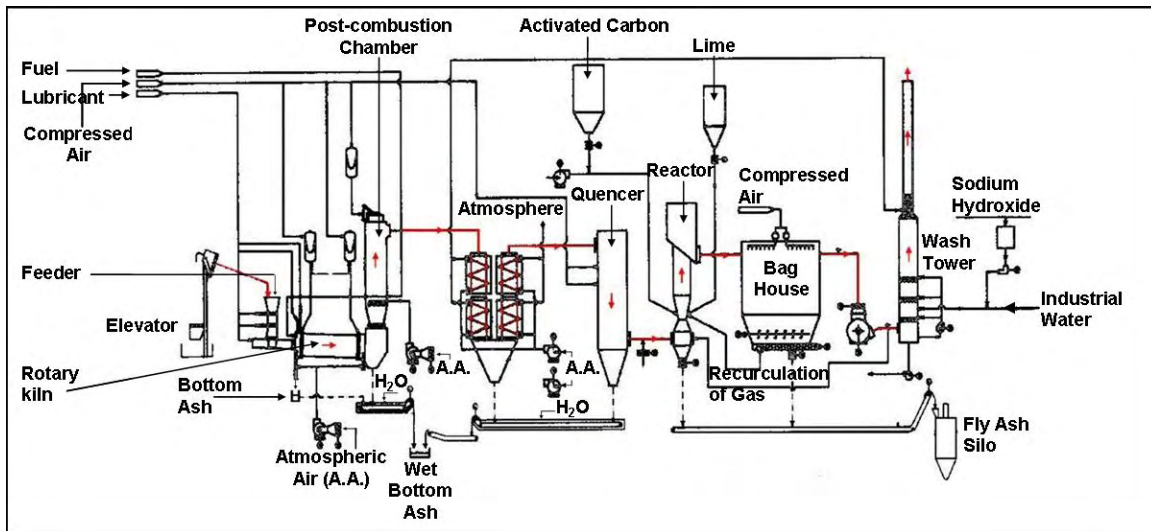


Figure 4.50 Flow diagram of the MWI<sup>(6)</sup>.

Because of their great importance, the issues regarding the air pollution control (APC) and ash management will be developed more analytically.

#### 4.5.3.2.1 *Air Pollution Control*

Before they are emitted to the atmosphere, the gases deriving from the incineration of medical wastes undergo a number of processes<sup>(6)</sup>:

After their production in the kiln, the gases enter the post-combustion chamber, a tower of 8 meters height, where they are treated with hydrogen chloride (500 milligrams per cubic meter HCl) at a temperature of 900 – 920°C (in some cases 850°C).

Then, they are being cooled at 450°C and subsequently sprayed with atmospheric gases at 180°C. This stage is followed by their entrance in the static reactor, where activated carbon (C) and lime ( $\text{Ca}(\text{OH})_2$ ) injection takes place at about the same temperature. In each module, 16 kilograms of lime ( $\text{Ca}(\text{OH})_2$ ) per hour are injected, which is equivalent to approximately 30 kilograms of lime ( $\text{Ca}(\text{OH})_2$ ) per ton of waste.

Then, the gases are led by two interior pipes to the wash tower, where they are mixed with sodium hydroxide (NaOH) for the extraction of dioxins from the gases and the reduction of the emissions of dust. It must be noted that the wash tower is very corrodible; therefore, it must be continuously monitored and frequently repaired.

Finally, the treated gases are either recirculated under turbulent flow to reenter the kiln, facilitating the combustion; or emitted to the atmosphere through the stack, the height of which is 20 meters.

Detectors have been placed in the stack, at about 4 meters below the point of exit of the treated gases to the atmosphere, in order to monitor their quality. These instruments provide continuous measurements of the gases' concentrations in carbon dioxide ( $\text{CO}_2$ ),

carbon monoxide (CO), sulphur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), Total Solid Particles and hydrogen chloride (HCl), as well as periodic measurements of their concentrations in dioxins, furans and mercury (Hg).

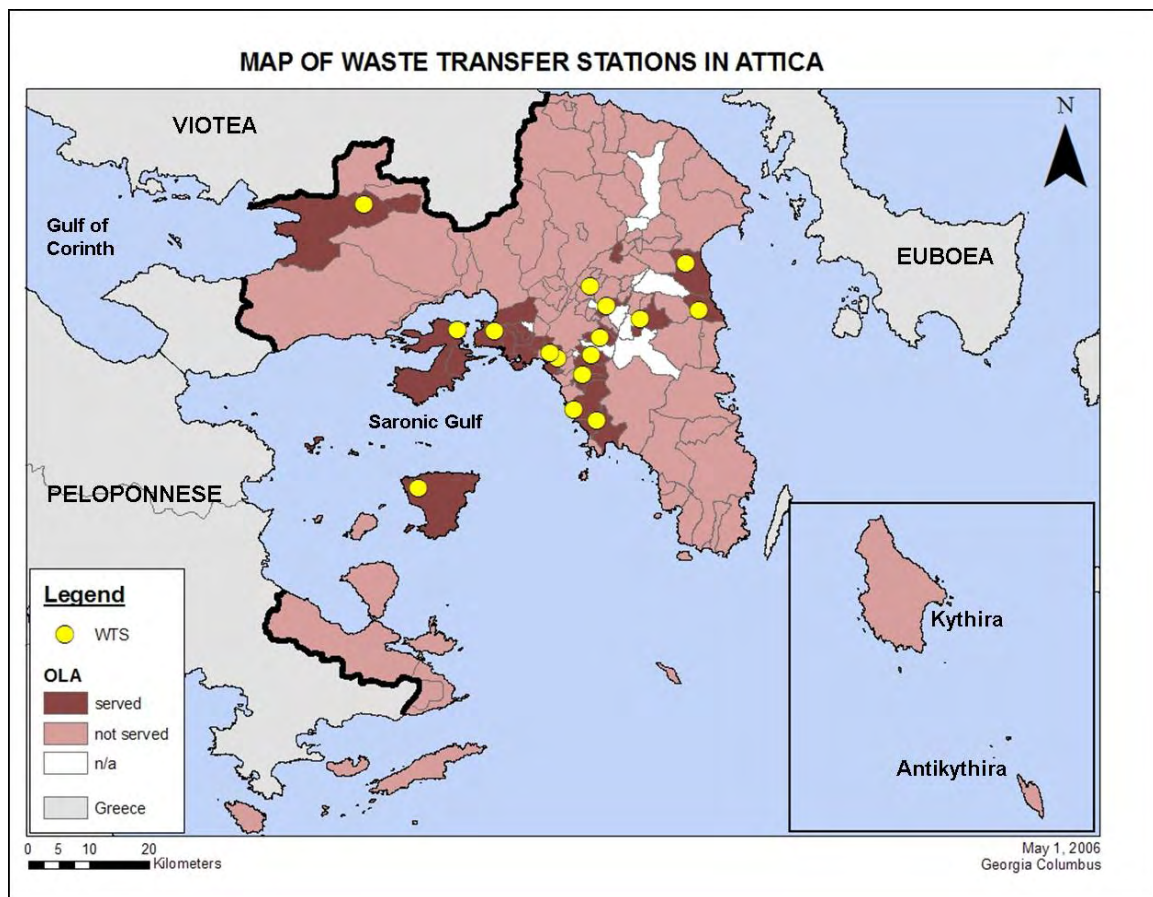
#### 4.5.3.2.2 *Ash Management*

The fly ash collected by the APC system that was described in the previous paragraph is considered as toxic; thus, cannot be disposed at Ano Liossia sanitary landfill.

The bottom ash produced from the combustion of the medical wastes is inert (non-toxic) and could be disposed at the sanitary landfill. However, this would reduce the volume of the buried waste that can produce landfill gas, which is collected for energy generation.

For this reason both types of ash are temporarily stored in special storage spaces until a decision is made for their disposal.

#### 4.5.4 Waste Transfer Stations



**Figure 4.51** Map of WTSs in Attica.

Currently, there are 16 WTSs operating at several locations of Attica Region (Figure 4.51), serving 31 OLAs. The WTS that serves most of the OLAs is located at “Schisto” site of the municipality of Perama and is described below.

#### 4.5.4.1 “Schisto” Waste Transfer Station

The WTS at “Schisto” is the first one in Greece and the second largest in Europe. It started operating under ACMAR in 1991. It occupies an area of 34,100 square meters and has the capacity to receive 1,800 tons of MSW per day<sup>(136)</sup>, serving 11 OLAs of the Region of Attica.

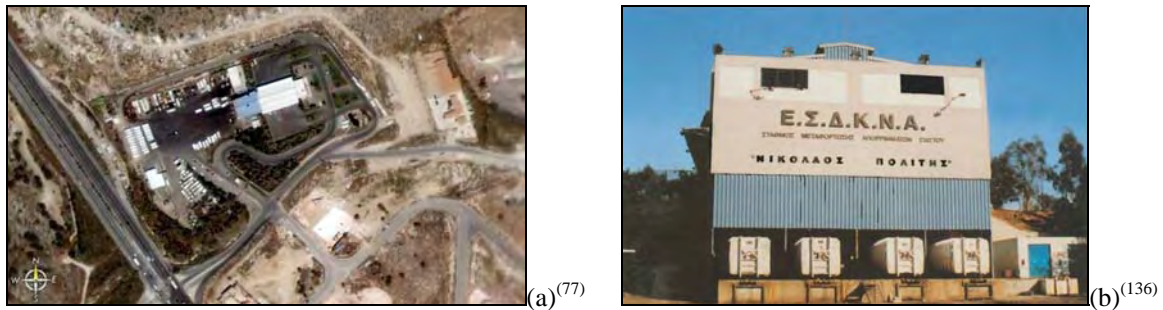


Figure 4.52 View of WTS at “Schisto”.

The closed building, which occupies an area of 1,800 square meters, has specially shaped receptors, where waste collection trucks unload their contents. The received MSW are compressed and then, placed into containers of capacity 18 – 20 tons in order to be transferred to Ano Liossia sanitary landfill<sup>(136)</sup>.

### 4.5.5 Ano Liossia Sanitary Landfill

The only sanitary landfill operating in the Region of Attica is that located at the municipality of Ano Liossia (Figure 4.27).

#### 4.5.5.1 General Information

Initially, there was an UWDS at that location, which had opened in 1965 and had received around 18 million tons of waste until 1995<sup>(8)</sup>. In 1996, it was transformed in a modern sanitary landfill, which had an area of 300,000 square meters and an initial capacity of 11 million cubic meters. EMPEDOS S.A. and KRUGER A.S. were two of the companies that were entrusted to prepare the location for its use as a sanitary landfill. Its construction was finished in 2003 at a total cost of about \$25.5 million (€20 million).

Nowadays, the sanitary landfill extends over an area of 2 square kilometers. At the beginning, the land was at an elevation of 70 meters, but now it has exceeded the height of 205 meters, which was set as the safety limit<sup>(34)</sup>. As past experience has repeatedly shown, overcoming this limit results in the occurrence of landslides, as those that took

place in 2003 and 2005, which partially destroyed the adjacent MRCF. According to experts, the sanitary landfill should have ceased operation since July 2005. Nevertheless, it continues receiving waste, due to lack of other controlled waste disposal sites.



**Figure 4.53** View of Ano Liossia sanitary landfill<sup>(29)</sup>.

The sanitary landfill receives an average of 6,930 tons of MSW, daily generated at 91 OLAs of the Region of Attica. Apart from MSW, the landfill receives other types of wastes, such as non-hazardous industrial wastes, and construction and demolition wastes, after certain procedures and subsequent approval.

According to Attica's former Regional Plan (2000 – 2001), the landfill's operational costs at that time reached \$26.1 (€20.5) per ton of MSW received. The tipping fee for unloading hazardous wastes on site is \$2.6 (€) per kilogram, while that of any other type of wastes is about \$36.7 (€28) per ton.



**Figure 4.54** The active cell of the sanitary landfill in 2005<sup>(21)</sup>.

It must be noted that the sanitary landfill includes leachate and LFG collection and treatment system, which are further described in detail; auxiliary facilities; and a

complete environmental monitoring program. Continuous observation and control of all the environmental parameters is employed in order to guarantee public health and prevent the environmental pollution from a possible leakage. This procedure involves sampling, recording of meteorological and other data, such as groundwater quality and possible LFG emissions, as well as continuous estimates of the volume and progress of subsidence of the area of the sanitary landfill.

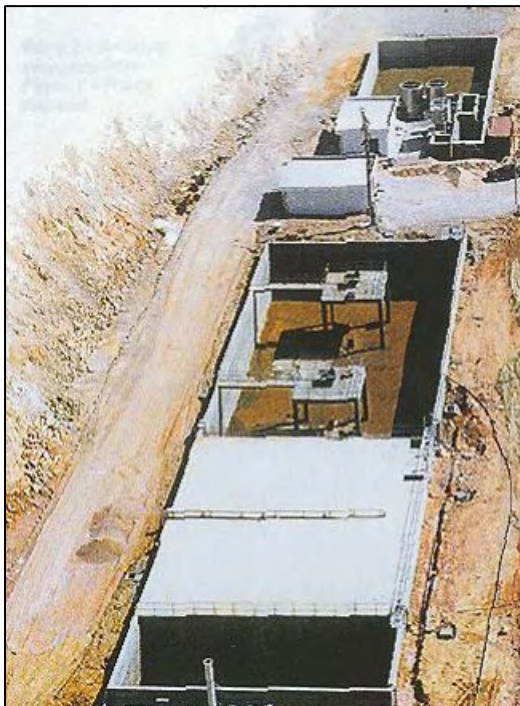
#### 4.5.5.2 Leachate Management

The leachate management system was designed in order to<sup>(27)</sup>:

- Maintain a minimal leachate head and to ensure landfill stability by continuous drainage of leachate throughout the landfill;
- Avoid the construction of vertical wells in the waste mass;
- Ensure the unproblematic monitoring of the leachate collection system; and
- Achieve full leachate treatment to a quality suitable for irrigation or disposal in the surface water collection system.

The base and sides of the landfill are lined with a drainage blanket. In order to uniformly drain the entire landfill, two main leachate collection pipes are installed at the base. Secondary perforated pipes are installed at areas, where slope changes. All drainage pipes are extended along the sides of the landfill towards appropriate inspection points, for monitoring and cleaning.

The aggregates used for the construction of the drainage layer mainly consist of gravel (16/32 millimeters) and were produced in situ using the limestone bedrock that



was excavated during the preparation works of the site. This carbonate material was selected after confirmation by laboratory leaching tests that it does not react when in contact with the leachate generated at the sanitary landfill.

Leachate flows from the main pipes to a central collection well, located outside the landfill. From this well the leachate is pumped to the Leachate Treatment Plant (LTP). The well is easily accessible, equipped with ventilation and gas traps, and allows the use of a camera-robot for monitoring the pipes.

Figure 4.55 View of the LTP<sup>(136)</sup>.

The LTP is located at the eastern part of the site. It incorporates primary settling and anaerobic treatment, which is followed by secondary treatment with sequencing batch reactor aeration. Finally, the tertiary treatment includes chemical precipitation and flocculation; sand filtering; and optional polishing with activated carbon (C). The processes that take place at the LTP are shown in Figure 4.56.

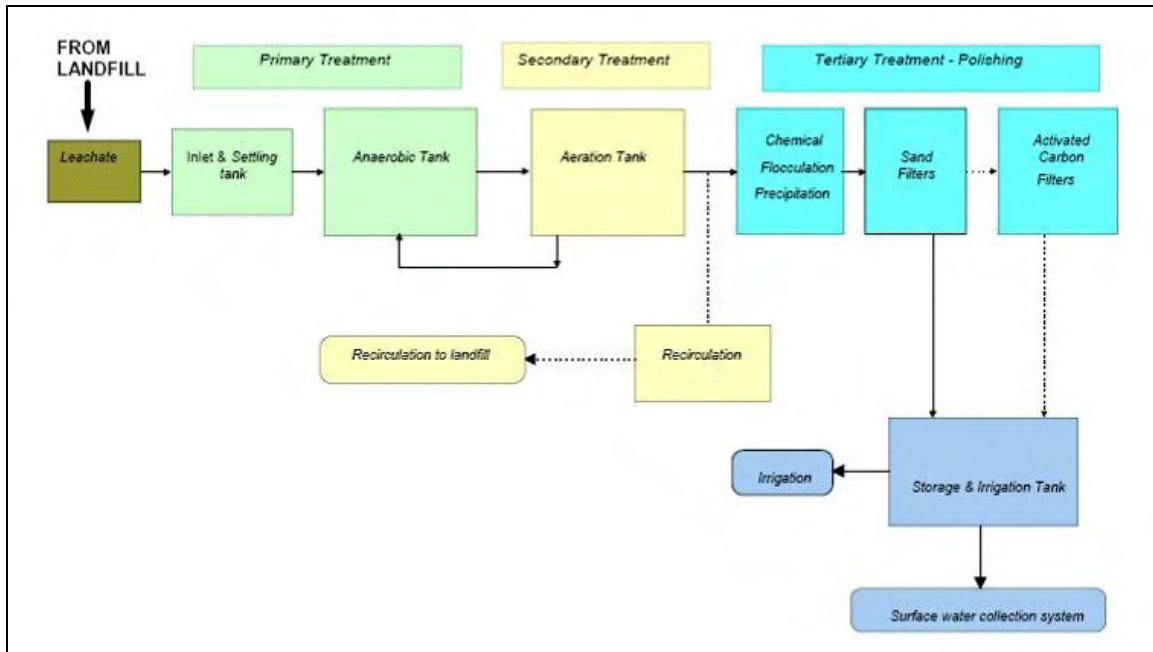


Figure 4.56 Schematic process diagram of LTP<sup>(27)</sup>.

The effluent is stored in a tank, from where it can be used for irrigating the plants of the revegetated areas of restored landfill surfaces, or may be disposed at the surface water collection system. Also, part of the effluent deriving from the secondary treatment is recirculated towards the landfill surface, following a special program relevant to the water balance of the landfill. Accordingly, biodegradation is promoted by maintaining adequate moisture in the waste volume. Recirculation is combined with the construction of a capillary barrier as a temporary landfill cover, which allows controlled moisture infiltration; thus, maintaining favorable conditions for rapid decomposition of waste and LFG production.

#### 4.5.5.3 Landfill Gas Management

##### 4.5.5.3.1 General Information

LFG is mainly a mixture of methane (49-52% CH<sub>4</sub>) and carbon dioxide (~ 44% CO<sub>2</sub>); as a consequence, its dispersion in the atmosphere has disastrous environmental impacts (greenhouse effect, danger of explosions and fires, negative impacts on flora)<sup>(6)</sup>.

The operation of the Cogeneration Power Station (CPS), which is located at the same area, was erected for the protection of the environment from the negative consequences of LFG generated at Ano Liossia sanitary landfill. Through the collection and combustion of LFG, the CPS conserves a significant quantity of fossil fuels by generating electricity and heat.

The construction of the CPS was a product of collaboration of the companies TOMI S.A. and ENERGY DEVELOPMENTS LIMITED, an Australian company that made its name over the past decade leading the field in energy generation from LFG by developing systems for its collection, cleaning and combustion in Caterpillar engines. The company has completed projects in USA, Europe and throughout Asia.

The construction of the CPS was funded by 40% by EU, while the remaining amount was supplemented by the municipality of Ano Liossia and the company TOMI S.A. in equal percentage. The capital costs reached the amount of about \$25 million (€19.7 million) and the amortization of the investment is estimated to be completed by 2007.



**Figure 4.57** View of the CPS<sup>(100)</sup>.

The CPS fully operates since September 2001 and is currently managed by HELECTOR S.A., a Greek construction company that is engaged in renewable energy and is affiliated with TOMI S.A. The LFG entrapment is achieved by a collection system

consisting of a grid of vertical wells and horizontal pipes. Partial vacuum created in the piping system causes LFG movement towards the wells. Once collected, it can be combusted for energy production.

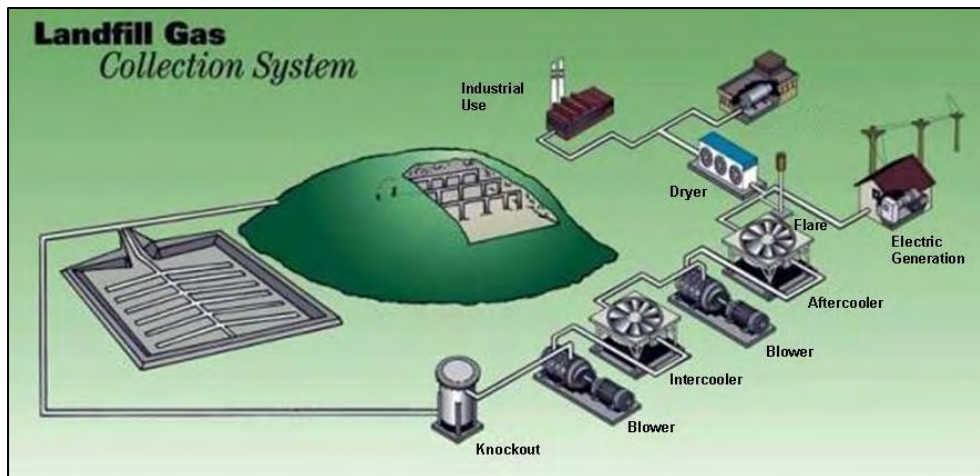
The installed capacity for generation of electricity of the CPS is 14.94 megawatts<sup>(121)</sup>; however, until the summer of 2005, the net output was 13 megawatts, which is enough energy to serve a town of 10,000 inhabitants. In addition, heat is produced at the facility.

It is estimated that the LFG exploitation has resulted in the reduction by approximately 20% of the pollution that could have been caused by the sanitary landfill at Ano Liossia<sup>(61)</sup>.

Currently, HELECTOR S.A. has applied to the Greek Government for a permit to install equipment to increase the production of electricity by 9.6 megawatts. The expansion of CPS is estimated to reach the amount of \$19.1 million (€15 million)<sup>(146)</sup>.

#### 4.5.5.3.2 *Technical Description*

The LFG produced at Ano Liossia sanitary landfill is extracted from the site, processed to remove moisture and particulate matter, and utilised as fuel for power generation. The gas collection system (Figure 4.58) includes 309 gas entrapment wells drilled into the landfill<sup>(100)</sup>. The wells are fitted with wellheads comprising valves and flow meters to control the flow from each well. LFG is transported via an underground pipeline network that connects the wells. Gas blowers maintain vacuum throughout the



pipe grid and compress the LFG to the pressure required for supply to the production plant.

**Figure 4.58** LFG collection system<sup>(50)</sup>.

The energy production plant consists of 11 completely autonomous mobile cogeneration modules, a closer view of which can be seen in Figure 4.59. Each module is in a sound proof container and includes a gas-engine electricity generator of capacity 1.26

megawatts that is fuelled with approximately 720 – 730 cubic meters per hour. The plant is interconnected to the Public Power Company (PPC; ΔΕΗ in Greek) distribution grid at 20 kilovolts through a double underground HV line. The electricity produced at the CPS feeds into the PPC power grid for a return of \$0.076 (€0.06) per kilowatt-hour<sup>(102)</sup>.



**Figure 4.59 Mobile energy production modules<sup>(50)</sup>.**

Moreover, the remaining thermal energy of the turbine gases is utilised in heat recovery for steam and hot water production. The total heat production is approximately 16 megawatts. The produced steam may be either traded as commodity at the nearby small-scale industries (MRCF, MWI, greenhouses, e.t.c.) or employed in processing of landfill leachates. Currently, steam corresponding to approximately 6 megawatts is utilised in leachate drying.

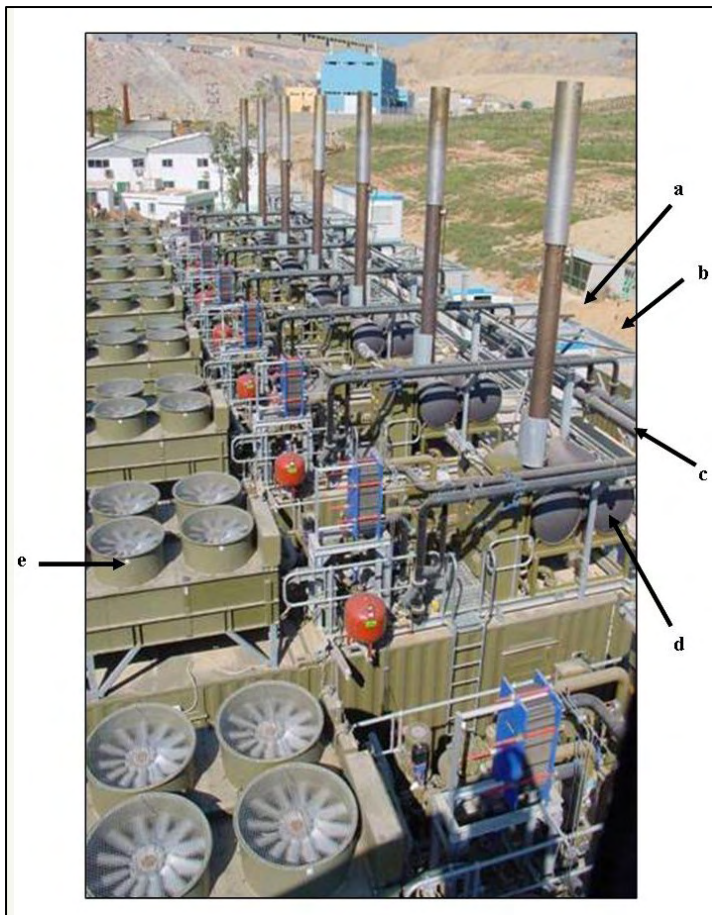


Figure 4.60 shows the components of the heat recovery system, while Figure 4.61 illustrates the heat recovery schematic process diagram.

**Figure 4.60 The heat recovery system<sup>(50)</sup>.**

- a: Installation point of by-pass valve and duct (to heat recovery boiler)
- b: Installation point of heat recovery boiler
- c: Main heat distribution ducts (extended to thermal consumption)
- d: Hot water transportation ducts (to the main network)
- e: Heat exchanger

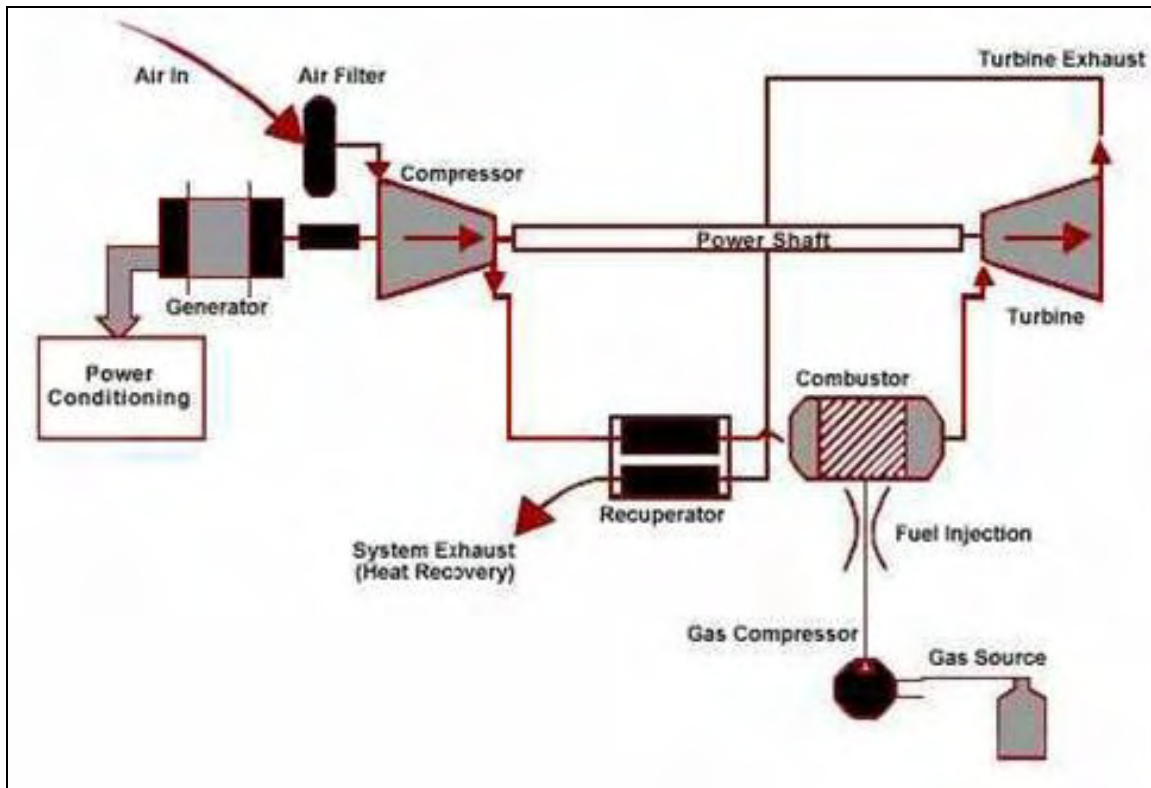


Figure 4.61 Heat recovery process schematic diagram<sup>(69)</sup>.

An integrated control system has been installed to meet the variations of the LFG quality and production rate in each landfill sector, and to achieve optimum plant operation. Specific landfill areas that no longer produce exploitable LFG can be isolated from the energy production system, and gas originating from such areas can be flared to atmosphere. Since cogeneration modules operation is influenced by LFG corrosion potential, moisture content is recorded in order to properly specify gas pre-treatment requirements. Considerations have also been made for problems resulting from high temperatures occurrence at the landfill site, i.e. during the summer, and solutions have been provided to environmental aspects arising from the landfill management, such as leachates processing.

## 4.5.6 Uncontrolled Waste Disposal Sites

### 4.5.6.1 Active Uncontrolled Landfills

The waste that is not recycled nor transferred to Ano Liossia sanitary landfill is discarded at local UWDSs (Figure 4.27). Some of the UWDSs are partly controlled, meaning that the waste they receive is repeatedly covered with earth or other inert materials for the reduction of the generated odors and avoidance of spontaneous fires.

Since 2000, the number of UWDSs has significantly decreased, due to the continuously rising environmental consciousness. Currently, Attica is served by 24 UWDSs, eight of which border with forests or reforestable areas. The remaining 16 are located in a distance less than 300 meters from forests. All these sites, which are listed in Table 4.12, receive 10.45% of the MSW generated in the Region as mentioned earlier.

**Table 4.12 Active UWDSs in Attica Region<sup>(45)</sup>.**

Prefectures	OLAs		Name of Sites
Athens-Piraeus	1	Aghistri	Sporeza
	2	Antikythira	Mili
	3	Hydra	Dump of Hydra
	4	Keratsini	Rema Cokinovrachou
	5	Keratsini	Lacomata Schistou
	6	Kythira	Lachnos
	7	Methana	Choni - Pro
	8	Poros	Cocorelli
	9	Spetses	Agriopetres - Xastano
Western Attica	10	Megara	Camliia
	11	Vilia	Drestani
Eastern Attica	12	Avlonas	Coutsi-Cotroni
	13	Calamos	Riza Catsoun
	14	Calyvia Thorikou	Tipot-Croudi
	15	Capandriti	Salamidi
	16	Cropia	Castron Christos
	17	Grammatico	Graves
	18	Keratea	Aghios Ioannis Fovoles
	19	Lavreotiki	Caminada
	20	Malakassa	Vrissi Passa
	21	Marcopoulo Mesogaeas	Choni Dagla
	22	Paeania	Aghios Nickolaos
	23	Palaea Fokaea	Yerakina
	24	Varnava	Drizes

In addition to the recorded UWDSs, there are cases, in which people illegally discard or burn their waste in randomly “selected” locations. Figure 4.62 shows several such sites.



**Figure 4.62 View of UWDSs.**

a: Municipality of Paeania, Eastern Attica.

b: Community of Ekali, Eastern Attica.

c: Municipality of Tavros, Athens.

d: Municipality of Elefsina, Western Attica.

e: Municipality of Mandra, Western Attica.

f: Municipality of Avlona, Eastern Attica.

As shown in Figure 4.27 and Table 4.12, the majority of Attica's UWDSs is located within the borders of Eastern Attica Prefecture. According to a study conducted by the National and Kapodistrian University of Athens (NKUA), the Agricultural University of Athens and the German Institute for Environmental Analysis on the UWDSs of

southeastern Attica, food produced in the areas surrounding the uncontrolled landfills in a radius of 4 kilometers exhibits very high concentrations of dioxins<sup>(93)</sup>. Samples of olive oil taken from areas within a radius of 50 – 100 meters of the Capandriti, Cropia, Marcopoulo Mesogaeas and Paeania uncontrolled landfills showed that the dioxin levels are seven times higher than the allowable limit. Also, samples of eggs taken in a radius of 4 kilometers showed that they contain six times higher level than the allowable limit. The following sections offer a brief description of the larger dumpsites.

#### 4.5.6.1.1 *Avlona Landfill*

This site, which is an old quarry, operates as a waste disposal site for more than 30 and has an annual capacity of 40,000 tons of waste.

In July 1999, about 60 square kilometers were burned, possibly because of a spontaneous fire that started at the landfill<sup>(94)</sup>.



**Figure 4.63** Aerial photograph of Avlona landfill<sup>(77)</sup>.



**Figure 4.64** Closer view of Avlona landfill.

#### 4.5.6.1.2 *Calamos Landfill*

The dumpsite of this community has operated for over 30 years and daily receives an average of 70 tons of MSW. During the winter it serves approximately 6,600 inhabitants; however, the residents increase to 50,000 in summer (touristic period).

#### 4.5.6.1.3 *Calyvia Thorikou Landfill*

The specific UWDS, which is surrounded by chaparrals and cultivable land, is in a distance of approximately 2 kilometers from residential areas. It opened in 1968 and continues to operate, serving about 14,800 inhabitants. Its operation cost approximately \$5,600 (€4,400) in 1995.

The waste discharged there is covered with earth twice annually, in March-April and September-October. Also, uncontrolled incineration of waste takes place. Since 1992, over 1.5 square kilometers of land has been burned, as a result of multiple fire ignitions that have occurred on site.

The waste is discharged on karstified limestone, which is highly permeable, allowing leachate leakage take place. This results in the contamination of the existent aquifers.

#### 4.5.6.1.4 *Capandriti Landfill*

The dumpsite “Salamidi” started operating in 1965. It is located in a forest area, 2 kilometers far from the center of the community, and serves approximately 3,500 residents.

It could be considered as an inactive landfill, as it does not receive waste generated at the community. The waste previously disposed has been covered with earth. Today, part of this site is used as a WTS. Nevertheless, people occasionally illegally dispose waste in the surrounding area.

In the past, fires started due to LFG accumulation and uncontrolled waste incineration, destroying small areas.

**Figure 4.65**  
**Aerial**  
**photograph**  
**of**  
**Capandriti**  
**landfill<sup>(77)</sup>.**



**Figure 4.66** Closer view of Capandriti landfill<sup>(31)</sup>.

#### 4.5.6.1.5 *Cropia Landfill*



The area surrounding Cropia UWDS is agricultural and mostly consists of olive groves. The site receives MSW generated by 26,000 residents during winter; however, the quantities increase by approximately 63% during the touristic season.

As one can see in Figures 4.68 and 4.69, fire has been set on site in order to increase the landfill's capacity.

**Figure 4.67** Aerial photograph of Cropia landfill<sup>(77)</sup>.



**Figure 4.68** View of the eastern part of Cropia landfill.



Figure 4.69 View from the entrance of Cropia Landfill.

#### 4.5.6.1.6 *Marcopoulo Mesogaeas Landfill*

This UWDS, which operates since 1990, is located within the area of an old quarry, near an archaeological site, and occupies an area of 20,000 square meters<sup>(70)</sup>. Its distance from residential areas is about 2.5 kilometers and it serves a population ranging from 19,000 in winter to 70,000 in summer.

It is considered as a partly controlled landfill, as it is frequently set on fire. Also, the waste is regularly covered with tailings from within the quarry, and construction and demolition wastes.



Figure 4.70 The landfill of Marcopoulo Mesogaeas<sup>(77)</sup>.

The absence of lining system results in leachate leakages through the highly karstified limestone, on which the waste is disposed. This has negative consequences, as it influences the quality of water collected through drills by the inhabitants of the wider area.

#### 4.5.6.1.7 *Paeania Landfill*

Paeania landfill operates since 1977 and is situated about 1 kilometer from the residential area, which in summer has around 20,000 residents. It must be noted that sports facilities that were used during the Olympic Games 2004 are within a small distance from the site. Figure 4.72 shows their relative location. The landfill is marked with a red circle, while the green arrow points to the sports facilities. Also, in the background (yellow arrow) one can see Athens International Airport (AIA).



**Figure 4.71 Aerial photograph of Paeania landfill<sup>(77)</sup>.**



**Figure 4.72 View of the western part of Paeania landfill.**

This landfill is considered as partly controlled, as the discarded wastes are frequently covered by earth. However, the absence of lining system results in leachate leakages given that the UWDS overlays limestone (Figure 4.73), as in previous cases.



**Figure 4.73** View of the southeastern part of Paeania landfill.

#### 4.5.6.1.8 *Palaea Fokaea Landfill*

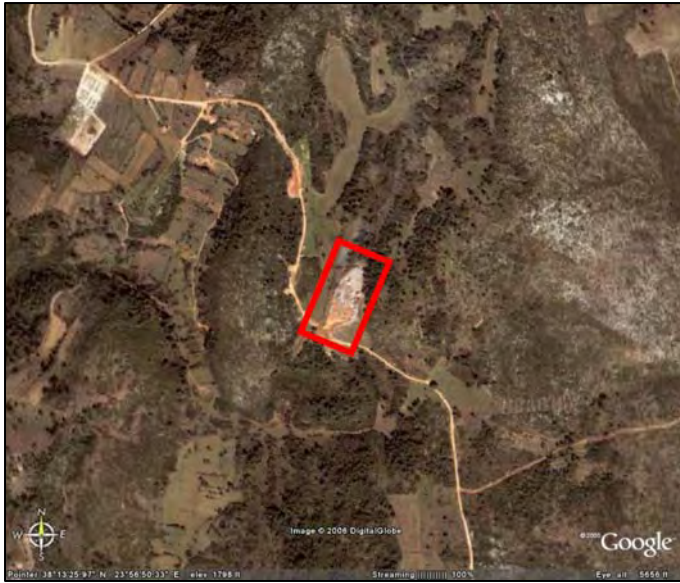
The landfill operates since 1976 and is located within the area of an abandoned quarry, in a distance of 600 – 700 meters from residential areas and 300 meters from the coastal road. During touristic season, it is estimated to receive over 130 tons of waste per day.

The morphology of the area facilitates the occurrence of rising winds, which in turn facilitate the transportation of waste to the surrounding forests. As a result, the landfill has been repeatedly (1979, 1987, 1994) the focus of fires that destroyed forests.

#### 4.5.6.1.9 *Varnava Landfill*

The UWDS of Varnava is located within a forest area, in a distance of 2 kilometers from the residential area and operates since 1965. In winter, it receives waste generated

by 2,000 permanent residents, as well as the personnel of three army facilities located within the community. In summer, the quintuple quantity of waste is discharged.



**Figure 4.74** Aerial photograph of Varnava landfill.

Occasionally, fire has been set aiming at the increase of the landfill's capacity. In the past (2002, 2003), spontaneous fires have resulted in the destruction of small areas of the surrounding forest. The frequency of such events is relevantly high, which is extremely dangerous considering the location of the dumpsite.



**Figure 4.75** View of Varnava landfill<sup>(30)</sup>.

#### 4.5.6.2 Inactive Uncontrolled Landfills

Action has been taken for the remediation of many UWDSs that have ceased operation. The sites that need to be restored are shown in Figure 4.27.

One successful example is the former uncontrolled landfill at “Schisto”, which was the second largest in the country and occupies 405,000 square meters. It started operating 1960 and had received over 15 million tons of MSW by its closure, in 1991. The site has now been transformed to a remarkable recreational park for cultural and athletic activities. A comparison of Figures 4.76 and 4.77, which are photographs of the site before and after restoration, illustrates the level of alteration that took place.



Figure 4.76 View of “Schisto” site before restoration<sup>(136)</sup>.



Figure 4.77 View of “Schisto” site after restoration<sup>(136)</sup>.

Something similar has been practiced at the municipality of Ano Liossia. The works for the remediation of a total area of 890,300 square meters have already started. The revegetation of the old UWDS, as well as the non-operating cells of the sanitary landfill, has been completed, as shown in Figure 4.78.



Figure 4.78 View of Ano Liossia site after restoration<sup>(136)</sup>.

Finally, another example is the site of the UWDS that served the municipality of Vari. As one can see in Figure 4.79, there is no sign that this area used to host an UWDS. The marked area shows the exact location of the dumpsite in the past.



Figure 4.79 View of the Vari uncontrolled landfill after restoration.

## 4.6 PLANNED WASTE MANAGEMENT FACILITIES IN ATTICA

The new Regional Plan of Attica for SWM proposes the operation of 24 new WTSs, as well as the establishment of three Integrated Waste Management Facilities (IWMFs). Moreover, two sanitary landfills will be constructed on the islands of Kythira and Antikythira. Finally, the plan includes revision of the temporary waste storage system and the remediation of UWDSs. The implementation cost of this plan is estimated to reach \$356.5 million (€280 million)<sup>(45)</sup>.

It must be noted that this scheme, especially the part regarding the construction of new sanitary landfills in continental Attica, currently faces vehement opposition by the residents of areas near the proposed sites. Some of the cases are still being examined by the Council of State, the country's highest administrative court.

### 4.6.1 Waste Transfer Stations

In Attica's Regional Plan for SWM, the establishment of 24 WTSs is proposed, the construction costs of which will reach \$76.4 million (€60 million)<sup>(45)</sup>.

Apart from one WTS that will be located at the OLA of Trizina and will serve the homonymous OLA, as well as those of Aghistri, Hydra, Methana, Poros and Spetses, the proposed WTSs will be located in continental Attica. Four of these WTSs will be fixed

and are estimated to cost 83% of the aforementioned amount. Figure 4.80 shows the potential sites for their establishment, while Table 4.13 presents their projected characteristics.

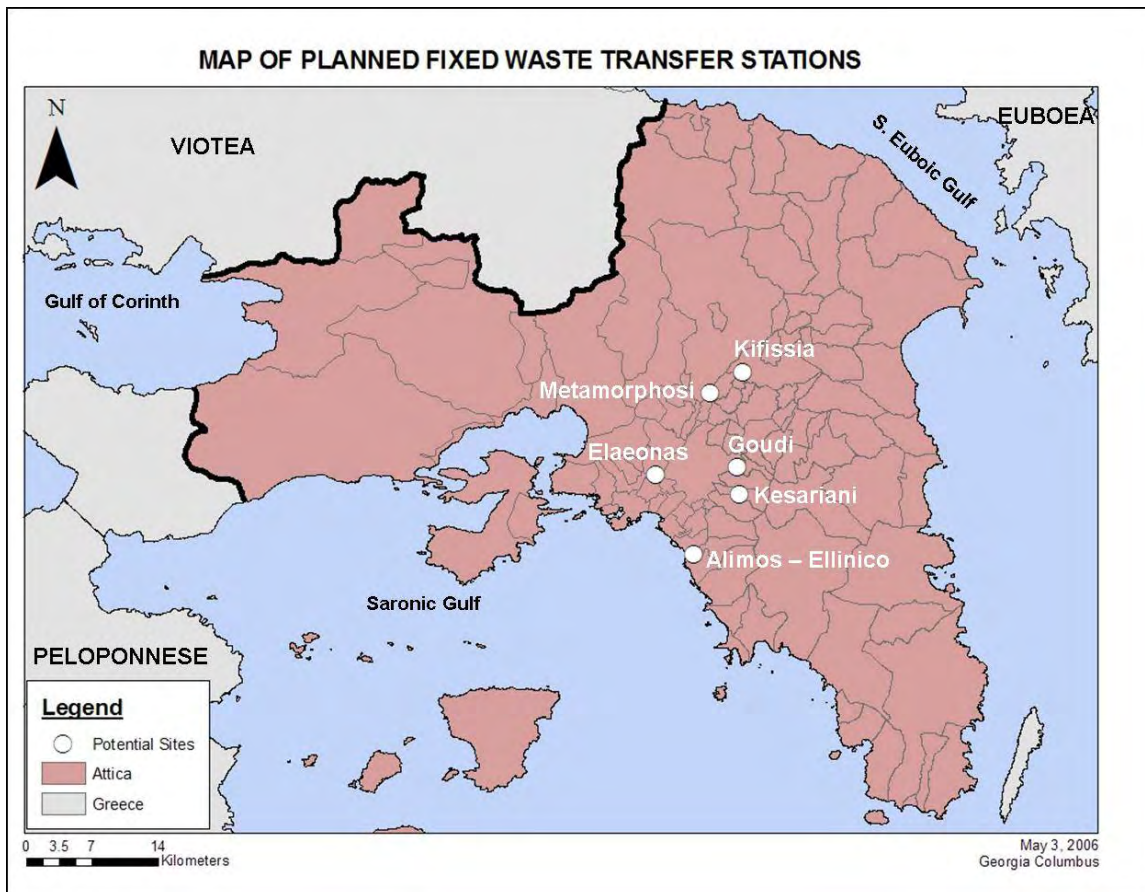


Figure 4.80 Potential Sites for fixed WTSS.

Table 4.13 Characteristics of future WTSSs.

WTS	Locations	Area (m <sup>2</sup> )	Capacity (t/d)
1	Aegaleo (Elaeonas)	20,000*	1,265 <sup>#</sup>
2	Alimos or Ellinico or Glyfada	20,000**	595 <sup>#</sup>
3	Goudi or Kesariani	20,000**	-
4	Kifissia or Metamorphosi	20,000**	455 <sup>#</sup>
* Reference 88			
** Reference 93			
<sup>#</sup> Reference 136			

#### 4.6.1.1 Elaeonas Waste Transfer Station

“Elaeonas” is an area of 9 square kilometers and consists of parts of the municipalities of Aegaleo (17%), Aghios Ioannis Rendis (44%), Athens (25%), Peristeri

(3%) and Tavros (11%). It has a population of approximately 5,000 inhabitants and houses 2,400 industries and businesses, which bring on site around 50,000 employees. The Elaeonas WTS is currently in the bidding process; however, its license is pending due to strong public opposition and environmental concerns. It is estimated to cost \$19.1 million (€15 million)<sup>(132)</sup> and to will have started operation by 2008. It will have the capacity to receive 1,265 tons of waste daily and will reduce the volume of the waste by 30%. Finally, it is planned to serve the municipalities of Aegalaeo, Aghia Varvara, Aghios Ioannis Rendis, Athens and Moschato.

#### 4.6.1.2 Alimos – Ellinico – Glyfada Waste Transfer Station

A local WTS used to operate in 2001 at the municipality of Alimos, on its borders with the former international airport of Athens, Ellinikon International Airport; nevertheless, it is not currently used. The Regional Plan for SWM includes the construction of a fixed WTS either at that location or the expansion of the currently operating WTS at the municipality of Glyfada.

#### 4.6.1.3 “Goudi” – Hymettus – Kesariani Waste Transfer Station

For the third proposed WTS, there are two potential locations: The first is located in an area of 200,000 square meters, which is intended to be transformed to a recreational park. This area is known as “Goudi” and is part of the municipality of Athens. The other is located at the municipality of Kesariani, at a site that is included in the protected areas of Hymettus.

#### 4.6.1.4 Kifissia – Metamorphosi Waste Transfer Station

The fourth WTS will be constructed within an industrial park either in Kifissia or in Metamorphosi (“Chamomili” site); however, the exact location has not yet been determined.

### 4.6.2 **Integrated Waste Management Facilities**

The three proposed IWMFs will be located at the OLAs of Phyli (western Attica), Grammatico (northeastern Attica) and Keratea (southeastern Attica), as shown in Figure 4.81. The IWMFs, more information on which is offered in the following paragraphs, will include at least one recyclables sorting facility, one composting facility and one sanitary landfill for the disposal of residual wastes. The facilities’ capacities may be differentiated from those initially stated at the Regional Plan for SWM, depending on the choice of the contractor/carrier and/or HERRCo.

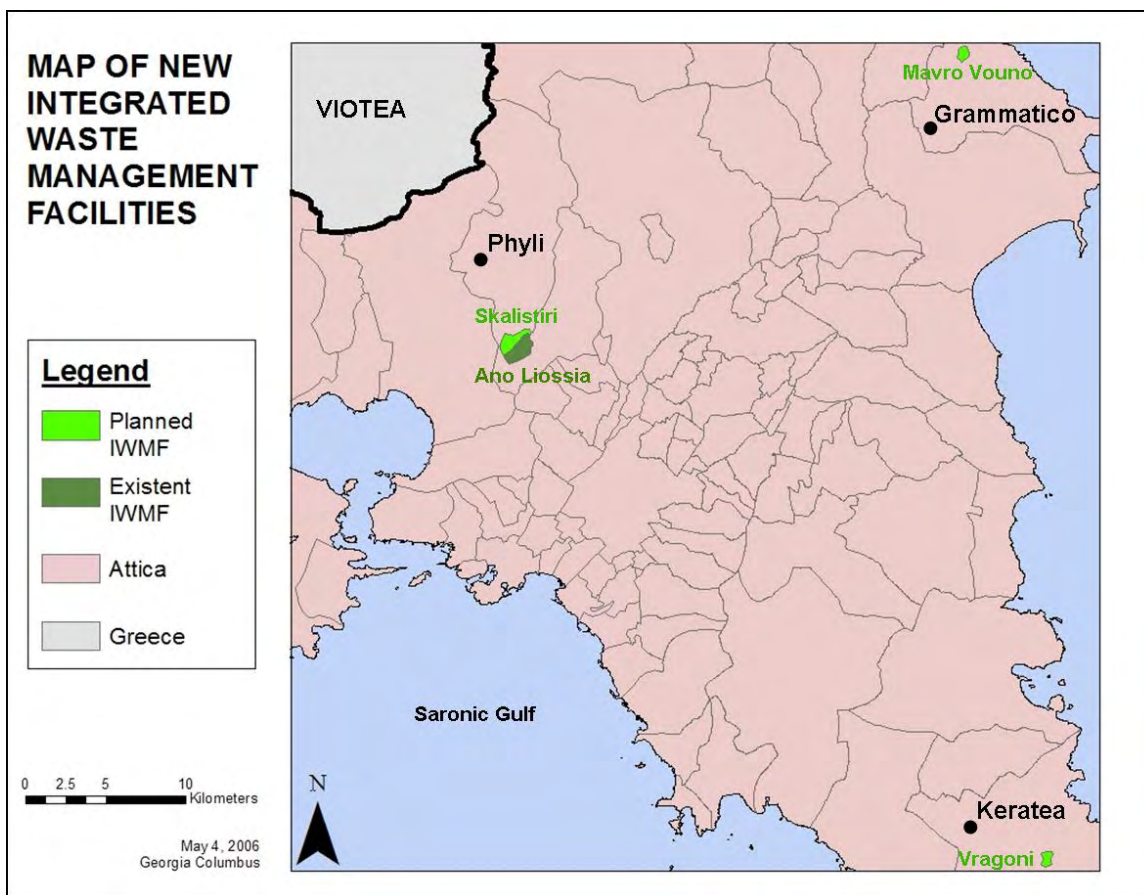


Figure 4.81 Sites of proposed IWMFs.

#### 4.6.2.1 Western Attica Integrated Waste Management Facility

As shown in Figure 4.81, the Western Attica IWMF is an expansion of the already existing IWMF at Ano Liossia, where the MRCF, MWI and Ano Liossia sanitary landfill are currently located. The new facilities of the Western Attica IWMF are estimated to occupy an area of 1.3 square kilometers and cost approximately \$90.1 million (€70.8 million), as shown in Table 4.14.

Table 4.14 Planned facilities in western Attica<sup>(45)</sup>.

Facilities	Construction Costs		Notes
	(\$)	(€)	
Sorting Facility	7,638,720	6,000,000	Part of costs may be covered by HERRCo
Composting Facility	15,277,440	12,000,000	-
Sanitary Landfill	67,220,736	52,800,000	Financed
<b>TOTAL COSTS</b>	<b>90,136,896</b>	<b>70,800,000</b>	

Regarding the proposed for this area sorting facility, the suggested capacity is 75,000 tons per year. Furthermore, the composting facility will receive pure organic

wastes and/or yard wastes for the production of high quality compost. It is expected to have a capacity of 80,000 tons of materials per year.

In addition to these facilities, the scheme for western Attica includes the construction of one more “waste processing” facility, which is suggested to have the capacity to process 1,000,000 – 1,100,000 tons of waste per year; however, the technology to be used has not yet been specified.

Finally, the new Western Attica sanitary landfill, the first phase of the construction of which has already been financed by the European Cohesion Fund, will be located at the area “Skalistiri” of the municipality of Phylli. It is estimated that it will receive 1,400,000 – 1,500,000 tons of MSW and 230,000 tons of sludge per year, in the first years of its operation. After the initiation of operation of the aforementioned facilities, the amount of waste transferred to the landfill is expected to significantly decrease.

#### 4.6.2.2 Northeastern Attica Integrated Waste Management Facility

The IWMF of northeastern Attica will occupy an area of 514,000 square meters at the community of Grammatico and will cost around \$48.1 million (€37.8 million). In the following Table the breakdown of costs for the construction of the new facilities of the Northeastern Attica IWMF are cited.

**Table 4.15 Planned facilities in northeastern Attica<sup>(45)</sup>.**

Facilities	Construction Costs		Notes
	(\$)	(€)	
Sorting Facility	7,638,720	6,000,000	Part of costs may be covered by HERRCo
Composting Facility	9,548,400	7,500,000	-
Sanitary Landfill	30,936,816	24,300,000	Financed
<b>TOTAL COSTS</b>	<b>48,123,936</b>	<b>37,800,000</b>	

Permission has been issued for the construction of a recyclables sorting facility of capacity 72,500 tons per year and a composting unit of capacity 40,000 tons per year.

Moreover, the “waste processing” facility, the technology of which has not hitherto been determined, will have an annual capacity of 127,500 tons.

The sanitary landfill will be located at the site “Mavro Vouno” (Figure 4.82) and



has also been financed by the European Cohesion Fund. Initially, it will receive approximately 127,500 tons of waste per year, amount which will be reduced when the aforementioned facilities initiate operation.

**Figure 4.82 View of “Mavro Vouno” site<sup>(93)</sup>.**

#### 4.6.2.3 Southeastern Attica Integrated Waste Management Facility

The municipality of Keratea will host the third proposed IWMF that will cost approximately \$37.7 million (€29.6 million), as shown in Table 4.16. It is estimated that it will occupy an area of 530,000 square meters.

**Table 4.16 Planned facilities in southeastern Attica<sup>(45)</sup>.**

Facilities	Construction Costs		Notes
	(\$)	(€)	
Sorting Facility	7,638,720	6,000,000	Part of costs may be covered by HERRCo
Composting Facility	9,548,400	7,500,000	-
Sanitary Landfill	20,497,232	16,100,000	Financed
<b>TOTAL COSTS</b>	<b>37,684,352</b>	<b>29,600,000</b>	

The sorting, composting and third undetermined “waste processing” facilities that will be constructed in this area are proposed to have the same characteristics as those proposed for the Northeastern Attica IWMF.

Regarding the sanitary landfill, it will be located at the area “Vragoni” (Figure 4.83), at the OLA of Keratea. As in the previous cases, the first phase of its construction has been financed by the European Cohesion Fund. It will be designed to receive 127,500 tons of waste per year until the initiation of operation of the aforementioned facilities.



**Figure 4.83 View of “Vragoni” site<sup>(93)</sup>.**

#### 4.6.3 Sanitary Landfills

Attica’s Regional Plan for SWM includes the construction of two more sanitary landfills: One will be located at the municipality of Kythira. It will have a capacity ranging from 1,000 – 1,100 tons of waste per year and is estimated to cost \$4.1 million (€3.2 million). The other will be located on the island of Antikythira and will have an annual capacity of 50 tons of waste. The cost for its construction is estimated to reach \$0.4 million (€0.3 million)<sup>(45)</sup>.

### 4.7 EVALUATION OF ATTICA’S WASTE MANAGEMENT SYSTEM

One of the most important environmental problems in Greece, and especially in Attica Region, is the rapidly increasing generation of waste. Lack of rational and efficient

waste management until recently, as well as social conflicts to any efforts to solve this problem, have resulted in the uncontrolled disposal of waste and, subsequently, in soil, air, surface and groundwater pollution, in addition to the aesthetic degradation of the landscape and the potential dangers for public health.

Since 1994, the increasing environmental consciousness and public awareness resulted in many improvements in the ecological performance of the Region of Attica. Numerous WTSs were constructed in order to facilitate the transportation of waste, while the separate collection rate of recyclables increased with time. Also, many UWDSs ceased operation and some sites were remediated. Finally, the first sanitary landfill was constructed.

Presently, the MSW management system in Attica aims to decrease the quantity of waste landfilled by increasing the recycling rates. Also, the public awareness of the need to recycle has increased in the recent years. The recycling projects organized by OLAs, institutions and private companies, in combination with the operation of sorting and recycling facilities have resulted in an increase of material recovery. More particularly, the operating waste management facilities have resulted in recycling an estimated 6% of the MSW generated in Attica. However, the recycling rates are still very low, failing to meet the European targets. This is due to the following reasons:

- The recycling projects that take place from time to time lack organization and coordination amongst carriers; as a result, they are not always successful;
- The MRCF does not operate at its full capacity; and
- Waste disposal is considered to be an “easy” solution and appears to be more economical than recycling, since the authorities and/or public do not take into consideration the long-term costs of this method.

Additionally, the operation of the MWI has reduced the quantities of medical wastes that were illegally disposed at UWDSs; nevertheless, it does not operate at its full capacity.

Another improvement towards Sustainable Development was the closure of numerous UWDSs, for some of which action for remediation has taken place. On the other hand, there are still UWDSs that must cease operation and/or must be rehabilitated.

Also, the majority of the MSW generated in the Region are disposed at one sanitary landfill (Ano Liossia), which is preferred to the disposal at uncontrolled landfills. After the operations at the sanitary landfill will have ended, revegetation and transformation of the area to recreational park or athletic establishments is planned. Nevertheless, there are some issues that should be taken into consideration; these concern not only Attica’s only sanitary landfill, but also the specific management method:

- Regarding Ano Liossia sanitary landfill, the most significant problem is its operational time. The sanitary landfill should have ceased operation, as it has exceeded the safety height limit a long time ago; this has repeatedly resulted in occurrence of landslides. However, Ano Liossia sanitary landfill continues to receive waste since the construction of the sanitary landfills included in the Regional Plan has not yet started. The fact that at least 18 months are required for their construction aggravates the situation;
- The method of waste disposal is characterized by numerous disadvantages. As aforementioned waste disposal at sanitary landfills is preferable to their disposal at UWDSs; however, in both cases, locations for new waste disposal sites are required after their closure. This comprises a tremendous problem for Attica Region, as it is densely populated (1,295 inhabitants per square kilometer, Table 3.1), which renders the land too scarce to contain new landfills. Moreover, the numerous archeological sites; the geomorphologic structures; the hydrological, stratigraphic, as well as tectonic and seismic features of the area of study make it harder to find new locations. Additionally, opening a new sanitary landfill outside the borders of the Region would create economical and political issues among the neighboring Regions. Furthermore, after the closure of sanitary landfills, the land cannot be used in many ways, because of its low stability. Especially, in the case that certain rules are ignored during its operation, there is a high probability of continual subsidence of the area. This is due to the high moisture of waste, as well as its heterogeneity, which results in its relevantly low density and continuous bioreaction. If a building is constructed over an old sanitary landfill, its weight will cause compaction of the underlying wastes and subsequent subsidence of the area. Also, mistakes in the construction and operation of a sanitary landfill or improper maintenance during and after its closure may lead in liquid leakages and gas – e.g. methane (CH<sub>4</sub>), mercury (Hg), methyl mercury (CH<sub>3</sub>Hg) – emissions long after its closure. It has been shown that for every ton of MSW landfilled at least 1.2 tons of carbon dioxide (CO<sub>2</sub>) are emitted. The reactions producing this greenhouse-gas may continue for decades or even centuries after its closure. If not properly constructed, operated and maintained, the sites of sanitary landfills may be cause degradation and low environmental quality. For the aforementioned reasons they face strong social opposition.

Finally, Attica's proposed Regional Plan for SWM is a step towards sustainability, as it will contribute to the increase of material recovery and to the sanitary disposal of residual wastes. Processing of the information regarding the generation rates of MSW in Attica Region; evaluation of the existing SWM system, as well as estimations regarding the implementation of the proposed Regional Plan for SWM indicate that approximately 16-18% of the generated waste is intended to be recovered by the currently operating and

proposed waste management facilities. Nevertheless, a large quantity of waste (82-84%) will be landfilled. Furthermore, the implementation of the Regional Plan is urgent, as Attica's only sanitary landfill has reached its capacity limits.

On the basis of the above information, one is led to the conclusion that the waste management problem in the Region of Attica is intense despite the efforts for its amelioration. Alterations in Attica's MSW management system are obligatory in order to comply with the European Regulations and achieve the targets towards Sustainable Development. These alterations should incorporate further utilization of the existent SWM system's assets and determination of solutions for its negative aspects.

It must be noted that for the conversion of the monetary values from euros (€) to dollars (\$) and vice-versa, the equivalence of May 7, 2006 (€1 = \$1.27312)<sup>(163)</sup> was used.

## **CHAPTER 5: WASTE-TO-ENERGY IN ATTICA REGION**

### **5.1 INTRODUCTION**

The preceding chapters described the basic characteristics of continental Attica and the assets and liabilities of the currently practiced Solid Waste Management (SWM) system of the Region of Attica. Consideration of this information and comparison with the waste situation in other countries leads to the conclusion that there is a solution to the waste problem.

Aiming at the improvement of the existing SWM system of Attica Region and the compliance with the European Union (EU) targets, a new Municipal Solid Waste (MSW) management system, friendlier to the environment, is developed in this section. This system is based on the five-level hierarchy of waste management mentioned in Chapter 1 and includes the application of Waste-to-Energy (WTE) as an integral part of the proposed Regional Plan for SWM.

The implementation of WTE will ameliorate not only the MSW management system, but also the quality of life of the surrounding area to a great extent, as it offers numerous benefits in various aspects. Firstly, WTE facilities reduce the amount of waste to be landfilled by 75% by weight. Secondly, electricity is recovered through controlled combustion of waste, thus, reducing air pollution deriving from lignite-fired powered plants. Thirdly, the surplus heat, remaining after the generation of electricity, can be distributed to neighboring buildings for cooling/heating purposes. Furthermore, recovery of metals takes place by processing the ash produced by the combustion of waste. Also, bottom ash may be used beneficially, for example in road construction and landfill



**Figure 5.1 Minato WTE facility in Tokyo**<sup>(156)</sup>.

construction and maintenance. Moreover, WTE facilities can play an educational role regarding waste management. Finally, if facilities are designed by taking into consideration the landscape of the surrounding area, they can become attraction sites, as in the case of the Minato WTE plant in Tokyo (Figure 5.1), and add value to the adjacent properties, rather than cause public opposition and disgrace.

Therefore, the hypothetical case of the first WTE facility in Attica Region will be examined in this chapter. The first step in applying WTE is the determination of the possible locations, where WTE facilities can be sited. The selection of the most promising site is followed by determination of technical specifications of the proposed WTE facility and a financial assessment. Finally, this chapter shows that further implementation of WTE can alleviate of the MSW management problem of the Region.

In order to accomplish the aforementioned tasks, certain parameters, such as existing regulations; the geography and geology of Attica; protected areas and land uses; the existent waste and transportation infrastructure; and the quantity and quality of MSW generated, were examined. Some of these criteria were integrated by means of Geographic Information Systems (GIS) technology in order to determine ways in which the WTE concept can be implemented in the Region of Attica.

## **5.2 SITING WASTE-TO-ENERGY FACILITIES**

In researching potential locations for siting WTE facilities, the main criteria to be examined are:

- Geographic features;
- Geologic and hydrogeologic conditions;
- Proximity to protected areas;
- Land Use;
- Transportation infrastructure;
- Waste management infrastructure;
- Proximity to sanitary landfills; and
- End market possibilities for energy and ash.

After examination of the criteria mentioned above, the map of Figure 5.2 was produced. This map shows the possible areas for siting WTE facilities taking into account the waste management and transportation infrastructure, as well as the residential, commercial and industrial land uses.

The most promising locations are the sites of the three Integrated Waste Management Facilities (IWMFs) in the Prefectures of Western and Eastern Attica proposed by Attica's Regional Plan for SWM that were described in Section 4.6.2.

Firstly, two of these locations, Grammatico and Keratea sites, are included in the regions of non-protected areas. Even though Phylli site is on the borders of the protected

Aegalaeo Mountain, it is adjacent to Ano Liossia sanitary landfill. Consequently, siting WTE facilities at any of these locations is permissible.

Secondly, the site at the municipality of Phylli is at an optimum location in terms of the road and railroad network. Also, Keratea site has also access to major roads and could be served in the future by the re-activation of the old railroad line. In contrast, siting a facility at the Organization of Local Administration (OLA) of Grammatico would require an expansion of the road and railroad network for transporting waste.

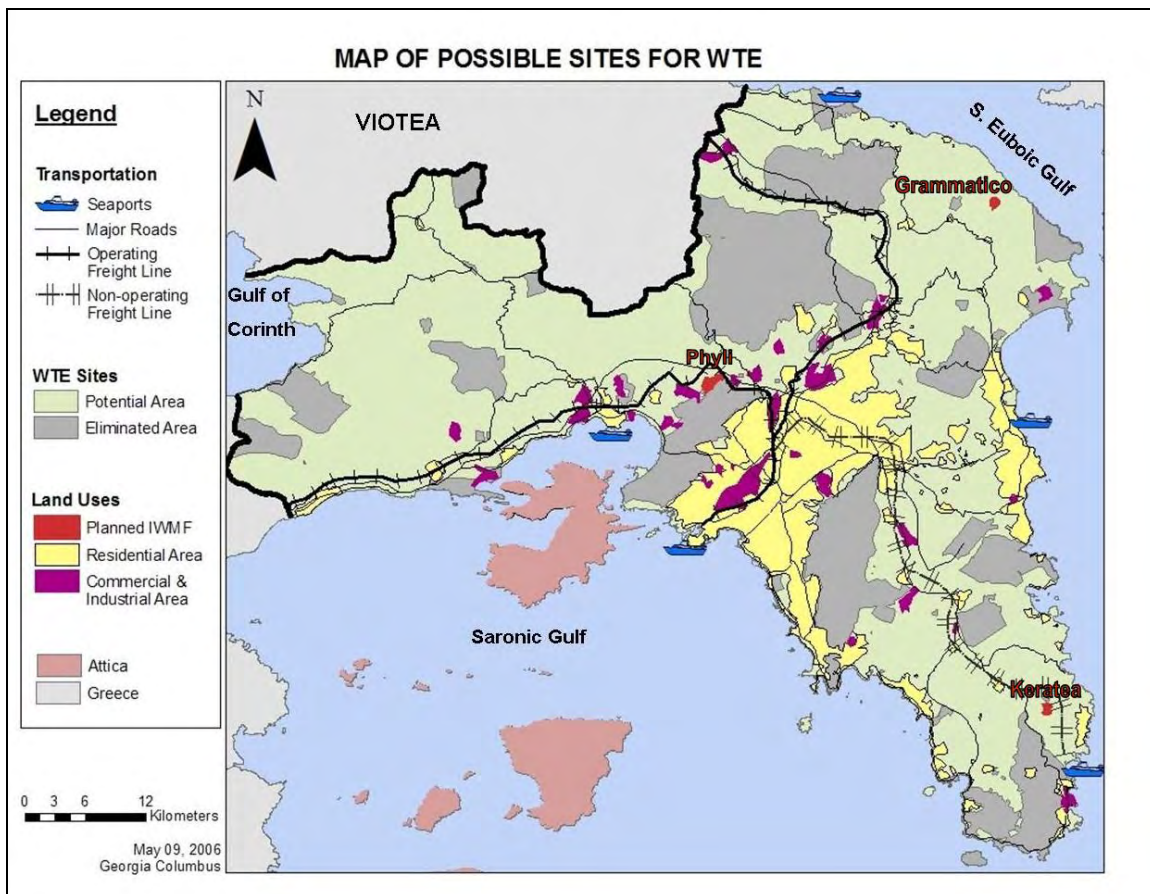


Figure 5.2 Possible sites for WTE facilities.

Thirdly, the proximity of all three locations to the sea allows for waste transportation by water. Waste from the OLA of Trizina and several of the Region's islands can be transferred to the WTE sites through operating seaports (Elefsina, Piraeus, e.t.c.) or new ones.

Moreover, the sanitary landfills will be located in a small distance from the WTE facilities in all three locations. Consequently, the expenditure for the transportation and disposal of ash will be relatively low.

Also, the Regional Plan includes the construction of "waste processing" facilities, of as yet undetermined technology at these sites. WTE is the only method that is excluded

from the Plan. The application of WTE will complete the attempted integrated SWM concept.

In addition, siting the WTE facilities at the abovementioned locations is an economical solution, as further expropriation of land will not be required.

Finally, the thermal energy produced by the WTE plants can be used for the operation of the adjacent waste management facilities. Also, it could be used for district heating of neighboring buildings, particularly in the case of Phyli site, which is located near industrial areas.

On the basis of the above information, the most suitable locations for siting a WTE facility in Attica Region are the sites proposed for the IWMFs. Moreover, the most promising site is that at the OLA of Phyli, as it currently satisfies the majority of the criteria. The following section focuses on the first WTE facility in Greece, which will be sited within the Western Attica IWMF at the municipality of Phyli.

### **5.3 WESTERN ATTICA WASTE-TO-ENERGY FACILITY**

#### **5.3.1 General Information**

##### **5.3.1.1 Assumptions**

The first step in the design of a WTE facility is the determination of its capacity. In order to reach a decision regarding the capacity of the proposed facility, the MSW generated in Attica and the current MSW management system of the Region must be taken into consideration.

In order to design the Western Attica WTE facility, several assumptions were made with regard to the SWM system of the Region of Attica when the WTE facility starts operation:

- The design (projected) capacity of the currently operating Mechanical Recycling and Composting Facility (MRCF) at Ano Liossia was assumed to be the actual capacity of the plant by the time the proposed WTE facility will have been constructed.
- Operation of the sorting and composting facilities proposed by Attica's Regional Plan for SWM was also assumed.
- A third assumption was that 20% of the waste delivered to the sorting facilities are non-recyclable residues, as in the case of the Aspropyrgos HERRCo Facility<sup>(63)</sup>.
- The compost products of the proposed composting facilities were assumed to be 41% of the incoming materials.
- Construction of two new mechanical recycling facilities of approximate capacity 400 tons per day at the OLAs of Grammatico and Keratea was assumed.

According to these assumptions, the implementation of Attica’s Regional Plan – excluding the “waste processing” facility of undetermined technology at the Western Attica IWMF – will result in recovering approximately 1,260 tons of recyclable materials and compost products, which corresponds to about 16% of the MSW generated in Attica Region, and landfilling about 6,500 tons daily. In order to maximize the material and energy recovery and minimize the quantity of waste to be landfilled, part or the entire amount of the amount to be landfilled should be thermally processed in one or more WTE facilities. In this study, it is assumed that part of the amount of MSW to be landfilled will be conveyed to Greece’s first WTE facility, the Western Attica WTE facility. More information on the facility’s capacity is presented in the following section.

Table 5.1 presents data regarding the incoming MSW and outgoing products of Attica’s waste management plants.

**Table 5.1 Daily material flows of Attica’s waste management plants.**

Facilities	Input MSW (t/d)	Output Materials (t/d)		
		Recyclables	Compost Products	Residual Wastes
Aspropyrgos Sorting	70	56	-	14
Maroussi Sorting	50	35	-	15
Western Attica New Sorting	237	189	-	47
Northeastern Attica New Sorting	229	183	-	46
Southeastern Attica New Sorting	229	183	-	46
Ano Liossia MRCF	1,200	41	361	687
Northeastern Attica MRF	402	14	-	206
Southeastern Attica MRF	402	14	-	206
Western Attica New Composting	111	-	90	18
Northeastern Attica New Composting	56	-	45	5
Southeastern Attica New Composting	56	-	45	5
<b>TOTAL (t/d)</b>	<b>3,041</b>	<b>715</b>	<b>541</b>	<b>1,294</b>
<b>TOTAL (%)</b>	<b>39</b>	<b>9</b>	<b>7</b>	<b>17</b>

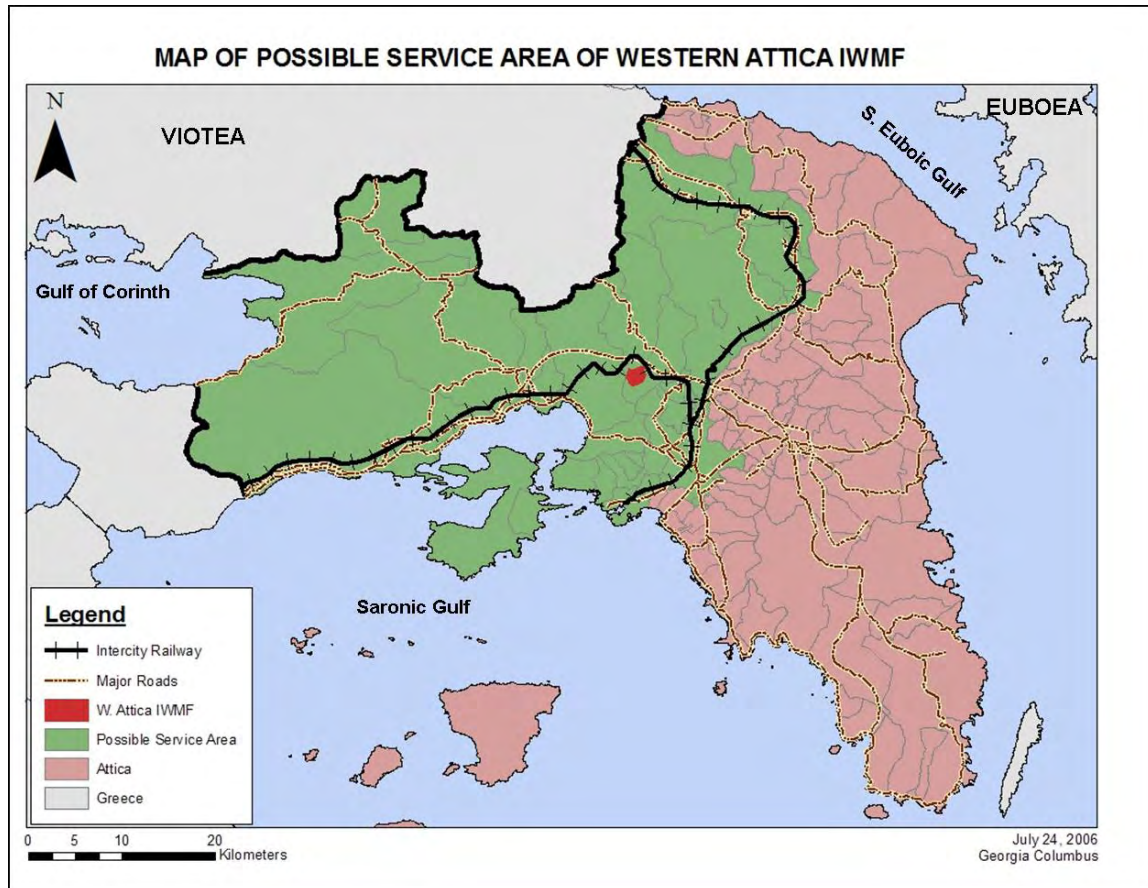
Moreover, the several assumptions were made regarding the hours of the proposed facility’s operation. In order to determine the hours of operation, a safety factor of 90% for maintenance and potential repair was considered. Thus, it will be considered that the proposed WTE plant will process MSW 330 days annually. Also, the facility will be open for reception of waste 24 hours per day, 7 days per week.

### 5.3.1.2 Capacity

The Western Attica WTE facility at Phyli is proposed to have a capacity of 3,000 tons per day. There are several plants of this capacity operating worldwide and, as in all other aspects, the facility’s design was based on well-proven industrial experience.

The WTE plant will be receiving daily around 2,235 tons of unprocessed MSW, as well as the residual wastes deriving from the neighboring waste processing facilities (i.e. Aspropyrgos sorting plant, Western Attica new sorting plant, Ano Liossia MRCF and Western Attica new composting facility), which are estimated to reach 20% of the total MSW entering the Western Attica IWMF.

Figure 5.3 shows a potential service area of the Western Attica IWMF (including the proposed WTE facility) that consists of 42 OLAs of approximately 2.7 million inhabitants that daily produce about 3,850 tons of MSW.



**Figure 5.3 Assumed service area of Western Attica IWMF.**

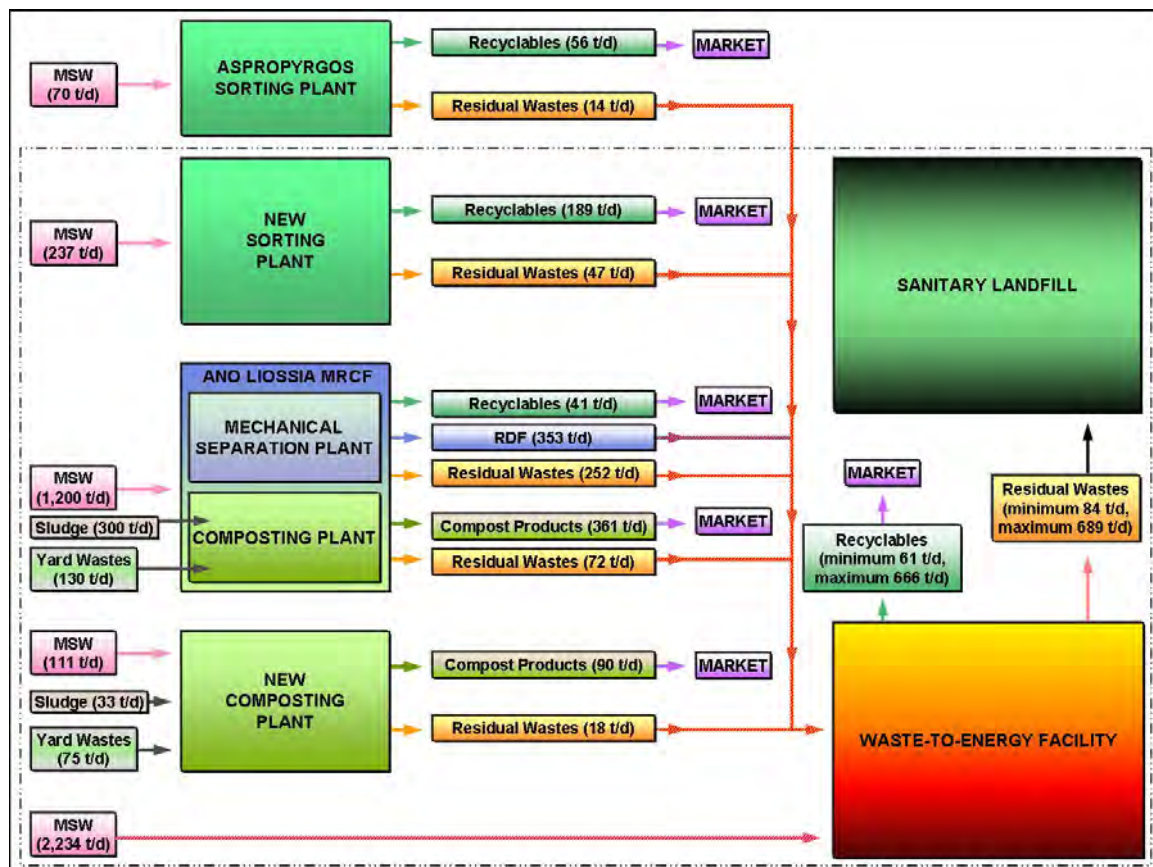
Table 5.2 presents the daily material flows that will take place at the Western Attica IWMF. Accordingly, the implementation of WTE in western Attica will result in a daily increase of material recovery in the service area from 19%, which is the estimated amount deriving from the proposed Regional Plan, to a minimum of 21% (if only ferrous metals are recovered) or a maximum of 36% (if ferrous and aluminum metals are recovered, and bottom ash is beneficially used). Simultaneously, the material recovery of the entire Region of Attica will increase from 16% of the MSW generated in the Region

to a minimum of 17% or a maximum of 25%, which corresponds to an increase of recycling rates by 5-53% in regards to that proposed by the Regional Plan for SWM.

**Table 5.2 Daily material flows at Western Attica IWMF.**

Facilities	Incoming MSW (t/d)	Outgoing Materials (t/d)				
		Recyclables		Compost Products	Residual Wastes	
		min	max		max	min
Aspropyrgos Sorting	70	56		-	14	
New Sorting	237	189		-	47	
Ano Liossia MRCF	1,200	41		361	687	
New Composting	111	-		90	18	
<b>TOTAL (t/d)</b>	<b>1,618</b>	<b>286</b>		<b>451</b>	<b>766</b>	
<b>TOTAL (%)</b>	<b>42</b>	<b>7</b>		<b>12</b>	<b>20</b>	
WTE	3000*	61	666	-	689	84
<b>TOTAL OUTGOING MATERIALS (t/d)</b>		<b>347</b>	<b>952</b>	<b>451</b>	<b>689</b>	<b>84</b>
<b>TOTAL OUTGOING MATERIALS (%)</b>		<b>9</b>	<b>25</b>	<b>12</b>	<b>18</b>	<b>2</b>

\* This amount includes the residual wastes from the aforementioned IWMF facilities



**Figure 5.4 Schematic diagram of the proposed SWM system for western Attica.**

Figure 5.4 shows a flow-sheet of the MSW management system proposed for the Prefecture of Western Attica. The implementation of this proposal will result in landfilling only a small amount of the MSW entering the Western Attica IWMF. Depending on the way in which residual ash will be managed, the amount of MSW to be landfilled may range from 2-18% of the MSW produced in the service area, which is equivalent to 40-48% of the MSW generated in the entire Attica Region. On the other hand, if WTE is excluded from the MSW management system, approximately 84% of the MSW generated in the Region will be landfilled. Consequently, the reduction of the amount of waste of the Region to be landfilled will range from 43-55% in regards to that proposed by the Regional Plan.

It must be noted that the annual recycling and landfilling rates will vary from the aforementioned values since the waste management facilities do not operate 365 days per year. For instance, the planned annual material recovery will reach 14% of the MSW generated in Attica Region and will change to a minimum of 15% or a maximum of 22% if WTE is included in the Regional Plan. Also, the annual MSW to be landfilled will be reduced from 83% to a minimum of 46% or a maximum of 53% assuming that the excess amount of MSW generated during this period (35 days) will be landfilled.

The operation of Western Attica WTE facility would result in compliance with the targets regarding material and energy recovery, as well as landfilling, set by EU (Section 4.2.1).

#### 5.3.1.3 Financing Plan

The Western Attica WTE facility will be partly owned and, in the long term, operated by the hosting OLA of Phyli. However, the project will be financed in the form of Public-Private Partnership (PPP), i.e. most of the funding will come from a combination of private equity and private debt (either in the form of bank loans or capital market bond issues). The remaining project capital will be provided by a grant from the EU, which offers financial assistance to environmental projects in Greece.

In terms of this study, it will be assumed that: (a) 25% of the capital costs will be provided by private investors; (b) 40% of the capital costs will be funded by EU, as in the case of the construction of the Ano Liossia Cogeneration Power Station (CPS); and (c) the remaining 35% of the amount will be a private debt from commercial banks and perhaps also from the European Investment Bank (EIB), which offers loans at the lowest interest rates and has financed numerous environmental and other projects throughout EU.

After the construction phase of the project, which will be considered to last 2 years, and the certification that the new plant operates according to the design specifications, the

project will be refinanced at a lower interest rate and at a higher debt-to-equity ratio, which will be paid in a period of 25 years.

It will be considered that the loan during the construction phase will be offered at an interest rate of 6.5%, while it will be reduced to 5.5% for the remaining years – after refinancing takes place. Also, the annual dividends for the holders of preferred equity will be set at 12.5% of amount of equity investment.

Finally, the cash flow after all expenses, taxes, principal repayment and equity dividends will be distributed by 50% to the municipality of Phyli, 25% to the investors and 25% to the sponsors.

### **5.3.2 Technical Specifications**

#### **5.3.2.1 Technology To Be Used**

The next step in the design of a WTE facility is the determination of the most suitable technology to be used.

For the combustion of MSW, either mass-burn or Refuse Derived Fuel (RDF) technologies may be used. They use similar systems with regard to steam generation, air pollution control (APC) and ash handling. However, there are a number of differences, the most important of which are the following<sup>(9)</sup>:

- Mass-burning is a simple, flexible and reliable technology, whereas RDF-burning is characterized by complex pre-processing lines that tend to have more mechanical shutdowns and lower overall availability.
- Due to the relative complexity of the pre-processing systems, RDF systems require operators with greater skill and experience.
- The mass-burn plants are more economical.
- RDF facilities may send a greater percentage of their incoming waste stream to landfills, since they screen out materials of low heating value. In a mass-burning system a certain amount of this material will end up in the ash, but some of it may burn and thus, need not be landfilled.
- RDF facilities produce approximately 5% more energy than mass-burning facilities of the same capacity, because of the removal from the feed during pre-processing of components of the waste stream with lower heating value.

A mass-burning system is recommended for the proposed WTE facility, as it is more economical and widely proven. The most suitable technology for this type of facilities is the moving grate combustion system, which is by far the most commonly used. The main advantages of the moving grate combustion system are that: (a) it can accommodate large variations in waste composition and calorific value (Figure 2.11); (b)

it allows for an overall thermal efficiency of up to 85%; and (c) each furnace can be built with a capacity of up to 1,200 tons per day<sup>(48)</sup>.

### 5.3.2.2 Number of Processing Lines

In the design of a WTE plant, it is generally required to incorporate at least two waste processing lines in order to ensure its continuous operation when maintenance or repairs are required on one unit.

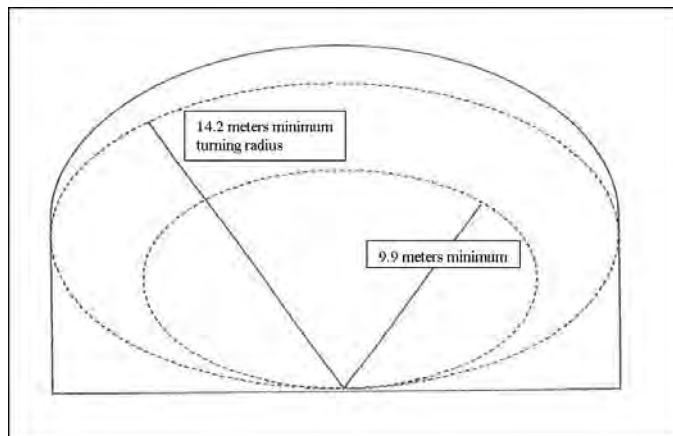
The proposed WTE facility will be designed with three waste processing lines, each of which will have a capacity of 1,000 tons of MSW per day or approximately 42 tons per hour. However, the design and construction of the plant will include the provision for addition of more processing lines in the future, if additional capacity is required.

### 5.3.2.3 Gates, Roads and Building Height

Based on the fact that the average waste collection truck is around 10 meters long, 2.5 meters wide and 4 meters high, the gates and any structure openings must be at least 5 meters high and 5 meters wide with no posts in the middle.

Moreover, the roads towards the tipping floor must have a minimum width of 3 meters per lane and a maximum inclination of  $7^{\circ}$ <sup>(159)</sup>.

The turning radius (Figure 5.5) of the trucks, which is about 14.2 meters, and a space of appropriate area for their maneuvering (at least 15.5 meters in length from the entrance of the building) must be also taken into consideration in the design of the facility.



**Figure 5.5 Turning path for waste collection trucks<sup>(10)</sup>.**

Finally, the ceiling of the buildings must be at least 10 meters high in order to allow enough space for the trucks to unload waste.

### 5.3.2.4 Scale House

The scale house will be located at the entrance of the facility. Underground computerized scales lying on both entering and exiting paths will weigh the waste collection trucks. The weighing of the collection trucks aims at the determination of the

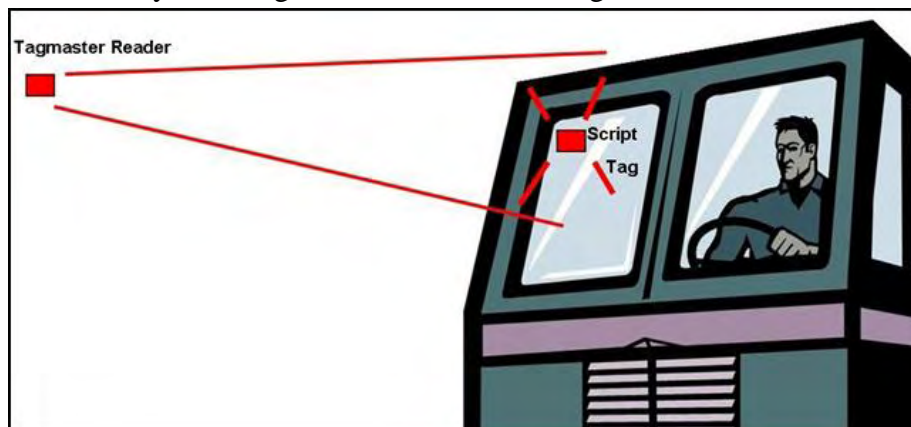
quantities of incoming and outgoing materials and is essential not only in defining financial data, but also in keeping records.

Figure 5.6 shows the scale house at the entrance of the Hugo Neu Material Recovery Facility (MRF) in Long Island City, New York.



Figure 5.6 Scale house at Hugo Neu MRF, NY, USA<sup>(10)</sup>.

Furthermore, a Tagmaster Radio Frequency Identification (RFID) system will be used in order to avoid time loss during weighing. The Tagmaster readers will be placed above the gate and the ScriptTags will be placed inside the trucks' windshields (Figure 5.7) in order to avoid their damage or removal. The long-range identification system will allow for precise identification, weighing and registration of trucks as they pass through the entrance or exit of the facility without stopping<sup>(173)</sup>. All the truck movements will be recorded by the TagMaster Reader and registered in a central database, which will



drastically avoid potential traffic problems.

Figure 5.7  
Tagmaster RFID  
system<sup>(10)</sup>.

Finally, a radiation monitor will be incorporated in the scale house for detection of radioactive materials and their prevention from entering the facility.

#### 5.3.2.5 Tipping Floor

The incoming MSW will be deposited and stored at the tipping floor, which will be located indoors in order to allow air be drawn for the combustion of MSW and, thus, inhibit odors escape. The tipping floor (Figure 5.8) will lay at ground elevation and will include the refuse bunker, where the waste collection trucks will unload the MSW, and the bays.



**Figure 5.8 View of the tipping floor of Veolia ES (Montenay) Dutchess LLC WTE facility at Poughkeepsie, NY, USA<sup>(10)</sup>.**

The refuse bunker will not only receive the daily amount of MSW unloaded by the collection trucks, but also be used as a storage space for MSW delivered in excess. The waste accumulated on site will ensure the continuous supply of materials to the combustion chamber, when the flow of incoming waste collection trucks is impeded by factors, such as weather or strikes.

The refuse bunker of the specific WTE plant is proposed to have a capacity of 18,000 tons of MSW, which is the sum of the amount of MSW to be processed daily and a 5-day supply, assuming that any obstacle for waste entering the facility will have been solved in a period less than 5 days. If the average density of the incoming MSW is assumed to be 300 kilogram per cubic meter, as determined by the National Technical University of Athens (NTUA), the volume of this amount of MSW corresponds to 60,000 cubic meters. The refuse bunker will be designed to have an additional 22.5% of storage space; hence, it will have a volume of approximately 73,500 cubic meters.

In addition, the peak loads of materials to be delivered were taken into consideration, as they play an important role in the identification of the dimensions of the waste bunker and the bays of the tipping floor. This parameter also determines the size requirements of a parking lot, if needed, to serve as a waiting area for the incoming trucks. In terms of this study, it was assumed that 90% of the trucks entering the facility each day will arrive in a period of 4 hours (e.g. 8 am – 12 pm), which is true for numerous operating WTE facilities.

According to estimations of this study, the average capacity of the refuse collection trucks used in the service area previously designated (Figure 5.3) is 8 tons. Consequently, during the aforementioned period, less than 10 trucks will be entering the facility every 7 minutes, which is considered to be the residence time of the trucks on the tipping floor.

If it is assumed that 5 meters in length are required for each regular waste collection truck, the length of the refuse bunker should reach at least 50 meters. Furthermore, in the case that side-unloading of MSW by larger trucks takes place, at least 25 meters in length are required. Moreover, the assumption that the required areas for the regular and large waste collection trucks are about 128 square meters and 500 square meters respectively indicates that the bays of the tipping floor should occupy an area of at least 1,775 square meters.

In order to define all the parameters involved in the design and construction of the specific part of the WTE facility, further research is required; nevertheless, the aforementioned information provides a broad view of the dimensions' requirements.

Figure 5.9 shows a plan of the tipping floor of the Western Attica WTE facility, as one possible option for its design. In this case, the refuse bunker has a depth of 15 meters and occupies an area of approximately 4,900 square meters. The total area of the tipping floor reaches 10,035 square meters. It must be noted that the dimensions of the tipping floor allow for simultaneous unloading of more than 10 waste collection trucks. Considering the typical residence time of each truck in the building, no queue of incoming trucks will be formed during the peak hours. Figures 5.10 and 5.11 are the two sections that are depicted in Figure 5.9.

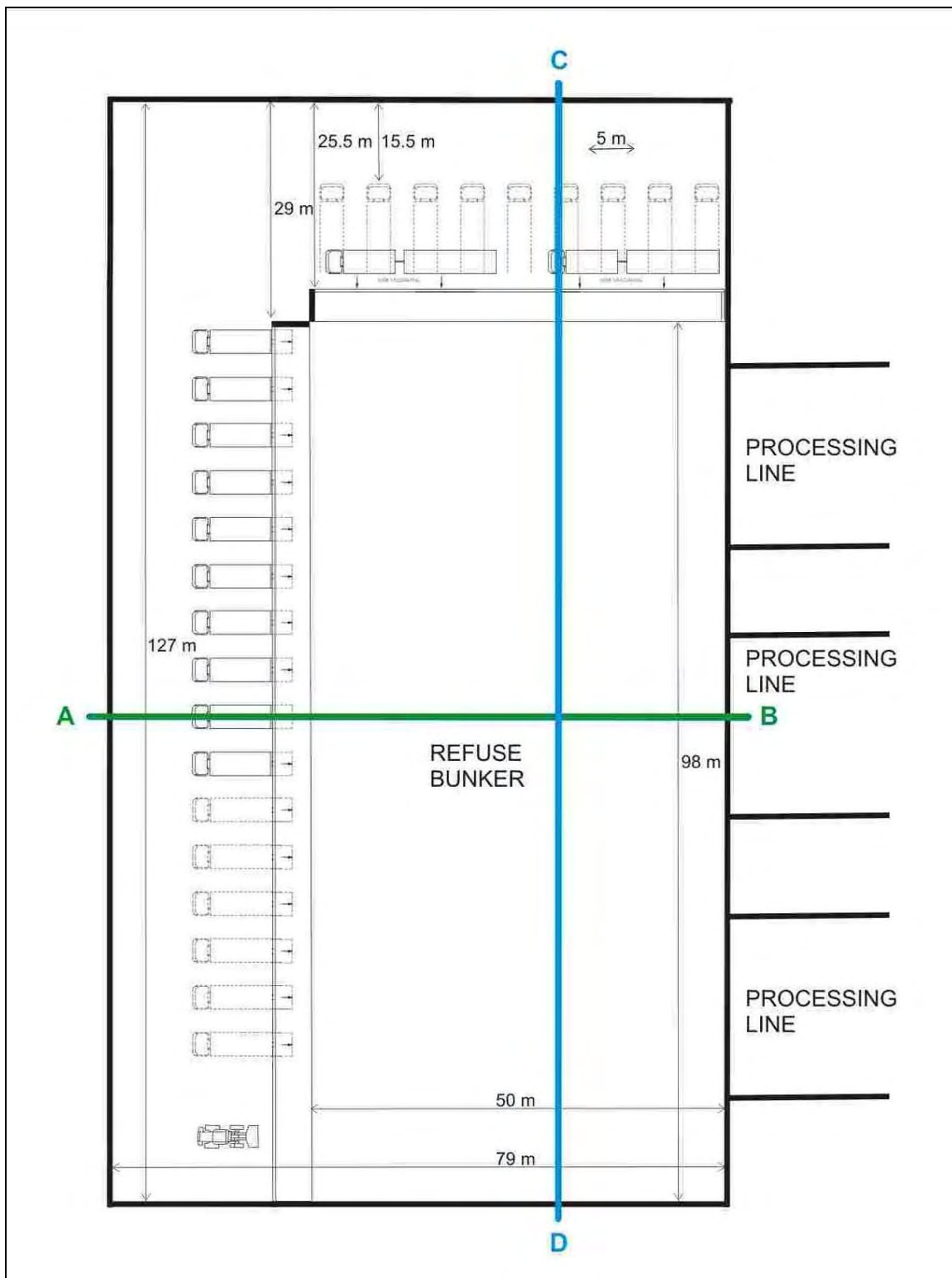


Figure 5.9 Plan of the tipping floor of the proposed plant (based on Reference 23).

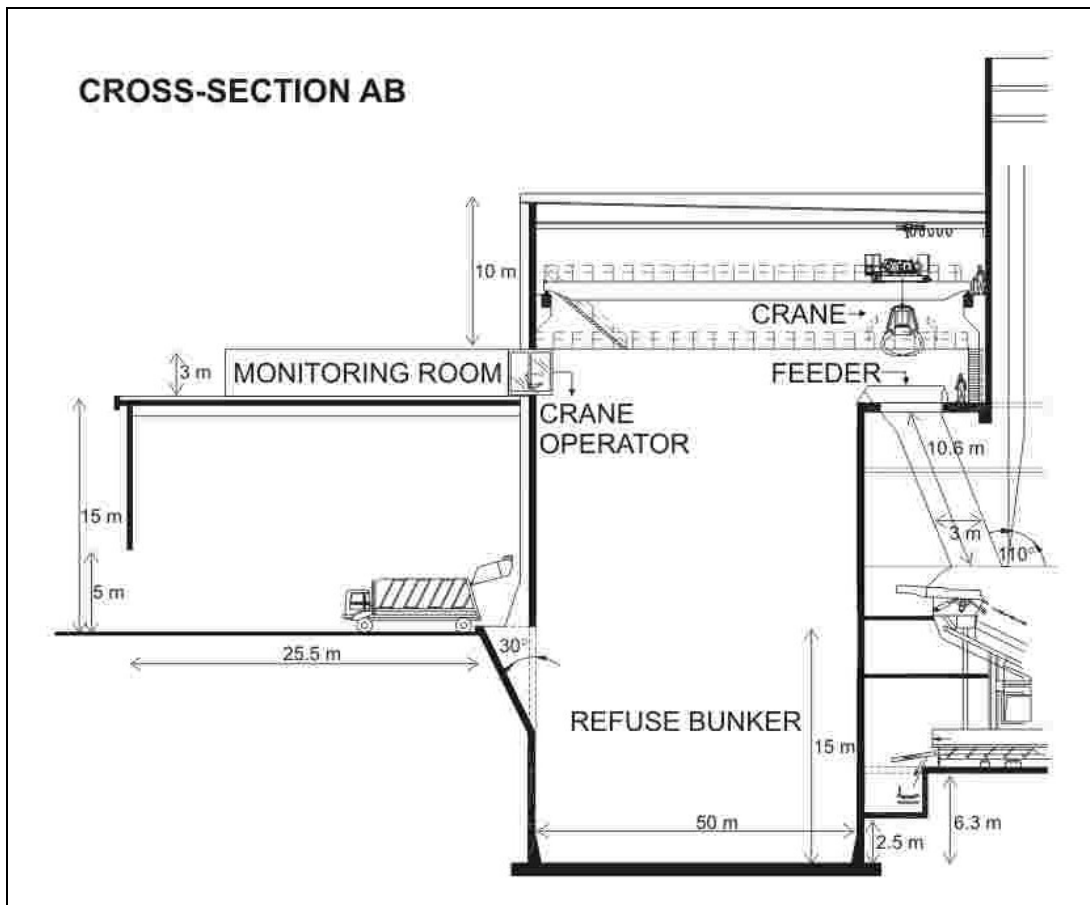


Figure 5.10 Cross-section AB (based on Reference 23).

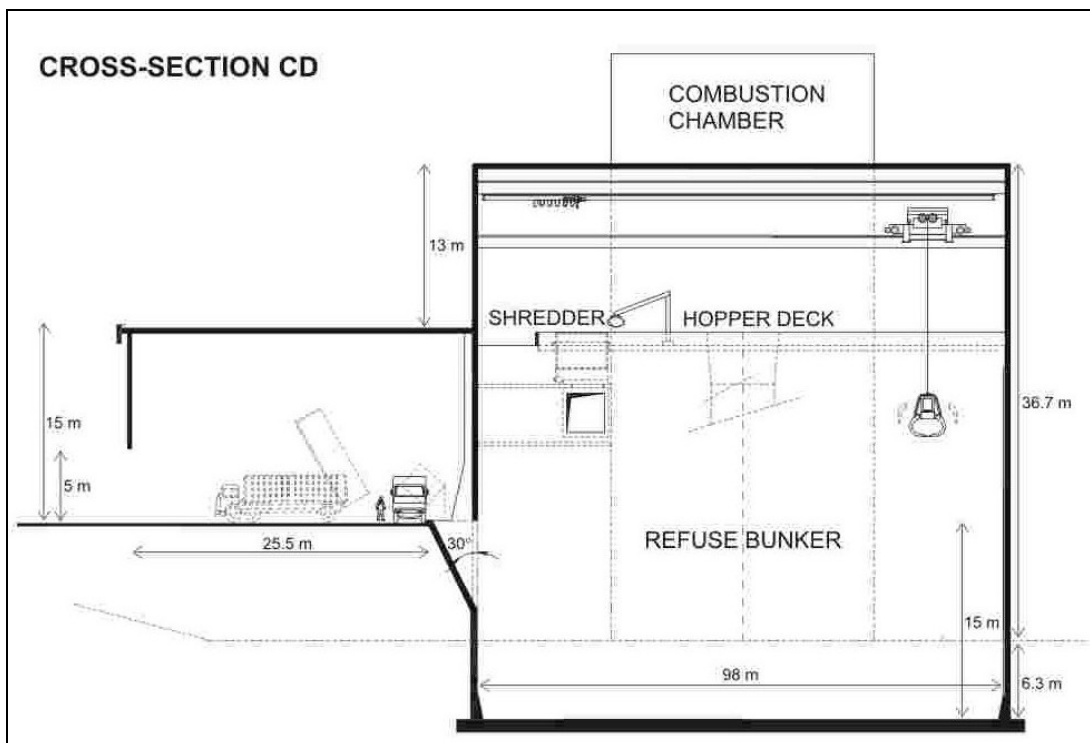
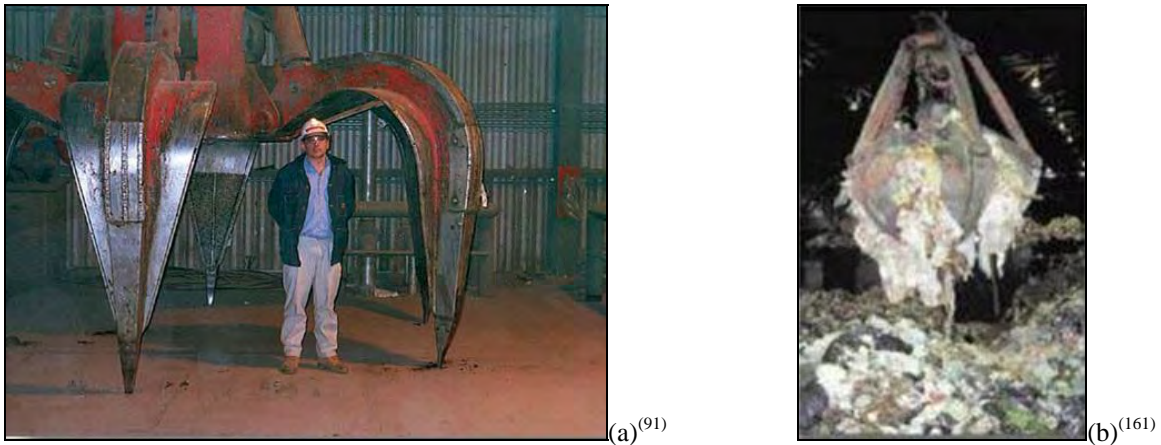


Figure 5.11 Cross-section CD (based on Reference 23).

### 5.3.2.6 Feeding System

As shown in Figures 5.10 and 5.11, rails will be installed on the ceiling of the waste bunker to allow for the overhead cranes to move, in order to periodically mix the MSW and deliver them into the chutes that feed the three hoppers supplying the three combustion lines. The cranes will be equipped with computerized scales in order to provide to the operator control of the MSW fed into each chute. Figure 5.12 shows cranes used currently in WTE facilities in the U.S. and Canada.



**Figure 5.12 Cranes: (a) Crane used to transfer 2,000 tons of MSW per day; (b) Crane in operation – Veolia ES (Montenay) WTE facility at Burnaby, BC, Canada.**

The number of cranes required depends on various factors, such as the density of the MSW, the volume of the cranes, the number of the processing lines and the dimensions of the WTE plant. In order to determine the actual number of cranes that are required for the proposed WTE facility, as well as their volume, the following equation was used<sup>(51)</sup>:

$$M = \frac{V_c \cdot \rho}{t}$$

where  $M$ : capacity of the crane to transport MSW (in tons per hour);

$V_c$ : volume of the crane “claw” (in cubic meters);

$\rho$ : density of MSW (in tons per cubic meter);

and  $t$ : total time required for a complete movement of the crane (in hours), calculated by the following formula:

$$t = 2 \cdot (t_k + t_e + t_s + t_y)$$

where  $t_k$ : time required for the crane to close its arms, the average value of which is 0.2 minutes;

$t_e$ : time required for the crane to lift MSW. This parameter is equal to the fraction of the average height divided by the lifting velocity, which ranges between 40 and 60 meters per minute;

$t_h$ : average time required for the crane to transfer MSW to the hopper on the horizontal axis. The value of this parameter is expressed by the fraction of the average distance of the crane on the horizontal axis divided by the crane's speed; and  $t_v$ : the maximum time required for the crane to transfer MSW to the hopper on the horizontal axis, which is equal to the maximum distance traveled by the crane divided by the crane's velocity on the horizontal axis.

It must be noted that the dimensions mentioned in Figures 5.9 – 5.11 and the maximum possible values for the horizontal and vertical velocities of the crane were assumed. These calculations led to the conclusion that three cranes of 5.71 cubic meters capacity are required for the proposed facility. However, two extra cranes will be stored at the facility in case of emergency.

Regarding the feeder chutes, each will be designed to allow the transit of about 42 tons or 139 cubic meters of waste per hour. Assuming a contingency 9%, the volume of the chute is estimated at about 152 cubic meters. As one possible option, the feeder chute could have an inclination of  $110^\circ$  and dimensions of 3 meters in length, 4.8 meters in width and 10.6 meters in depth (Figure 5.10).

#### 5.3.2.7 Combustion Chamber

The main processes that take place in a combustion chamber (furnace) are described in Chapter 2.

The size, volume, and geometry of the combustion chamber of the proposed facility will be designed to minimize the risk of slag deposits and ash fouling on the furnace walls, which require an adequately low thermal furnace load (about 1 megawatt of thermal energy released per square meter of grate surface area) and a low relative flue gas velocity (lower than 3.5 – 4 meters per second)<sup>(48)</sup>. Generally, the combustion chamber is designed with a large volume and height (about 20 meters), so that the flames of the combustion reactions do not reach the furnace walls.

Furthermore, the combustion chamber will be designed so as to use to recirculated flue gas through the secondary tuyeres, in order to partially replace secondary air to the furnace. Part of the flue gas stream (20-30%) will be recirculated through an insulated duct to the furnace and injected through a set of separate nozzles in the combustion chamber. The operational, economic and environmental advantages of the flue gas recirculation are:

- Higher thermal efficiency, as excess air and oxygen ( $O_2$ ) content can be significantly reduced and thermal efficiency increased by 1-3%;
- Reduction of nitrogen oxides ( $NO_x$ ) of as much of 20-40% can be attained when recirculating 20-30% of the flue gas;

- Reduction of dioxin generation;
- Stabilization or improvement of flow and turbulence conditions;
- Minimization of risk of hot spots on the waterwall of the furnace; and
- Decrease of the amount of flue gas entering the APC system.

#### 5.3.2.7.1 *Grate System*

The grate system's performance plays an important role in the operational reliability and the combustion efficiency, since it has two principal functions: to shift, mix and level the waste; and to supply and distribute primary combustion air.

The grate system must be divided into individually adjustable sections, the number of which depends on factors, such as the grate type, the waste composition, the required capacity, and the requirements made for operation at partial and maximum load at varying calorific values. Depending on the type of grate, the longitudinal division may vary from one to six sections.

Moreover, the variations in load and heating values require a flexible primary air supply system in respect to both the amounts supplied and the supply spots. Consequently, a number of adjustable air zones must be established under the grate. Also, the primary combustion air must be supplied to the MSW through slots in the front side of or between the grate bars at a typical rate of 10 – 15 meters per second. Experience has shown that in order to ensure satisfactory air distribution, the air supply area should be no more than 1.5-2% of the total grate area<sup>(48)</sup>.

The detailed technical specifications of the grate system to be used in the proposed facility will be provided by the suppliers of the combustion system.

#### 5.3.2.8 *Boiler System*

The furnace enclosure will be lined up with waterwall, which serves to minimize heat losses from the outer surface of the furnace and ensures heat transfer from the combustion gases, mostly by radiation, to evaporate the water flowing through the waterwall (Figure 2.8). The hot gases leaving the furnace enclosure will, then, enter the convection section where the saturated steam will be heated to a temperature of 450°C or higher, in order to maximize the generation of electricity in the subsequent steam turbine. Preferably, the convection section is horizontal rather than vertical. An economizer section will serve to heat the water fed to the boiler to the boiling temperature and maximize the energy recovery from the combustion gases before they are conveyed to the APC gas cleaning system<sup>(61)</sup>.

### 5.3.2.9 Air Pollution Control System

The APC system is an integral component of a modern WTE facility; hence, particular attention will be given to its design. It must be noted that flue gas must be cooled to at least 200°C before the treatment technology can be applied.

For the Western Attica WTE plant it is proposed to install APC equipment of the most advanced level, which can be accomplished by dry scrubbing, ammonia (NH<sub>3</sub>) and activated carbon (C) injections, and baghouse filters.

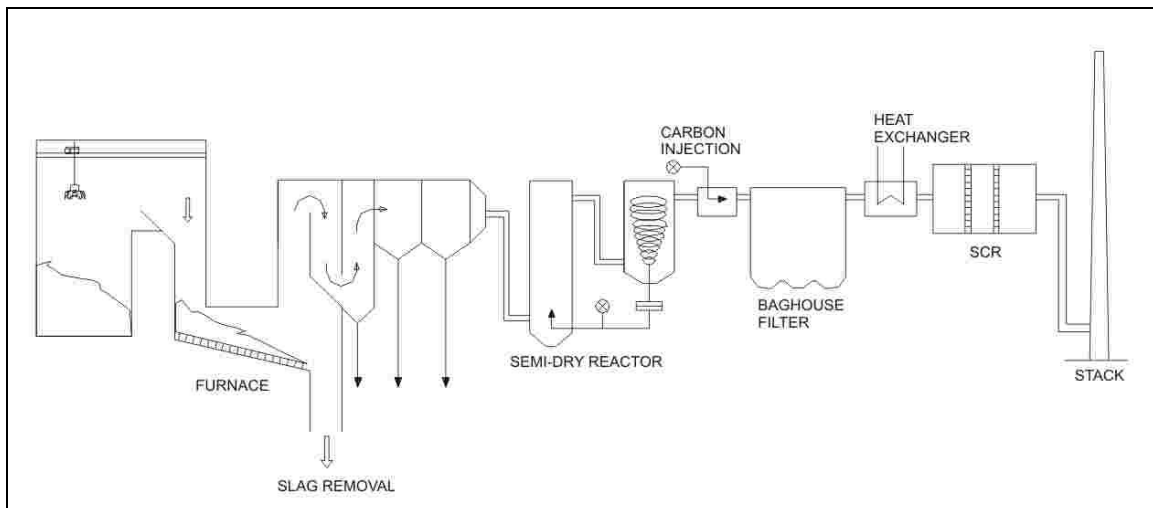
The treatment efficiencies of a *dry* or *semi-dry system* towards hydrogen chloride (HCl), hydrogen fluoride (HF) and sulphur dioxide (SO<sub>2</sub>) depends on the addition of chemicals. Increased consumption of lime (Ca(OH)<sub>2</sub>) can contribute to the advanced control of these three pollutants. However, a completely dry system will need lime (Ca(OH)<sub>2</sub>) in excessive quantities. Also, mercury (Hg) and dioxin emissions are controlled by adding activated carbon (C) to lime (Ca(OH)<sub>2</sub>).

On the other hand, an advanced *wet system* includes an additional wet scrubber, in which sulphur dioxide (SO<sub>2</sub>) is reduced by reacting with a sodium hydroxide (NaOH) solution or a calcium carbonate (CaCO<sub>3</sub>) suspension. Due to excess oxygen (O<sub>2</sub>) in the flue gas, the reaction products are a sodium sulfate (Na<sub>2</sub>SO<sub>4</sub>) solution and a gypsum (CaSO<sub>4</sub> 2H<sub>2</sub>O) suspension, respectively. If sodium hydroxide (NaOH) is applied, the scrubber system requires an additional water treatment unit, in which the sulfate ions of the sodium sulfate (Na<sub>2</sub>SO<sub>4</sub>) solution are precipitated as gypsum (CaSO<sub>4</sub> 2H<sub>2</sub>O) by calcium ions. If calcium carbonate (CaCO<sub>3</sub>) is used, the gypsum (CaSO<sub>4</sub> 2H<sub>2</sub>O) is formed directly and may be removed by dewatering in a hydrocyclone or by settling as sludge. Moreover, the gas from the sulphur dioxide (SO<sub>2</sub>) scrubber is reheated in the gas/gas heat exchanger and is led to a baghouse filter, before which activated carbon (C) or a mixture of lime (Ca(OH)<sub>2</sub>) and activated carbon (C) is injected into the duct. When the gas penetrates the bags of the fabric filter, mercury (Hg) and dioxins are removed, while hydrogen chloride (HCl), hydrogen fluoride (HF), sulphur dioxide (SO<sub>2</sub>), dust and other heavy metals are further reduced.

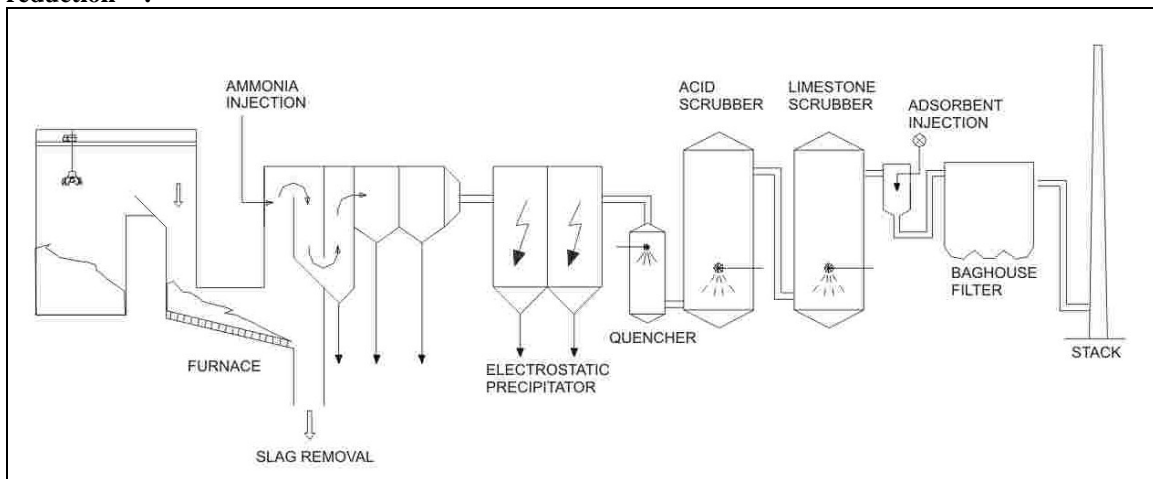
None of these processes, however, controls the emissions of nitrogen oxides (NO<sub>x</sub>), which should first be controlled by primary measures, such as temperature control in the combustion chamber by means of flue gas recirculation as mentioned earlier. Nitrogen oxides (NO<sub>x</sub>) may be further controlled by injection of ammonia (NH<sub>3</sub>) that selectively reduces the nitrogen oxides (NO<sub>x</sub>) to elemental nitrogen (N<sub>2</sub>) and water vapor, both of which are environmentally harmless. This can be achieved by two processes, either the *Selective Non-Catalytic Reduction* (SNCR) or the *Selective Catalytic Reduction* (SCR). The chemical reactions are the same in both processes, but the former requires a temperature around 900°C, while the latter is effective around 250°C. SNCR requires

ammonia ( $\text{NH}_3$ ) to be added in excess of the stoichiometric consumption, whereas SCR may be run at stoichiometric conditions. Accordingly, SNCR is applied simply by injecting ammonia ( $\text{NH}_3$ ). The surplus ammonia ( $\text{NH}_3$ ) passes with the flue gas to the APC system. If the APC system is wet, the surplus ammonia ( $\text{NH}_3$ ) is quantitatively removed as ammonium chloride ( $\text{NH}_4\text{Cl}$ ), in the hydrogen chloride ( $\text{HCl}$ ) scrubber and is discharged with the treated wastewater. Nevertheless, for dry and semi-dry systems, SCR tends to be the best choice, because they do not have the same ability to remove ammonia ( $\text{NH}_3$ ). The SCR process is usually applied after the wet scrubbers or after a dioxin filter in wet APC systems, and after the baghouse filter in dry and semi-dry systems. This requires gas to be reheated by heat exchange and a clean fossil fuel. Consequently, the SCR process is expensive, both in investment and operating costs.

Figures 5.13 and 5.14 show possible designs of semi-dry and wet APC advanced systems, respectively; while Table 5.3 lists their advantages and disadvantages.



**Figure 5.13** Example of a semi-dry APC system with dioxin removal and selective catalytic reduction<sup>(48)</sup>.



**Figure 5.14** Example of a wet APC system with selective non-catalytic reduction, limestone scrubber and dioxin filter<sup>(48)</sup>.

**Table 5.3 Advantages and disadvantages of the semi-dry and wet APC advanced systems<sup>(48)</sup>.**

Advanced APC Systems	Semi-dry system with dioxin removal and SCR	Wet system with SNCR, limestone scrubber and dioxin filter
<b>Advantages</b>	<ul style="list-style-type: none"> <li>▪ No wastewater treatment required</li> <li>▪ Less prone to corrosion</li> <li>▪ No visible plume</li> </ul>	<ul style="list-style-type: none"> <li>▪ Nearly stoichiometric consumption of chemicals</li> <li>▪ Inexpensive NOx removal process</li> <li>▪ Economic SO2 removal with CaCO3</li> <li>▪ Destruction of dioxins</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>▪ Expensive NOx removal process</li> <li>▪ High consumption of chemicals and energy</li> <li>▪ More solid residues</li> <li>▪ Dioxins are not destroyed, only adsorbed</li> </ul>	<ul style="list-style-type: none"> <li>▪ High investment costs</li> <li>▪ Wastewater treatment required</li> <li>▪ Quencher and scrubbers must be made of plastic</li> <li>▪ White plume in cold and humid weather</li> </ul>

Continuous Emission Monitoring (CEM) equipment, which typically monitors stack emissions of nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), oxygen (O<sub>2</sub>), particulate via opacity meters and acid gases via monitoring hydrogen chloride (HCl) and sulfur dioxide (SO<sub>2</sub>), will be installed at the proposed WTE plant to ensure full and continuous compliance with the regulations. Gas temperatures will be also monitored to control the scrubber process and to ensure safety of the baghouse filters<sup>(68)</sup>.

Finally, a double redundant APC system is proposed to be installed at each processing line of the Western Attica WTE facility in order to avoid air pollution in case of damage of the equipment.

#### 5.3.2.10 Stack Height

In general, the stack height ranges roughly from 50 to 110 meters depending on several parameters. First, it depends on the efficiency of the APC system and CEM system, as mentioned in the previous section.

Second, it depends on the terrain of the facility's site and the prevailing weather conditions, such as rainfall, wind direction and speed. The meteorological data of the area in combination with the application of a dispersion and deposition model will determine the optimum stack height.

Another key parameter is the height of the neighboring buildings. In particular, the stack should be twice as high as the tallest building in a radius of about 1 kilometer from the WTE facility.

Finally, the distance of the WTE facility from airports plays an important role. A WTE plant that is located in the vicinity of airports or heliports must comply with the aviation regulations. For example, according to the U.S. Federal Aviation Administration (FAA), sponsors who propose any of the following constructions or alterations should notify the FAA<sup>(165)</sup>:

- Any construction or alteration of over 61 meters in height above the ground level at its site.
- Any construction or alteration of greater height than imaginary surface extending outward and upward at one of the following slopes:
  - 100 to 1 for horizontal distance of 6.1 kilometers from the nearest point of the nearest runway of each airport with at least one runway more than 975 meters in actual length, excluding heliports.
  - 50 to 1 for horizontal distance of 3.5 kilometers from the nearest point of the nearest runway of each airport with its longest runway no more than 975 meters in actual length, excluding heliports.
  - 25 to 1 for a horizontal distance of 1.5 kilometers from the nearest point of the nearest landing and takeoff area of each heliport.

The nearest airport to the Western Attica WTE facility is the airport of Elefsina, the nearest point of which is located at a distance greater than 6.1 kilometers. Accordingly, no limitations are posed by the aviation regulations regarding the height of the stack of the proposed WTE facility.

Nevertheless, it must be noted that according to the U.S. FAA regulations, any structure higher than 76 meters above ground level should normally be marked and/or lighted in order to maintain aviation safety.

### **5.3.3 Ash Generation and Management**

The combustion of MSW results in the reduction of its weight by approximately 75%. Therefore, it will be assumed that the amount of combined ash generated at the proposed WTE facility will be equal to 25% of the total incoming MSW. It will be also assumed that the bottom ash generated will amount to 600 tons per day (20% of the total MSW entering the WTE facility), and the fly ash to 150 tons per day (5% of the total incoming MSW).

The ash generated at the WTE facility will be processed for material recovery and then, discarded in an environmentally sound manner, as described in the following section.

#### **5.3.3.1 Material Recovery**

Material recovery from WTE ash can be achieved by processing the generated ash for the extraction of ferrous and non-ferrous metals and also by using the ash beneficially in applications, such as road base, substitute aggregate material, and landfill infrastructure and maintenance, in place of soil and stone aggregate. In terms of this

study, it will be assumed that only recovery of ferrous metals and aluminum will take place at the Western Attica WTE facility.

At the lower end of the inclined grate, the bottom ash will fall into a water quenching tank. It will then be conveyed to a vibrating grizzly screen for the extraction of bulky materials. These materials (Figure 5.15) consist mostly of bulky metal parts, such as beams and large metal objects, and some non-combustible materials (i.e. concrete).



**Figure 5.15** Materials extracted from ash by grizzly – Veolia ES (Montenay) Dutchess LLC WTE facility at Poughkeepsie, NY, USA.

The remaining bottom ash will undergo magnetic separation for the extraction of ferrous metals by passing the bottom ash under a rotating electromagnetic drum (Figure 5.16).



Figure 5.16 illustrates the type of ferrous materials extracted by an electromagnetic separator.

**Figure 5.16** Magnetic separator – Veolia ES (Montenay) Dutchess LLC WTE facility at Poughkeepsie, NY, USA.

**Figure 5.17**  
**Ferrous metal**  
**fraction after**  
**magnetic**  
**separation –**  
**Veolia ES**  
**(Montenay)**  
**Dutchess LLC**  
**WTE facility**  
**at**  
**Poughkeepsie,**  
**NY, USA<sup>(54)</sup>.**



After the extraction of ferrous metals, the bottom ash will be conveyed to an eddy-current separator for the removal of non-ferrous metals (Figure 5.18). The non-ferrous metals will be further processed mechanically for the extraction of pure aluminum.



**Figure 5.18** **Extracted non-ferrous metal fraction – Resource Recovery, LLC, Pinellas Facility at St. Petersburg, FL, USA<sup>(53)</sup>.**

Based on data acquired from numerous WTE facilities, it can be safely assumed that 61 tons of ferrous metals (8% of the produced ash) and 5 tons of aluminum (0.6% of the produced ash) will be recovered at the proposed WTE facility daily.

Moreover, on the basis of current markets for metal scrap, it will be assumed that ferrous metals and aluminum will be sold to the market at a price of approximately \$101 (€128)<sup>(83)</sup> and \$1,655 (€1,300) per ton, respectively.

In this study, it has been assumed that the remaining fraction of bottom ash will be combined with the generated fly ash, loaded on trucks and transferred to the adjacent sanitary landfill for use in landfill maintenance. This represents U.S. practice, but in EU much of the bottom ash is used beneficially for construction used outside landfills. This avenue can be explored in more detailed studies of the first WTE facility in Greece.

### 5.3.4 Energy Output

For a WTE plant to operate properly, the minimum required heating value of the materials to be incinerated must be 6 megajoule per kilogram throughout all seasons. The annual average calorific value of the waste must be at least 7 megajoule per kilogram. The Lower Heating Value (LHV) of the MSW of Attica Region was calculated to be around 12.7 megajoule per kilogram, which ensures the normal operation of the proposed WTE facility. Nevertheless, studies must be continued in order to determine more precisely the standing values.

Regarding the production of energy, it will be assumed that one ton of MSW feed will generate around 650 kilowatt-hours of net electricity and 500 kilowatt-hours of thermal energy<sup>(61)</sup>. Consequently, the proposed WTE facility will daily generate approximately 2 gigawatt-hours of electricity and 1.5 gigawatt-hours of heat.

It should be noted that the above numbers are for net generation, after use of energy by the proposed WTE plant itself; therefore, there will not be any costs for electricity and thermal energy consumption.

The net electricity will be sold to the Public Power Company (PPC) network. Considering the MSW composition of Attica Region, approximately 88% of the electricity produced will be considered as renewable energy and about 12% as non-renewable; as per current prices of energy, they will be sold at market prices of \$0.089 (€0.07) and \$0.057 (0.045) per kilowatt-hour<sup>(38)</sup>, respectively.

Since the concept of district heating is not widespread in Greece, it will be assumed that for the first years of the WTE plant's operation thermal energy will be partly used by the plant and partly distributed to the adjacent waste management facilities of the Western Attica IWMF at no charge.

Finally, a certain fraction of the generated electricity will be provided at no charge to the residents of the municipality of Phyli, more details on which will be provided in a following section.

### 5.3.5 Other Sections of the Facility

The design of the WTE facility will include an administration building, an analytical laboratory, the employees' facilities and a visitors' center. As education of the public regarding proper SWM methods is crucial, the facility will be constructed in such a way to allow demonstration of all the processes that occur in the plant. The educational tours will take place after interested parties contact the personnel.

Additionally, a maintenance building will be located on the facility's premises for the systematic maintenance of the vehicles and machinery.

The entire facility must be constructed with consideration to the specific site's parameters, such as the landscape and geological conditions.

One possible design of the proposed WTE plant is shown in Figure 5.19. Taking into account the aforementioned information the building occupies an area of approximately 21,100 square meters. The total surface required for the facility is estimated at 90.000 square meters.

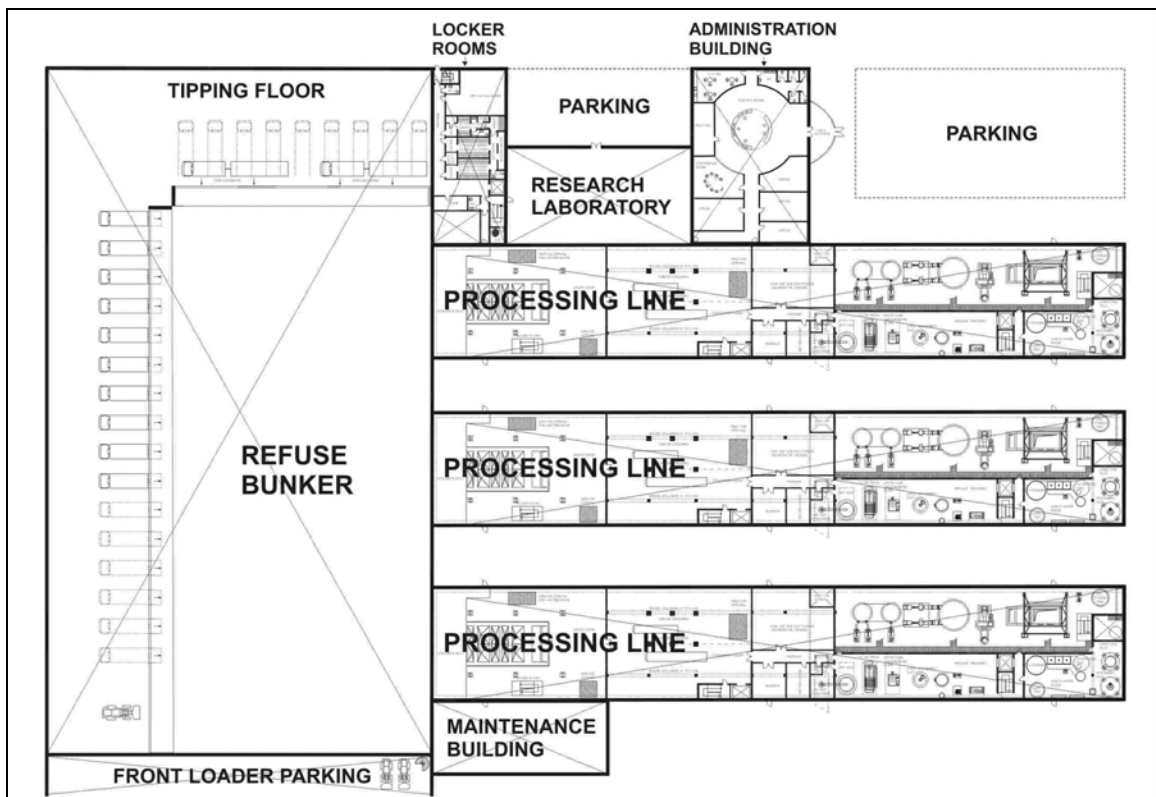


Figure 5.19 Possible plan of the proposed WTE plant (based on Reference 23).

Figure 5.20, which presents the daily material flows in the proposed WTE facility and was based on the above assumptions.

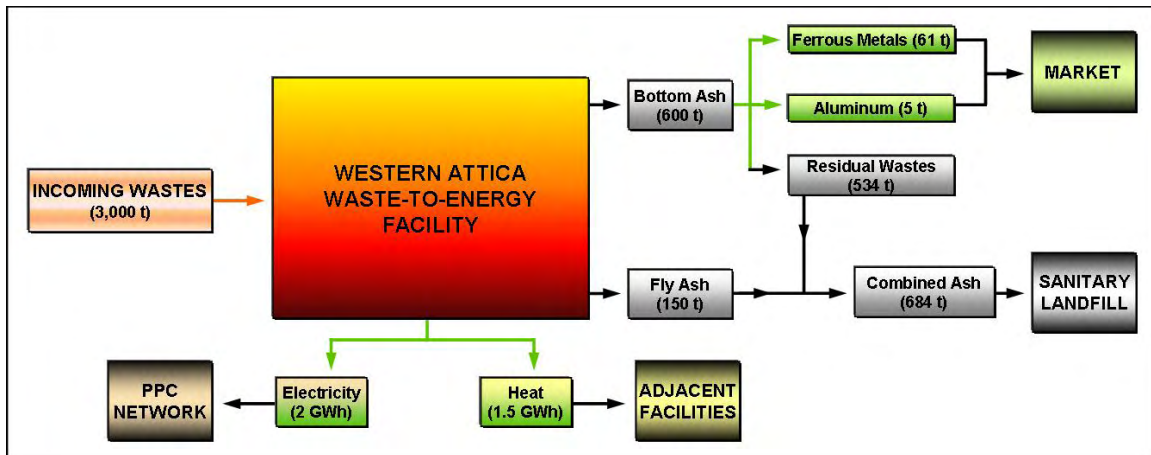


Figure 5.20 Daily material flow of the Western Attica WTE facility.

### 5.3.6 Economic Aspects

The capital costs for a WTE plant, as well as the operating costs, depend on several factors. In terms of this study, several assumptions were made in order to estimate the total expenditure, including construction, operating and maintenance costs, as well as the revenues, of the Western Attica WTE facility:

- The proposed mass-burning WTE facility will have the capacity to process 3,000 tons of MSW daily.
- The WTE plant will process MSW for 330 days annually and will receive material 24 hours per day, 7 days per week.
- The incoming MSW will be combusted in three lines of 1,000 tons daily capacity each (42 tons per hour).
- The proposed WTE facility will be constructed in an area that, according to Attica's Regional Plan for SWM, is already intended for waste management facilities. Therefore, no expenses will be required for purchase of land.
- The capital required will be estimated by considering a cost of approximately \$178,237 (€140,000) per ton of MSW processed daily.
- Approximately 40% of the capital costs of the project will be covered by EU funds, while the equity investment will equal 25% of the capital costs.
- The remaining 35% of the amount will be borrowed from banks or EIB at an interest rate of 6.5%.
- The construction of the facility will last approximately 2 years.
- After the construction phase is over, the project will be refinanced. New amortizing debt will be issued at an interest rate of 5.5% and will be paid in a period of 25 years.
- The insurance of the WTE facility will cost 0.6% of the capital costs per annum.

- The facility's personnel will include a general manager, assistant managers, engineers, shift supervisors and others, totaling 65 employees, who will work in three shifts per day. In some jobs, a fourth shift was assumed for relief purposes. The number of required employees, as well as their assumed salaries and fringe benefits are shown in the Table 5.4, the values of which were based on the information acquired by the Region's OLAs.

**Table 5.4 Salaries and fringe benefits of WTE facility employees.**

Employees	Salary and fringe benefits		Number of employees per shift	Shifts	Number of employees per year	TOTAL	
	(\$/year)	(€/year)				(\$/year)	(€/year)
General Manager	76,387	60,000	1	1	1	76,387	60,000
Assistant Managers	31,828	25,000	3	1	3	95,484	75,000
Engineers	25,462	20,000	2	4	8	203,699	160,000
Laboratory	21,643	17,000	7	1	7	151,501	119,000
Shift Supervisors	21,388	16,800	1	4	4	85,554	67,200
Accountant	21,134	16,600	2	1	2	42,268	33,200
Control Room	21,134	16,600	2	4	8	169,070	132,800
Security	20,370	16,000	1	4	4	81,480	64,000
Entrance	20,370	16,000	1	4	4	81,480	64,000
Crane Operators	19,097	15,000	3	4	12	229,162	180,000
Maintenance	16,551	13,000	2	4	8	132,404	104,000
Other	16,551	13,000	4	1	4	66,202	52,000
<b>TOTAL</b>					<b>65</b>	<b>1,414,691</b>	<b>1,111,200</b>

- The operating and maintenance costs, excluding labor expenses, were calculated according to Table 5.5, the values of which were based on an analysis of the annual report of the WTE plant at Brescia, Italy, that is similar in size and scope as the proposed WTE plant.

**Table 5.5 Operating and maintenance costs of Western Attica WTE facility (based on Reference 3).**

Operating and Maintenance Costs	(\$/t)	(€/t)
Chemicals	3.82	3.00
Maintenance	22.28	17.50
APC	11.46	9.00
Miscellaneous	3.18	2.50
<b>TOTAL per ton of MSW</b>	<b>40.74</b>	<b>32.00</b>
<b>TOTAL ANNUAL</b>	<b>40,332,442</b>	<b>31,680,000</b>

- The tipping fee will be approximately \$38.2 (€30) per ton of MSW received.

- The facility will generate 600 tons of bottom ash and 150 tons of fly ash daily.
- Bottom ash will be processed for recovery of ferrous metals and aluminum, the amount of which will reach approximately 61 tons and 5 tons per day, respectively.
- The recovered ferrous metals will be sold at \$101 (€128) per ton, while the recovered aluminum will have a value of about \$1,655 (€1,300) per ton.
- The remaining bottom ash will be combined with the fly ash and will be disposed at the adjacent sanitary landfill. Because of the beneficial use of the ash for landfill construction and maintenance, the ash disposal handling costs were assumed to be \$15.3 (€12) per ton.
- The facility will daily generate a net of 2 gigawatt-hours of electricity and 1.5 gigawatt-hours of thermal energy.
- The electricity generated will be sold to the PPC network.
- The amount of electricity considered as renewable (around 88%), will be sold at a price of \$0.089 (€0.07) per kilowatt-hour, while that considered as non-renewable (roughly 12%) at about \$0.057 (€0.045) per kilowatt-hour.
- Each household of the municipality of Phylli will have 200 kilowatt-hours of free electricity per month.
- The investors' annual dividends for preferred shares of equity will be set 12.5% of amount of equity investment.
- Depreciation of the facility will be estimated as a straight line for 20 years.
- Taxes will equal 25% of the net profit of the operating facility.
- Inflation was assumed to be equal to 2%.
- For a period of three years, an amount equal to 20% of the earnings after taxes will be retained, so as to set aside in a special escrow account with adequate funds to pay for 6 months of the loan interest and principal amounts.
- The OLA of Phylli will annually receive 50% of the WTE facility's net cash flow, while the remaining amount will be equally divided to the investors and sponsors.

The entire project is estimated to cost approximately \$534.7 million (€420 million). Table 5.6 shows the capital costs and the planned financing structure for the construction phase of the Western Attica WTE project.

**Table 5.6 Capital costs and financing of the Western Attica WTE facility.**

Capital Costs	(\$)	(€)
<b>WTE Construction Cost</b>	<b>534,710,400</b>	<b>420,000,000</b>
EU grant (40%)	213,884,160	168,000,000
Equity Investment (25%)	133,677,600	105,000,000
Debt (35%)	187,148,640	147,000,000

The projected expenditures and projected revenues of the Western Attica WTE facility for the first, second and third year of operation, according to the above assumptions, are shown in Tables 5.7 and 5.8, respectively. The detailed analysis of the financial calculations is provided in Appendix D.

**Table 5.7 Annual expenditures of the Western Attica WTE facility.**

Annual Expenditures	Operation Year 1		Operation Year 2		Operation Year 3	
	(\$)	(€)	(\$)	(€)	(\$)	(€)
Operating & Maintenance	43,633,117	34,272,588	44,505,780	34,958,040	45,395,895	35,657,201
Labor	1,414,691	1,111,200	1,442,985	1,133,424	1,471,844	1,156,092
Ash Disposal	2,688,588	3,422,895	2,742,360	3,491,353	2,797,207	3,561,180
<i>Subtotal</i>	<i>45,047,808</i>	<i>35,383,788</i>	<i>45,948,764</i>	<i>36,091,464</i>	<i>46,867,740</i>	<i>36,813,293</i>
Contingency	4,504,781	3,538,379	4,594,876	3,609,146	4,686,774	3,681,329
<b>Total</b>	<b>49,552,589</b>	<b>38,922,167</b>	<b>50,543,641</b>	<b>39,700,610</b>	<b>51,554,514</b>	<b>40,494,622</b>
Insurance	3,208,262	2,520,000	3,272,428	2,570,400	3,337,876	2,621,808
Loan Principal Repayment	5,253,036	4,126,112	5,549,348	4,358,857	5,862,375	4,604,731
Annual Interest	14,941,041	11,735,768	14,644,729	11,503,023	14,331,702	11,257,149
Corporate Taxes	2,602,815	2,044,438	2,929,879	2,301,338	3,252,718	2,554,918
Dividends to Equity	10,025,820	7,875,000	10,025,820	7,875,000	10,025,820	7,875,000
Retained Earnings	4,769,951	3,746,663	4,966,190	3,900,803	5,159,893	4,052,951
<b>GRAND TOTAL</b>	<b>90,353,515</b>	<b>70,970,148</b>	<b>91,932,034</b>	<b>72,210,031</b>	<b>93,524,897</b>	<b>73,461,180</b>

**Table 5.8 Annual revenues of the Western Attica WTE facility.**

Annual Revenues	Operation Year 1		Operation Year 2		Operation Year 3	
	(\$)	(€)	(\$)	(€)	(\$)	(€)
Tipping Fee/ton	37,697,083	29,610,000	38,451,025	30,202,200	39,220,045	30,806,244
Renewable Electricity	50,105,277	39,356,287	51,107,382	40,143,413	52,129,530	40,946,281
Non-Renewable Electricity	4,488,263	3,525,405	4,578,028	3,595,913	4,669,589	3,667,831
Ferrous Metals	3,281,154	2,577,254	3,346,777	2,628,799	3,413,713	2,681,375
Aluminum	2,722,567	2,138,500	2,777,018	2,181,270	2,832,559	2,224,895
Interest income	67,498	53,018	276,902	217,499	429,206	337,130
<b>TOTAL</b>	<b>98,361,843</b>	<b>77,260,464</b>	<b>100,537,133</b>	<b>78,969,094</b>	<b>102,694,642</b>	<b>80,663,757</b>

Based on all of the above assumptions, the internal rate of return on equity is calculated to be 19.5%, while the net present value of the equity is approximately \$257.4 million (€202.2 million) at a 6% discount rate.

#### **5.4 IMPLEMENTATION OF MORE WASTE-TO-ENERGY FACILITIES**

The inclusion of the proposed Western Attica WTE project in Attica's Regional Plan for SWM will bring the Region closer to the EU goals for Sustainable Development by materializing the philosophy of integrated waste management that must include WTE, as shown in the western nations of EU, in Japan and in other environmentally advanced countries.

Even though the Western Attica WTE project is an excellent solution for the area that it will serve, it is only an improvement regarding the entire MSW issue of Attica. The implementation of the WTE concept in other parts of the Region is necessary to completely resolve the MSW management problem of the Region of Attica and possibly alleviate the waste management situation in the surrounding regions.

In order to completely solve the existent MSW management problem of Attica Region under the present conditions of waste generation and treatment, approximately 6,500 tons of MSW per day should be subjected to thermal treatment. This would increase material and energy recovery significantly and also reduce the need to locate more and more landfills for several generations.

In this study, two possible options of subjecting over three quarters (77.6%) of the MSW generated in the Region to thermal processing were examined:

- **SCENARIO 1:** The simultaneous operation of two WTE facilities of capacity 3,000 tons per day each, one located in western Attica, as proposed in this report, and a second in southeastern Attica. The location of this second WTE plant was chosen, because of the well-developed transportation infrastructure of that area. In this option, it is assumed that the residual wastes produced at the waste management facilities of the Northeastern Attica IWMF will be transferred to the Southeastern Attica IWMF.
- **SCENARIO 2:** The implementation of three WTE facilities to be located at the three IWMF sites (Phyli, Keratea and Grammatico) proposed by Attica's Regional Plan for SWM. In this case, the specifications of the Western Attica WTE facility remain the same, while the other two WTE plants will have a capacity of 1,500 tons of MSW per day each.





Tables 5.9 and 5.10 present data regarding the projected daily material flows taking place at the three IWMFs that have been proposed by Attica's Regional Plan for SWM according to the abovementioned two Scenarios.

**Table 5.9 Daily material flows of Attica's IWMFs as per Scenario 1.**

Facilities	Incoming MSW (t/d)	Outgoing Materials (t/d)				
		Recyclables		Compost Products	Residual Wastes	
		min	max		max	min
<b>WESTERN ATTICA IWMF</b>						
Aspropyrgos Sorting	70	56	-	-	14	
New Sorting	237	189	-	-	47	
Ano Liossia MRCF	1,200	41	361	-	687	
New Composting	111	-	90	-	18	
<b>TOTAL (t/d)</b>	<b>1,618</b>	<b>286</b>	<b>451</b>	<b>-</b>	<b>766</b>	
<b>TOTAL (%)</b>	<b>21%</b>	<b>4%</b>	<b>6%</b>	<b>-</b>	<b>10%</b>	
WTE	3,000 <sup>(1)</sup>	61	666	-	689	84
<b>TOTAL OUTGOING MATERIALS (t/d)</b>		<b>347</b>	<b>952</b>	<b>451</b>	<b>689</b>	<b>84</b>
<b>TOTAL OUTGOING MATERIALS (%)</b>		<b>4%</b>	<b>12%</b>	<b>6%</b>	<b>9%</b>	<b>1%</b>
<b>NORTHEASTERN ATTICA IWMF</b>						
Maroussi Sorting	50	35	-	-	15	
New Sorting	229	183	-	-	46	
New MRF	402	14	-	-	206	
New Composting	56	-	45	-	9	
<b>TOTAL (t/d)</b>	<b>687</b>	<b>232</b>	<b>45</b>	<b>-</b>	<b>276</b>	
<b>TOTAL OUTGOING MATERIALS (t/d)</b>		<b>232</b>	<b>45</b>	<b>45</b>	<b>276</b>	
<b>TOTAL OUTGOING MATERIALS (%)</b>		<b>3%</b>	<b>1%</b>	<b>1%</b>	<b>4%</b>	
<b>SOUTHEASTERN ATTICA IWMF</b>						
New Sorting	229	183	-	-	46	
New MRF	402	14	-	-	206	
New Composting	56	-	45	-	9	
<b>TOTAL (t/d)</b>	<b>687</b>	<b>197</b>	<b>45</b>	<b>-</b>	<b>261</b>	
<b>TOTAL (%)</b>	<b>9%</b>	<b>3%</b>	<b>1%</b>	<b>-</b>	<b>3%</b>	
WTE	3,000 <sup>(2)</sup>	61	666	-	689	84
<b>TOTAL OUTGOING MATERIALS (t/d)</b>		<b>258</b>	<b>863</b>	<b>45</b>	<b>689</b>	<b>84</b>
<b>TOTAL OUTGOING MATERIALS (%)</b>		<b>3%</b>	<b>11%</b>	<b>1%</b>	<b>9%</b>	<b>1%</b>
<sup>(1)</sup> This amount includes the residual wastes from the other facilities of the Western Attica IWMF <sup>(2)</sup> This amount includes the residual wastes from the other facilities of the Northeastern and Southeastern Attica IWMFs						

Table 5.10 Daily material flows of Attica's IWMFs as per Scenario 2.

Facilities	Incoming MSW (t/d)	Outgoing Materials (t/d)				
		Recyclables		Compost Products	Residual Wastes	
		min	max		max	min
<b>WESTERN ATTICA IWMF</b>						
Aspropyrgos Sorting	70	56		-	14	
New Sorting	237	189		-	47	
Ano Liossia MRCF	1,200	41		361	687	
New Composting	111	-		90	18	
<b>TOTAL (t/d)</b>	<b>1,618</b>	<b>286</b>		<b>451</b>	<b>766</b>	
<b>TOTAL (%)</b>	<b>21%</b>	<b>4%</b>		<b>6%</b>	<b>10%</b>	
WTE	3,000*	61	666	-	689	84
<b>TOTAL OUTGOING MATERIALS (t/d)</b>		<b>347</b>	<b>952</b>	<b>451</b>	<b>689</b>	<b>84</b>
<b>TOTAL OUTGOING MATERIALS (%)</b>		<b>4%</b>	<b>12%</b>	<b>6%</b>	<b>9%</b>	<b>1%</b>
<b>NORTHEASTERN ATTICA IWMF</b>						
Maroussi Sorting	50	35		-	15	
New Sorting	229	183		-	46	
New MRF	402	14		-	206	
New Composting	56	-		45	9	
<b>TOTAL (t/d)</b>	<b>737</b>	<b>232</b>		<b>45</b>	<b>276</b>	
<b>TOTAL (%)</b>	<b>10%</b>	<b>3%</b>		<b>1%</b>	<b>4%</b>	
WTE	1,500*	31	333	-	344	42
<b>TOTAL OUTGOING MATERIALS (t/d)</b>		<b>263</b>	<b>565</b>	<b>45</b>	<b>344</b>	<b>42</b>
<b>TOTAL OUTGOING MATERIALS (%)</b>		<b>3%</b>	<b>7%</b>	<b>1%</b>	<b>4%</b>	<b>1%</b>
<b>SOUTHEASTERN ATTICA IWMF</b>						
New Sorting	229	183		-	46	
New MRF	402	14		-	206	
New Composting	56	-		45	9	
<b>TOTAL (t/d)</b>	<b>687</b>	<b>197</b>		<b>45</b>	<b>261</b>	
<b>TOTAL (%)</b>	<b>9%</b>	<b>3%</b>		<b>1%</b>	<b>3%</b>	
WTE	1,500*	31	333	-	344	42
<b>TOTAL OUTGOING MATERIALS (t/d)</b>		<b>228</b>	<b>530</b>	<b>45</b>	<b>344</b>	<b>42</b>
<b>TOTAL OUTGOING MATERIALS (%)</b>		<b>3%</b>	<b>7%</b>	<b>1%</b>	<b>4%</b>	<b>1%</b>
* This amount includes the residual wastes from the other facilities of the specific IWMF						

Another environmental benefit would be the increase of daily material recovery from 16% of the MSW currently generated in the Region to a minimum of 18% (if only ferrous metals are recovered) or a maximum of 33% (if ferrous and aluminum metals are

recovered, and bottom ash is beneficially used); and the reduction of the amount of MSW to be landfilled from 84% of the MSW generated to a minimum of 2% or a maximum of 18%. These values are equivalent to an increase of material recovery by 10-106% and a reduction of the amount of MSW to be landfilled by 79-97% in regards to that proposed by the Regional Plan for SWM.

In terms of annual values, the material recovery would increase from 14% to a minimum of 16% or a maximum of 30%, and the landfilling rate would decrease from 86% to a minimum of 9% or a maximum of 23%.

Accordingly, the implementation of either scenario exceeds the targets for material/energy recovery and landfilling set by EU (Section 4.2.1).

In case that the rates of recycled materials in the Region of Attica increase further in the future, the IWMFs of the Region would be able to serve surrounding regions, such as a number of the Cyclades Islands or parts of the Region of Viotia and/or Euboea.

## **5.5 COMMENTS**

This preliminary study examined the integration of WTE in Attica's Regional Plan for SWM. Several technical and economic assumptions were made and, on this basis, the cash flow of the first WTE facility in Greece, to be located in western Attica, was analyzed. However, it is important to examine the WTE perspective more thoroughly in order to reach accurate results and more specific conclusions.

It must be noted that for the conversion of the monetary values from euros (€) to dollars (\$) and vice-versa, the equivalence of May 7, 2006 ( $€1 = \$1.27312$ )<sup>(163)</sup> was used.

## **CHAPTER 7: CONCLUSIONS AND FUTURE WORK**

Greece faces a Solid Waste Management (SWM) crisis, because of lack of environmental consciousness and deficient national plans of the past. The situation is most critical in the Region of Attica, where over 58% of the country's Municipal Solid Wastes (MSW) are generated. This study examined the current management of MSW in Attica and the potential implementation of one or more Waste-to-Energy (WTE) facilities in the Region as a solution to this problem.

A brief reference to the definitions of solid wastes and the main methods for managing solid wastes were presented in Chapter 1, followed by an introduction of the WTE technology and the advantages that it offers in Chapter 2.

Chapter 3 described the Region of Attica by providing basic information on geography, population, morphology, climatology, geology, land uses and transportation infrastructure. Attica Region includes continental Attica, a small part of Peloponnese and several islands, and has a population of about 4.9 million inhabitants. Continental Attica, on which this chapter focused, is characterized by a variety of morphological features, resulting in an uneven relief, and by intermediate to high seismicity levels. In terms of transportation, the area of study is characterized by a relatively well-developed network of roads and railroads. On the other hand, the fact that Attica receives such a high volume of transportation media results in traffic congestion and air pollution, especially in the basin of Athens. Also, the rail network needs to be expanded. Finally, continental Attica is nearly surrounded by sea and, therefore, has access to waterways that connect the mainland to the islands.

Chapter 4 presented a broad view of the MSW situation in Greece and described in detail the generation and disposition of MSW in the Region of Attica. SWM in Greece has been upgraded remarkably during the last five years. It is becoming a well-organized and environmentally responsible activity with specific goals, mostly in urban areas, but also to a large extent in rural areas. A significant improvement can be seen in the development of collection, waste treatment facilities and material recovery. At the same time, it is obvious that the MSW management system in Greece must be further improved and, most importantly, it must be transformed in order to achieve the environmental goals set by the European Union (EU).

The research conducted on the existent MSW management system in the Region of Attica led to the conclusion that it has several assets and numerous liabilities. Currently, the MSW generated in the Region are mainly transferred either directly, or indirectly

through Waste Transfer Stations (WTSs), to Attica's only sanitary landfill that has reached its permitted capacity; also, some are disposed at illegal Uncontrolled Waste Disposal Sites (UWDSs). To alleviate this situation, the construction of three Integrated Waste Management Facilities (IWMFs) has been planned, but not yet implemented. The above reasons render the study for an alternative SWM system obligatory.

In the search for long-term solutions to the existing problem, the advantages and disadvantages of the SWM system currently practiced were taken into consideration in order to develop an effective MSW management plan, which will greatly improve the quality of life in the Region of Attica.

Therefore, a preliminary assessment of WTE as a possible solution to the MSW issue in the Region of Attica was carried out in Chapter 5. This alternative was chosen, because of its demonstrated environmental and economic viability throughout Europe and other nations. It is a well proven means of environmentally sound treatment of solid wastes that also generates renewable electricity and heat. Controlled combustion of as received MSW on moving grates allied with stringent Air Pollution Control (APC) technologies can consistently and reliably process not only untreated MSW, but also post recycling/composting waste residues in an environmentally safe fashion with minimal impact on the environment. Additionally, the volume of waste to be landfilled is reduced by 90%, resulting in alleviation of traffic congestion and the reduction of air pollution caused by trucks. Finally, the electrical and thermal energy produced by the processing of waste is a major source of profit and also can be used for the operation and for cooling/heating of the WTE plant and/or neighboring facilities. For all these reasons, WTE is considered to be a long-term solution to the waste problem situated in Attica Region.

Hence, the case of the first WTE facility in Greece was studied in detail. The proposed facility to be constructed in the Region of Attica was assumed to have a daily capacity of 3,000 metric tons of MSW. The most promising site was found to be the municipality of Phyli in western Attica and the construction costs were estimated to reach \$534.7 million (€420 million). The Western Attica WTE facility will daily approximately generate 2 gigawatt-hours of electricity and 1.5 gigawatt-hours of thermal energy, part of which will be provided to the Public Power Company (PPC) network and to the residents of the municipality of Phyli. Also, the facility will result in the recovery of at least 61 tons of metals and potential beneficial use of 539 tons of bottom ash at the most per day. These numbers correspond to a potential increase of materials recycled in Attica by 5-53%, in reference to the rate of recycling that will result from the implementation of the Regional Plan for SWM. Also, the amount of MSW to be landfilled in Attica will decrease by 43-55%, in reference to that proposed by the Regional Plan.

Furthermore, the possibility of diverting 6,000 tons of the Region's MSW to thermal treatment was studied. This would result in the recovery of at least 122 tons of metals and potential beneficial use of 1,078 tons of bottom ash maximum per day. These numbers correspond to a potential increase of materials recycled in the Region by 10-106%, in reference to the rate of recycling that will result from the implementation of the Regional Plan for SWM. Also, the amount of MSW to be landfilled would be reduced by 79-97%, in comparison to the rates proposed by the Regional Plan. Additionally, a net of 3.9 gigawatt-hours of electrical and 3 gigawatt-hours of thermal energy would be daily generated. The construction of at least one Marine Transfer Station (MTS) would be required in such a plan. The MTS would provide an efficient containerized collection system, as it would receive MSW from the area of Trizinea and other islands of the Region to prepare it for its transportation to continental Attica.

To sum up, the integration of WTE in Attica's Regional Plan for SWM will lead not only to compliance of the Region with the EU targets towards Sustainable Development, but also to the solution of the MSW problem of the Region.

Finally, Chapter 6 presented alternatives for the transportation of waste to the WTE facilities. In order to ameliorate the circulation of vehicles and reduce their emissions of pollutants into the atmosphere, several alternatives were examined: Firstly, part of the cargo movement taking place on the road network should be conveyed to water and rail. This can be easily accomplished in the area of study since it is surrounded by sea and is characterized by a relatively well-expanded railroad network. In addition, the usage of alternative trucks fuels should be encouraged as it would contribute to a great extent in the effort towards a cleaner environment.

This research provides a complete view of the MSW situation of the Region of Attica and the potential of the implementation of WTE aiming at the solution of this problem. However, this is only a preliminary study and requires a more thorough examination of several aspects. Future work may include:

- An analytical description of the MSW collection system;
- A more precise characterization of the Region's MSW;
- Determination of a more accurate quantity of the MSW generated in the Region;
- More accurate values of the MSW processed at the Region's waste management facilities and their products; and

The materialization of any WTE project, such as the Western Attica WTE facility proposed in this study, requires permitting by the Ministry of Environment, Physical Planning, and Public Works (MEPPPW) and the hosting Organization of Local Administration (OLA); collaboration of experts from other fields, such as geologists, civil engineers, architects and economists; cooperation of other stakeholders, such as the

PPC and other OLAs that will be served by the WTE facility or facilities to be constructed; approval of EU for financial assistance; and consent of the host communities, which can be achieved by an informative campaign that will emphasize the environmental, social and financial advantages of the implementation of WTE.

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