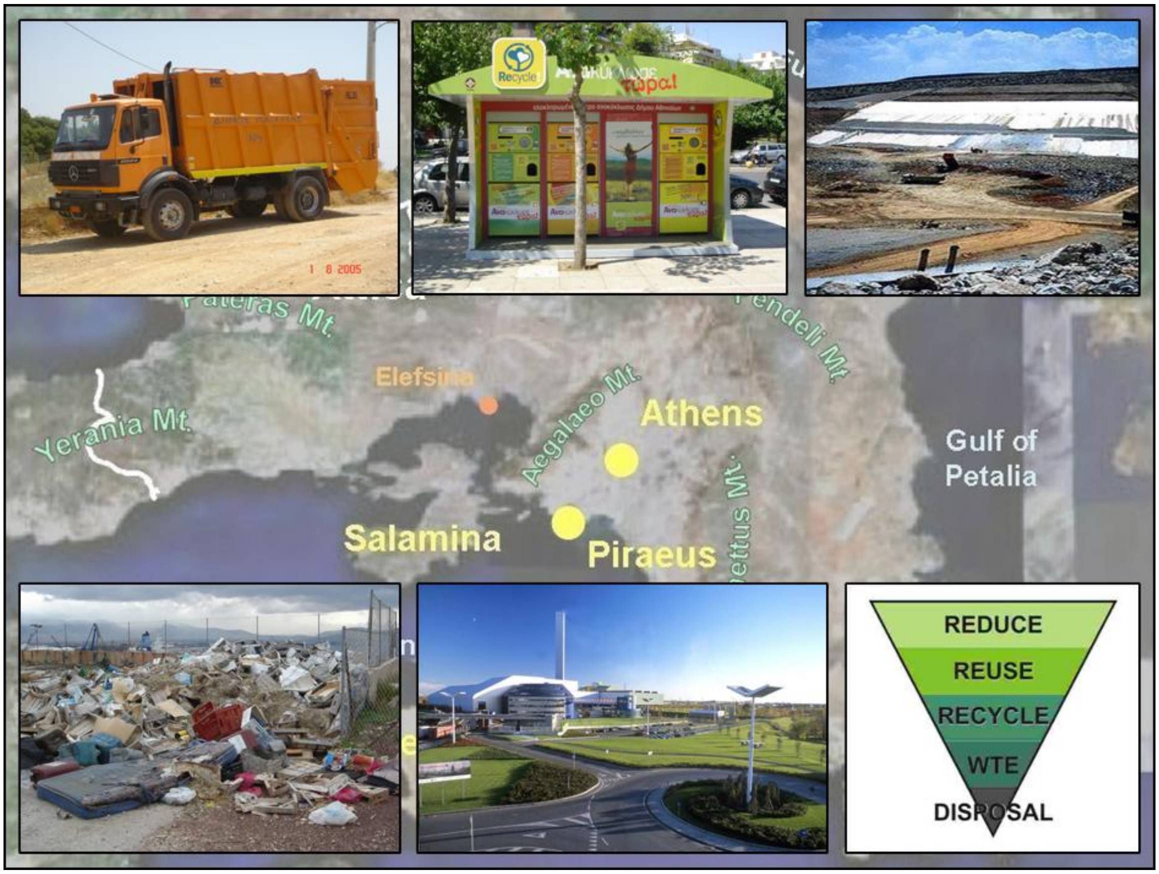
MANAGEMENT OF MUNICIPAL SOLID WASTES IN ATTICA REGION OF GREECE, AND POTENTIAL FOR WASTE-TO-ENERGY

GEORGIA COLUMBUS
Advisor: Professor Nickolas J. Themelis

Submitted in partial fulfillment of the requirement for the M.S. in Earth Resources Engineering
Department of Earth and Environmental Engineering
Columbia University, November, 2006



Research sponsored by:
Waste-to-Energy Research and Technology Council (WTERT)

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

GEORGIA COLUMBUS
Advisor: Professor Nickolas J. Themelis

Submitted in partial fulfillment of the requirement for the M.S. in Earth Resources Engineering
Department of Earth and Environmental Engineering
Columbia University, November, 2006

Research sponsored by:
Waste-to-Energy Research and Technology Council (WTERT)

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 Phyli 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.

CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

ABBREVIATIONS

ACMAR	Association of Communities and Municipalities of Attica Region
AIA	Athens International Airport
APC	Air Pollution Control
AWSSC	Athens Water Supply and Sewerage Company
CAMCG	Central Association of Municipalities and Communities of Greece
CAMS	Collective Alternative Management System
CEM	Continuous Emission Monitoring
CNG	Compressed Natural Gas
CPS	Cogeneration Power Station
EEA	European Environment Agency
EIB	European Investment Bank
EPA	Environmental Protection Agency
EU	European Union
FAA	Federal Aviation Administration
GDP	Gross Domestic Product
GIS	Geographic Information Systems
HERRCo	Hellenic Recovery and Recycling Corporation
ISWA	International Solid Waste Association
IWMF	Integrated Waste Management Facility
JMD	Joint Ministerial Decision
LFG	Landfill Gas
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LTP	Leachate Treatment Plant
MEPPPW	Ministry of Environment, Physical Planning, and Public Works
MRCF	Mechanical Recycling and Composting Facility
MRF	Material Recovery Facility
MSW	Municipal Solid Wastes
MTS	Marine Transfer Station
MWI	Medical Waste Incinerator
NKUA	National and Kapodistrian University of Athens
NOA	National Observatory of Athens
NTUA	National Technical University of Athens
OEP	Operational Environmental Program
OLA	Organization of Local Administration (municipalities and communities)
PATHE	Patras – Athens – Thessaloniki – Evzoni Motorway
PPC	Public Power Company
PPP	Public-Private Partnership
RDF	Refused Derived Fuel
RFID	Radio Frequency Identification
SCR	Selective Catalytic Reduction
SNCR	Selective Non-Catalytic Reduction
SWM	Solid Waste Management
UWDS	Uncontrolled Waste Disposal Site
WTE	Waste-to-Energy
WTS	Waste Transfer Station

AKNOWLEDGEMENTS

I would like to express my gratitude to the people, without the decisive contribution of whom the completion of this thesis would not be possible.

Firstly and foremost, I would like to express my deepest gratitude to my advisor, Director of the Earth Engineering Center and Chair of U.S. Waste-to-Energy Research and Technology, Professor Nicholas J. Themelis, for entrusting me with this subject and for showing complete confidence in me throughout the elaboration of this study. In addition, I thank him for his guidance and technical expertise throughout the synthesis of the thesis, as well as for his strong support.

Secondly, I am particularly grateful to Mr. Nicholas Mitsos, Managing Director of Financial Sciences Corporation, for his time, remarks and the invaluable help that he offered, especially in the financial section of this study.

Thirdly, I would like to show my appreciation to Professors Marco Castaldi and Yuri Gorokhovich for their time and the significant recommendations that they offered.

Moreover, I would like to recognize the following people for their willingness to provide essential for this study information:

- Mr. Arvanitis and Mr. Sypsas, employees of the Association of Communities and Municipalities of Attica Region (ACMAR), Division of the Mechanical Recycling and Composting Facility (MRCF);
- Mr. Karakasis, Mr. Kritikakos and Mrs. Maniati, employees of the Association of Communities and Municipalities of Attica Region (ACMAR), Division of Ano Liossia sanitary landfill;
- Mr. Galenianos, Mr. Katsoulis and Mr. Papadopoulos, employees of ARSI S.A.;
- Mr. Kolokythas, Ms. Kritsova, Mr. Razis, Mr. Tsoutsos and Mr. Tsiloglou, employees of the Hellenic Recovery and Recycling Corporation (HERRCo);
- Mr. Rotas, employee of the Recycling Center for Aluminum Cans;
- Professor Maria Loizidou, Department of Chemical Engineering, National Technical University of Athens;
- Dr. Lolonis, Head of Planning Office, KTIMATOLOGIO S.A. (Hellenic Cadastre S.A.);
- Mr. Vakalopoulos and Mr. Patramanis, employees of the Region of Attica; and
- The employees of the Region’s municipalities and communities, especially Mr. Gliatis, Mr. Koniaris, Mr. Nikitopoulos, Mr. Papadakis, Mr. Philippou and Mr. Stathis.

Furthermore, I would like to thank my colleague and friend, PhD candidate at the National and Kapodistrian University of Athens, Mr. Karalemas, for his help in multiple aspects and strong support.

I would also like to thank my colleagues and friends, PhD candidates at the National and Kapodistrian University of Athens, Mr. Andreadakis, Mr. Foumelis and Mr. Gouliotis, for the information they provided.

In addition, I would like to acknowledge my colleagues and friends from the Department of Earth and Environmental Engineering of Columbia University, who have provided their friendship, suggestions and encouragement; and, more particularly, Mr. Barrai, Ms. Belova, Ms. Brusciotti, Ms. Estevez, Mr. Kaufman, Mr. Kwon, Mr. Lee, Mr. Nakamura, Mr. Penque, Mr. Simmons, Mr. Sunk and Ms. Ulloa, as well as Ms. Labor, Mr. Rennée, Mrs. Themelis and Mr. Usman.

Finally, I would like to express my gratitude to my family that has guided and supported me in all aspects of my life.

INTRODUCTION

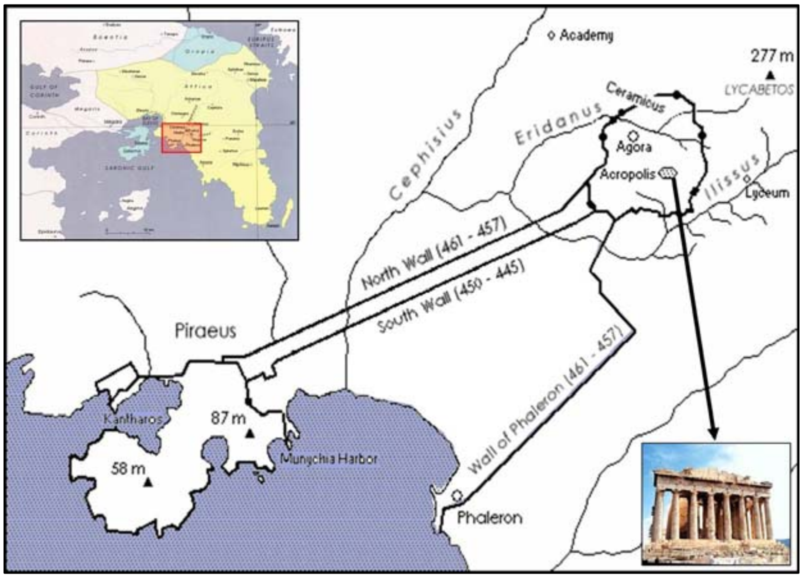
Solid wastes have been an issue for humans from the moment that people began to live together in permanent settlements. When humans abandoned nomadic life at around 10,000 B.C., they began to live in communities, resulting in the production of solid wastes.

At about 3,500 B.C., in the city of Ur (northwest of the Persian Golf), 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(82).

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

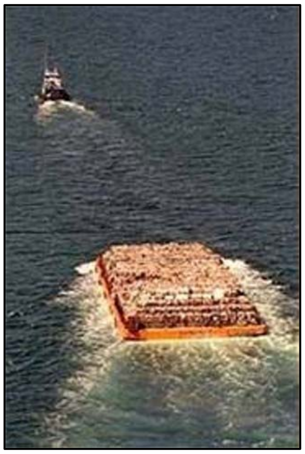
In 1,300 B.C., the Mosaic Law referred specifically to public sanitary practices. Everyone was expected to act as his or her own scavenger, removing refuse and burying it in the earth.

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(2). The figure on the right shows a map of the ancient city of Athens and the location of the city walls(9).



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(71).

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 (€292.2 billion) for the improvement of the quality of life and the environment in Greece in terms of the Operational Program "Environment" (2000 – 2006)(41).

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(12) 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(111). 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(56). 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 = $1.27312)(163) was used.

CHAPTER 1: SOLID WASTES

1.1 DEFINITION OF SOLID WASTES

In general, the definition of solid wastes is ambiguous, due to the vast diversity of their types and sources. This leads to disagreements on the estimated quantities and composition. This chapter will provide the description of “solid wastes”, the characterization of “municipal solid wastes”, and the way in which they can be managed.

Solid wastes include all solid or semi-solid materials arising from human and animal activities that are no longer considered of sufficient value to be retained in a given setting. As useless or unwanted, they are discarded as heterogeneous mass.

Solid wastes can be classified on the basis of their origin, composition, physical aspects, chemical or hazardous properties; and their method of disposal. Classifications are rarely comprehensive or entirely comparable, because waste can be addressed from a variety of view points, each of which requires different types of information. Moreover, because of their nature, solid wastes are rarely constant and predictable in form, size or composition and a precise determination of their properties is considered tedious, expensive and of limited use.

1.1.1 Types of Solid Wastes

As aforementioned, the term “solid wastes” is all-inclusive, encompassing all sources, types of classifications, compositions and properties. In the following paragraphs, the types of solid wastes by composition and origin are cited suggestively.

1.1.1.1 Types by Composition

Depending on their composition, solid wastes can be divided in the following categories(46):

- ***Food Wastes***: Food wastes are the animal, fruit or vegetable residues (also called “garbage”) resulting from the handling, preparation, cooking and eating of foods. The most important characteristic of this type of wastes is that they are putrescible and decompose rapidly, especially in warm weather;
- ***Rubbish***: Rubbish consists of combustible and non-combustible solid wastes, excluding food wastes or other putrescible materials. Typically, combustible rubbish consists of materials such as paper, cardboard, plastics, textiles, rubber, leather, wood,

furniture and garden trimmings. Non-combustible rubbish consists of items such as glass, crockery, tin and aluminum cans, ferrous and non-ferrous metals, dirt and construction wastes;

- ***Ash and Residues***: These are the materials remaining from the burning of wood, coal, coke, and other combustible wastes. Residues from power plants normally are composed of fine, powdery materials, cinders, clinkers, and small amounts of burned and partially burned materials;
- ***Demolition and Construction Wastes***: Wastes from razed building and other structures are classified as demolition wastes. Wastes from the construction, remodeling, and repair of commercial and industrial buildings, and other similar structures are classified as construction wastes. This type may include dirt, stones, concrete, bricks, plaster, lumber, shingles, and plumbing, heating and electrical parts;
- ***Wastewater Treatment Plant Wastes***: This classification includes the solid and semi-solid wastes from water, wastewater and industrial waste treatment facilities;
- ***Agricultural Wastes***: Wastes and residues resulting from diverse agricultural activities, such as planting and harvesting of row; field, tree and vine crops; production of milk; production of animals for slaughter; and operation of feedlots, are collectively called agricultural wastes; and
- ***Special Wastes***: Wastes such as street sweepings, roadside litter, catch-basin debris, dead animals, and abandoned vehicles are classified as special wastes.

1.1.1.2 Types by Origin

Depending on their source, solid wastes can be divided in the following groups(48):

- ***Domestic*** (or residential) are generated by household activities including food preparation, cleaning, fuel burning, old clothes and furniture, obsolete utensils and equipment, packaging, newsprint and yard wastes;
- ***Commercial*** wastes derive from shops, offices, restaurants, hotels and similar establishments. They typically consist of packaging materials, office supplies, and food wastes and generally, resemble to domestic wastes;
- ***Institutional*** wastes derive from schools, hospitals, clinics, governmental offices, military bases, e.t.c. This type is alike to the aforementioned, but involves more packaging than food wastes. Hospital and clinical wastes include potentially infectious and hazardous materials, which must be separated from the non-hazardous components in order be treated individually as to reduce health risks;
- ***Industrial*** wastes: Their composition depends on the type of industry engaged. Besides materials similar to domestic and commercial, it contains chemical substances and may include hazardous materials;

- ***Street Sweepings***, which mostly consist of dust and soil. Other types of material can be paper, metals, and other litter from the streets;
- ***Demolition and Construction Wastes***; and
- ***Agricultural Wastes***, which were previously described.

1.2 MUNICIPAL SOLID WASTES

Municipal Solid Wastes (MSW) are defined as the mixture of household, commercial and/or institutional refuses. This type includes materials, such as paper, wood, yard wastes, tree trimmings, plastics, leather, rubber, glass, metals, and other combustible and non-combustible materials. Refuse Derived Fuel (RDF) is considered as a type of solid wastes that is shredded, and in some cases pelletized. MSW do not include industrial process rejects, manufacturing discards nor solely segregated medical wastes. Sludge and incineration residues are also excluded.

MSW also contain a small quantity of hazardous wastes (detergents, batteries, drugs, e.t.c.), which are difficult (sometimes impossible) to separate. Even though small, these amounts affect the efficiency of their treatment.

MSW are collected from and managed by municipalities or private companies. In order to have a plan for an effective management of MSW, it is important to acquire data relevant to the amounts and rates of MSW generation; their variation through time and space; their physical, chemical and biological properties; and the associated costs for their collection and disposal.

1.2.1 Characterization of Municipal Solid Wastes

1.2.1.1 Quantitative Characteristics

Data on the generation of MSW in a particular geographic area are obtained directly by successive measurements or indirectly from archives with relevant data.

In case that no information exists for a certain area or period of time, material balance is used as the method to make a coarse estimation of the amount of MSW generated. In order to make a prediction for the probable amount of MSW to be generated in the future, one can use the following formula(42):

$$MSWamount = \sum_{i}^{n} w_i \cdot P_i$$

where w_i: the average amount of MSW produced per capita in the year i;

n: the number of years, for which one wants to make the estimation;

and P_i: the population in year i, which can be obtained from census data.

The amounts of MSW generation are expressed in units of mass per capita per day in order to facilitate the comparison of values for various countries, population and periods of times.

1.2.1.2 Qualitative Characteristics

Information on the quality of MSW is important in evaluating alternative equipment requirements, systems, and management plans.

More particularly, ***physical*** properties include identification of the individual MSW components, density, and moisture content; and are essential in the determination of the equipment that will be used.

Information on the ***chemical*** composition is important in evaluating alternative processing and recovery options. If waste is to be used as fuel, the four most important properties to be known are:

- Proximate analysis including moisture, volatile matter, ash, and fixed carbon (C, remainder);
- Fusion point of ash;
- Ultimate analysis, percent of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and ash;
- Heating value (in kilojoules per kilogram);
- Chlorine concentration.

Finally, the ***biological*** properties, which relate to bacteria and odor, have a great impact on the efficiency of the alternative processes that will be used.

1.2.1.3 Important Factors

The composition and generation rates of MSW vary enormously depending on numerous factors. The socio-economy of the waste collection area plays a key role. MSW collected in affluent areas are typically less dense, as they contain more packaging and other lighter materials, and less ash and food wastes. This is due to the fact that more man-made products are used or consumed and much of the food processing takes place in the commercial/industrial sector. Furthermore, high-income areas generate more waste than low- or middle- income areas. On a national scale, the socio-economical level of various countries is reflected by their Gross Domestic Product (GDP), even though it does not always provide accurate results.

Similarly, the population density is an important factor. The highest waste generation rates per area are observed in densely populated areas.

In the last few years, the values of MSW production demonstrate an increase, as a result of the increase of the population and the GDP in many countries. The generation of

MSW nowadays ranges from a few kilograms in developing countries to 3.64 kilograms per capita per day in developed countries.

In addition, difficulties have been encountered in monitoring MSW quantities and composition due to the change of seasons. The observed variety in quantity and quality of MSW is due to factors, such as tourism and the availability of different seasonal products throughout the year. For instance, annual variations in moisture content depend on harvest seasons for vegetables and fruit and the climatic conditions of each area. According to numerous studies, during periods of high temperature waste tends to have higher moisture.

1.2.2 Municipal Solid Waste Management Systems

MSW management systems include a combination of processes from the production of MSW to their disposal, which may modify their physical, chemical and biological properties in order to reduce the volume or hazardous properties, facilitate transportation and the potential recovery of useful materials and energy. An example is shown in Figure 1.1.

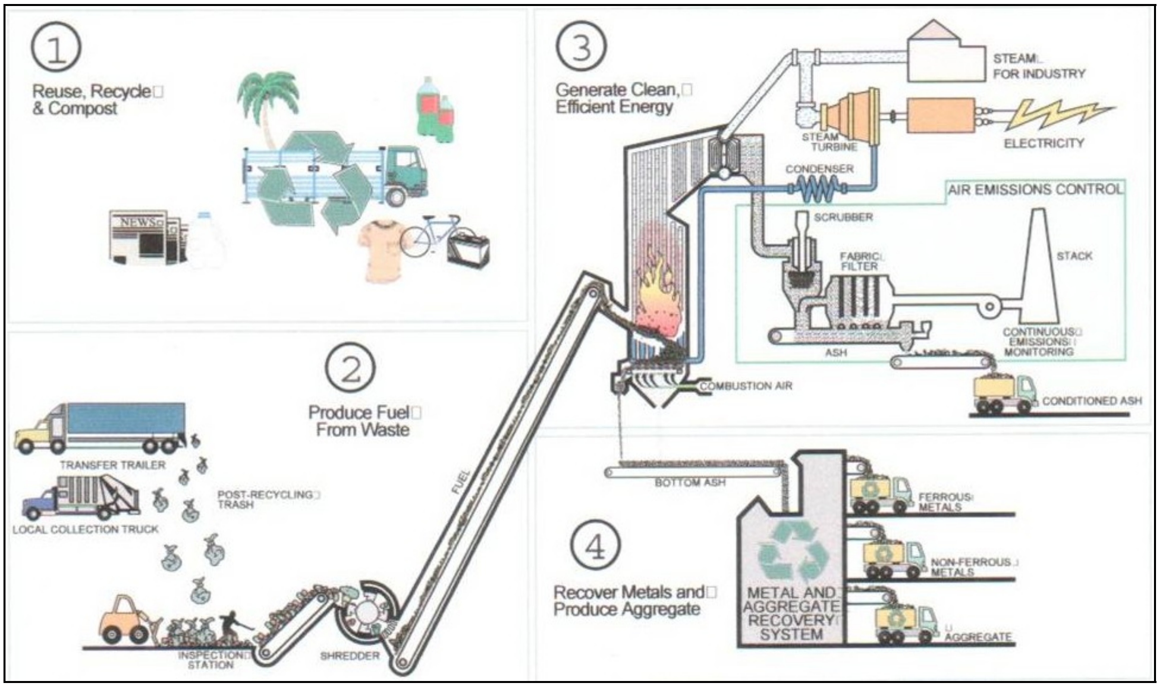


Figure 1.1 Resource Recovery Processes(32).

The most common systems include some or all of the following procedures:

- On-site handling, storage and processing;
- Collection, transfer and transport;
- Processing and resource recovery;

- Ultimate disposal – landfilling.

These processes are described in the following sections.

1.2.2.1 On-site Handling, Storage and Processing

On-site handling refers to the activities associated with the handling of MSW until they are placed in the containers used for storage before collection. Depending on the type of collection service, handling may also include moving loaded containers to the collection point and returning the empty containers to the collection site.

Factors that must be considered in the storage of MSW on-site include the location and type of containers to be used, public health and aesthetics, collection and transport methods.

On-site-processing methods are used to recover usable materials from solid wastes, reduce the volume or alter the physical form. The most common on-site-processing operations as applied to large commercial sources include manual sorting, compaction and incineration.

1.2.2.2 Collection, Transfer and Transport

Information on collection, one of the most costly elements of managing MSW, is presented in four parts dealing with types of collection services and systems, analyses of the collection systems to be used, and the methodology involved in setting up collection routes.

The functional element of transfer and transport refers to the means used to transfer MSW from relatively small collection vehicles (Figure 1.2) to larger vehicles and to transport them over extended distances to either waste processing facilities or disposal sites. Transfer and transport operations become a necessity when haul distances to the disposal sites are such, that direct hauling by the initial collection vehicles is no longer economically feasible.

Figure 1.2 Rear loading compactor(87).

1.2.2.3 Processing and Resource Recovery

Processing techniques are used in Solid Waste Management (SWM) systems to improve their efficiency, to sort out usable materials and to prepare materials for recovery of conversion products and energy. The more important techniques used for processing solid wastes are summarized in Tables 1.1 and 1.2.

Table 1.1 Mechanical methods for separating solid waste components[(46)].

Method	Function	Equipment and/or facilities and applications	Method	Function
Screening	Used to separate solid waste components by size	Trommels and horizontal and vibrating screens for unprocessed and processed wastes; disk screens with processed wastes	Pneumatic Separation (stoners)	Used to separate light and heavy materials in solid wastes
Air Separation	Used to separate light (organic) materials from heavy (inorganic) materials in solid wastes	Zig-zag-air, vibrating-air, rotary-air and air-knife classifiers used with processed wastes	Optical sorting	Used to separate plastics
Jig Separation	Used to separate light and heavy materials in solid waste by means of density separation		Sink-float, flotation, inertial, inclined-table, shaking-table	Used to separate light and heavy materials in solid wastes

Table 1.2 Summary of techniques used for processing solid wastes[(46)].

Processing technique	Function	Representative equipment and/or facilities and applications
Manual component separation	Separation of recoverable materials, usually at point of generation	Visual inspection and removal via conveyor belt picking stations
Storage and transfer	Storage and transfer of wastes to be processed	Open storage pits for unprocessed wastes, storage bins and silos for processed wastes; transfer equipment including front-end loaders, metal and rubber belt conveyors, vibratory conveyors with unprocessed wastes, pneumatic conveyors, and screw conveyors with processed wastes
Mechanical volume reduction	Reduction of solid-waste volume; alteration of shape of solid-waste components; all modern collection vehicles essentially equipped with compaction equipment	Hydraulic piston-type compactors for collection vehicles, on-site compactors, and transfer-station compactors; roll crushers used to fracture brittle materials and to crush tin and aluminum cans and other ductile materials
Chemical volume reduction	Reduction of volume of solid wastes through burning (incineration)	Mass-fired incinerators, with and without heat recovery, for unprocessed wastes; rotary kilns for hazardous/containerized and bulk solid/sludge waste
Mechanical size and shape alteration	Alteration of size and shape of solid-waste components	Equipment used to reduce the size of solid waste including hammer mills, shredders, roll crushers, grinders, chippers, jaw crushers, rasp mills, and hydro-pulpers; briquettes
Mechanical component separation	Separation of recoverable materials, usually at a processing facility	
Magnetic and electro-mechanical separation	Separation of ferrous and nonferrous materials from processed solid wastes	Magnetic separation for ferrous materials; eddy-current separation for aluminum; electrostatic separation for glass from wastes free of ferrous and aluminum scrap; magnetic fluid separation for nonferrous materials from processed wastes
Drying and dewatering	Removal of moisture from solid wastes	Convection, conduction, and radiation dryers used for solid wastes and sludge; centrifuge and filtration used to dewater treatment-plant sludge

Paper, rubber, plastics, textiles, glass, metals and natural organic materials are the principal recoverable materials contained in MSW. Once a decision has been made to recover materials and/or energy, process flow sheets must be developed for the removal of the desired components, subject to pre-determined material specifications. The combustible materials recovered are often identified as RDF.

The design and layout of the physical facilities that make up waste-processing-plant flow sheets are important in the implementation and successful operation of such systems. A typical flow sheet for the recovery of specific components and the preparation of combustible materials for use as a fuel source is presented in Figure 1.3.

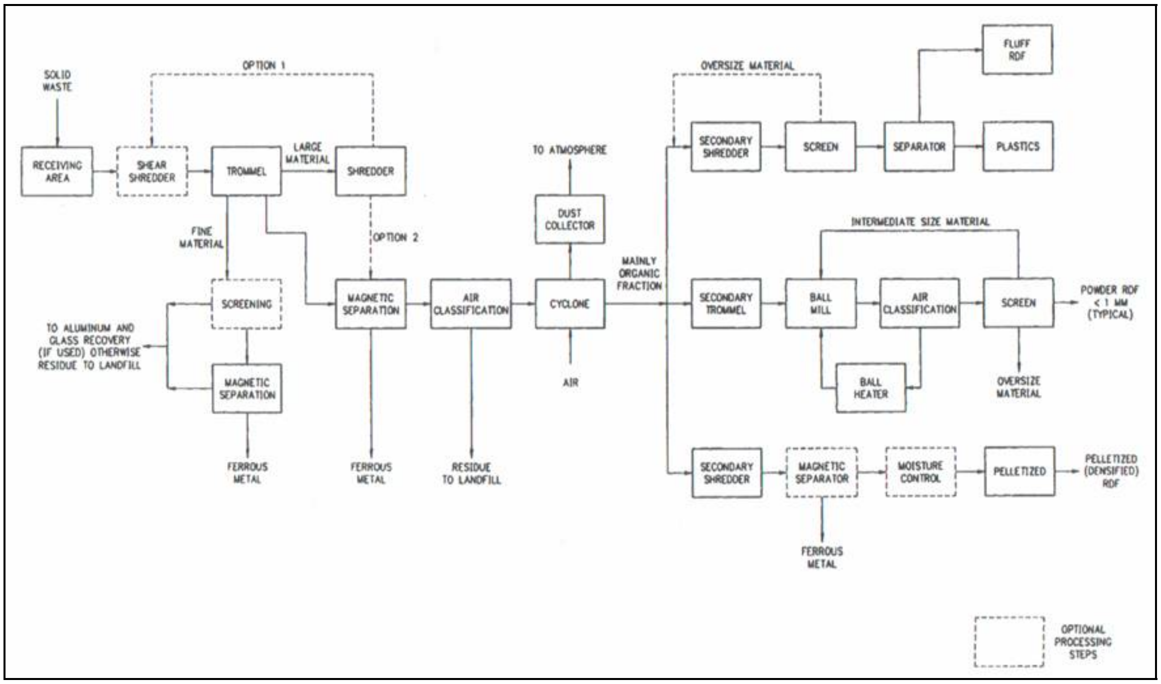


Figure 1.3 Typical flow sheet for the recovery of materials and production of RDF(46).

MSW treatment for energy recovery takes place in Waste-to-Energy (WTE) facilities and includes a sophisticated multi-stage process, which will be analytically described in the following chapter.

Important factors that must be considered in the design and layout of such facilities include performance efficiency, reliability and flexibility, ease and economy of operation, aesthetics, and environmental controls.

1.2.2.4 Ultimate Disposal – Landfilling.

Disposal on or in the ground is, at present, the most common method for long-term handling of MSW that are collected and are of no further use; the refuses remaining after MSW have been processed; and the residual ash remaining after the material and energy recovery has been accomplished. The three land disposal methods that are most commonly used are landfilling, landfarming and deep-well injection. Recently, the concept of using mud in the ocean floor as a waste storage location has also received some attention; nevertheless it will not be examined in this study.

Landfilling involves the controlled disposal of MSW on or in the upper layer of the earth's mantle (Figure 1.4). Important aspects in the implementation of controlled landfills include site selection; landfill and operation design; and Landfill Gas (LFG) and leachate collection.

Figure 1.4 Typical landfill(87).

Landfarming is a waste disposal method that can be applied only to natural organic wastes. The biological, chemical and physical processes that occur in the surface of the soil are used to treat biodegradable industrial wastes.

Deep-well injection (Figure 1.5) has been used for the disposal of liquid wastes and involves injecting the waste deep in the ground into permeable rock formation (typically limestone or dolomite) or underground caverns.

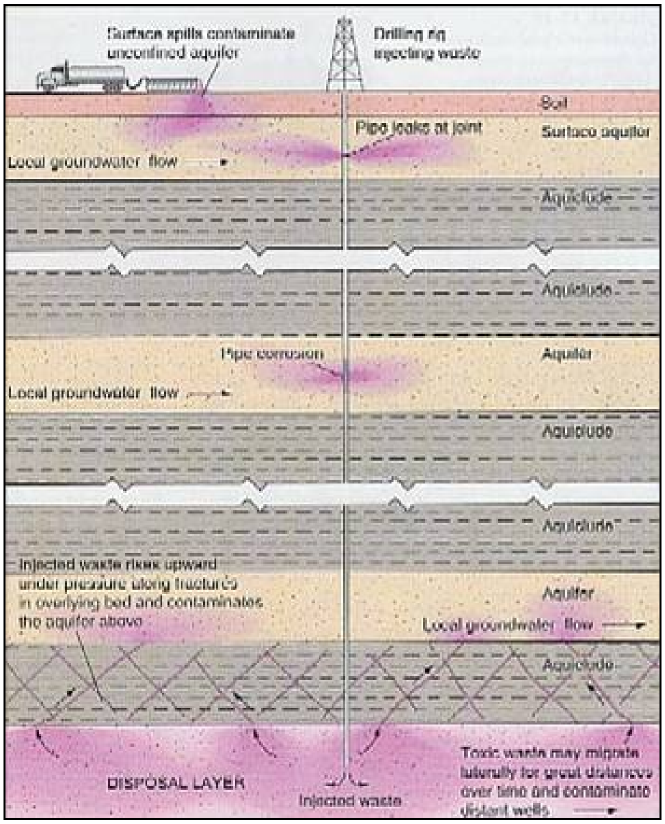


Figure 1.5 Deep-well injection(9).

1.2.3 The Ideal Solid Waste Management System

In the effort towards environmental sustainability, a five-level hierarchy (Figure 1.6) of actions for SWM is globally required: Reduce, Reuse, Recycle, WTE and Disposal. This concept is proposed to be employed in the area of study, as well.

Figure 1.6 Waste management Hierarchy(10).

"***Reduction***" at the source, also called "pollution prevention" in industry or "waste reduction" on the household level, can be achieved in three basic ways: (a) by reducing the amount of material used per product, without sacrificing the utility of that product; (b) by increasing the lifetime of a product; and (c) by eliminating the need for the product.

"***Reuse***" is an integral part of society. Many products that have utility and value for more than one purpose are reused. For example, bags obtained in the supermarket are often used to pack refuse to be transferred from the house to the trash can, or coffee cans are used to hold bolts and screws.

The process of "***Recycling***" requires mostly public participation. People should contribute to the separation at source, according to which the recyclable wastes must be discarded separately from the rest. After that, collection trucks transfer the recyclables from the bins to Material Recovery Facilities (MRFs) for further processing.

"***Waste-to-Energy***" (WTE) refers to the energy recovery through combustion of waste and possible material recovery after thermal processing.

Finally, "***Disposal***" of solid wastes refers actually to burying the waste either in the oceans, which is prohibited by federal law, or on land. Disposal should be practiced in environmentally sound methods.

This study will concentrate on the implementation of WTE in the Region of Attica in order to ameliorate the MSW management system currently practiced. WTE and the numerous advantages of this concept will be analytically described in Chapter 2.

CHAPTER 2: WASTE-TO-ENERGY

2.1 INTRODUCTION

Energy and metals can be recovered by combusting Municipal Solid Wastes (MSW) in specially designed boilers. Another advantage the MSW combustion is the substantial reduction of its weight (up to 75%) and volume (up to 90%). The generation of electrical and thermal energy from the combustion of solid wastes is known as Waste-to-Energy (WTE).

By reducing the amount of waste that needs to be discarded at landfills, and therefore, the generation of Landfill Gas (LFG), WTE facilities contribute to the reduction of greenhouse-gas emissions.

Apart from the reduction of waste volume and the reduction of greenhouse-gas emissions, another environmental benefit of WTE incineration is the conservation of natural resources. Waste that would otherwise end up in landfills is used to generate energy, thus conserving fossil fuels. A WTE plant that provides 550 kilowatt-hours per ton of MSW of net electricity output to utilities is equivalent to a saving of 50 gallons of fuel per ton(58). Hence, WTE has been recognized by the US Environmental Protection Agency (EPA) as a renewable source of energy. Although WTE facilities are energy producers, they cannot produce electricity on the scale of a normal-sized fossil-fired power plant. In any case, revenues from energy sales usually cover a portion of the plant’s operating expenses and debt service.

WTE is typically only cost-effective in regions where land suitable for landfilling is scarce, which is the case of continental Attica. Such landfill scarcity can arise due to geographic constraints, as with a highly urbanized regions, or environmental and geologic conditions, as in regions where there is sandy soil and the water table is high. Jurisdictional and political boundaries can also constrain the size and number of sites available for landfilling, thereby increasing the attractiveness of WTE.

The most urbanized regions of industrialized countries have considerable experience with WTE facilities, as land prices are often high, landfill space is limited and environmental controls are stricter.

The primary environmental issues associated with MSW combustion are air pollution and ash disposal. Nevertheless, many improvements in air pollution control (APC) and other technologies in the last 20 years have resulted in significant reduction of the quantities of major air pollutants emitted from WTE facilities and in the attenuation of the negative impacts deriving from ash disposal.

Figure 2.1 is a graph comparing the mercury (Hg) emissions deriving from WTE and coal-fired facilities in USA through the years. According to a study conducted by the National Renewable Energy Laboratory in 1989, the WTE plants used to emit almost double the amount of mercury (Hg) discharged by coal-fired plants. However, in 2001, the mercury (Hg) emissions of WTE facilities in USA had been reduced by 98% (Themelis, Gregory, 2001).

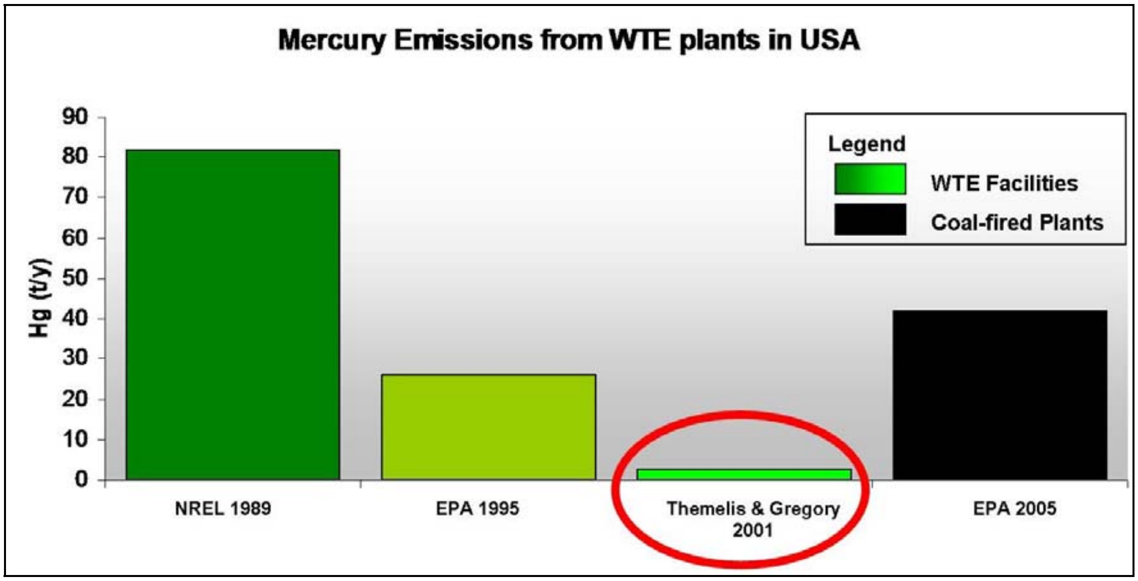


Figure 2.1 Mercury emissions of WTE facilities in USA (based on Reference 57)**.**

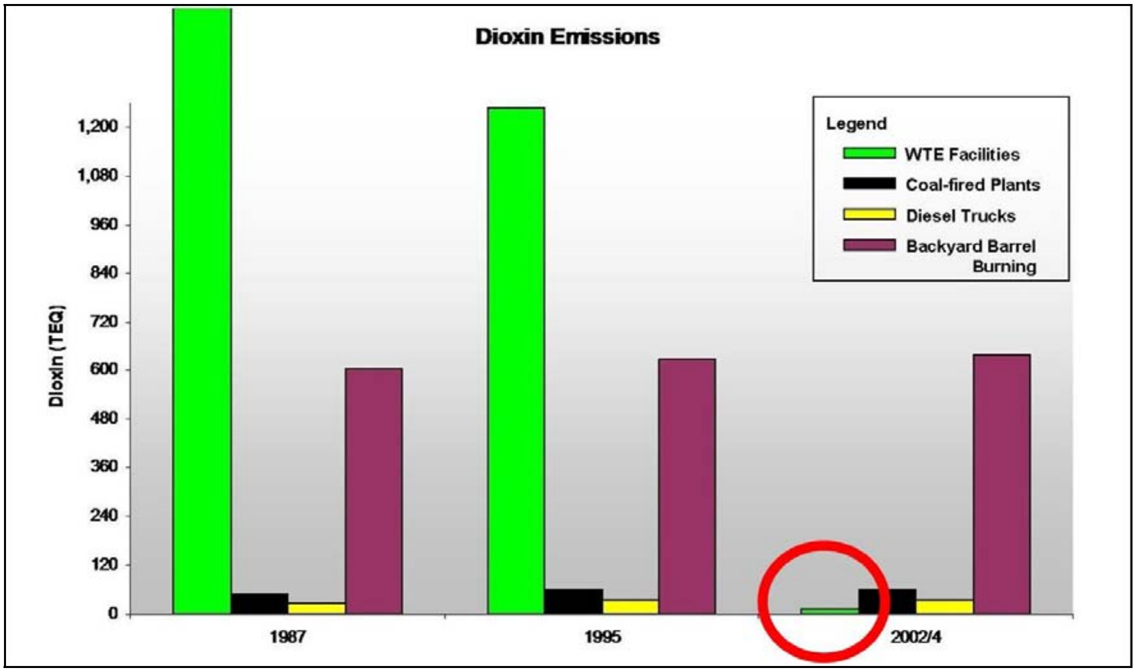


Figure 2.2 Comparison of dioxin emissions (based on Reference 57)**.**

Figure 2.2 compares the amount of dioxins emitted from WTE facilities, coal-fired plants, diesel trucks and backyard barrel burning over time. The enormous reduction of dioxin emissions from WTE facilities through the years is obvious.

In considering WTE as an option in Solid Waste Management (SWM), decision makers must weigh the economic benefits of energy generation and metal recovery, as well as the environmental benefits of combustion versus landfilling, against the significant higher capital and operating costs of WTE.

Worldwide, about 140 million tons of MSW are combusted annually in over 640 WTE facilities that produce electricity, steam for cooling/heating purposes, and recovered metals for recycling. The US WTE industry represents about 23% of the global capacity, 66% of which is concentrated in seven states on the East Coast (Table 2.1).

Table 2.1 Major users of WTE in the USA(56).

States	Number of plants	Capacity (short US t/d)
Connecticut	6	6,500
New York	10	11,100
New Jersey	5	6,200
Pennsylvania	6	8,400
Virginia	6	8,300
Florida	13	19,300
TOTAL	**53**	**69,600**

In the highly industrialized European countries waste incineration plants have been used increasingly over the past 50 years, mainly because it has been difficult to find new sites for landfills in densely populated areas. As mentioned earlier, during the last 20 years, these plants have attained great developments in technological and environmental aspects.

A 2002 review of the European WTE industry by the International Solid Waste Association (ISWA) showed that the total installed capacity was over 40 million tons per year and the generation of electrical and thermal energy was 41 million gigajoules and 110 gigajoules, respectively (Table 2.2). Figure 2.3 shows the amount of waste incinerated in several European countries.

Table 2.2 Reported WTE capacity in Europe(56).

Country	t/y (in 1999)	kg/capita	Thermal energy (GJ)	Electric energy (GJ)
Austria	450,000	56	3,053,000	131,000
Denmark	2,562,000	477	10,543,000	3,472,000
France	10,984,000	180	32,303,000	2,164,000

Country	t/y (in 1999)	kg/capita	Thermal energy (GJ)	Electric energy (GJ)
Germany	12,853,000	157	27,190,000	12,042,000
Hungary	352,000	6	2,000	399,000
Italy	2,169,000	137	3,354,000	2,338,000
Netherlands	4,818,000	482		9,130,000
Norway	220,000	49	1,409,000	27,000
Portugal	322,000	32	1,000	558,000
Spain	1,039,000	26		1,934,000
Sweden	2,005,000	225	22,996,000	4,360,000
Switzerland	1,636,000	164	8,698,000	2,311,000
UK	1,074,000	18	1,000	1,895,000
TOTAL REPORTED	40,484,000	154.5 (average)	109,550,000	40,761,000

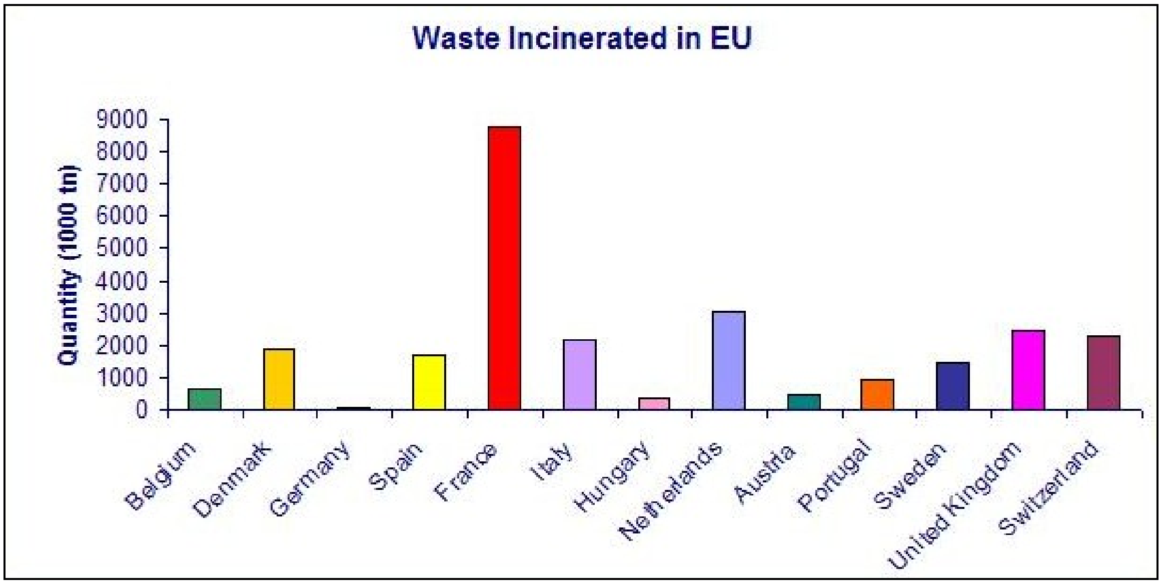


Figure 2.3 Amount of waste incinerated in countries of the EU (based on Reference 84)**.**

It should be noted that, in contrast to Europe, USA makes very little use of the exhaust steam from the power-generating turbines for either district or industrial heating. A good example of cogeneration of electrical and thermal energy is the WTE facility in Brescia, Italy(56).

Greece is one of the few countries-members of the European Union (EU), where WTE facilities do not exist. Taking into account the waste management problems of the country in whole, an assessment of the costs and benefits of the construction and operation of WTE facilities throughout the country should be considered for the entire nation.

However, priority should be given to the Region of Attica. The intensity of the current waste situation in Attica, due mainly to the continuously increasing MSW generation rates and the acute land scarcity for new waste disposal sites, requires drastic measures to reduce the volume of the waste that needs to be disposed at landfills. This renders a study for applying the WTE in this region compulsory.

The following sections describe the European laws regarding incineration and cover more analytically certain aspects of WTE.

2.2 REGULATIONS FOR MUNICIPAL SOLID WASTE COMBUSTION

2.2.1 European Laws

The EU regulations are partially determined by the European Environment Agency (EEA), an organization that is analogous to the US EPA. EEA, which is operational since 1994, *"aims to support Sustainable Development and to help achieve significant and measurable improvement in Europe's environment, through the provision of timely, targeted, relevant and reliable information to policy making agents and the public"*(89).

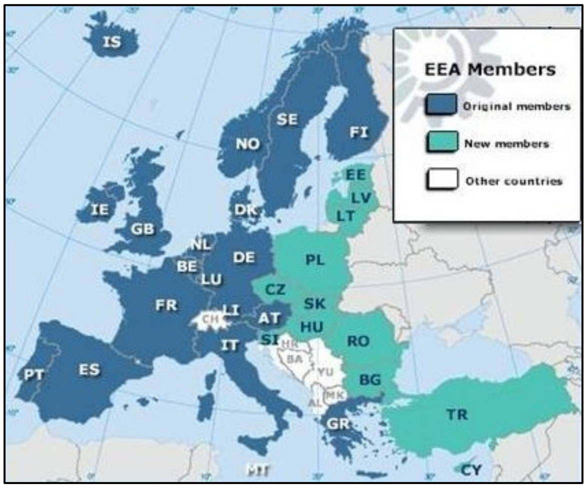


Figure 2.4 Members of the EEA(89).

The EU regulations were instituted in order to prevent or, where that is not practicable, reduce as far as possible negative effects on the environment caused by the combustion or co-combustion of wastes. In particular, they are intended to reduce pollution caused by emissions into the air, soil, surface water and groundwater, and thus lessen the risks that they pose to human health.

Until December 2005, the Community's existing waste incineration system was covered by Directives 89/369/EEC and 89/429/EEC (new and existing municipal waste incineration plants) and 94/67/EC (incineration of hazardous wastes)(84).

The most recent directive (Directive 2000/76/EC) of the European Parliament on the incineration of waste was adopted on December 4, 2000, with the intention to fill the existing gaps in legislation. It was published on December 28, 2000, in the Official Journal of the European Communities (L332, p.91). Apart from the incineration of non-toxic municipal wastes, its scope extends to the incineration of non-toxic non-municipal wastes (such as sewage sludge, tyres and medical wastes) and toxic wastes not covered by Directive 94/67/EC (such as waste oils and solvents).

At the same time, the directive intends to incorporate the technical progress made on monitoring incineration-process emissions into the existing legislation and to ensure that the international commitments entered into the Community are met in terms of pollution reduction, and more particularly those laying down limit values for the emissions of dioxins, mercury (Hg) and dust arising from waste incineration (protocols signed in 1998 under the aegis of the United Nations' Economic Commission Convention on long-distance cross-border atmospheric pollution). The directive is based on an integrated approach: limits for discharges into water are added to the updated limits for emissions to atmosphere.

Unlike Directives 89/369/EEC and 89/429/EEC mentioned above, the most recent Directive applies not only to facilities intended for waste incineration ("dedicated incineration plants"), but also to "co-fired" plants (facilities that use both fossil fuels and MSW, such as cement plants). This Directive does not cover plants treating only vegetable wastes from agriculture and forestry (biomass); the food processing or paper production industry; wood wastes; cork wastes; radioactive wastes; animal carcasses; waste resulting from the exploitation of oil and gas; and incinerated on board offshore installations.

By establishing Community emission standards and conditions for discharges of wastewater, Directive 2000/76/EC fills a gap in the existing Directive on the incineration of waste. It makes a clear distinction between incineration plants (which may or may not recover heat generated by combustion) and co-incineration plants (such as cement kilns, steel or power plants, whose main purpose is the generation of energy or the production of material products).

All incineration or co-incineration plants must be authorized. Permits are to be issued by the competent authority and should list the categories and quantities of hazardous and non-hazardous wastes that may be treated; the plant's incineration or co-incineration capacity; and the sampling and measurement procedures that are to be used.

In order to guarantee complete waste combustion, the Directive requires all plants to keep the incineration or co-incineration gases at a temperature of at least 850°C for at least two seconds.

The limit values for incineration plant emissions to atmosphere concern heavy metals, dioxins and furans, carbon monoxide (CO), dust, total organic carbon (TOC), hydrogen chloride (HCl), hydrogen fluoride (HF), sulphur dioxide (SO_2), nitrogen monoxide (NO) and nitrogen dioxide (NO_2).

In addition, special provisions are laid down relating to cement kilns, other industrial sectors and combustion plants which co-incinerate wastes. The daily average air emission limit values of pollutants' concentrations for combustion plants co-incinerating wastes are presented in the following Table.

Table 2.3 Limit values for pollutant emitted from incineration(84).

Pollutants	Concentration
Cd, Tl	0.05*
Hg	0.05*
As, Co, Cr, Cu, Mn, Ni, Pb, Sb, V	0.50*
dioxins, furans	0.10**
* Average values in milligrams per cubic meter over the sample period of a minimum 30 minutes and a maximum of 8 hours. ** Average values in nanograms per cubic meter over the sample period of a minimum 6 hours and a maximum of 8 hours	

All discharges of effluents caused by exhaust gas clean up must be authorized. Rain or firefighting water will be collected and analyzed before being discharged.

The quantity and harmfulness of incineration residues must be reduced to a minimum and residues must be recycled as far as possible. When dry residues are transported, precautions must be taken to prevent their dispersal in the environment. Tests must be carried out to establish the physical and chemical characteristics, and polluting potential of residues.

The Directive provides for the mandatory provision of measurement systems enabling the parameters and relevant emission limits to be monitored. Emissions to the atmosphere and into water must be measured periodically in accordance with Article 11 of the Directive.

Applications for new permits must be made accessible to the public, so that the latter may comment before the competent authority reaches a decision.

For plants with a nominal capacity of 2 tons or more per hour, the operator must provide the competent authority with an annual report on the functioning and monitoring of the plant, to be made available to the public. A list of plants with a nominal capacity of less than 2 tons per hour must be drawn up by the competent authority and made available to the public.

By December 31, 2008, the Commission must report to Parliament and the Council on the application of the Directive, progress achieved in emission control techniques and experience with waste management(84).

Article 8(1) and the Annex to Directive 75/439/EEC; Directive 89/369/EEC; Directive 89/429/EEC; and Directive 94/67/EC will be repealed as of December 28,

2005. Directive 2000/76/EC was applied to new plants as of December 28, 2002 and will take effect to existing plants as of December 28, 2005.

The Member States must determine the penalties applicable to breaches of the provisions established by the Directive.

2.3 WASTE-TO-ENERGY FACILITIES

2.3.1 A Typical Plant

The following processes take place in a typical modern WTE facility:

When waste collection trucks arrive at the WTE facility, they are weighed on a scale, built into the roadway. The waste intake area usually includes a tipping floor, a storage pit, cranes, and sometimes conveyors. Trucks enter the tipping floor and unload (tip) waste either onto the floor or directly into the pit (refuse bunker), which stores the waste. When waste is tipped onto the floor, a front-end loader or a bulldozer is used to push it into the pit or onto a conveyor. Either way, the incoming waste is inspected to make sure it contains only allowable materials. Large exhaust fans in the receiving building use the building air as combustion air in the furnace and, thus, keep any unpleasant odors from escaping outside.

Cranes lift the waste from the storage pit and place it into feeder chutes that lead to a furnace, where it is combusted at temperatures over 1,000°C. A special grate system moves the waste gradually through the furnace. As noted earlier, part of the combustion air is provided from the exhaust fans from the loading dock.

The wall of the combustion chamber is lined with heat exchanger tubes (waterwall) that use the heat of the combustion gases to evaporate water to steam. The steam is superheated in a later section of the furnace that contains superheater tubes. The superheated steam is sent to a steam turbine generator for the production of electricity.

The leftover ash after combustion is quenched and metal pieces are recovered by means of screens and magnetic separators. The ash is tested to make sure it is safe and then trucked to landfills for disposal or used beneficially, for example in road construction projects.

After the heat exchanging system, the gases and soot particles generated by combustion flow through an APC system, typically consisting of a dry scrubber, activated carbon (C) injection and a baghouse filter. The cleaned process gas is tested continuously to ensure that it is below regulation levels and then exhausted through a stack.

Figure 2.5 shows the basic components of a typical modern WTE plant.

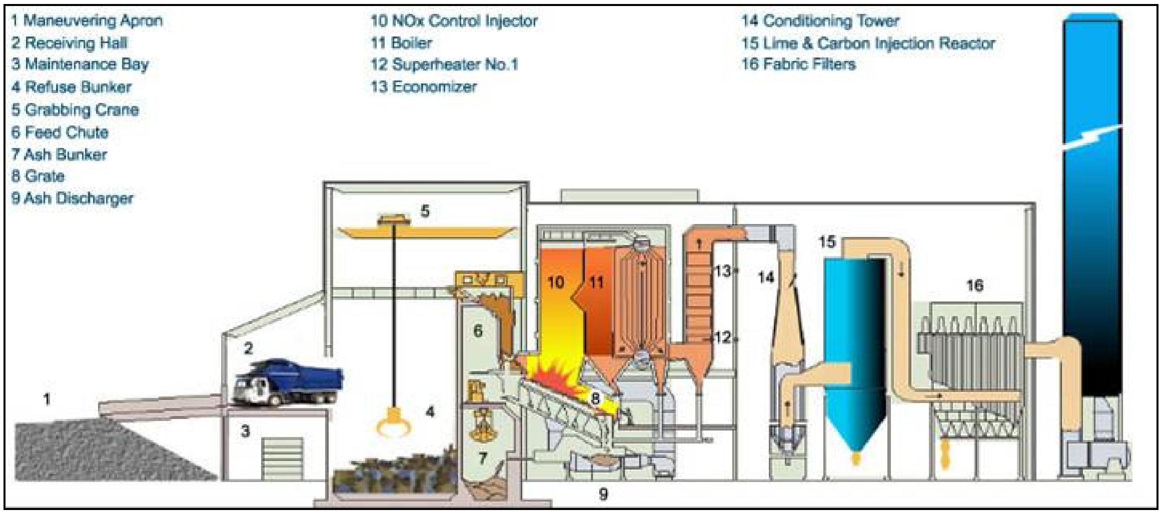


Figure 2.5 Cross-section of a modern WTE facility – Veolia ES (Montenay) facility at Burnaby, BC, Canada(161).

2.3.2 Types of Waste-to-Energy Facilities

Several types of WTE facilities exist. The most widely used and technically proven type is mass-burning, which requires little or no treatment of waste prior to its incineration. The production and incineration of Refuse Derived Fuel (RDF) has also been used, primarily in Europe and in several plants in the U.S. The RDF-burning facilities include processes of pre-shredding of waste into small pieces and partial separation of the non-combustible materials (metals and glass). These two options are further discussed below.

2.3.2.1 Mass-Burning

Mass-burning systems are the predominant form of MSW incineration. They are applied for large-scale combustion of mixed or source-separated wastes and generally consist of either two or three processing lines ranging in capacity from 50 to 1,000 tons per day; thus, facility capacities range from about 100 to 3,000 tons per day. These facilities accept refuse that has undergone little pre-processing other than the removal of oversized items, such as refrigerators and sofas.

Although this versatility makes mass-burning facilities convenient and flexible, local programs to separate household hazardous wastes (e.g. cleaners and pesticides) and recover certain materials (e.g. iron scrap) are necessary to help ensure environmentally responsible incineration and resource conservation.

After the incoming waste is fed into a chute by cranes, it is led to the grate system (Figure 2.6) in the combustion chamber. MSW are constantly fed to onto the stoker grate, where grate bars agitate them continuously. Air is not only supplied by a fan, but also is injected through the walls to enhance the combustion. The heat converts the water contained in the MSW to steam, which is further heated by a superheater and then, led to a turbine generator for the production of electricity. Ash falls into a water quench and the gases enter the APC system.

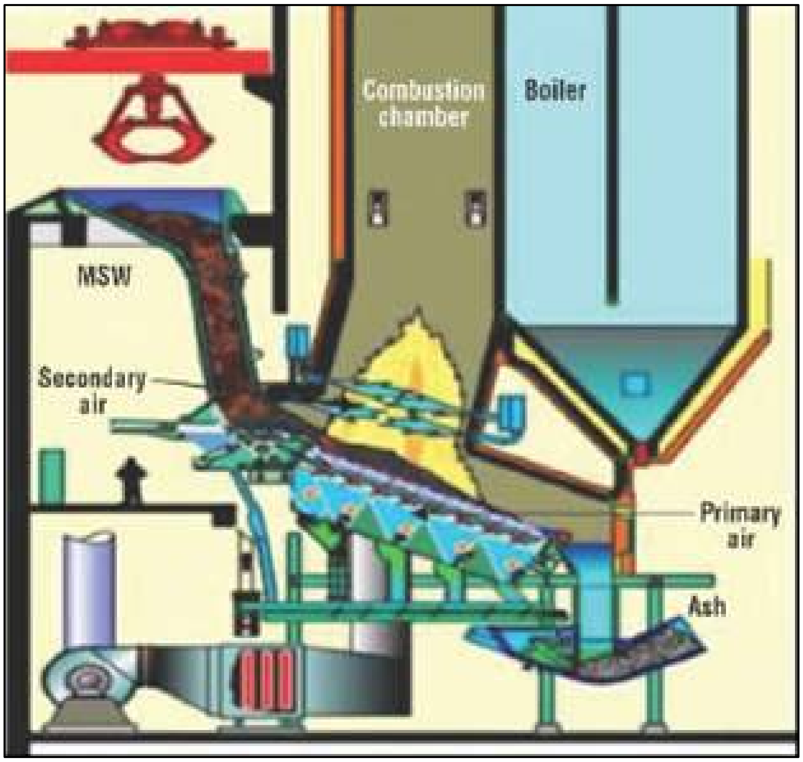


Figure 2.6 Schematic diagram of a mass-burning combustion chamber (Brescia, Italy)(56).

The mass-burning technology with a movable grate has been successfully applied for decades and was developed to comply with the latest technical and environmental standards. The foremost process used is that developed by Martin GmbH (Munich, Germany) with installed annual capacity of about 59 million tons. The Von Roll (Zurich, Switzerland) mass-burning process follows with 32 million tons worldwide. Other mass-burning technologies are the roller grate (DB) and the Westinghouse process(171).

An example of a mass-burning WTE facility that uses grate furnaces is that of Brescia, Italy (Figure 2.7), which generates 582 kilowatt-hours of electricity and 595 kilowatt-hours of heat for district heating per ton of waste combusted(3). The fuels used for the energy production are: (a) MSW; (b) industrial non-hazardous wastes; (c) dried sludge from sewage treatment plants; and (d) biomass. The waste is processed in two combustion lines, each of which has a nominal capacity of 23 tons per hour. A third processing line started in 2004 and is used to combust mainly biomass wastes.

Figure 2.7 The WTE plant in Brescia, Italy(56).

2.3.2.2 Refuse Derived Fuel-Burning

Although their share has grown, RDF systems represent a much smaller number of WTE facilities than traditional mass-burning plants. RDF systems may have two basic components: RDF-production and/or RDF-combustion. RDF-production facilities produce RDF in various forms through material separation; size reduction; and, in some cases, pelletizing.

Although RDF-burning facilities have the advantage of removing recyclables and certain contaminants from the combustion stream, the complexity of the systems used results in high operating and maintenance costs; and low reliability. On average, the capital costs per ton of capacity for incineration units that use RDF are higher than for other incineration options.

RDF-burning facilities, like mass-burning WTE faclities, typically have an indoor tipping floor. In an RDF-burning plant, waste is typically fed onto an inclined conveyor, which is either below grade or hopper fed. Once on the conveyor, the waste travels through a number of processing stages, usually beginning with shredding. The processing steps are tailored to the desired products, and typically include one or more screening stages, using trommels or vibrating screens; shredding or hammer-milling of waste with additional screening steps; pelletizing or baling of combustibles; and, depending on the local recycling markets and the design of the facility, may include a manual sorting line.

After its production, RDF is fed into a chute leading to the furnace, where it is distributed continuously. Air is supplied through the walls. The heat converts the water of the waterwall tubes into steam, which drives the turbine generator. The ash falls into a water quench and is then removed, while the gases enter the APC system.

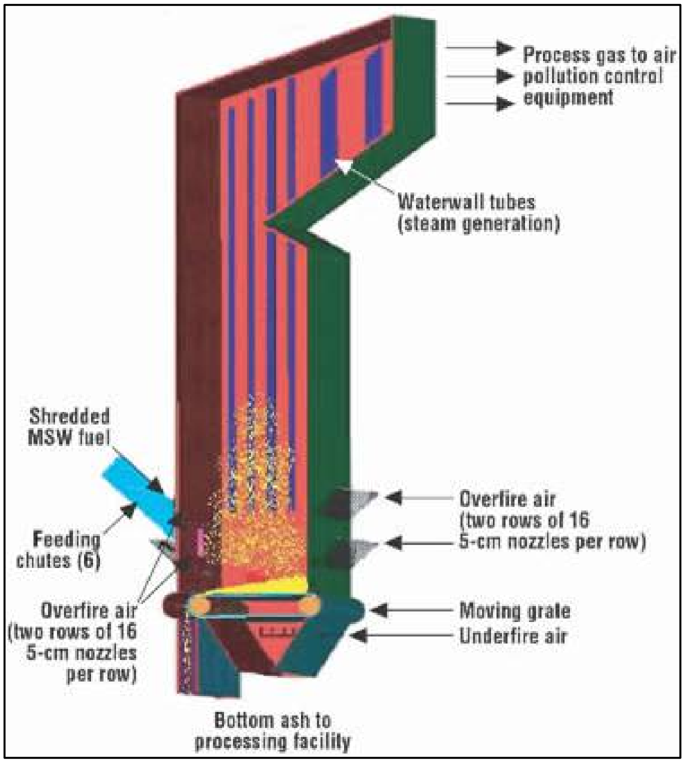


Figure 2.8 Schematic diagram of the SEMASS furnace at Rochester, MA, USA(56).

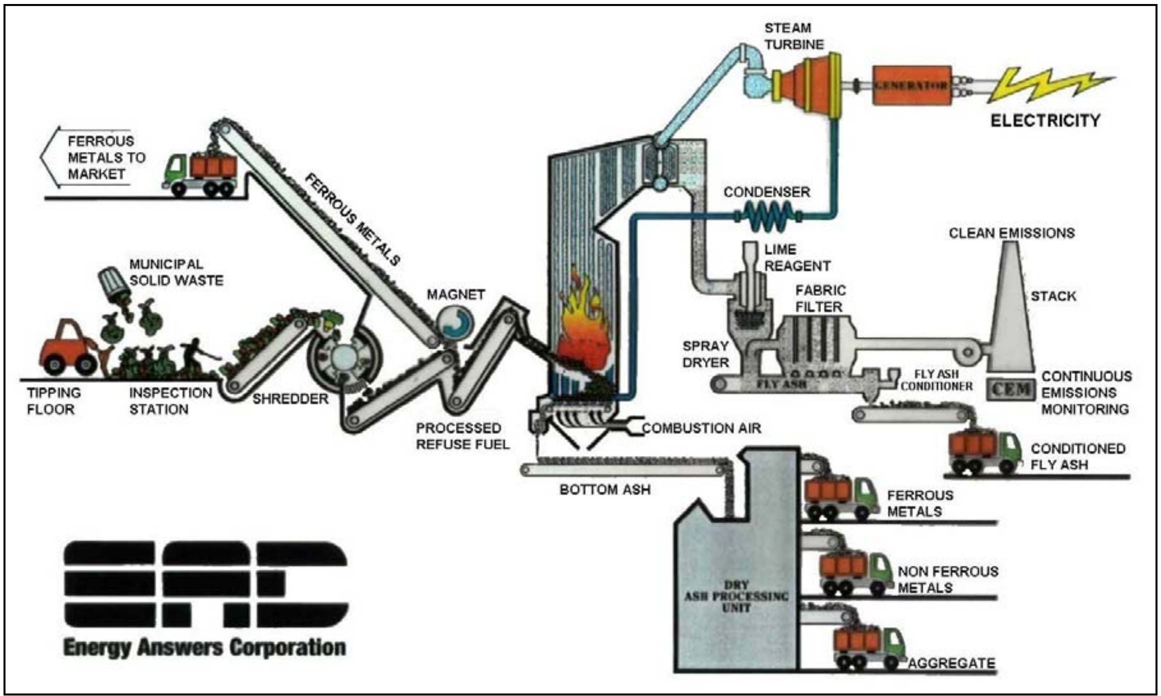


Figure 2.9 Schematic process diagram of the WTE plant at Rochester, MA, USA(57).

A successful RDF-burning example is the SEMASS facility in Rochester, Massachusetts, USA. It was developed by Energy Answers Corporation and is now operated by American Ref-Fuel. It has a capacity of 0.9 million tons per year. The MSW are first pre-shredded. Then, the ferrous metals are separated magnetically. Finally, the combustion is carried out partly by suspension firing and partly on the horizontal moving grate.

Figure 2.10 The WTE plant at Rochester, MA, USA(130).

2.4 WASTE-TO-ENERGY TECHNOLOGIES

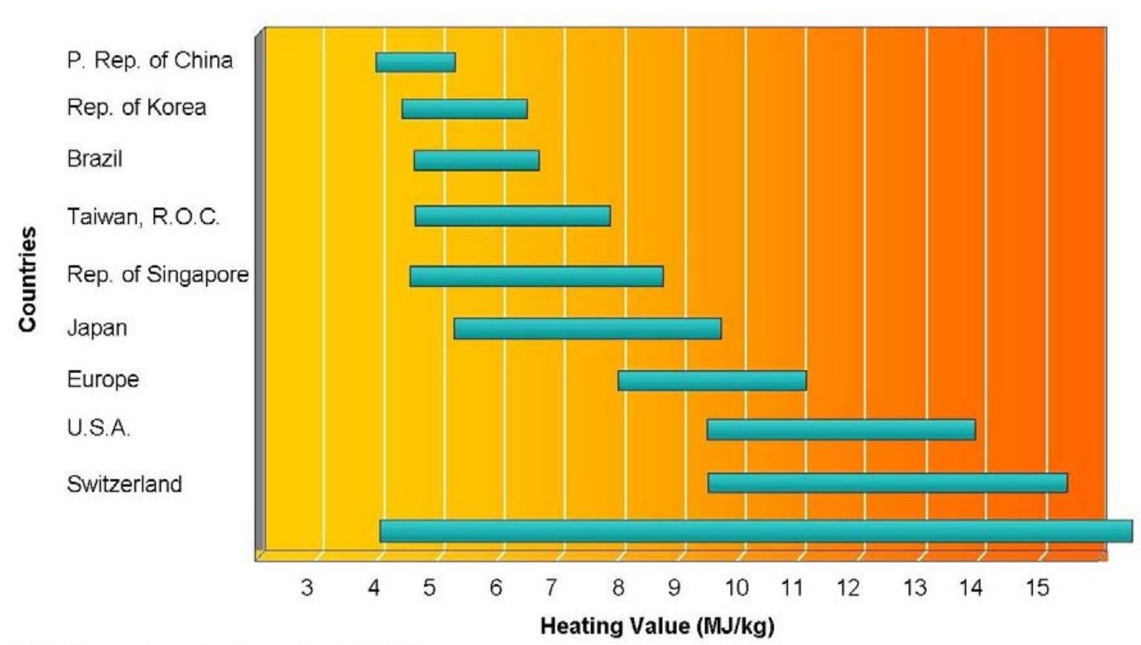
2.4.1 Combustion

Waste combustion is not always performed under the same technology, which is constantly evolving in order to meet stricter environmental standards. In the following paragraphs, the main technological advances used for waste combustion will be briefly described.

In all types of furnaces, energy recovery occurs through a boiler, which uses circulating water to recover the heat from the combustion gases in the form of steam or hot water. A number of different designs are used to that effect, such as waterwall and bundles of water filled steel tubes.

2.4.1.1 Grate Furnaces

Grate furnaces are by far the most common technology for the combustion of MSW. They are usually operated in mass-burning WTE facilities, which require minimal pre-processing of the incoming materials and allow the combustion of wastes of extremely variable calorific values, as shown in Figure 2.11.



NOTE: The maximum heating value is 18 MJ/kg

Figure 2.11 Range of heating values of MSW combusted in various countries(61).

In this type of furnaces waste burns over a grate at a temperature range from 750°C to over 1,000°C. The large excess of air (100%) required for combustion is supplied by fans or blowers under and over the grates(4).

The grates can be either fixed or moving. The moving grates are designed to increase mixing and air flow in the mass of burning wastes in order to achieve a more complete combustion. The variations of the design of the grates result in significant differences in terms of gaseous emissions and in both quantity and quality of the ash produced.

2.4.1.1.1 *Martin GmbH Grates*

As aforementioned, the most commonly used grate systems in WTE plants are those of Martin GmbH, which have filed out over 630 incineration lines all over the world. This system is reliable, sturdy and proven. It guarantees a long service life and is suitable for a large variety of fuel types. Therefore, the grate system of Martin GmbH and, in terms of this study, the reverse-acting grate will be explained more analytically.


Figure 2.12 Reverse-acting grate(156).

The Martin reverse-acting grate is inclined in the direction of transport and comprises several stair-like grate steps, which are equipped with surface-ground grate bars. Every second step slowly moves up and down against the grate inclination, as shown in Figure 2.13. This not only constantly rakes and agitates the fuel bed, but also mixes the hot mass of waste with new materials. The waste begins to burn even at the grate front end and the fuel bed temperatures reach over 1,000°C. The waste is combusted to inert mineral bottom ash through the slow uniform mixing and agitating motion of the fuel bed.


Figure 2.13 Motion of the grate bars(156).

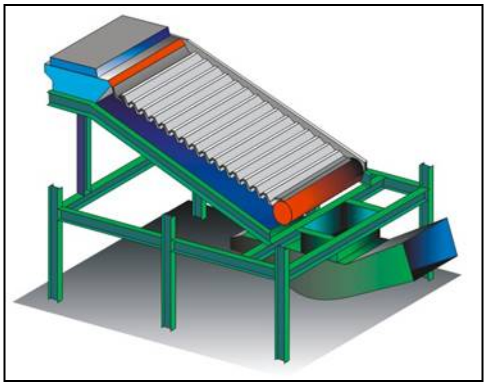


Figure 2.14 One-run reverse-acting grate(156).

The residence time of waste on the grate and the intensity of the raking action can be set independently. The height of the fuel bed and bottom ash layer is controlled via a slowly rotating clinker roller or a clinker weir, which is located at the end of the grate and the height of which can be adjusted.

Seen longitudinally, the grate is subdivided into three to six separate air zones, these zones being used to supply under-fire air in a controlled manner. The under-fire air flows through narrow gaps at the head of the grate bars into the fuel bed. As a result of the high aerodynamic resistance offered by the bars, which are made of cast chromium steel, and the narrow air gaps in the bars, the under-fire air is distributed uniformly over the fuel bed. Due to the grate movement, which acts against the direction of transport, the grate surface is always covered by fuel and remains effectively protected against thermal radiation. Consequently, the grate bars have a long service life.

Over-fire air is injected into the furnace above the fuel bed via nozzles arranged opposite each other in the front and rear furnace walls. Thus, the flue gas, mixed in an extremely efficient manner, is subjected to turbulence and burns out completely in the temperature range 1,000 – 1,200°C.

The reverse-acting grate is of modular design. Each module comprises a complete grate run with a width of 1.5 – 2.5 meters. It can be completely pre-assembled at the factory and delivered to the site. Up to eight grate-run modules can be arranged in parallel to give a total grate width of over 15 meters. Figure 2.14 shows a one-run Martin grate.

2.4.1.2 Rotary Kiln Furnaces

Rotary kilns are not so popular for the mass-burning of MSW; they are commonly used for the incineration of hazardous wastes. They can handle large quantities of gases, liquids, pastes, solids and even some items that are somewhat bulky. Even though they are mostly used in a continuous mode, they can also be operated in a batch mode.

Rotary kilns are inclined cylinders with fire-resistant interior surface and have a diameter ranging from 1 – 5 meters and a length from 8 – 20 meters(51). Their inclination ranges from 2° – 6° and they usually operate in a temperature range of 800 – 1,400°C and resist well to high temperatures.

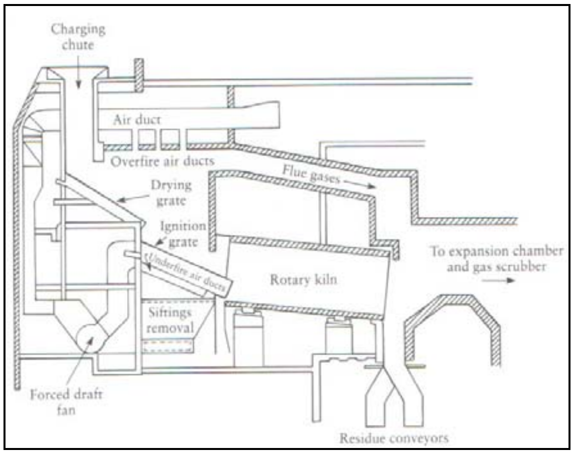


Figure 2.15 Schematic diagram of a rotary kiln(71).

Figure 2.16 View of a rotary kiln(162).

The volume of waste that is fed into the rotary kilns should not exceed 20% of the kiln's volume. The kilns rotate to optimize mixing of waste, which enhances the rate and completion of combustion.

2.4.1.3 Fluidized Bed Furnaces

Fluidized beds can handle liquids, solids, pastes and gases as long as they can be injected through nozzles. This forbids the incineration of bulky items, but has the advantage of maintaining a more uniform temperature in the furnace. For this reason, they are mostly used for the incineration of RDF. In rare cases, fluidized beds are also used for MSW combustion, but the implementation of this technology is expected to grow in the next few years.

Also, fluidized beds have an advantage over grate furnaces in terms of efficiency of energy recovery: they can operate with less excess air (only 30-40%), whereas grate furnaces need 100%(4).

In this method, the stoker grate or rotary kiln is replaced by a bed of limestone or sand that can withstand high temperatures and is fed by an air distribution system. The heating of the bed and the increasing of the air velocities cause the bed to bubble, which gives rise to the term "fluidized". The temperatures at which fluidized beds typically operate vary from 750 – 1,000°C (typically from 750 – 850°C).

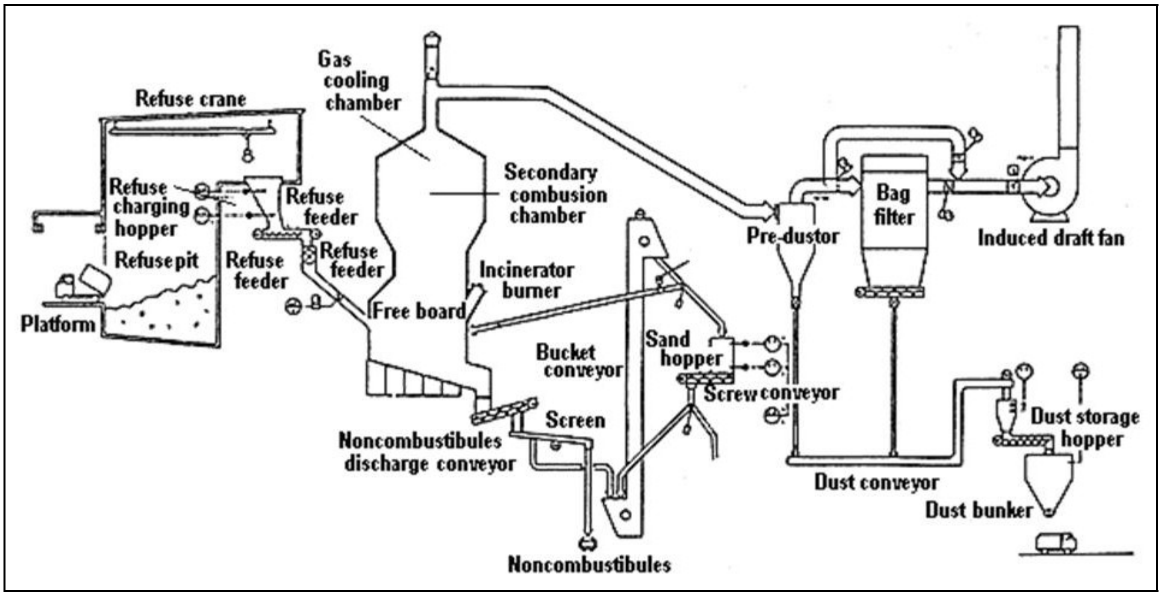


Figure 2.17 Fluidized bed incineration system(141).

There are two types of fluidized-bed designs, the "bubbling beds" and the "circulating beds". The differences are reflected in the relationship between air flow and bed material, and have implications for the type of wastes that can be burned, as well as the heat transfer to the energy recovery system. More particularly, in "***bubbling beds***", air velocity is maintained close to the maximum, above which bed material is carried away, while in "***circulating beds***", air velocity is high enough to entrain part of the bed material, which is then captured and returned to the bed. The second design allows more fuel to be burned on the bed, because more heat can be carried out of the bed by the re-circulated material.

2.4.2 Gasification

Unlike the classic waste combustion technologies, gasification is the thermal degradation of organic matter in the presence of a small percent of oxygen (O_2). This process has long been used for biomass in some countries, but is newly being developed for MSW.

Gasification systems may operate in several ways; some involve heating waste to high temperatures with minimal oxygen (O_2), which create what is known as "producer gas", a mixture of mostly carbon monoxide (CO). Usually, gasifiers use a combustion reaction with part of the waste as fuel inside the gasifier to produce the heat required for gasification. Others use superheated steam as a catalyst to gasify red-hot coke or charcoal, resulting in "water gas", which is carbon monoxide (CO) and hydrogen (H_2). However it is done, gasification turns the fuel into gas, which can be used to generate energy. Most gases from gasification contain mostly carbon monoxide (CO), hydrogen (H_2) and smaller quantities of methane (CH_4) and carbon dioxide (CO_2).

An advantage of gasification systems is that they appear to be able to meet the air emissions requirements for solid waste combustion; nevertheless, the heterogeneous nature of MSW has resulted in numerous failures in the past. In any case, the process has its supporters, because of its success in its implementation on homogeneous fuels, such as sugarcane bagasse, which resulted in the production of highly valuable gaseous fuel; therefore, research in this area is being continued.

2.4.3 Pyrolysis

Pyrolysis is a thermal physico-chemical pre-treatment method in the absence of oxygen (O_2); it does not achieve complete oxidation of waste. In the non-integrated pyrolysis processes, the closed reactor produces combustible gases containing condensable hydrocarbons and a solid material, which is called "char" and can be burned elsewhere. In the integrated processes, both gases and solids are directly burned or gasified (syngas). This leads some people to consider pyrolysis as a recycling technology, not to be considered in a discussion about the incineration of waste. Others consider that non-integrated pyrolysis is a pre-treatment of waste(4).

During pyrolysis, the organic matter is decomposed by external heat ranging from 450 – 750°C. In modern installations, about 10% of the energy generated by pyrolysis is, thus, used to provide the process heat. Classic incinerators can also be operated locally, close to the grates, in a deficit of oxygen (O_2) and perform pyrolysis to some extent.

One of the main advantages of pyrolysis is its capacity to produce combustible gases and a type of char that can be used in industrial operations. Typically, 1 ton of pyrolyzed MSW produces approximately 200 kilograms of water during pre-drying; 390 kilograms of hot gases (heating value: 13,000 kilojoules per kilogram); and 410 kilograms of solid residues containing 240 kilograms of char (17,000 kilojoules per kilogram) and 160 kilograms of minerals and metals. These values may vary depending on the treated MSW and process conditions: For example, a higher temperature will lead to a higher production of gas and a lower production of solids. The solid carbon (C) residue is like a char or a low volatile high ash bituminous coal, poor in sulfur (S), but contaminated with some heavy metals(4).

Regardless of the process, after the extraction of ferrous and non-ferrous metals and minerals, the char can be either sent to a combustion or gasification unit in an integrated process, or washed with water in order to be stored. In the non-integrated process, the char is an alternative fuel for cement works, lime industry, steel works or classic power plant. The design size of integrated facilities is large (over 100,000 tons per year). Non-integrated facilities are smaller (typically less than 50,000 tons per year) and are adapted to conditions of dispersed waste generation.

Unlike the classic grate incinerators, which require operating close to their nominal capacity (60-100%) to avoid problems, pyrolysis installations can reportedly operate in a wider range of capacity (40-150%). If this technology gains acceptance, this could provide the flexibility to adapt to variations, such as seasonal tourist population or changes in waste types and management systems.

The technology for pyrolysis is still considered by many as lacking industrial maturity, but a number of small capacity plants (around 30,000 tons per year) are in operation or in start up phase in several locations globally, such as in Germany and Japan.

Figure 2.18 shows a schematic diagram of the processes that will take place at a WTE facility that is studied currently in Japan. This facility will combine pyrolysis and gasification aiming at the production of energy in higher efficiency.

In spite of the recent progress in the development of this technology, many voices call for further demonstration of the merits of pyrolysis at industrial scale. A number of uncertainties about costs and final residues also need to be addressed.

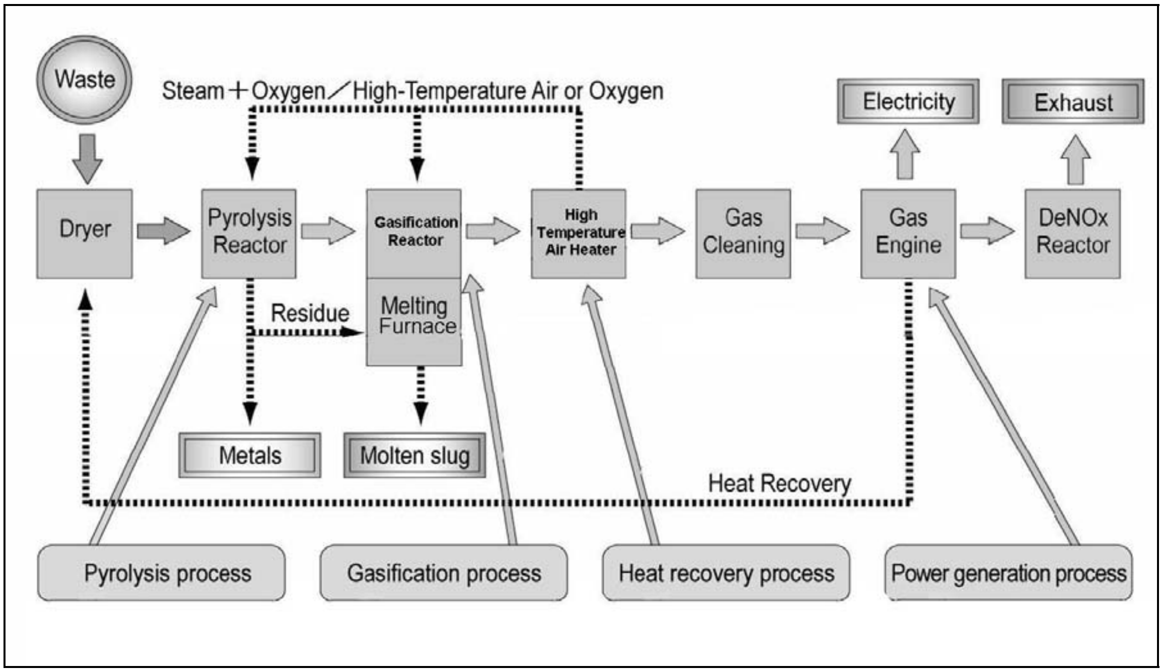


Figure 2.18 Schematic process diagram of the pyrolysis and gasification WTE facility(149).

2.5 ENERGY PRODUCTION

In WTE plants, heat from the burning wastes is absorbed by water circulating in the water-cooled walls of the boiler or by steam circulating in the waterwall, superheater and economizer tubes, suspended in the path of the combustion gases. At that point, either the steam is used for cooling/heating or it is used to turn turbines to produce electricity. The amount of energy recovered from waste is a function of the amount of waste combusted, the energy value of the waste stream, and the efficiency of the combustion process.

Most of the cases of MSW combustion currently practiced in industrialized countries incorporate energy recovery. In the past, it was common to simply burn MSW in incinerators to reduce their volume and weight, but energy recovery has become more prevalent since the eighties.

The three basic types of WTE combustion involve the generation of electricity, that of thermal energy or the co-generation of both electricity and steam. In North America, about 90% of operating mass-burning facilities generates only electricity. This trend is due partly to a preference for relatively stable electricity markets, such as utilities, as compared to industrial customers of steam, who are perceived as less reliable purchasers. However, deregulation of electricity markets (e.g. in Britain and the US) may increase steam production.

In Europe, as shown in Figure 2.19, steam generation for cooling/heating has been the primary product of WTE. A key factor to consider in evaluating the practicality of MSW combustion is the presence of an existing infrastructure for steam district heating. In Japan, the waste steam produced by WTE plants is widely used for heating community swimming pools or air-conditioning, sometimes as compensation to nearby communities for being in the vicinity of the facilities.

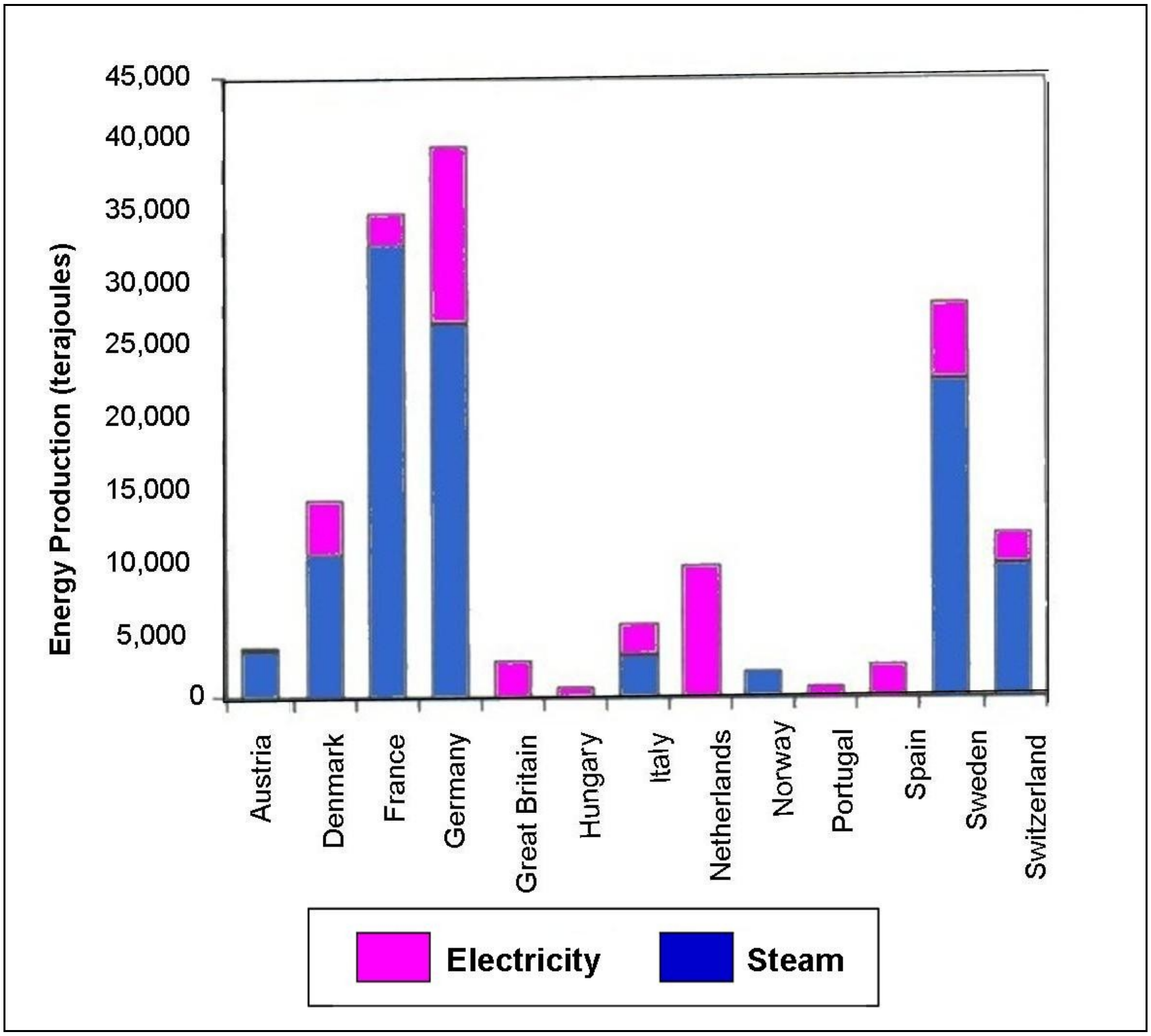


Figure 2.19 Energy generation from WTE in the EU(49).

2.5.1 Electricity Production

Electricity-producing WTE facilities use steam to drive a turbine connected to an electric generator. Approximately 15-20% of the electricity produced in these facilities is used for their operation. The remaining electricity is sold to public and private utilities in many countries, which provide a stable market for this renewable energy. The availability of purchasers and rates for electricity sales, however, vary by region.

2.5.2 Steam Production

The energy generated by WTE plants typically provides steam to district heating and cooling loops. The intense reliance on district heating and the resultant market for steam is part of what makes WTE so attractive to European cities.

Steam generated in WTE facilities can also be used directly by customers through a steam line for manufacturing operations. Condensed steam is returned by a second line.

To ensure a consistent supply of steam to end users, WTE facilities sometimes have a back-up boiler. Also, in order to adjust for variations in demand for steam, facilities may need to be equipped with a by-pass to allow temporary halts in steam generation and/or steam delivery.

Marketing steam to end users requires: (a) identifying industries and institutions (e.g. hospitals, colleges, public buildings, and factories) that use steam in the vicinity of the facility; or (b) purposely siting the facility near potential steam purchasers. Some cities may also have commercial steam distribution utilities, which facilitate steam sales.

The WTE facility at Harrisonburg, Virginia, is a successful example of a plant that produces steam to supply the adjacent campus of James Madison University, which occupies land of about 1.6 square kilometers and supports approximately 16,200 students. The facility, which is shown in Figure 2.20, processes daily 200 tons of MSW, including small amounts of medical and industrial wastes, and generates about 57,000 pounds of steam per hour.

Figure 2.20 Harrisonburg WTE plant(114).

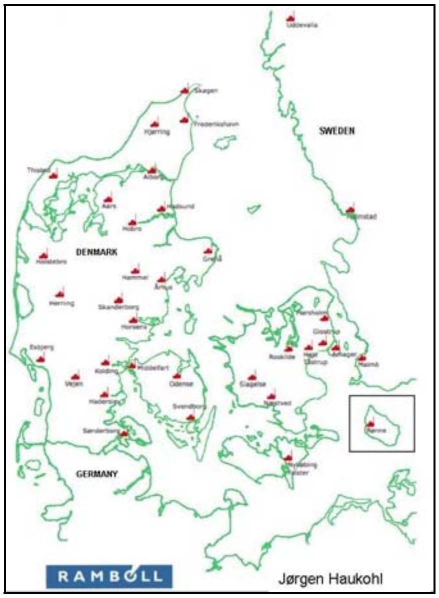


Figure 2.21 Map of WTE plants in Denmark(23).

Another great example is the practice of WTE in Denmark, where 31 WTE plants of small capacity have been allocated in various neighborhoods throughout the country not only to manage the generated MSW, but also for district heating purposes. Figure 2.21 is map showing the WTE locations.

2.5.3 Combined Energy Production

Combined production of thermal and electrical energy is referred to as "co-generation of steam and electricity" and can occur in two ways. If the energy customer requires steam conditions (pressure and temperature) that are less than the WTE plant's design specifications, a turbine-generator is used to produce electricity and thus, reduce steam conditions to appropriate levels for the customer. In the case that the steam purchaser cannot accept all the steam produced by the facility, the excess can be converted to electricity.

The coupling of waste combustion with electricity generation is quite rare in EU, mostly because European countries do not have utility rate structures that allow non-utility-generated electricity to be sold to the grid.

2.6 FACTORS TO CONSIDER

The major concerns about the environmental risks of WTE facilities are the potential emission of contaminants into the air through exhaust stacks and into water through ash leachate. Also, the public resistance and investment costs should be taken into consideration when designing the construction of such facilities. Proper planning to minimize environmental damage, as well as public education and involvement that directly address these issues, are essential for the successful implementation of WTE.

2.6.1 Air Emissions

The combustion of any substance generates byproduct emissions that may be released to the air. The following air emissions are usually of main concern associated with incineration facilities: volatile metals, such as mercury (Hg), lead (Pb), and cadmium (Cd); chlorinated organics, such as dioxins and furans; acid gases, such as sulfur dioxide (SO_2) and hydrogen chloride (HCl); particulate matter, such as dust and grit; nitrogen oxides (NO_x), which are ozone precursors; and other substances, such as carbon monoxide (CO).

Inhalation, ingestion or skin contact with these gases may have tremendous consequences on human health. In addition, flora and fauna could also be adversely affected by such emissions. The ultimate effects depend on the concentrations of the contaminants in emissions, the type of environmental controls employed, the height of the emission stack, the location of the facility, topography and the prevailing weather and conditions.

In order to meet current environmental standards, modern APC systems are designed to remove the vast majority of the emissions of concern. Research from a wide variety of facilities in the US and elsewhere has found that, when properly operated, the best available APC technologies can potentially remove up to 99% of dioxins and furans, over 99% of heavy metals, over 99% of particulate matter, over 99% of hydrogen chloride (HCl), over 90% of sulfur dioxide (SO_2), and up to 65% of nitrogen oxides (NO_x).

The major APC equipment available for modern combustion plants is the following:

- ***Electrostatic precipitators***: They are used to control particulate emissions. They electrically charge particulate emissions and then, draw the particles to oppositely charged collection plates, which are shaken periodically to remove the particles (fly ash). Figure 2.22 shows electrostatic precipitators of a WTE plant near Milan, Italy.

Figure 2.22 Electrostatic Precipitator(117).

- ***Scrubbers***: Scrubbers are used primarily to control acid gases, but they also remove some heavy metals. For the neutralization of acids either wet or dry scrubbers can be used. Wet scrubbers (Figure 2.23) apply a moving alkaline liquid solution, while dry scrubbers use either a fine alkaline spray or powder. The generally accepted state-of-the-art APC system is dry scrubbing followed by a fabric filters.

- ***Fabric filters***: They are also known as "bag" or "baghouse filters" (Figure 2.24) and are extremely effective in controlling emissions of metals and organic compounds that attach to fine particulates. Fabric filters consist of several cylindrical bags that filter emissions and may remove nearly all the particulates, including submicron sizes. Their basic mechanism is thought to be similar to the action of sand filters in water quality management. The particles adhere to the fabric due to entrapment and surface forces.


Figure 2.23 Wet Scrubber(150).


Figure 2.24 Fabric Filter(116).

Proper control of air emissions, however, requires more than the presence of the equipment described above. MSW WTE facilities must be well operated and maintained to ensure that emissions are as low as possible. Good combustion practices reduce emissions by ensuring that the temperature in the combustion chamber and the residence time of MSW in the combustion chamber are kept at optimal levels. Modern WTE facilities are equipped with computer control systems to help maintain a high degree of consistency in plant operations. APC equipment must also be carefully maintained to prevent releases of contaminants.

2.6.2 Residual Incinerator Ash

MSW incineration generates ash, representing about 10% by volume and 25-35% by weight of the burned wastes. Ash is divided into two categories: "bottom ash" and "fly ash". "***Bottom ash***" is completely or partially combusted material that passes through or is discharged from the combustion grate. "***Fly ash***" is the term used for particulate matter captured from flue gas by the APC system; it can include what is shaken from the electrostatic precipitators, scrubber residue, and baghouse filter dust.

Incinerator ash can contain concentrations of heavy metals, such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), copper (Cu), and zinc (Zn), which originate from plastics, colored printing inks, batteries, certain rubber products, and hazardous wastes from households and small industrial generators. Organic compounds, such as dioxins and furans, have also been detected in incinerator ash.

The total ash generated at mass-burning WTE facilities consists of 80-85% bottom ash and 15-20% fly ash, by weight. Localities considering the implementation of WTE must plan the way, in which ash will be managed in an environmentally sound manner; this planning is best to be done in the early stages of the project development.

In USA, bottom ash and fly ash are often mixed together and referred to as "***combined ash***".

WTE ash is usually disposed either at a regular MSW landfill, in part for maintenance purposes or an ash-only landfill, known as an ash monofill. Ash monofills are specially designed to reduce the migration of heavy metals into the environment and are often co-located within MSW WTE plants or existing landfills to reduce transportation distances and siting difficulties.

Tables 2.4 and 2.5 show materials found in a sample of a typical MSW WTE ash and a representative array of some heavy metals found in combined ash from a MSW WTE unit, respectively.

Table 2.4 Materials found in typical ash(10).

Materials	**% by weight**
Ferrous metals	18.3
Non-Ferrous metals	2.7
Combustibles	4
Glass	26.2
Ceramics	8.3
Other	40.5
TOTAL	**100**

Table 2.5 Metals in combined ash(10).

Metals	**mg/kg of ash by weight**
Aluminum	17,800
Calcium	33,600
Sodium	3,800
Iron	20,400
Lead	3,100
Cadmium	35
Zinc	4,100
Manganese	500
Mercury	< 3

The principal environmental concern of the public regarding WTE ash is that when ash is disposed at landfills, metals and organic compounds may leach (i.e., dissolve and move from the ash through liquids in the landfill) and migrate into groundwater or nearby surface water. In addition to possibly contaminating water supplies, ash could also affect human health through direct inhalation or ingestion of airborne or settled ash. The actual magnitude of these risks has been intensely debated by researchers, industry, and the public.

Because WTE ash in USA is usually discarded at MSW landfills, the environmental controls typically installed for environmentally sound sanitary landfills (e.g. liners and leachate collection/treatment) become more important.

Ash can be stabilized and solidified by encasing in concrete prior to disposal, thereby significantly reducing the potential for the contaminant to migrate. Some researchers also advocate managing fly ash and bottom ash separately, with additional stabilization of the fly ash through vitrification or pyrolysis, as fly ash can contain higher concentrations of metals.

In addition to landfilling, WTE ash has been used in the production of road bedding, concrete, brick, cinder block, and curbing. Figure 2.25 shows a sample of boiler aggregate from the bottom ash produced in the SEMASS WTE plant in Rochester, Massachusetts, USA. This material is used in construction projects.

Figure 2.25 Boiler Aggregate(130).

2.6.3 Public Perception

The WTE concept faces a great deal of public resistance, because people consider WTE facilities being similar to the unregulated incinerators of the past. Nevertheless, locally, state-of-the-art WTE facilities have gained public acceptance, since they are highly controlled and generate energy. With proper education and emphasis on the advantages of this concept, any opposition will simmer down.

2.6.4 Financial Factors

2.6.4.1 Investment Costs

WTE implementation in a country like Greece would involve substantial investment with a large share of foreign currency and high operating and maintenance costs. Hence, the resulting net treatment cost per ton of waste processed in a WTE facility would be higher compared to the alternative, which is landfilling. This is a critical issue when considering the implementation of WTE. Financing can be planned in terms of tipping fees, a general levy, public subsidies or combinations thereof.

The investment costs for a WTE plant depend on a wide range of factors, the most important of which are the capacity of the plant and calorific value of the waste to be combusted. The investment costs, as a function of the annual and daily capacity for a typical new WTE plant, are presented in the Figure 2.26.

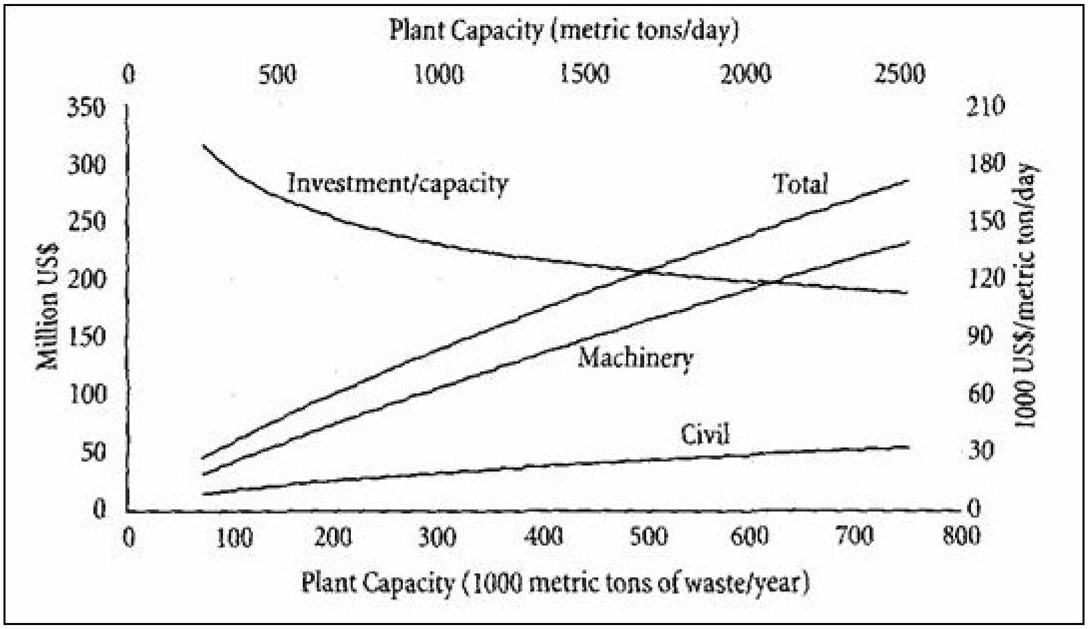


Figure 2.26 Investment costs[48]**.**

It must be noted that the aforementioned graph, as well as those shown in Figures 2.27 and 2.28 were produced by following certain pre-conditions corresponding to a typical plant configuration in southern and southeastern Asia.

2.6.4.2 Operating and Maintenance Costs

Efficient and competent operation and maintenance is the key to applying WTE technology successfully and securing the optimum benefit of the investments made. Such operation and maintenance require a well-managed facility organization; trained and skilled employees, managers and operating personnel at all levels; a well-planned financial scheme with sufficient cash flow for procuring local and imported spare parts and consumables; a safe working environment; and efficient archiving. Figure 2.27 presents a diagram useful in determining the annual operating and maintenance costs of WTE plants.

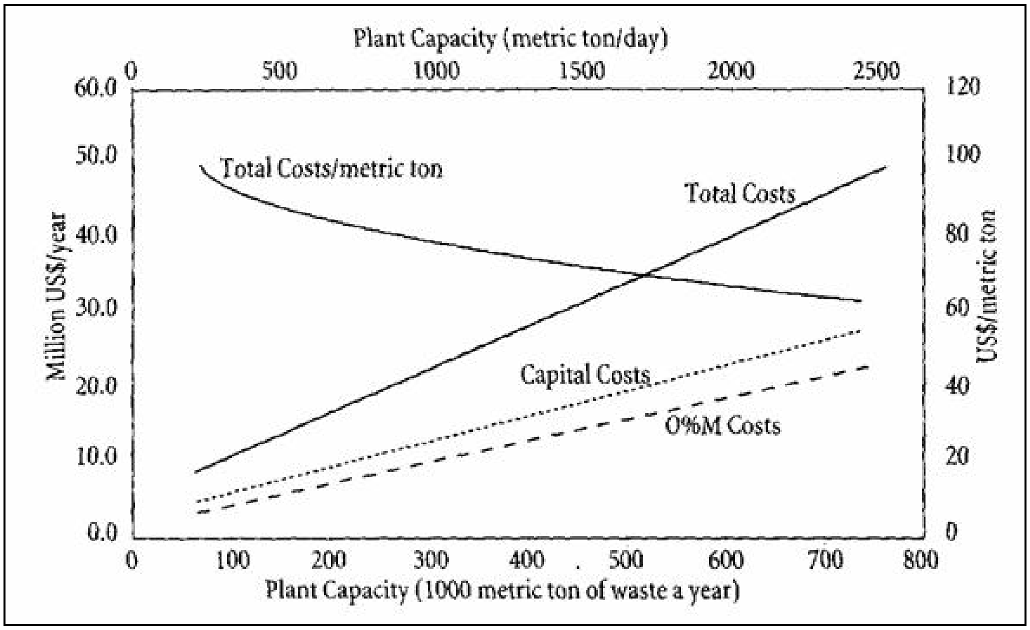


Figure 2.27 Operational and maintenance costs of incineration per year(48).

2.6.4.3 Net Treatment Costs

The net treatment costs can be calculated based on estimates of costs and revenues from sales of energy produced and materials recovered. Figure 2.28 provides a rough estimate of the net costs of WTE facilities.

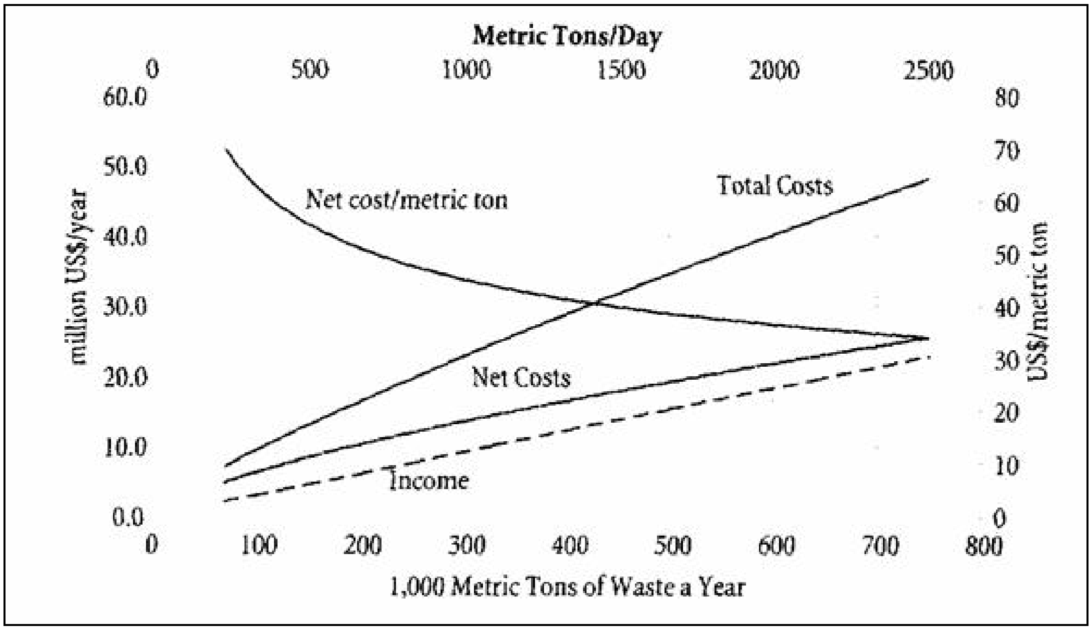


Figure 2.28 Net treatment costs for revenues to balance capital and operating costs(48).

2.6.4.4 Approximate Total Expenditure in European Union

In general, the capital costs of new WTE plants in EU approximately range from \$31.8 million (€25 million) to \$204 million (€160 million)(64). The following Table shows the typical values for grate incineration in EU.

Table 2.6 Typical expenses for a WTE plant in the EU(64).

Capacity (ton/year)	**Typical Capital Costs**		**Typical Operating Costs**	
	(\$)	**(€)**	**(\$/year)**	**(€/year)**
50,000	31,828,000	25,000,000	1,209,464	950,000
100,000	57,290,400	45,000,000	2,227,960	1,750,000
200,000	114,580,800	90,000,000	5,092,480	4,000,000
500,000	203,699,200	160,000,000	8,657,216	6,800,000

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)(163) was used.

CHAPTER 3: THE REGION OF ATTICA

3.1 GENERAL DESCRIPTION

This section describes the geography, administration, and population of the Region of Attica. Moreover, it portrays the Region by providing its main morphological features, general climatologic data, major geologic elements, basic land uses and transportation systems. This information not only offers an overview of the area of study, but also plays an essential role in appropriately designing a MSW management system for the Region of Attica and siting new waste management facilities.

Greece is located at the southernmost part of the Balkan Peninsula (Figure 3.1). It is bordered on the northwest by Albania; on the north by the Former Yugoslav Republic of Macedonia and Bulgaria; and on the northeast by Turkey. The total land area is about 132,000 square kilometers(96), of which about one fifth comprises of islands. The Greek coastlines are approximately 16,500 kilometers in length. In 2005, Greece had a population of approximately 11.1 million(84), and an average population density of about 84 people per square kilometer.

Figure 3.1 Map of Europe(155).

For administrative purposes Greece is divided into 13 Regions (Figure 3.2) that are subdivided into 52 Prefectures. Each Prefecture is further subdivided into Organizations of Local Administration (OLAs; OTA in Greek), which are municipalities (Δήμοι) of over 5,000 inhabitants and communities (Κοινότητες) of less than 5,000 inhabitants, and must comply with laws set by the Prefectural and Regional authorities. It must be noted that several OLAs of more than 5,000 inhabitants are called “communities”, because of their historic names; while others of less than 5,000 residents are considered as “municipalities”, because their population is expected to increase in the near future.

Figure 3.2 Map of Greece(180)**.**

This study focuses on the Region of Attica (Αττική), which has its administrative center in Athens, the capital and the largest city of Greece. Modern Attica is the principal commercial, financial and diplomatic center and contains about 50% of the country’s industry.

Figure 3.3 Aerial photograph of Attica(77)**.**

The total area of the Region is around 3,800 square kilometers. Geographically, it consists of continental Attica, which lies in a triangle of an area of about 2,900 square kilometers; a small part of Peloponnese (Trizinea) and several islands.

On the north, it borders with the Region of Viotea and is bounded by Kitheronas Mountain, Parnitha Mountain and Avlona Valley. On the east, it is watered by the Southern Euboic Gulf and the Gulf of Petalia and on the south, by the Saronic Gulf and the Myrtoo Sea. On the west, it is bordered with the Region of Corinth and the Gulf of Corinth.

The Region of Attica consists approximately of 30% mountains, 6% lowlands and 65% intermediate morphological features. It is mostly surrounded by sea – roughly 1,200 kilometers of coastline. Hence, Attica has attracted marine trade since antiquity. Examples of such marine trade centers that exist until today are the areas of Elefsina, Piraeus and Lavrio.

After World War II, the Region of Attica embarked on a program of rapid construction and industrialization. Its character and layout today is largely a product of this era of expansion and population growth. Lately, the expansion of its population is influenced by the incoming flow of emigrants mostly from Balkan countries. In 2001, its population was recorded to be approximately 3.8 million(172), i.e. about one third of the Greek population. Currently, the population of the entire Region is estimated to be 4.9 million.

Because of its large area and population density, the Region of Attica is subdivided in three Prefectures: Athens-Piraeus, Western Attica and Eastern Attica. In turn, these Prefectures are subdivided in 122 OLAs. The borders of the Prefectures and OLAs are shown in Figure 3.4.

The most densely populated Prefecture is that of Athens-Piraeus – almost 85% of the population of the Region. Today, it is estimated to have close to 4.2 million inhabitants. For administrative purposes, this Prefecture is further divided in two parts: The first consists of Metropolitan Athens and a number of suburbs. The members of the second division are Piraeus; the area of Trizinea in Peloponnese; and the islands of Aegina, Antikythira, Hydra, Kythira, Poros, Salamina and Spetses.

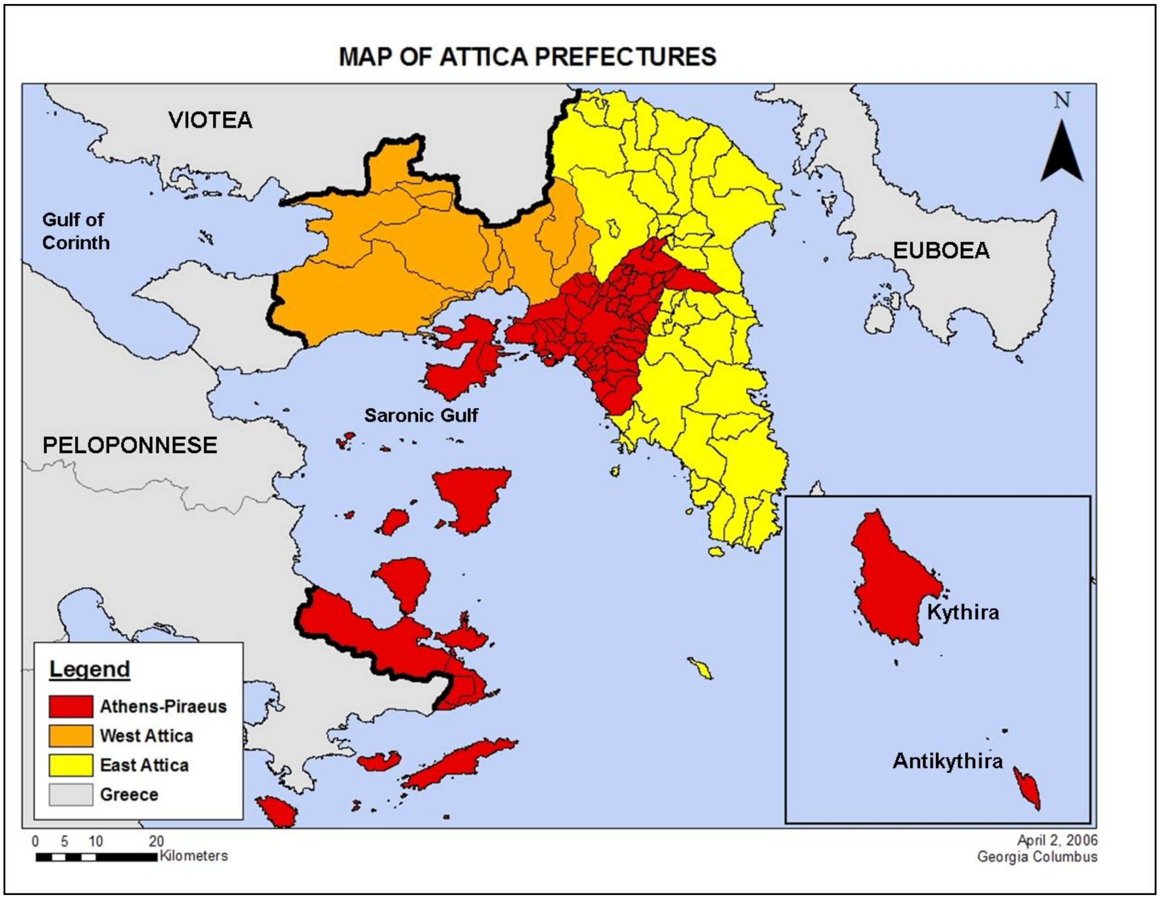


Figure 3.4 Map of Attica Prefectures.

Table 3.1 presents the area, population and population density of Greece, Attica and the Prefectures, in which it is subdivided. The graph of Figure 3.5 was produced based on information on the change of Attica's population for the period of 1839 – 2001. More information on the area and population of each OLA of the Region can be found in Appendix A. Finally, graphic illustrations of the population distribution of Attica per OLA for the years 2001 and 2006 are shown in Figure 3.6.

Table 3.1 Area, population and population density in the Prefectures of Attica.

Region	Area (km^2)	Population 2001[#]	Population Density 2001 (inhabitants/km^2)	Population 2006	Population Density 2006 (inhabitants/km^2)
Greece	**131,957**	**10,964,020**	**83**	**11,075,700[*]**	**84**
Attica	**3,806**	**3,761,810**	**988**	**4,929,695**	**1,295**
Prefecture of Athens-Piraeus	1,284	3,206,280	2,497	4,207,569	3,277
Prefecture of Western Attica	1,004	151,612	151	190,642	190
Prefecture of Eastern Attica	1,518	403,918	266	531,484	350
[#] Reference 172 [*] Value of 2005 - Reference 84					

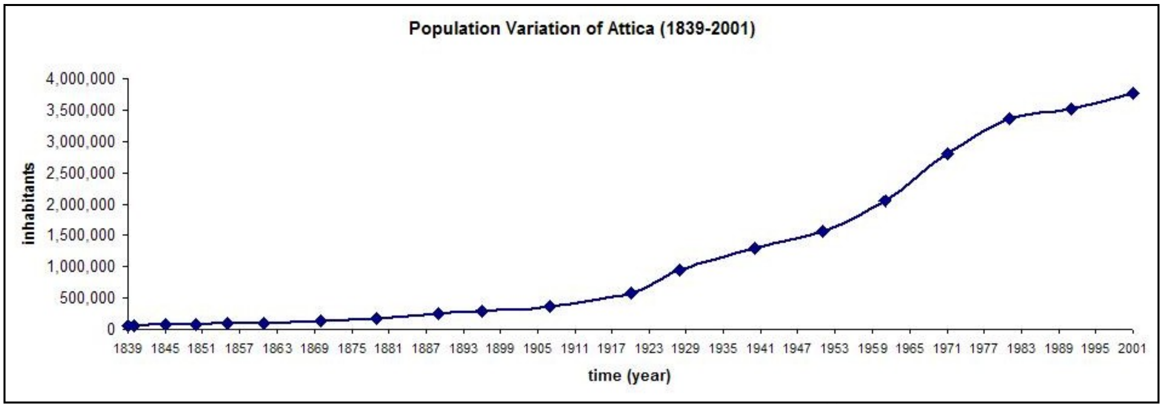


Figure 3.5 Variation of Attica's population for the period of 1839 – 2001(1).

In the following section certain parameters of continental Attica, which play an important role in planning a SWM system, will be described. This section concentrates on continental Attica, because it constitutes the main part of the Region. In addition, it is characterized by a more severe waste situation, due to higher population density. Moreover, the solutions for continental Attica proposed in this study will contribute to the alleviation of the waste management issues encountered at the other parts of the Region as well.

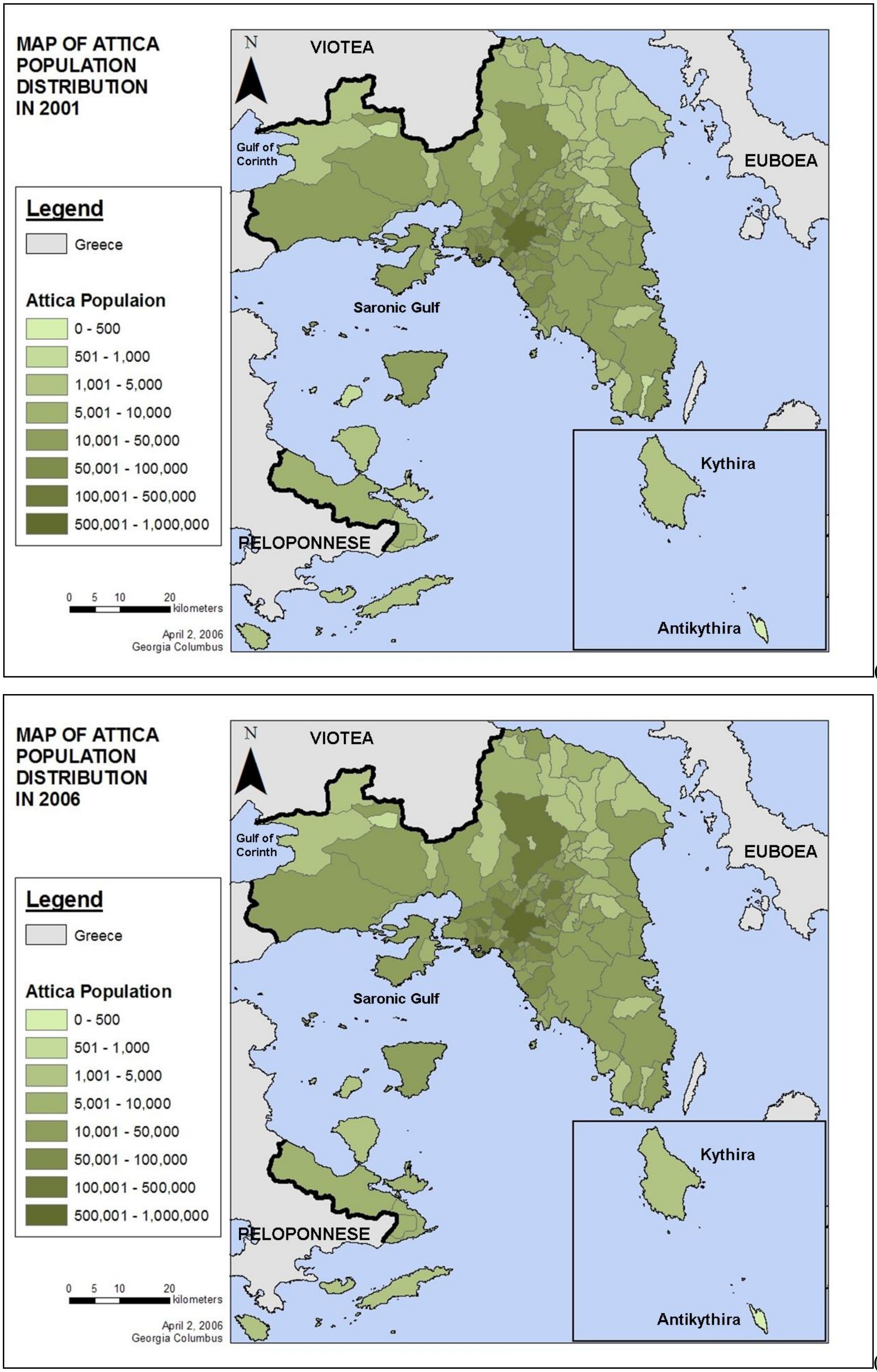


Figure 3.6 Distribution of Attica’s population for (a) 2001 and (b) 2006.

3.2 CONTINENTAL ATTICA

3.2.1 Morphology and Relief

The intense activities of weathering and endogenous factors, such as orogenesis, volcanoes and earthquakes, have formed the present uneven relief of Greece.

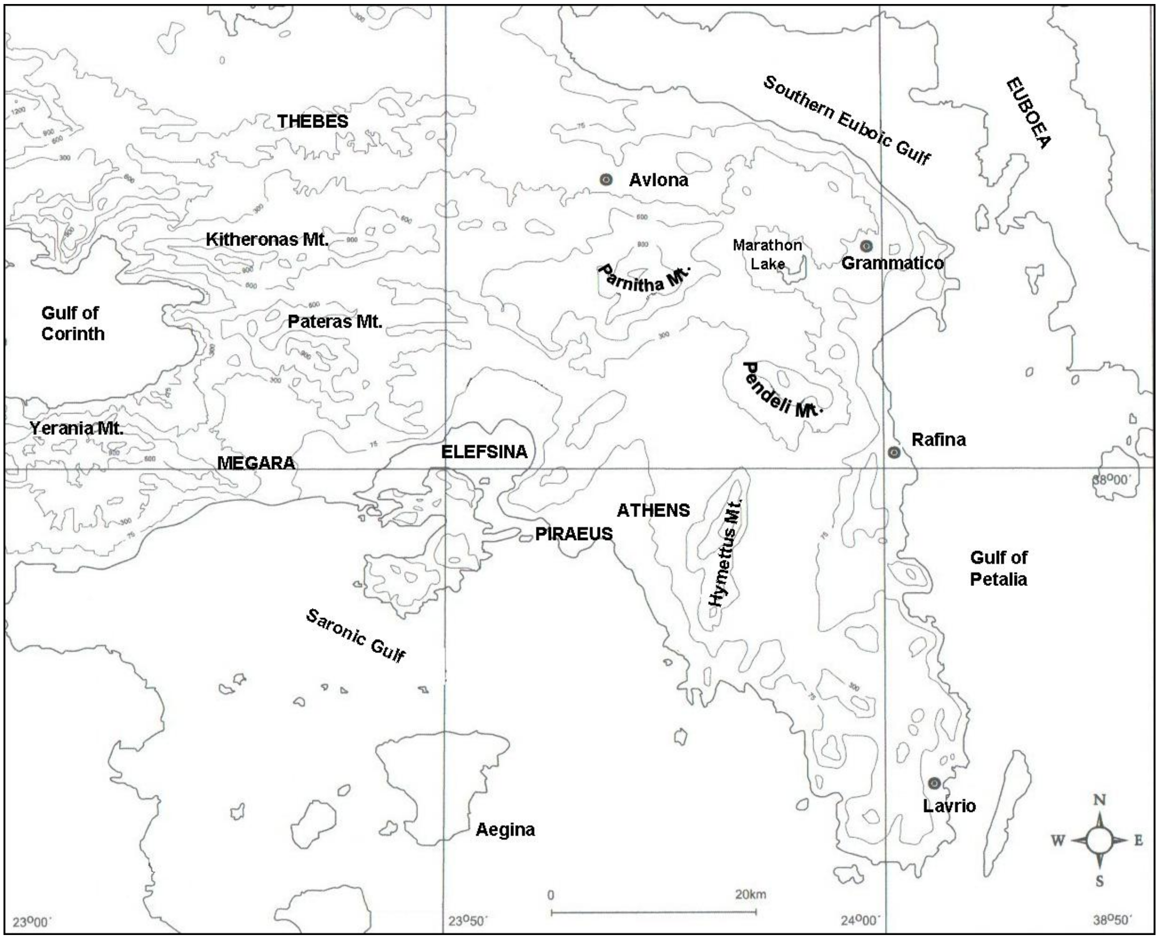


Figure 3.7 Topographic map of the Attica(1).

Attica's landscape consists of mountains and tectonic grabens that were created during the alpine orogenesis and were influenced by the subsequent tectonic dynamics (faults, subductions). Its current appearance exists since 8,000 B.C., when the last ice age ended and the ongoing interglacial period, known as the "Holocaine Optimum", initiated(25).

The main features of Attica's relief are mountains and hills; caves and sinkholes; plains and valleys; rivers, lakes and wetlands; and the wavelike shoreline. An analytical list of the aforementioned features is cited in Appendix A.

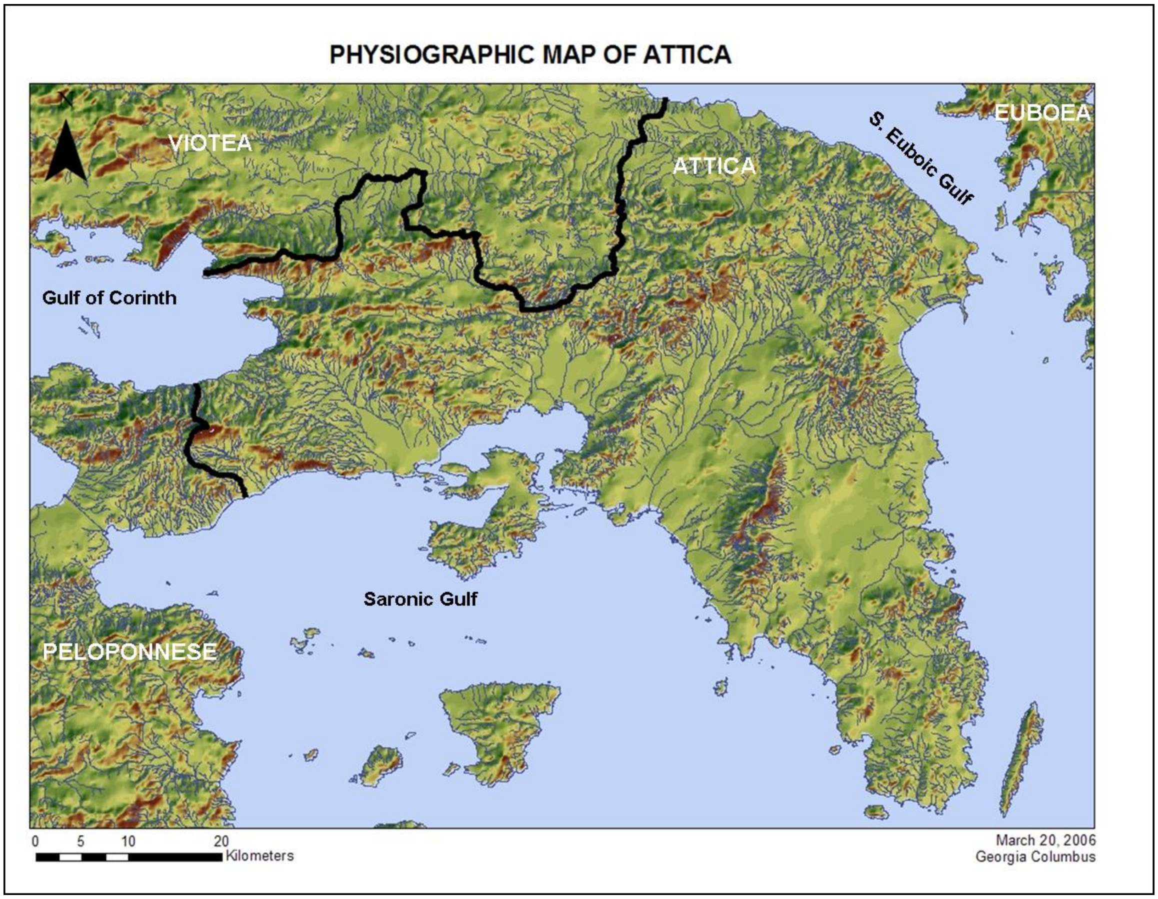


Figure 3.8 Physiographic map of Attica.

The highest mountains of continental Attica are Parnitha (1,413 meters), Kitheronas (1,409 meters), Yerania (1,369 meters), Pateras (1,132 meters), Pendeli (1,108 meters) and Hymettus (1,026 meters). The mountains consist of karstified limestone; hence, there are numerous caves, in some of which objects of the Neolithic era were found; Prophetis Helias and Panas are two examples of such caves. However, the cave that mostly attracts visitors is the Coutouki Cave, which was discovered 1926 on the eastern slope of Hymettus Mountain. Its elevation is 510 meters and its area reaches the 3,800 square meters.

The largest plains are the Basin of Athens, the Mesoghia Valley, and the Elefsina Plain, which is also known as “Thriassio Pedio”.

The most significant rivers passing through Attica until the nineteenth century were Ilissos and Kifissos. Ilissos flowed from Hymettus Mountain, while Kifissos from Parnitha Mountain. Both discharged in Phaliron Bay.

Figure 3.9 is the map of ancient Attica (500 B.C.), showing the location of the two riverbeds. Currently, their riverbeds are mostly covered; as a result, they become violent during rainy periods and often overflow, causing damages (Figure 3.11) to the neighboring areas. Their destructive force, however, is known since ancient times. According to the ancient geographer Stravon (around 100 B.C.), Ilissos and Kifissos flooded during the winter, while in summer the quantity of water was minimal.

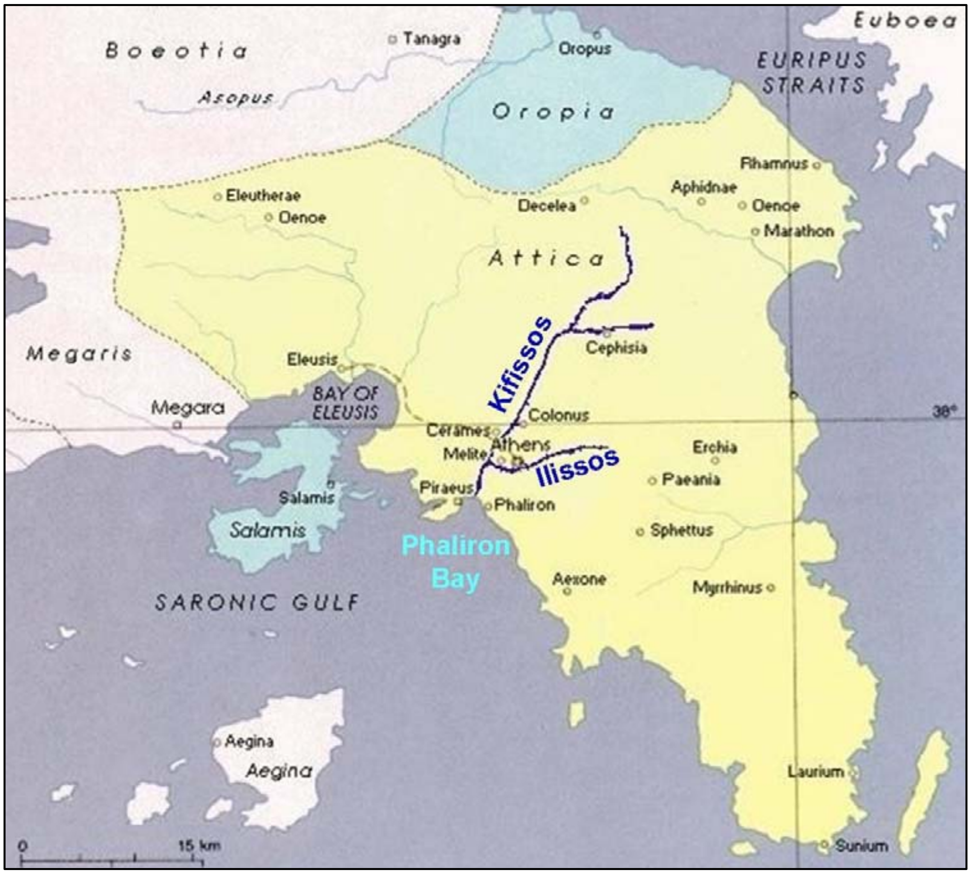


Figure 3.9 Map of ancient Attica(90).

In Figures 3.10 and 3.11 one can see a photograph of Ilissos River, which was taken in 1905, and a view of Kifissos River, respectively. Figure 3.12 shows some of the damages that took place in 2002, because of a flood of Kifissos.

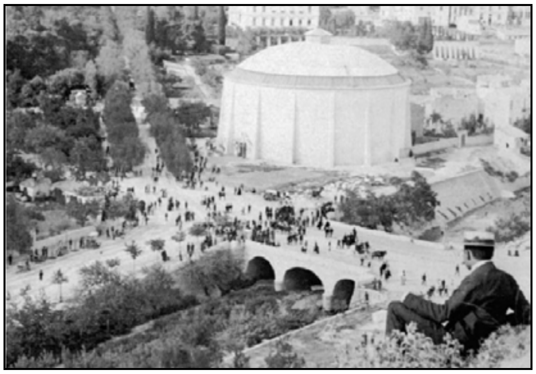


Figure 3.10 Photograph of Ilissos River(94).

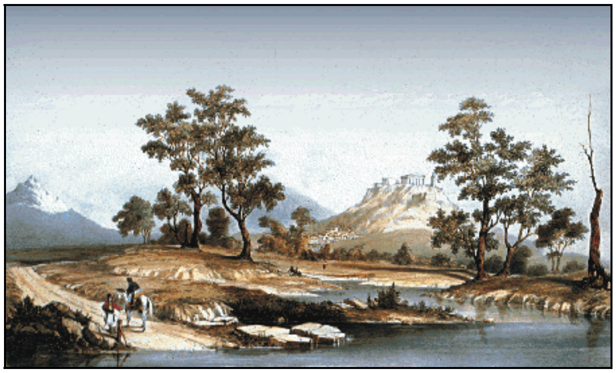


Figure 3.11 View of Kifissos River Lithography of 1850 by H. Cook(140).


(a)(152)


(b)(93)

Figure 3.12 Damages caused by flood of Kifissos.

The most important lake in continental Attica is the artificial lake at Marathon. The dam's construction started in 1926 and lasted three years. It is an arcaded dam faced with marble from the Pendeli Mountain. Its height and length are 54 meters and 285 meters, respectively(140). Figure 3.13 is shows the dam at its construction phase in 1928, while Figure 3.14 is a view of the artificial lake in 2000.

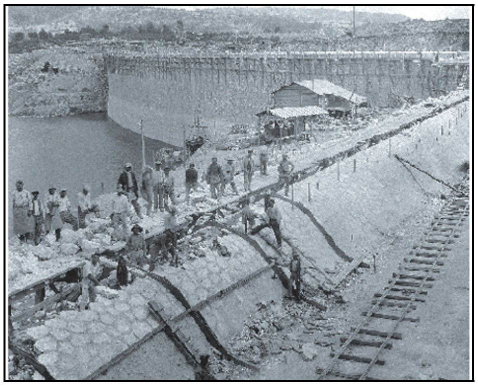


Figure 3.13 Photograph of Marathon dam in 1928(140).

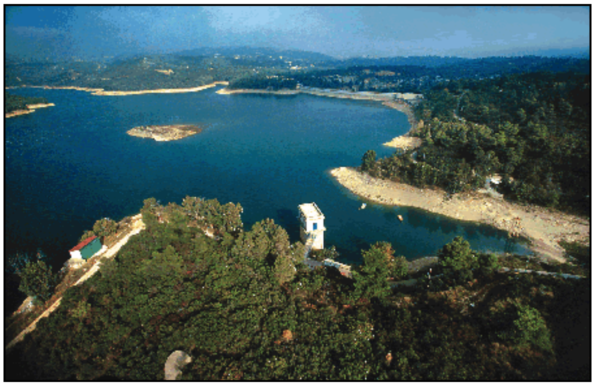


Figure 3.14 Photograph of Marathon lake in 2000(140).

The shoreline is approximately 450 kilometers long and forms numerous bays and gulfs, such as Lavrio Bay on the northeast; Elefsina Bay and the port of Piraeus on the west.

Figure 3.15 Lavrio Bay(135).

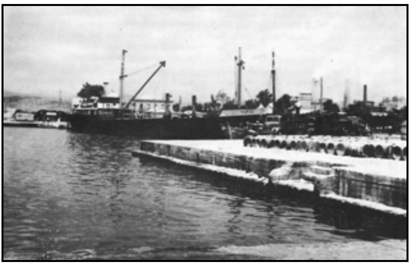


Figure 3.16 Elefsina Bay(126).

Figure 3.17 Port of Piraeus(160).

3.2.2 Climatology

The climate of Greece is mediterranean and, thus, is characterized by mild rainy winters with small rainfall of a 406-millimeter(133) average, extremely dry summers, and ample sunshine. More particularly, temperatures range between 6 – 12°C in winter and 26 – 28°C in summer. These generic conditions vary by location depending on the elevation and distance from the sea. Figure 3.18 presents the variations of average annual rainfall by location.

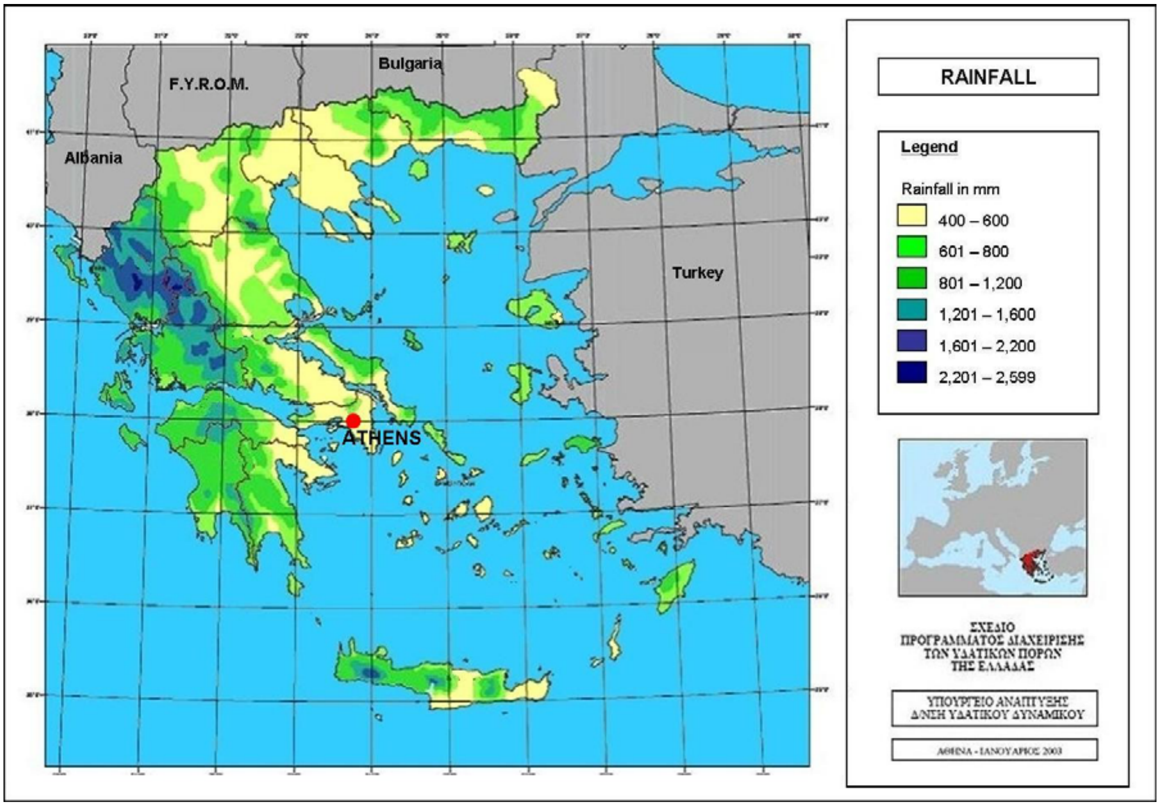


Figure 3.18 Map of average annual rainfall in Greece(65).

Based on information collected by the National Observatory of Athens (NOA) for the period of 1931 – 1990, the average annual temperature in Attica is 17.5°C, while the average annual rainfall is about 500 millimeters(65). The average number of sunny days is 114. Typically, northeastern winds prevail 120 days annually, while 88 days per year southwestern winds blow. During spring the northern winds increase the temperature of the basin. An appraisal of the meteorological information of the aforementioned period showed that their values present small differences – less than 5% – with time(1).

3.2.3 Geology

3.2.3.1 Lithostratigraphy

The area of continental Attica consists of alpine and post-alpine geologic formations (Figure 3.19), which appear as a combination of sedimentary, igneous and metamorphic rocks.

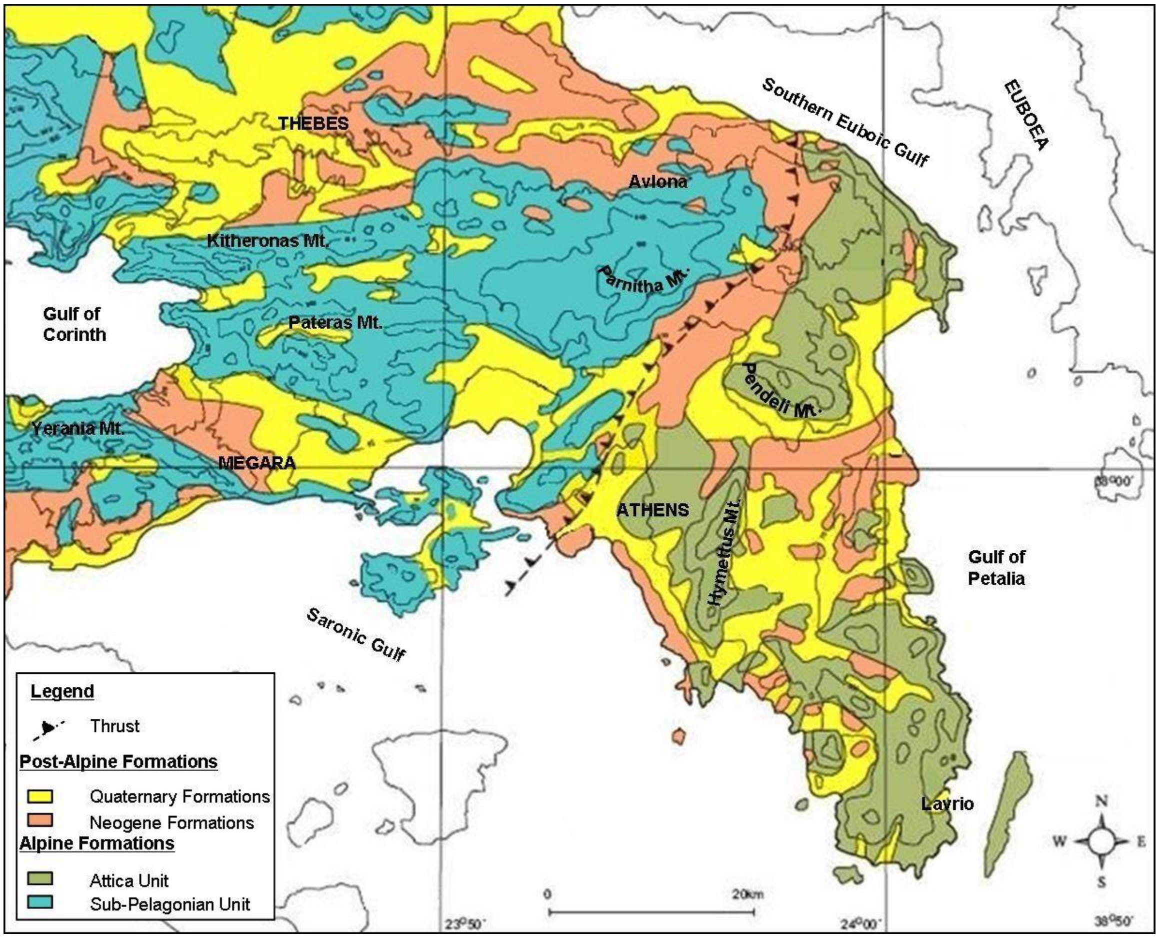


Figure 3.19 Geologic map of Attica(1)**.**

3.2.3.1.1 *Post-Alpine Formations*

These formations were created in the post-alpine neo-tectonic grabens of the area of study and are influenced by the tectonic structures that are continuously developing since Miocene.

The aforementioned grabens are partly delimited by sea and can be geographically divided in two large sections, the graben of Thebes and that of Megara – Athens – Mesoghia. The ***Graben of Thebes*** is parallel to the main faults of the area with a west to east direction. This graben is separated from the other by the mountains Kitheronas and

Parnitha. The group of ***Megara – Athens – Mesoghia Grabens*** is delimited by northwestern and northeastern tectonic structures. It encloses the grabens of Megara-Elefsina, Athens and Mesoghia. The first two basins are delimited by the island of Salamina, and Yerania and Aegalaeo Mountains. The third basin is separated from that of Athens by the mountains of Hymettus and those of the area Lavreotiki.

The post-alpine sediments of the period from Miocene to Pleistocene evolved in brackish and marine environment, while the overlaying Pleistocenic formations were mostly stream and lake deposits.

Regarding their formation period, the post-alpine formations are of two types: The ***Quaternary formations*** that are further divided in Holocenic and Pleistocenic; and the ***deposits of Neogene***, which are subdivided in Pliocenic and Miocenic.

3.2.3.1.2 *Alpine Formations*

The geologic structure of continental Attica consists of two groups of alpine basement rocks(44):

The upper group mostly consists of Mesozoic carbonate rocks (limestone and dolomite of Triassic and Jurassic age) that overlie a clastic formation of shale and sandstone, which includes olistholites deriving from Permian limestone. Some ophiolitic rocks, which were tectonically emplaced during the palaeo-alpine orogenesis of Late Jurassic – Early Cretaceous, are locally preserved over the carbonate platform. These formations belong to the geotectonic unit of Eastern Greece, which in Attica consists of the palaeo-tectonized Sub-Pelagonian Unit and the ophiolite nappe of Axios-Vardar oceanic basin; these formations are overlaid by the upper-cretaceous transgressive platform that is covered by Upper Cretaceous shallow-water carbonate rocks and early Tertiary flysch. This upper group extends only to the northwestern part of Attica, forming the major mountain range of Parnitha and other minor mountains, like Aegalaeo.

The lower group, which is known as the geotectonic unit of Attica, mainly consists of metamorphic rocks, including marble and mica-schist, and appears in the area of Pendeli Mountain to the east and Hymettus Mountain to the south of the Basin of Athens.

The tectonic contact between the two aforementioned groups strikes in the northeast to southwest direction and dips towards the northwest. Even though this tectonic contact is not clearly visible as it is mostly covered by post-alpine sediments, its position is roughly marked by Kifissos River (Figure 3.9).

It must be noted that despite the numerous studies that have been conducted in Attica, unanswered questions still exist, which indicates the extent of the complexity of Attica’s geologic structure.

3.2.3.2 Tectonics – Neo-tectonics

The tectonic structure of continental Attica involves a network of faults. As shown in Figure 3.20, the major faults strike in the east to west and northwest to southeast direction. The most active neo-tectonic faults exceed the length of 7 – 8 kilometers and have a seismic potential of magnitude over 5 Richter(44).

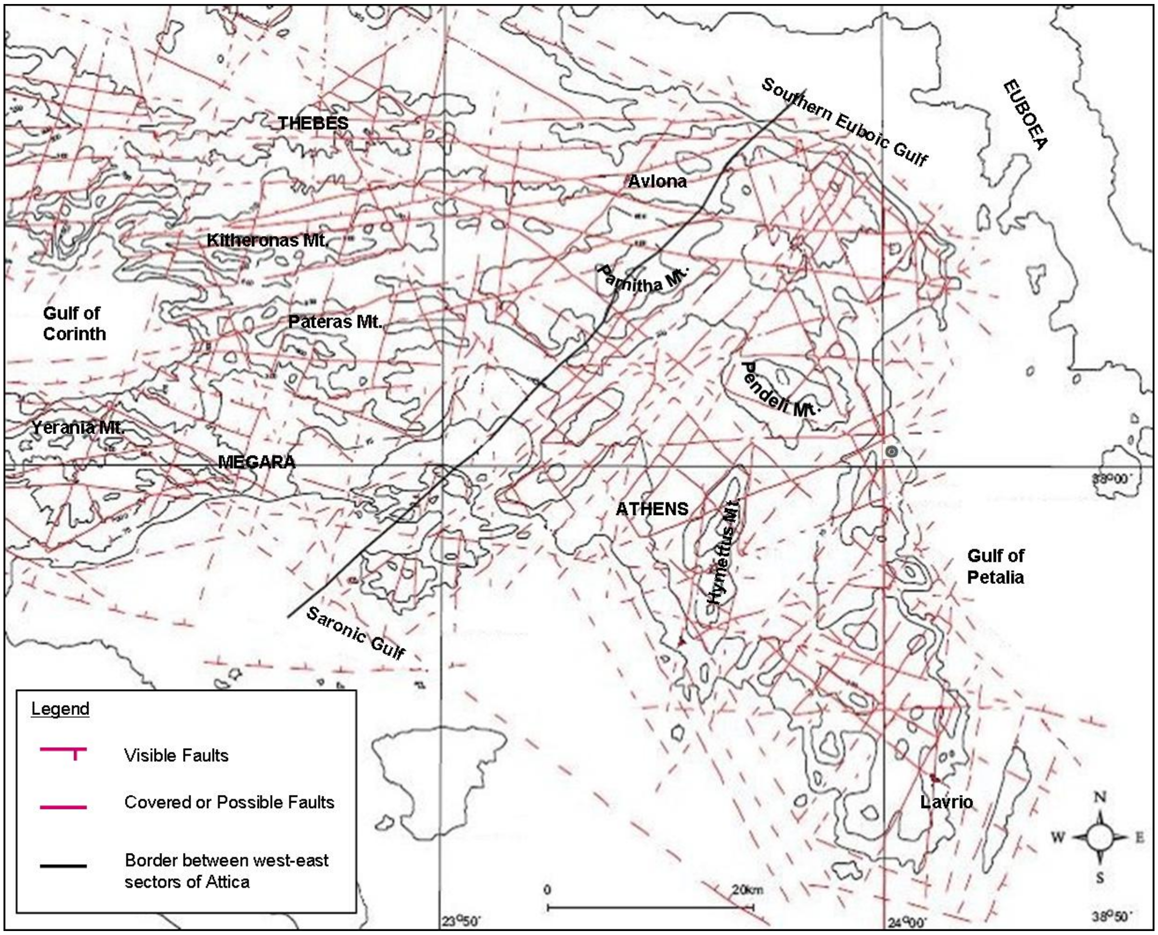


Figure 3.20 Map of fault network at continental Attica(1).

The east-northeastern – west-southwestern and eastern – western neo-tectonic trends in the region between the Gulf of Corinth and Saronic Gulf are related to earthquakes of magnitude ranging from 6.5 – 7 Richter. On the contrary, the northwestern – southeastern neo-tectonic trend of eastern Attica, which also extends to the western coast of Southern Euboic Gulf, is related to earthquakes of 6-Richter approximate magnitude.

3.2.3.3 Seismicity

Greece is part of the eastern Mediterranean basin, where the Anatolian plate extends, and is one of the world's most intense seismic zones; therefore, destructive earthquakes occur frequently. Since 1964, over 20,000 earthquakes have been recorded around Greece(120). Figure 3.21 shows the seismic hazard map of Greece, while Figure 3.22 is a map obtained by the Institute of Geodynamics, NOA, presenting data on the earthquakes that occurred in Greece in February 2006.

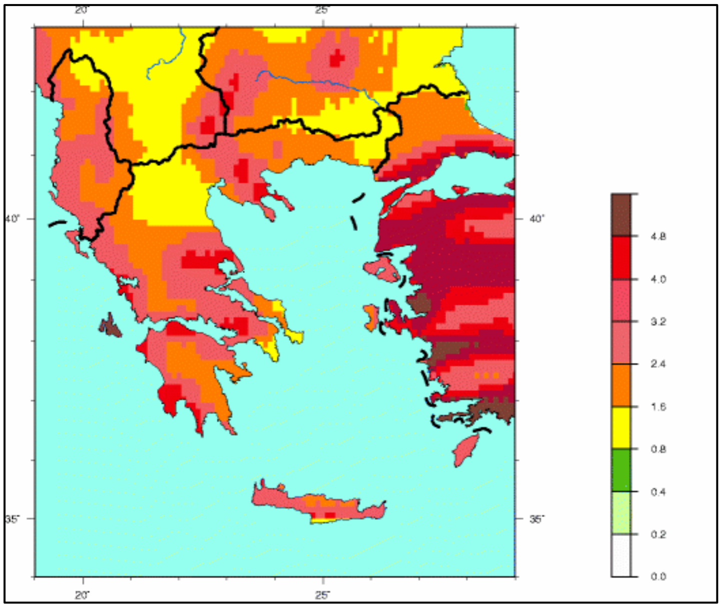


Figure 3.21 Seismic hazard map of Greece(78).

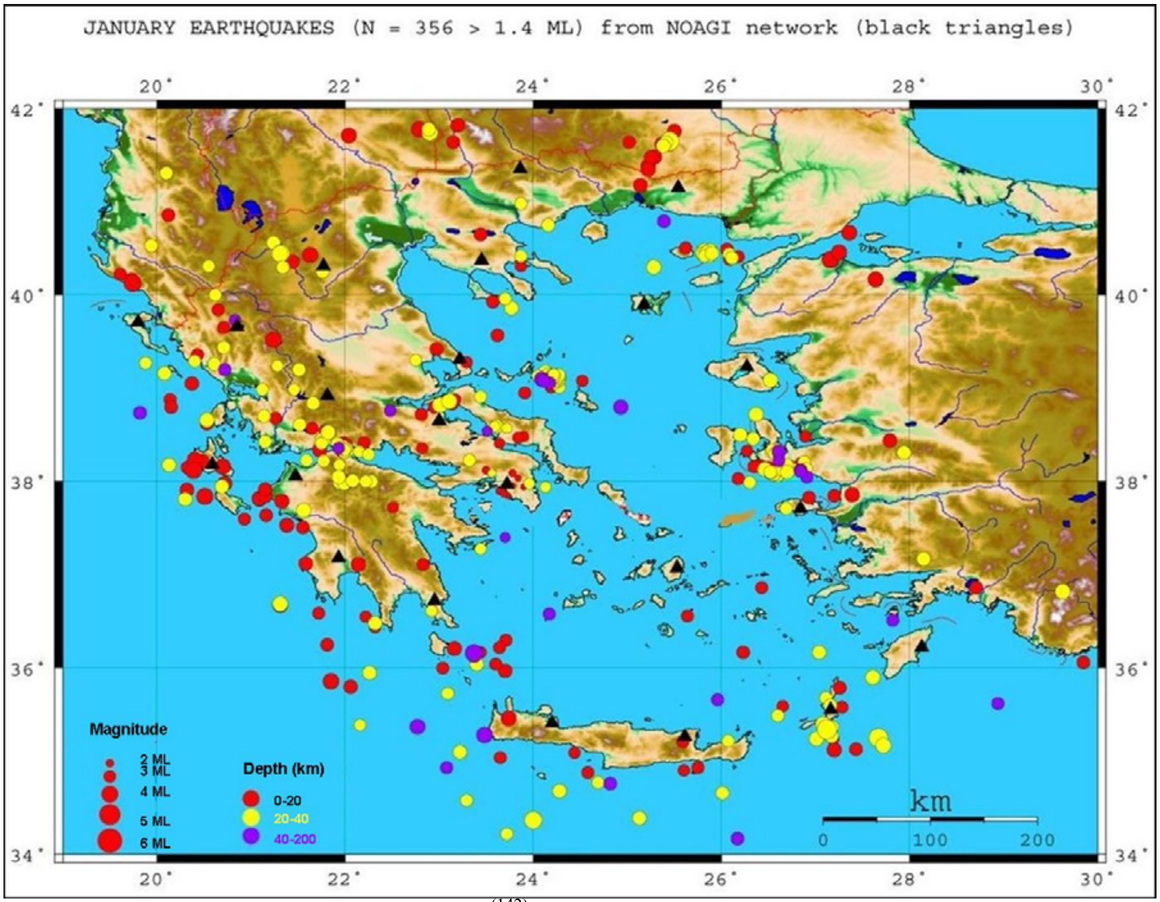


Figure 3.22 Earthquakes in Greece in 2006(142).

The geologic instability and the resulting earthquakes are owed to the following reasons:

- The subduction of the African tectonic plate under the southern margins of the Eurasian plate (Hellenic plate of the Aegean). This type of earthquakes, which are of intermediate depth, occurs at the southern Aegean and Ionian Seas;
- The active movement of the Anatolian plate that is wedged against the continental plates of Africa, Eurasia and Arabia. As these larger tectonic plates grind against the Anatolian plate, Asia Minor and Greece move under compression or tension. The 805-kilometer North Anatolian fault, which is the northern boundary of the Anatolian plate with the Eurasian plate, appears to be moving eastward at the present time. At its western border, it influences the North Aegean fault, which in turn activates the faults of Ionian and Adriatic Seas;
- The deformation, to which the Aegean plate is subjected, due to main tectonic stresses of compression and tension, which are caused by the aforementioned factors. This results in the occurrence of mainly shallow earthquakes in the Greek territory; and
- The magmatic processes and geothermal activities of the post-alpine volcanoes. Most of these earthquakes arise on the volcanic arc of southern Aegean.

Figure 3.23 illustrates the relation of the aforementioned neighboring tectonic plates and shows the direction of their movement.

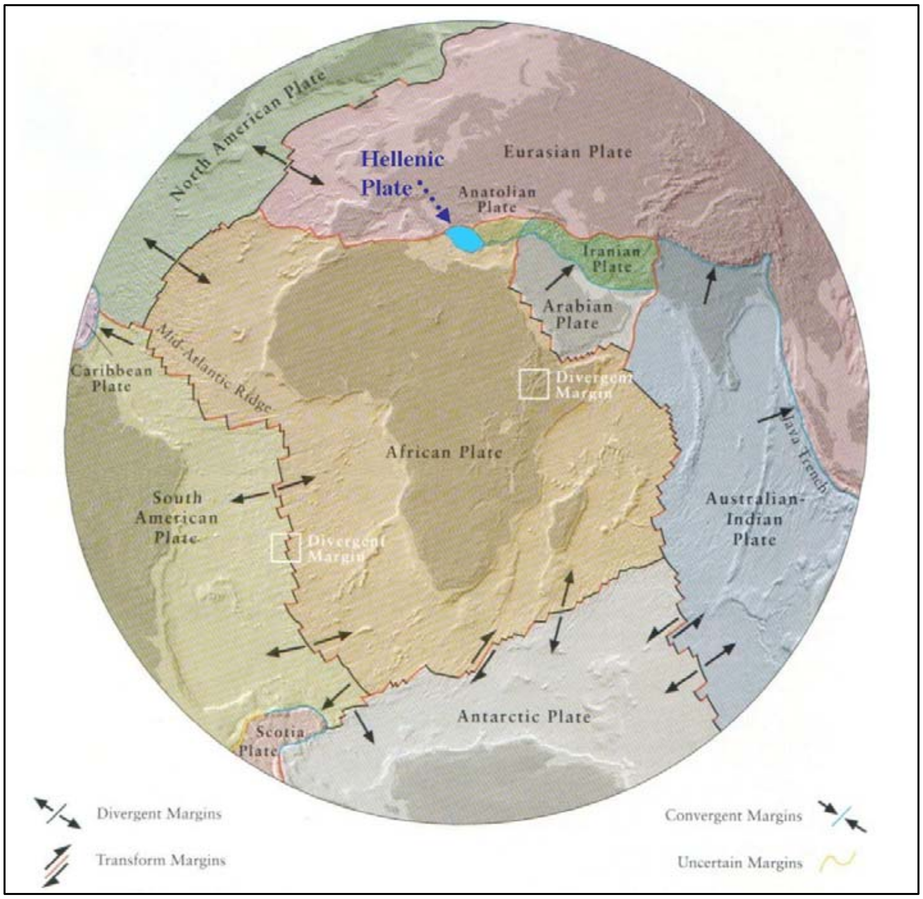


Figure 3.23 Movement of lithospheric plates(39).

Continental Attica, as well as its neighboring regions, is characterized by intensely active seismic foci at the following areas (Figure 3.24):

- ***Northern Euboic Gulf***, where earthquakes of 7-Richter magnitude usually take place. This area is influenced by Atalandi’s fault zone;
- ***Eastern part of the Region of Viotea***, where movement of the active faults of Plataees – Caparelli – Thebes result in earthquakes of 7-Richter magnitude;
- ***Grammatico – Rafina***, where the occurring earthquakes are recorded to have magnitude of about 5.5 Richter; and
- ***Eastern Gulf of Corinth***, where the most seismic foci are located. The earthquakes occurring in this area have a magnitude of approximately 7 Richter.

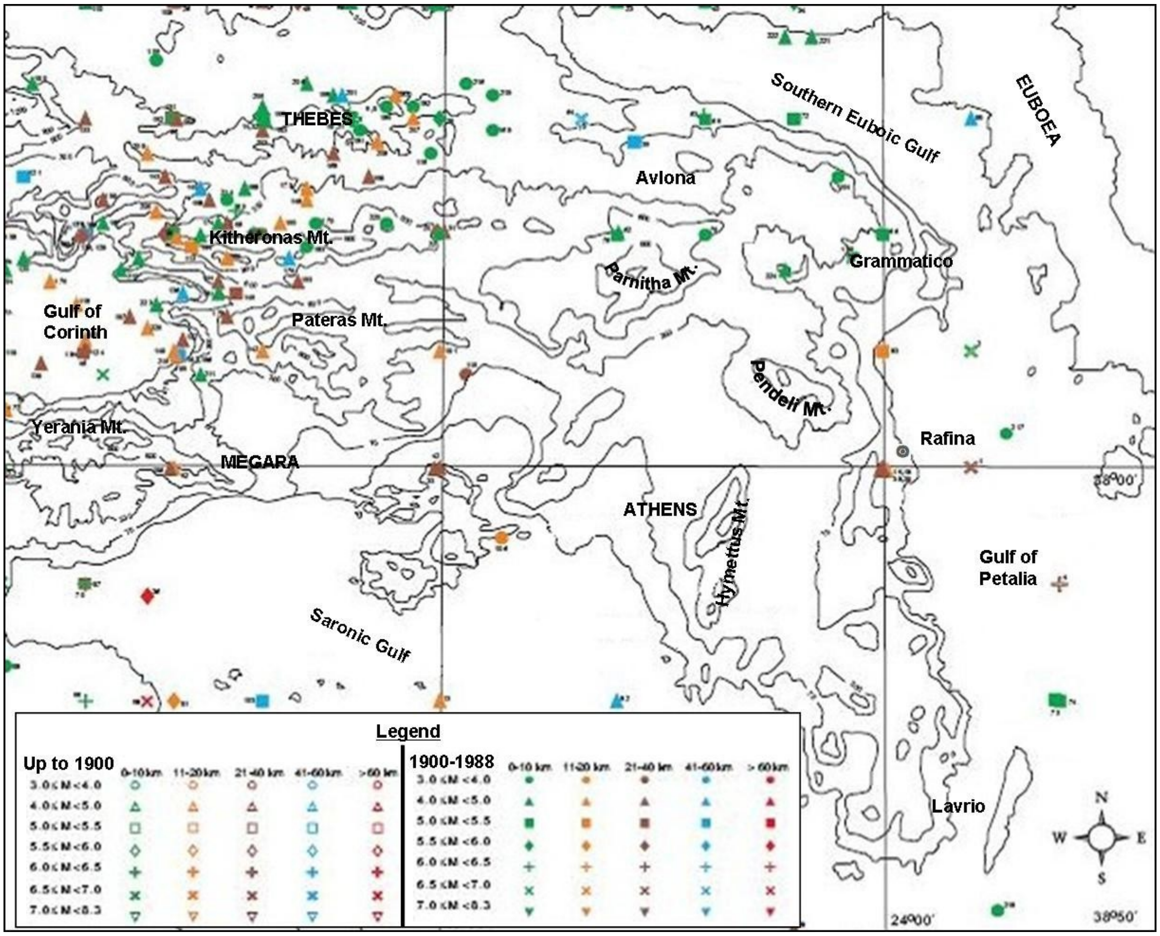


Figure 3.24 Map of epicenters of Attica’s main earthquakes(1)**.**

In general, the majority of earthquakes that takes place in continental Attica is shallow and is located mainly at the eastern part of the Gulf of Corinth. According to Greek Antiseismic Regulations, Attica’s seismicity is considered to range from intermediate to high levels.

Figure 3.25, shows that the maximum intensities of earthquakes in Attica for the period of 1700 – 1981 range from V to IX on Mercalli scale. The most possible magnitudes of earthquakes expected in the next century in Attica range between 6.6 – 7 Richter, as shown in Figure 3.26. Table 3.2 lists the earthquakes that were destructive for Attica through time.

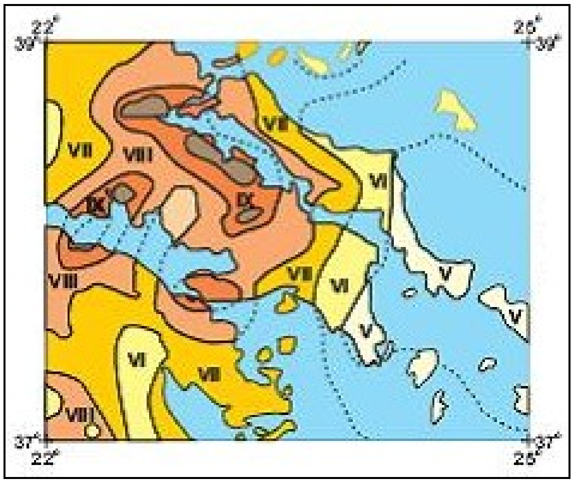


Figure 3.25 Map of maximum intensities of earthquakes(1).

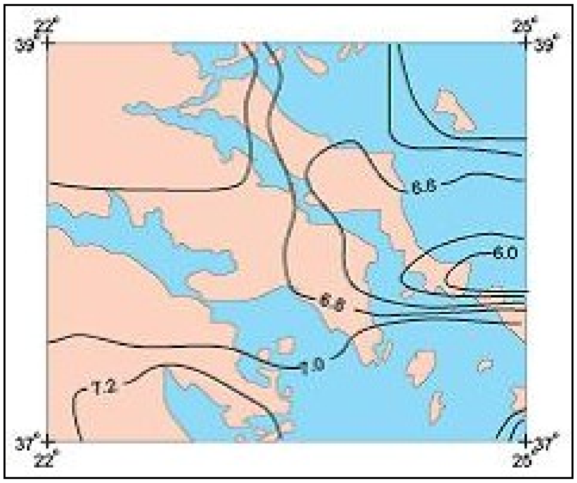


Figure 3.26 Future earthquakes Attica(1).

Table 3.2 Earthquakes with catastrophic impacts on Attica(45, 80).

Year	Region	Magnitude (in Richter)	Year	Region	Magnitude (in Richter)
450 B.C.	Salamina	6.3	1858	Corinth	6.7
426 B.C.	Orchomenos	6.6	1876	Nemaea	6.0
77	Corinth	6.3	1893	Thebes	6.2
524	Corinth	6.6	1894	Locrida	7.0
551	Chaeronia	7.2	1914	Thebes	6.0
1457	Hydra	6.0	1928	Corinth	6.3
1694	Athens	6.4	1930	S. Saronic Gulf	5.9
1805	Athens	6.0	1938	Parnitha	6.0
1837	S. Saronic Gulf	6.4	1981	Halcyonides	6.7
1853	Thebes	6.8	1999	Parnitha	5.9

The most recent destructive earthquake occurred in September 1999. This was the strongest earthquake to hit Athens in nearly a century and the worst to hit Greece in nearly 20 years. The earthquake's epicenter was approximately 20 kilometers northwest of Athens, between the municipality of Acharnae and Parnitha Mountain. According to the Athens Seismological Institute, the earthquake's magnitude was 5.9 Richter. It was felt across the Aegean Sea and as far away as 290 kilometers east of Athens, at Turkey. In Athens, the earthquake was felt with great intensity, due to the orientation of the fault that produced it and to the shallow depth of its focus, which was approximately 10 kilometers$^{(120)}$. The main shock was followed by over 700 aftershocks, including one with magnitude 4.7 Richter and eight over 4 Richter.

Figures 3.27 to 3.29, provided by the Seismological Laboratory of the Department of Geophysics and Geothermics of the National and Kapodistrian University of Athens (NKUA), illustrate the tremendous damages of the earthquake: Many people were killed; hundreds were injured; and thousands were left homeless. According to relevant studies, 672 houses were destroyed beyond repair, while 2,217 more were in need of repair. The greatest damage to buildings occurred in the municipalities of Acharnae, Ano Liossia, Nea Philadelphia, Nea Ionia, Kifissia and Zefyri. There was no apparent damage to the Acropolis, the Temple of Zeus or other monuments in the area.

Figure 3.27 Photograph of demolished house on the national highway towards south(76).

Figure 3.28 Photograph of demolished house at Nea Philadelphia(76).

Figure 3.29 Photograph of the "Ricomex" demolished factory, Acharnae(76).

3.2.3.4 Mineral Resources

Continental Attica's mineral resources are remarkable, which is proved by the numerous quarries in various locations (Figure 3.30), such as Mandra of the municipality of Elefsina and Lavrio.

Most of the existing quarries operate for the exploitation of marble and various types of limestone. In the past, such quarries were situated on the hills and mountains of the basin of Athens (Tourkovounia, Lycabettus, Philopappou, Aegalaeo, e.t.c.). Globally recognized is the white marble of Pendeli Mountain, as it was used for the construction of many ancient monuments in and near Athens. Currently, marble is exploited at the municipality of Dionyssos.

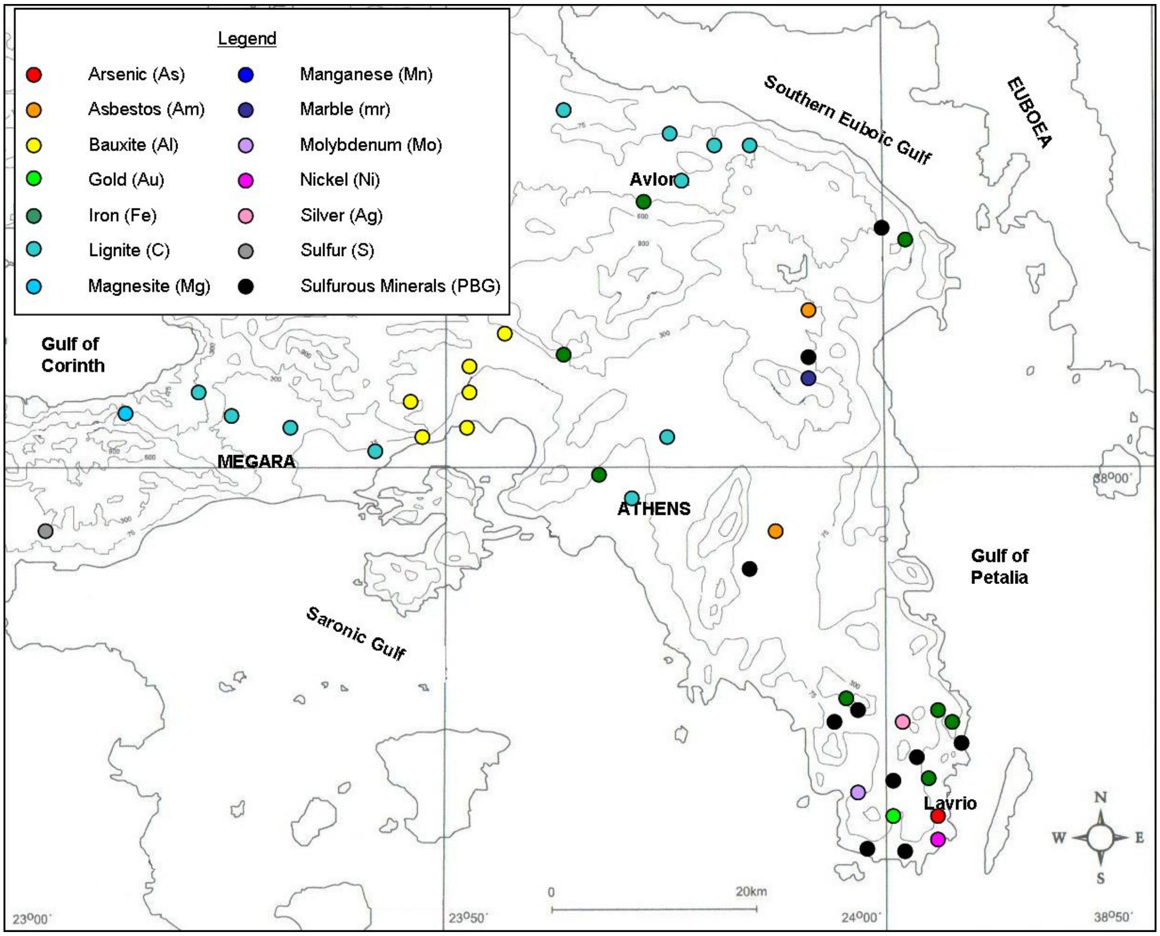


Figure 3.30 Map of main mineral resources of continental Attica(1).

Moreover, the mine of Lavrio, which is the most ancient in Greece, is known for the exploitation of sulfurous minerals. The area of Mandra of Elefsina is rich in bauxite; while deposits of lignite can be found in Megara, Oropos and Rafina.

3.2.4 Hydrogeology

In general, the rate of groundwater flow depends on the lithology of the geologic formations through which the water moves, as well as on their relative position that is influenced by tectonics.

In the area of study, one can find three types of aquifers(24):

- ***Karstic aquifers***: Carbonate formations are characterized by high permeability. Their karstic drains and large voids allow large quantities of water circulate through them. As a result, this type of aquifers is characterized by higher capacity in Storability (S) and Transmissivity (T) of groundwater in comparison to others. In continental Attica, the carbonate formations that appear in the stratigraphic columns of the alpine geotectonic units are limestone, dolomite and marble, and overlay nearly impermeable clastic rocks (aquicludes). This relative position of permeable – impermeable rocks results in groundwater flowing in the karstic formations. Such aquifers can be found in mountains Aegalaeo and Parnitha.

- ***Aquifers that occur in cracks of hard rocks***: Groundwater flows in the main mass of hard rocks that have been subjected to tectonic stresses, which create cracks. These cracks create secondary porosity, allowing water to easily percolate to the main mass of the rocks. Even though groundwater appears in large quantities in these aquifers, it is highly contaminated in minerals.
- ***Granular aquifers***: This kind of aquifers can be found in both post-alpine and alpine formations. Concerning the quantity of water, the most valuable granular aquifers lie in post-alpine formations, and can be divided in confined and unconfined (Figure 3.31) depending on their relative position to impermeable formations. The alpine granular aquifers are developed in the disintegrated mantle of clastic formations.

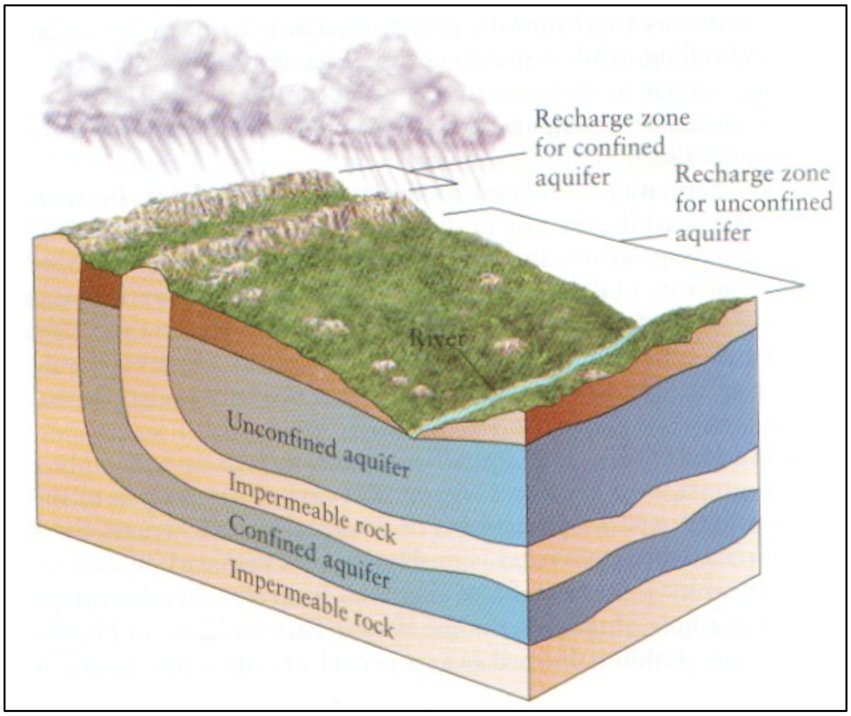


Figure 3.31 Confined and unconfined aquifers[39].

As one can observe in Figure 3.19, most of the karstic aquifers are on the mountains of the area of study, while most of the granular appear in plains. Occasionally, lowlands cover their needs in water by drilling in karstic aquifers, as in the case of Mesoghia.

The basin of Athens comprises a particular case, as there are limited open spaces and most of the riverbeds are covered, which constrains the natural supply of water to aquifers. The existent aquifers are mainly fed by leaks of Athens' water supply network and are mainly used for irrigation.

3.2.5 Land Uses

The main land use categories that appear in continental Attica are pastures, forests, surface water, residential and cultivable areas. The distribution of the land uses is presented in the following Table and Figure.

Table 3.3 Land Uses of continental Attica(172)**.**

Land Use	**Area (km^2)**
Cultivable Areas	947.7
Pastures	858.4
Forests	1,127.6
Water	33.8
Residential Areas	741.2
Other	99.6
TOTAL	3,808.3

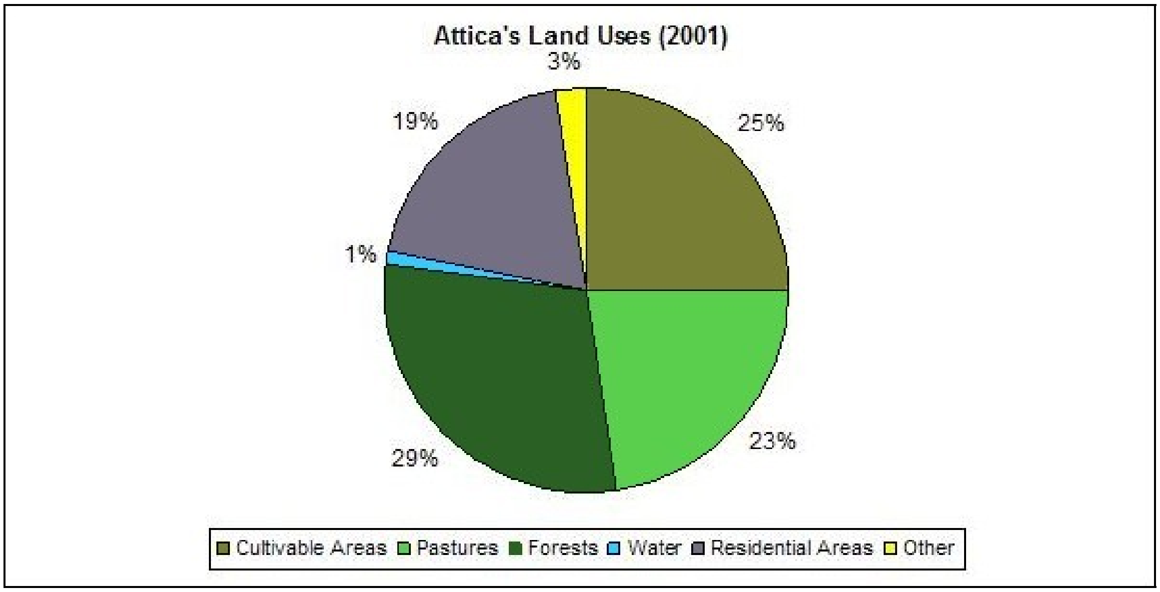


Figure 3.32 Diagram of Attica's land uses (based on Table 3.3)**.**

3.2.6 Protected Areas

Since 1937, Greece has started to identify natural areas of specific ecological importance, such as forests and wetlands, in order to place them under special protection. There are seven categories of protected areas(125):

- ***National parks***: Areas of special ecological interest for their vegetation, flora, fauna, and other characteristics.
- ***Aesthetic areas***: Areas of landscape aesthetics and ecological importance.
- ***Natural monuments***: Small areas of specific ecological, historical or cultural interest.

- ***Wetlands***: According to the Ramsar Convention, ratified by the Greek Parliament in 1974, the Greek wetlands should be preserved and protected.
- ***Controlled hunting areas***: These areas have sizes ranging from 5 to 50 square kilometers. Hunting is allowed only to those who hold special permits and only under severe restrictions.
- ***Game refuges***: There are numerous areas all over Greece, where hunting is absolutely forbidden to ensure the protection and reproduction of game species.
- ***National marine parks***: This is a very recent development for Greece. So far, only one such park has been established, in the Sporades Islands, for the protection of the monk seal.
- ***Special protected areas***: Directive 79/409/EEC on the Conservation of Wild Birds was ratified in Greece by the Joint Ministerial Decision (JMD) of the Ministers of National Economy and of Agriculture, No. 414985/85. The directory "Important Bird Areas in Europe" included 113 sites of importance in Greece. Of these sites, 50 are protected under the "Special Protection Areas" regime.

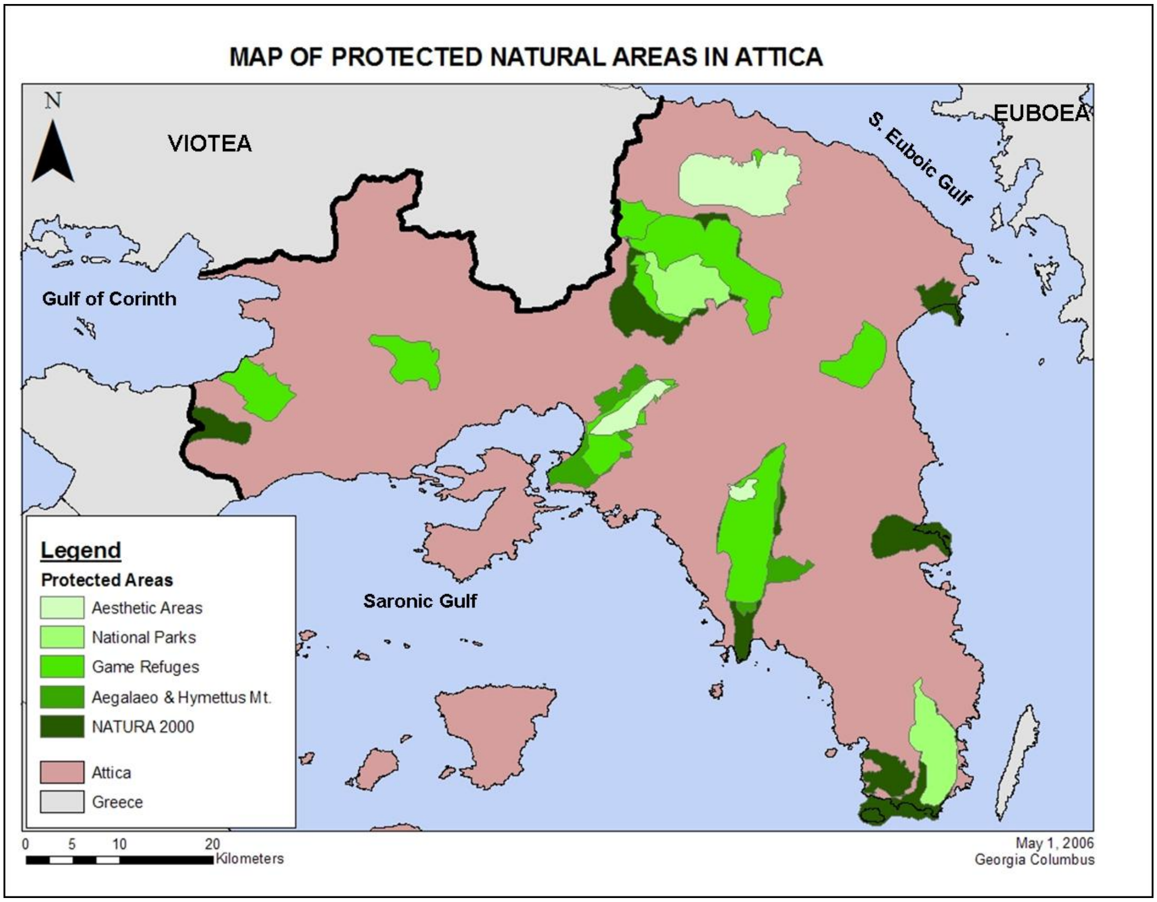


Figure 3.33 Protected natural areas of Attica (based on Reference 45)**.**

In addition, Council Directive 92/43/EEC, also known as the “Habitats Directive”, is a recent legislative instrument in the field of conservation of nature. Following on from the Directive on the Conservation of Wild Birds, it establishes a common framework for the conservation of natural habitats, wild fauna and flora species; and provides for the creation of a network of Special Areas of Conservation called “***Natura 2000***” to “*maintain or restore, at favorable conservation status, natural habitats and species of wild fauna and flora of Community interest*”.

Moreover, the protected areas of Greece include a plethora of archaeological sites and monuments, which are of great global significance and should undoubtedly be preserved. Even though many of these sites are located near the center of Athens, the rest are distributed throughout Attica.

Figures 3.33 and 3.34 demonstrate the most important protected areas of Attica, regarding the natural environment and the historical heritage, respectively.

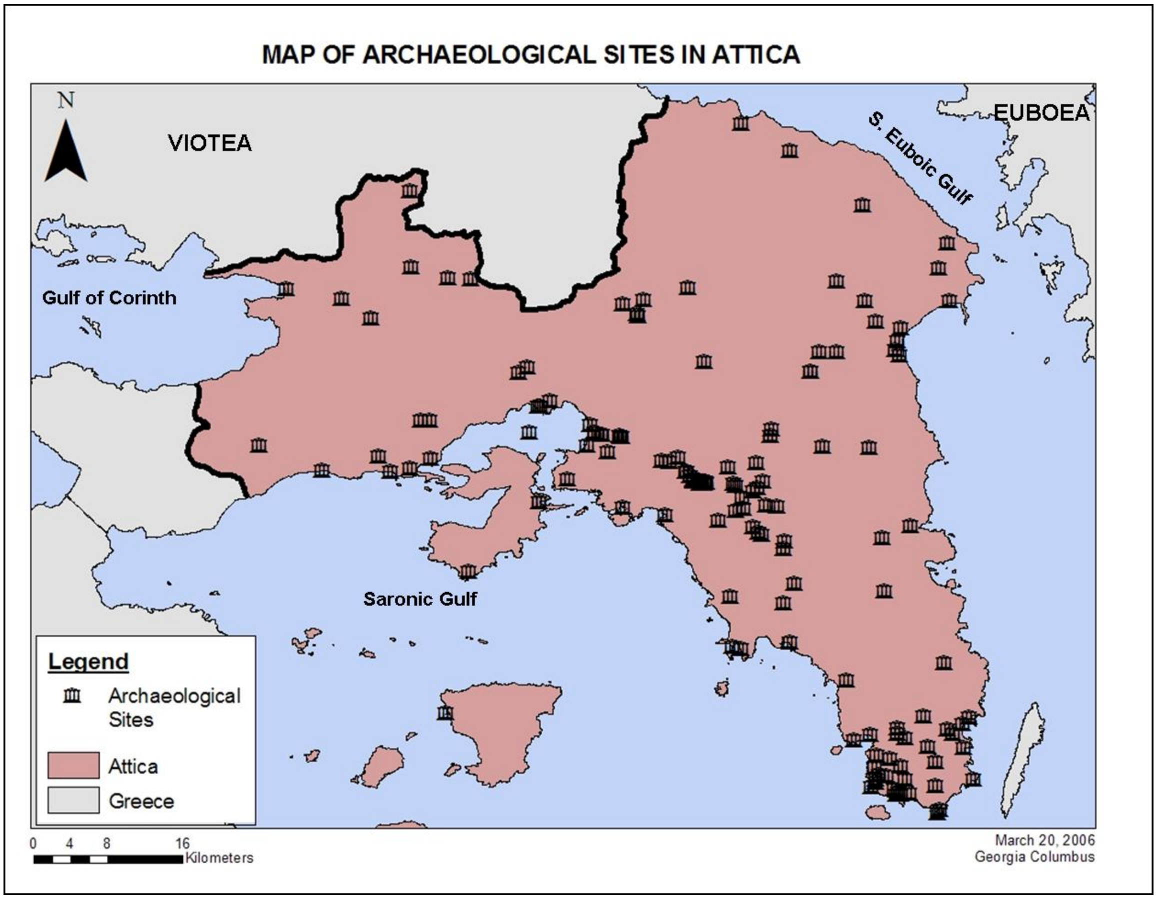


Figure 3.34 Protected archaeological sites (based on References 45 and 35)**.**

3.2.7 Transportation System

In this section, the infrastructure of continental Attica will be described in terms of transportation by land, water and air. It must be noted that in order to better understand the transportation system, in some cases it is essential to refer to an area wider than Attica.

Since 1986, about $30.6 billion (€24 billion), part of the funds that Greece has received from European Union (EU), was spent on improvements of the transport infrastructure (roads and bridges, railways, seaports and airports). As a result, Attica's transportation system is currently one of the most modern and efficient systems in Europe. It consists of a dense road network and a well-expanded mass transit system. Also, Attica is served by ferries, which connect the main land to the islands, and the Eleftherios Venizelos International Airport, also known as Athens International Airport (AIA).

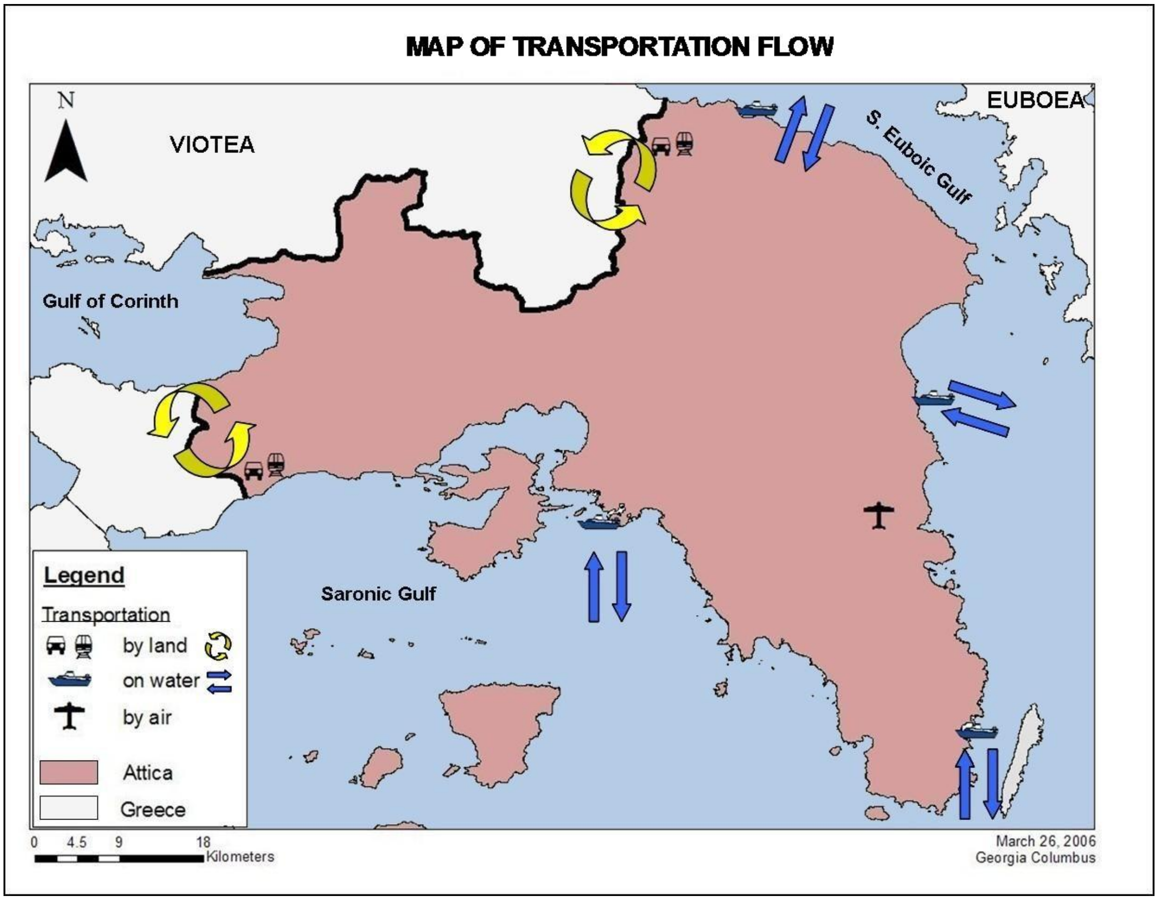


Figure 3.35 Transportation flow in Attica.

3.2.7.1 Road Network

Continental Attica is traversed by two major roads: The National Highway, also known as Patras – Athens – Thessaloniki – Evzoni (PATHE; ΠΑΘΕ in Greek) Motorway, and Attiki Odos. Figure 3.36 shows Attica's network of main roads.

PATHE is the major highway of the Greek national road network that connects north to south. More particularly, it connects six Regions, 11 Prefectures, 14 cities, nine major seaports and six airports. Thus, it plays an essential role in the financial and social development of the country. Its total length until now is 744 kilometers(66) and is still under development.

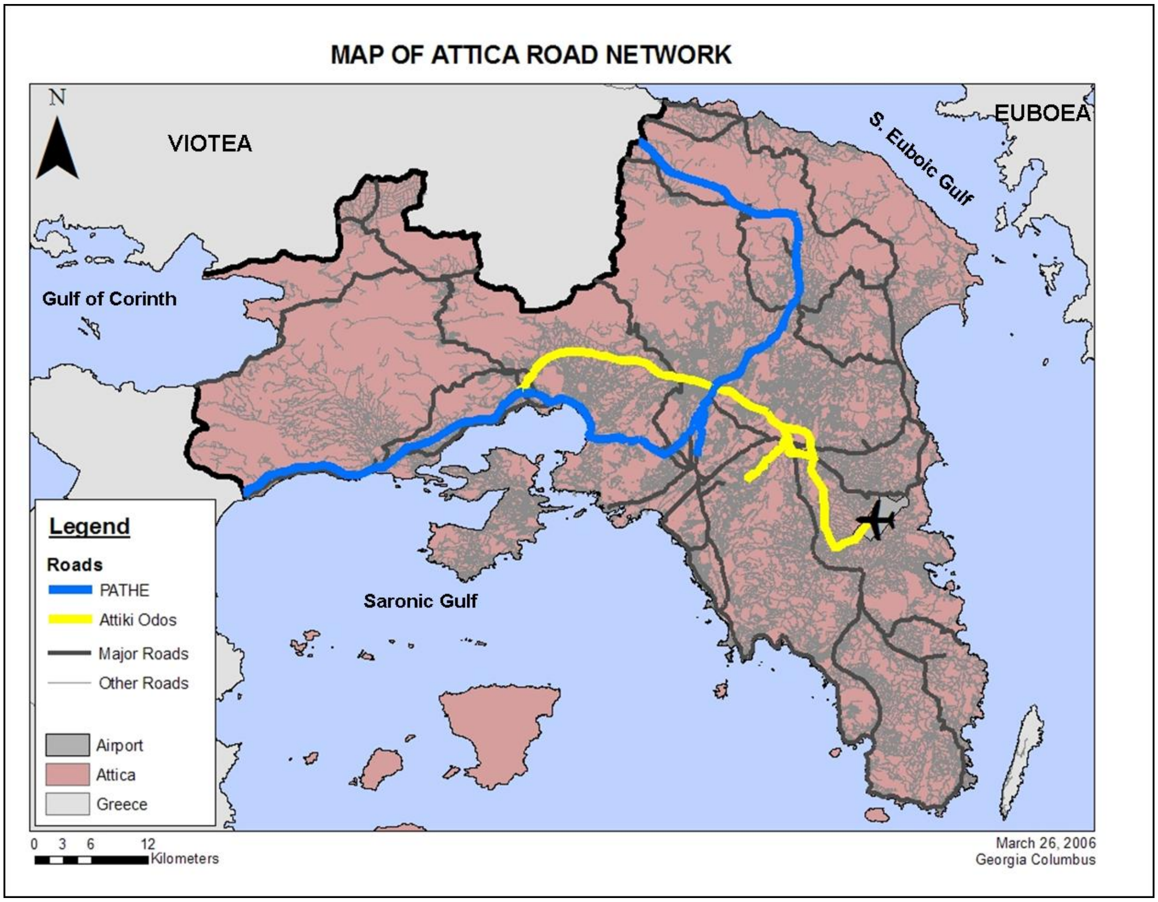


Figure 3.36 Major roads of Attica.

Attiki Odos is a toll-expressway of a general west to east direction. Its construction started in 1997 and was completed in 2004. The estimated capital costs reached the amount of $3.3 billion (€2.6 billion)(170). Attiki Odos consists of two main parts: The Elefsina – Stavros – Spata Motorway and the Hymettus western Peripheral Motorway. It has a total length of 65.3 kilometers and is estimated to receive 35,000 vehicles daily(104). Figure 3.37 shows the connection of Attiki Odos to PATHE.

Figure 3.37 Photograph of Attiki Odos – PATHE Interchange(109).

The main road network of Attica has a length of approximately 2,380 kilometers and receives 43.6% of the vehicles that circulate in Greece, which results in a serious traffic congestion situation. The average circulation speed in the center of Athens is about 18 kilometers per hour, whereas in the surrounding areas it reaches 22 kilometers per hour(45). The traffic condition is aggravated by the unregulated movement of trucks.

3.2.7.1.1 *Buses*

There is a dense network of intercity bus-routes that connects not only various areas within Attica, but also Attica Region to other Regions.

Also, the bus service within continental Attica consists of a huge well-developed network of routes that are served by a fleet of about 2,100 buses that use either diesel or natural gas. They are operated by ETHEL S.A., which stands for "Greek Thermal Buses", and serve daily approximately 1.3 million passengers with 323 routes(164). It must be noted that Attica's fleet of almost 300 natural-gas-run buses is the largest in Europe.

Figure 3.38 Photograph of a diesel bus(137).

Figure 3.39 Photograph of a natural-gas bus(137).

Another type of buses used for commuting are electric trolleys. The fleet currently consists of 400 trolleys that cover 23 routes in the Prefecture of Athens-Piraeus and will be expanded in the near future. The trolleys are operated by ILPAP S.A. and carry 20% of the passenger of the entire Attica mass transit system(164).

Figure 3.40 Photograph of a trolley(112).

3.2.7.2 Rail Network

3.2.7.2.1 *Intercity Railway*

The Greek railway system, the length of which is approximately 2,400 kilometers, is rather undeveloped. Its average density is 0.019 kilometers per square kilometer, while that of EU is 0.067 kilometers per square kilometer(66). This is due to the country's particular morphology that is mostly mountainous and to the fact that a big part of its area is covered by sea.

OSE (ΟΣΕ in Greek; Hellenic Railways Organization), is the national railway company, operating freight and passenger trains on a network that includes lines in the Peloponnese, mainland Greece, and several parts of Macedonia and Thrace.

The intercity rail network includes what is possibly the longest metric gauge railway system still in operation in Europe, the Peloponnese network. One line runs from Athens to Corinth, where it divides into two parts encircling the northern Peloponnese. It is about 730 kilometers in length and has its terminus at Piraeus(81). Piraeus is also the southern terminus of the gauge line, which runs to Thessaloniki and then, to Constantinople through the Greek-Turkish borders. The distance from Athens to Thessaloniki is 520 kilometers(81). Figure 3.41 shows the intercity railway in Attica.

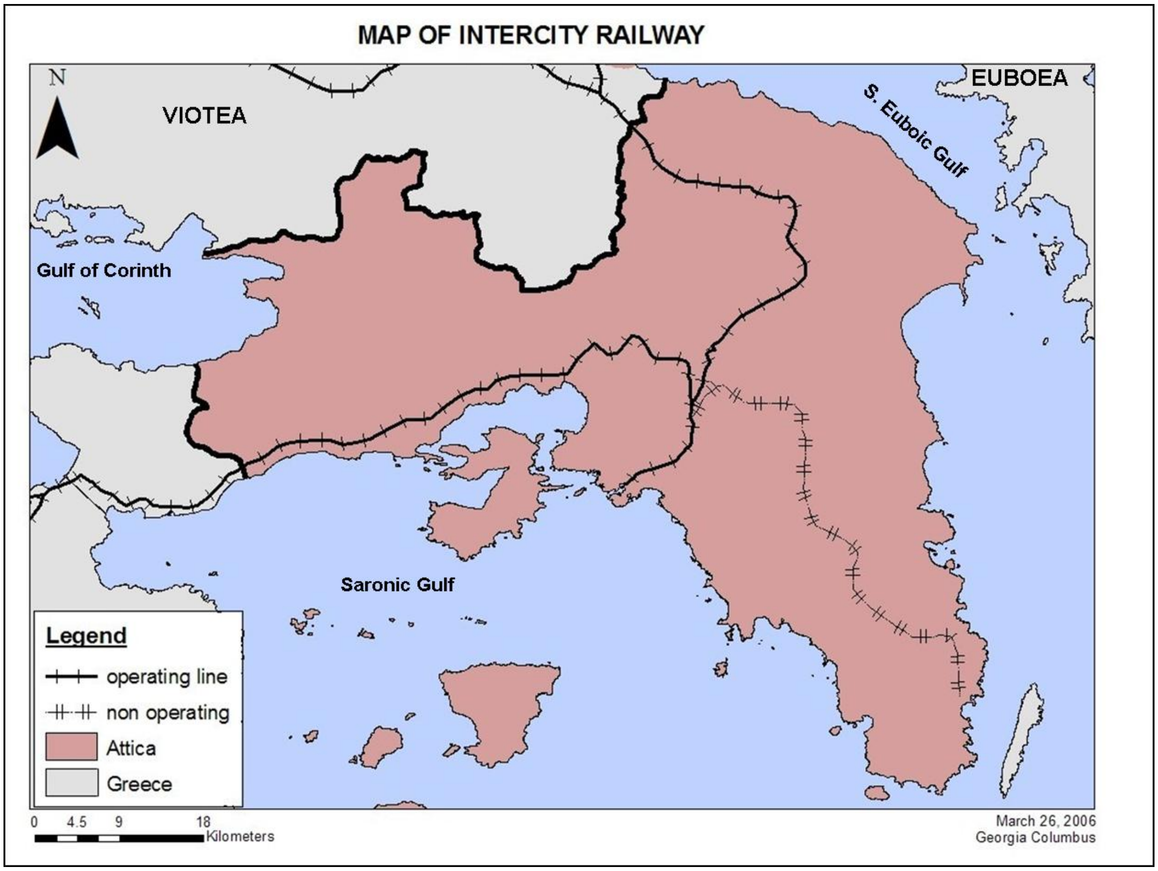


Figure 3.41 Intercity railway.

Presently, OSE is working on the modernization of the intercity railway system, which is estimated to cost $5.6 billion (€4.4 billion)(167). This project includes the construction of a station at Elefsina Plain for freight transportation, which can play an important role in the Solid Waste Management (SWM) system that will be proposed in this study.

3.2.7.2.2 *Suburban Railway*

The suburban railway system of continental Attica, which is called Proastiakos, extends from Corinth to AIA and is operated by OSE. It is connected with Attica's intercity and urban railway, as well as the Athens subway.

The route of its line was first marked out in 1994. The construction of the part towards the airport, which is parallel to Attiki Odos and has a length of almost 40 kilometers(169), was completed in 2004; while the works for the line towards Corinth finished in 2005.

Figure 3.42 Photograph of the suburban train(169).

There are plans to extend the line of the suburban railway by 2012 at a total distance of 281 kilometers. It is estimated that it will serve around 420,000 passengers per day.

3.2.7.2.3 *Urban Railway*

The urban railway is the oldest public transport mode in the city and one of the oldest in EU. It was inaugurated in 1869 as a steam train connecting Athens to Piraeus and was electrified in 1904. Today, the line is 26 kilometers long extending to the suburb of Kifissia and is operated by ISAP S.A., a subsidiary of OSE. On a daily basis, the transit serves an estimated 400,000 passengers with 233 vehicles(164). Figures 3.42 and 3.43 show Piraeus station in 1926 and 2006, respectively.

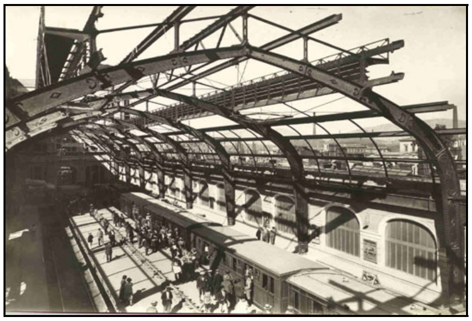


Figure 3.43 Piraeus station in 1926(151).

Figure 3.44 Piraeus station in 2006.

3.2.7.2.4 *Subway*

The subway in continental Attica, which is also called Athens Metro, is one of the most impressive systems in the world. The fact that most of the subway's stations have been decorated with works of art created by Greek artists and Greek archaeological finds discovered during its construction, render it globally unique. Figure 3.45 shows a painting, which was created by Karras C and decorates Chalandri Station, while Figure 3.46 a work of art by Tsoklis C., entitled "Underground Park", at Ethinki Amyna Station. Figure 3.47 is a photograph of a showcase of archaeological finds at Evanghelismos Station.

Figure 3.45 Chalandri subway station(106).

Figure 3.46 Ethniki Amyna subway station(106).

Figure 3.47 Evanghelismos subway station(106).

The subway's two lines are operated by Attiko Metro Operations Company S.A., and are distinguished by the colors used in the relevant maps (Blue and Red). The construction of the lines began in 1991 to decrease traffic congestion and reduce the smog level in Athens. The first sections of the subway opened in 2000. The Blue Line runs from the center of Athens (Monastiraki) to the municipality of Chalandri, while the Red Line from the municipality of Peristeri (Aghios Antonios) to that of Aghios Dimitrios.

Figure 3.48 Athens Metro train(106).

It is estimated that 580,000 passengers use the Athens Metro on a daily basis(106). The subway network has a current length of 65 kilometers and it is expected to reach 100 kilometers by 2009. Extensions to both Blue and Red lines, as well as a new line, are under construction.

3.2.7.2.5 *Tram*

There is one tram line in continental Attica, connecting the southern suburbs to the city center. The construction of the line was initiated in 2002 and operates since 2004. Currently, further extensions of the tram network are being planned.

Figures 3.49 and 3.50 are views of the tram and the tram line on the seashore, respectively. Figure 3.51 is a map showing the railway network in the metropolitan area of Athens.

Figure 3.49 View of the tram[85].

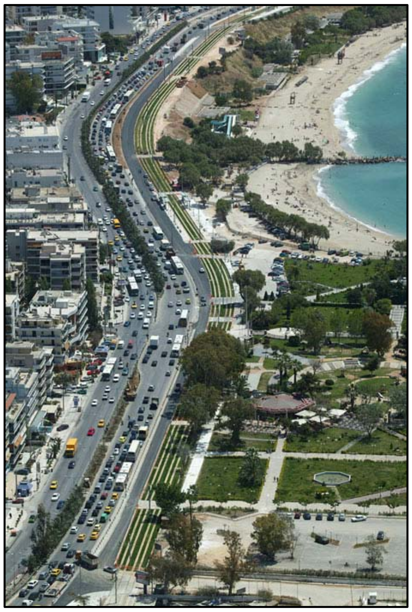


Figure 3.50 Coastal part of tram line[85].

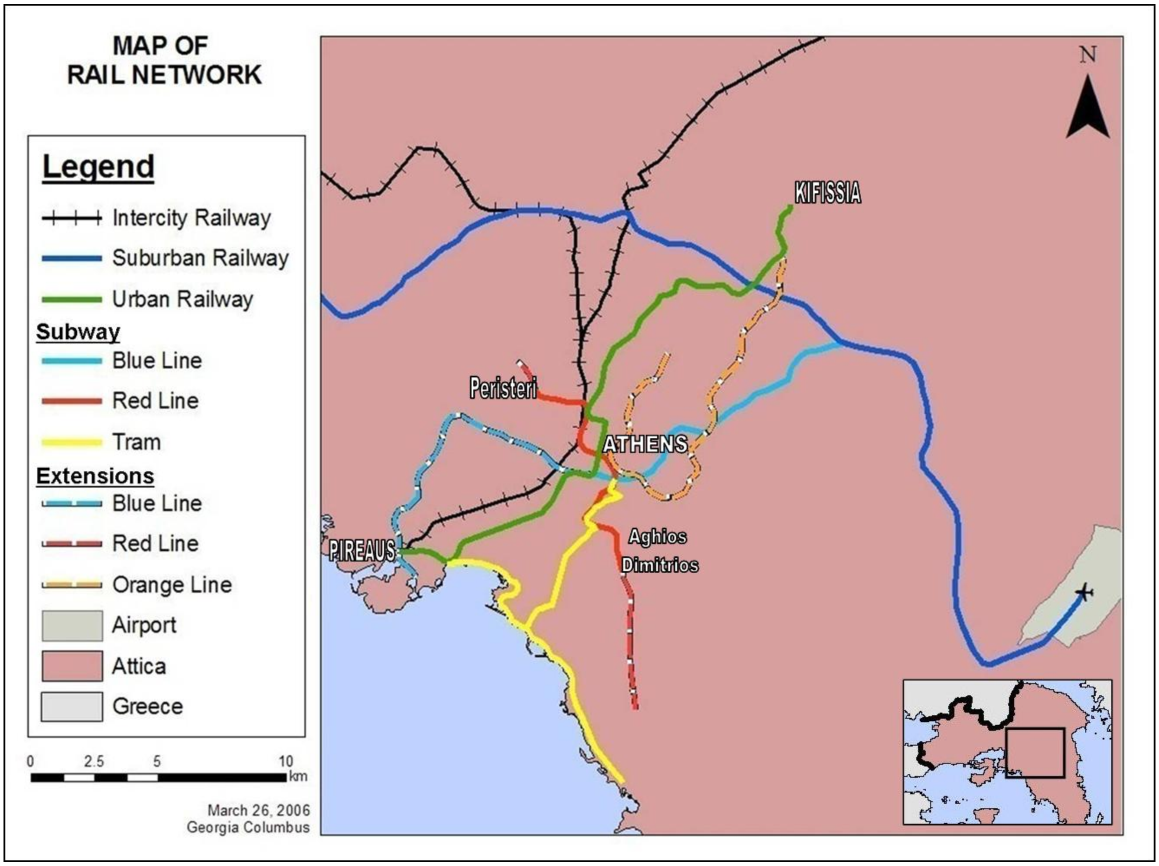


Figure 3.51 Map of railway network in Athens.

3.2.7.3 Seaports

In general, the marine transportation in Greece is highly developed, as its continental part is a peninsula. Except its northern part, Greece is surrounded by sea and has many islands.

However, the center of the Greek navigation is Attica, to which the majority of islands is connected. Its major seaports are located at the areas of Elefsina, Piraeus, Lavrio, Rafina and Oropos, as one can see in Figure 3.52.

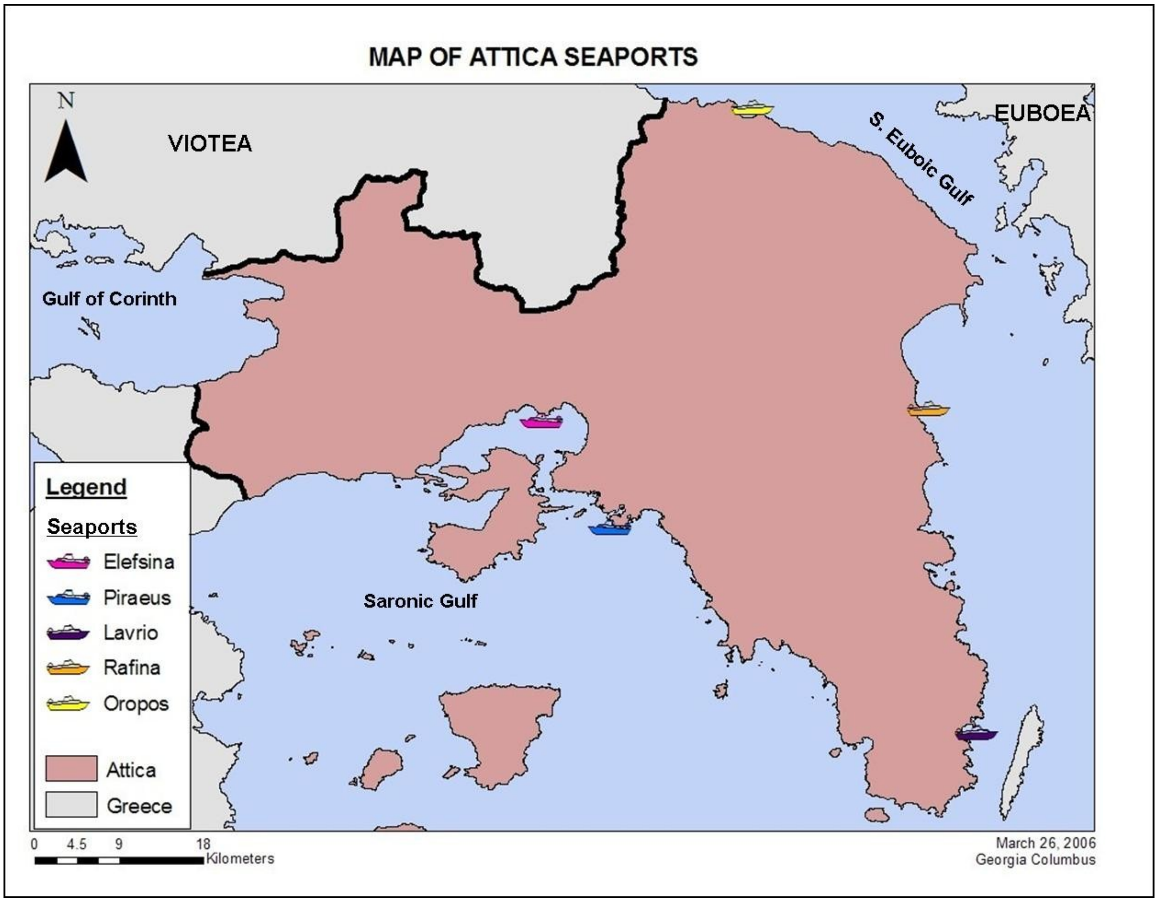


Figure 3.52 Map of seaports.

The port of Piraeus plays an essential role in the financial system of the country, as it possesses a strategic location that connects Europe, Africa and Asia. It is the biggest port of the country as far as area, commodity trading, and passenger transportation is concerned. The port is divided in three sections(166):

- The ***Container terminal***, which operates within a short distance from the center of Piraeus and occupies an area of 900,000 square meters. There are open-air storage areas, one container freight station of 19,200 square meters and a workshop of 5,800 square meters for the maintenance and repair of the handling equipment. The depth in that area ranges from 11.5 to 16 meters.

- The ***Passenger port***, which is divided in the area designated for the coastal shipping and that for the reception of cruise ships. It serves 72% of Greece's total passenger marine transportation(143), receiving an average of 20.3 million passengers annually. This renders Piraeus the biggest passenger seaport in the Mediterranean region and the third biggest worldwide.

Figure 3.53 View of the container terminal(166).

Figure 3.54 View of the passenger port(166).

- The ***Shipyard area*** that has the ability to host ships with capacities ranging from 12,000 to 40,000 registered tons.

Figure 3.55 Floating dock of the ship repair zone(166).

Tables 3.4 and 3.5 present information for years 2002, 2003 and 2004 on the passenger and cargo traffic at Piraeus, correspondingly.

Table 3.4 Passenger traffic at port Piraeus(166).

Years	2002	2003	2004
Domestic			
Coastal Shipping	7,593,359	8,008,139	7,554,200
Argosaronicos	3,532,414	3,705,130	3,605,074
Overseas			
Liner	50,122	46,104	95,195
Cruise	152,433	127,777	153,089
Transit	469,528	649,458	509,268
Ferry	8,168,496	8,397,292	8,339,053
TOTAL	**19,966,352**	**20,933,900**	**20,255,879**

Table 3.5 Cargo traffic at port Piraeus(166).

Years	2002	2003	2004
Domestic			
General Cargo	3,257,663	3,968,560	4,283,550
Bulk Cargo	761,760	801,250	303,749
Overseas			
General Cargo	13,990,955	16,209,747	15,724,084
Bulk Cargo	413,802	445,821	275,382
TOTAL	**18,424,180**	**21,425,378**	**20,586,765**

3.2.7.4 Airports

Currently, there are four operating airports in continental Attica (Figure 3.56); one civil, AIA at the municipality of Spata, and three military, located at the areas of Megara, Elefsina and Tatoi.

As shown in Figure 3.56, two more airports used to operate in continental Attica: The first was Marathon Airport, a general aviation airfield, which was closed in 2000. The other was the former Athens' International Airport at the municipality of Ellinico that ceased operation in 2002(113) in order to initiate the appropriate actions for its transformation into a recreational park.

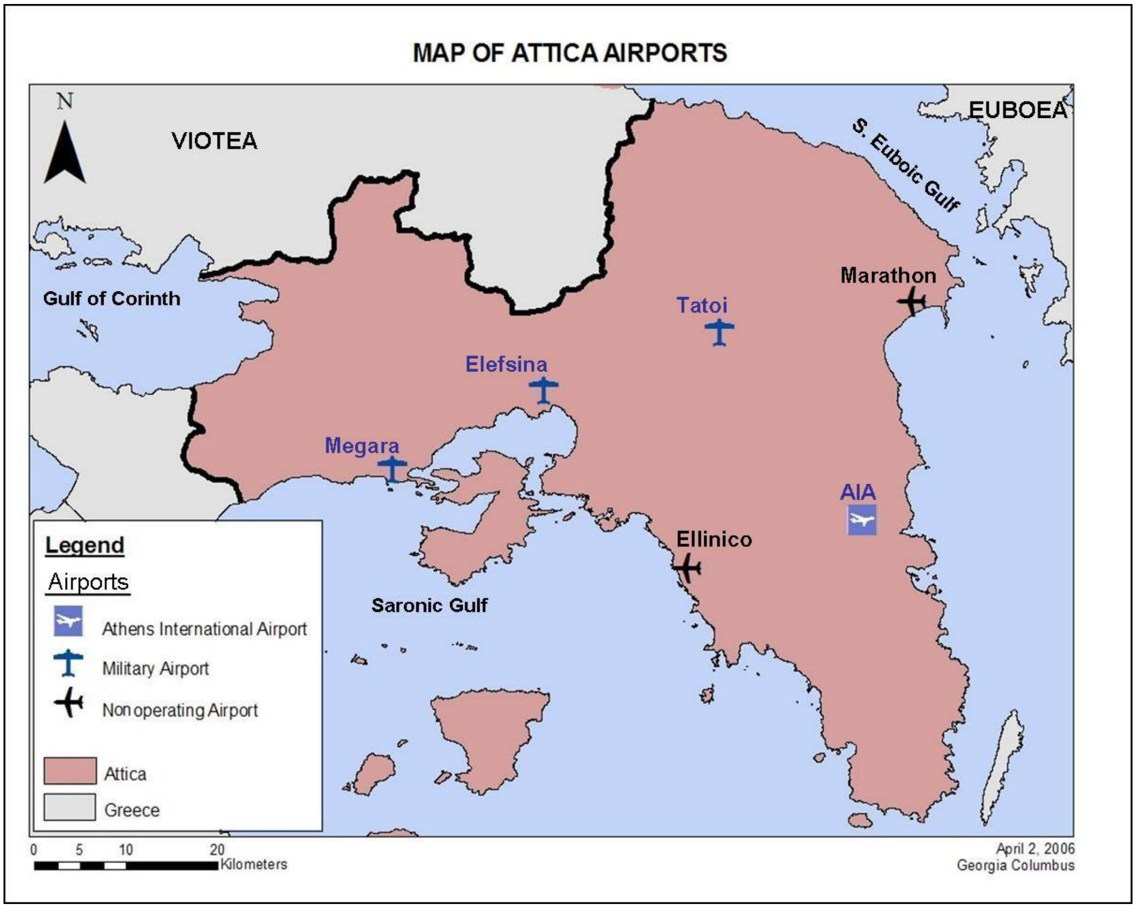


Figure 3.56 Map of Attica airports.

AIA began operation in 2001, replacing Ellinikon International Airport. In 2004, it was honored as "The European Airport of the Year" within the framework of the annual Institute of Transport Management Awards, for its innovative entrepreneurial scheme, as well as its successful operation and achievements.

Figure 3.57 View of AIA(86).

AIA is located about 20 kilometers east of Athens, at Spata, occupies an area of 17.5 square kilometers and its two runways are approximately 4 kilometers in length(105). In 2005, the airport served approximately 14.3 million passengers. Table 3.6 presents the number of passengers and flights of AIA from 2002 – 2005.

Table 3.6 Statistical data of AIA(105).

Years	2002	2003	2004	2005
Passengers				
Domestic	4,142,353	4,365,258	5,109,136	5,169,049
International	7,685,155	7,887,136	8,553,196	9,111,971
TOTAL	**11,827,508**	**12,252,394**	**13,662,332**	**14,281,020**
Flights				
Domestic	79,858	83,573	92,499	88,031
International	79,609	86,557	98,549	92,905
TOTAL	**159,467**	**170,130**	**191,048**	**180,936**

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)(163) 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 ration 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(40).

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 where 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(158).

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 “Packages 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(84), 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.

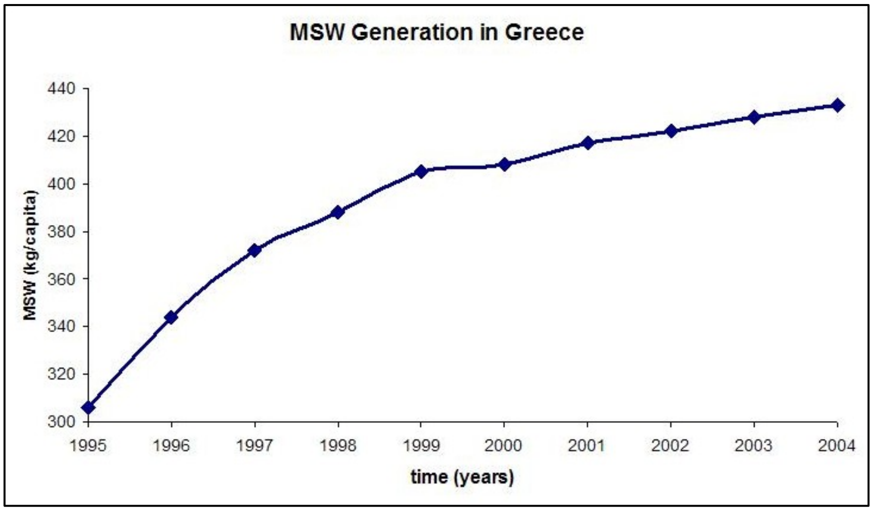


Figure 4.1 Generation rates of MSW per capita in Greece (based on Reference 84).

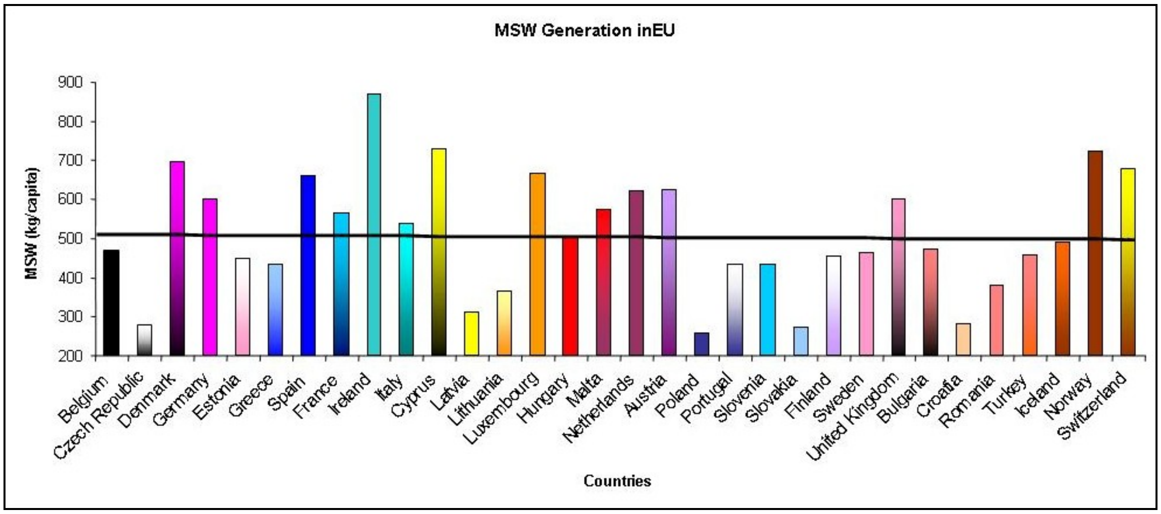


Figure 4.2 Generation rates of MSW per capita in EU for 2003 (based on Reference 84)**.**

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.

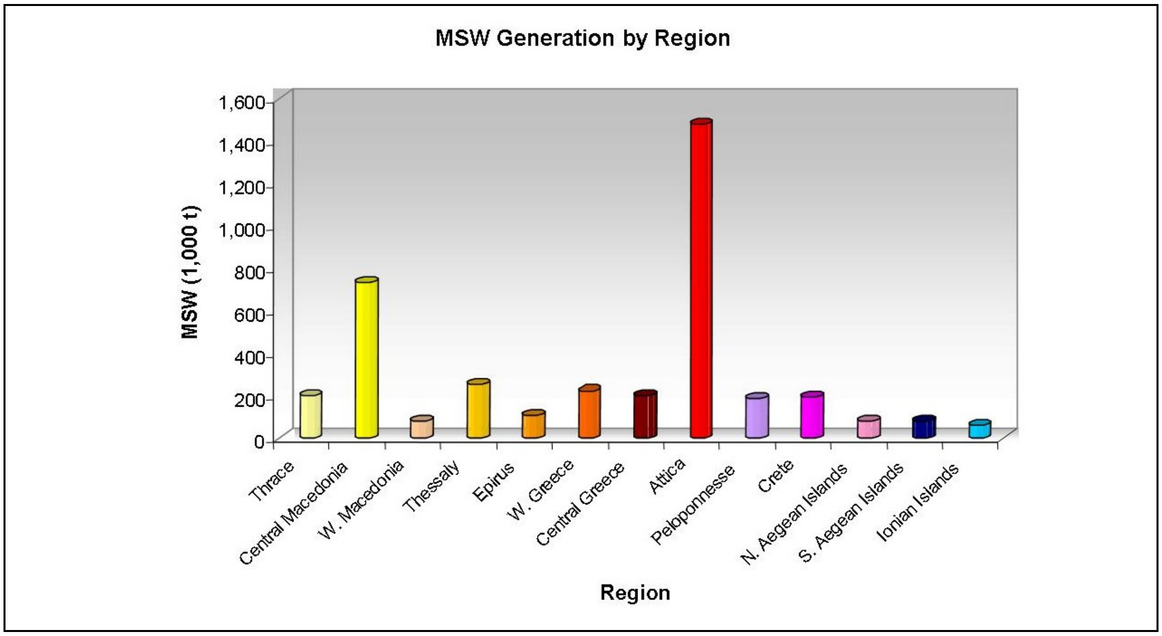


Figure 4.3 MSW generation in the Greek Regions in 1997(62)**.**

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(29)	1990(29)	1995(29)	1996(29)	1997(51)	2003(45)
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

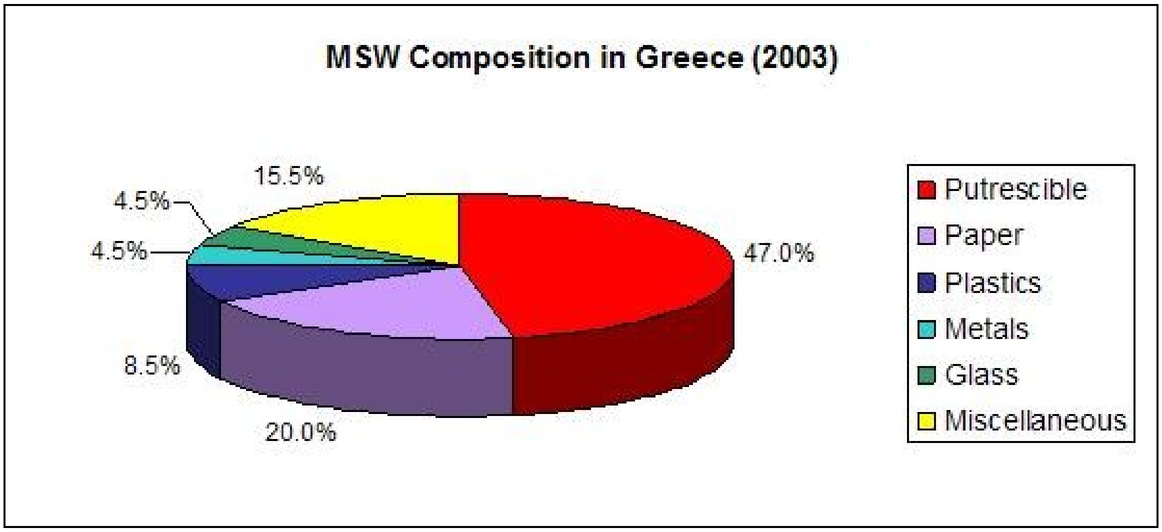


Figure 4.4 Greek MSW composition in 2003.

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(29)	56.0	20.0	7.0	3.0	2.5	4.0	7.5
Thessaloniki(43)	52.0	18.0	7.0	5.0	4.0	8.0	6.0
Patras(36)	56.3	19.3	12.2	3.3	3.0	n/a*	5.9
Rhodes(43)	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(43) (Crete)	55.0	19.0	8.0	4.0	4.0	4.0	6.0
Kos(43)	37.0	25.0	11.0	5.0	12.0	5.0	5.0
Calamata(43)	47.0	25.0	7.5	3.5	3.0	6.0	8.0
Naxos(43)	48.0	22.0	9.0	3.0	6.0	5.0	7.0
Xanthi(74)	61.2	15.1	7.1	3.2	2.1	n/a	11.3
Comotini(17)	67.0	9.0	6.0	3.0	2.0	n/a	13.0
Carpenisi(139)	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(69).

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(84).

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
Greece	**51.00**	**18.00**	**10.00**	**3.00**	**3.00**	**4.00**	**11.00**
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(51).

Types of wastes	C (%)	H (%)	O (%)	N (%)	Cl (%)	S (%)	H_2O (%)	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(42)	Greece(51)
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(20) recorded waste disposal sites all over Greece, of which only 30% were controlled in some way.

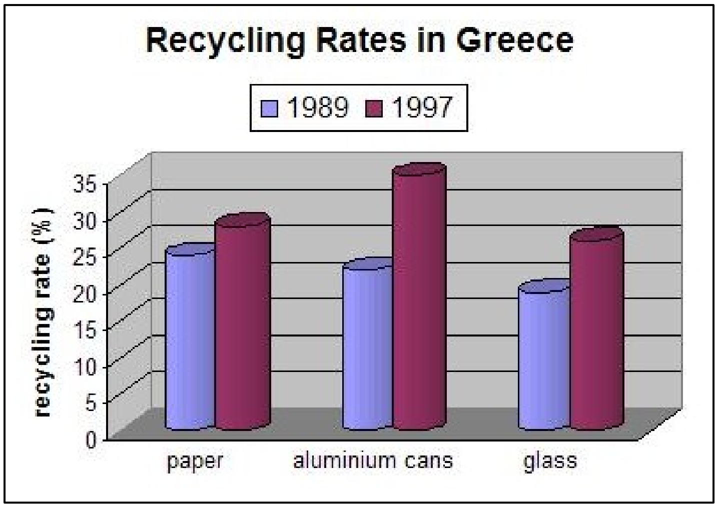


Figure 4.5 Recycling rates in Greece in 1989 and 1997(62).

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.

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(134):

- 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(37).

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
TOTAL	**934,500**	**311,100**	**33.29**	**974,500**	**325,300**	**33.38**

Moreover, the percentage of waste discarded at sanitary landfills increased to 51% and many UWDSs were closed, reaching the number of 2,180(40) 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(79). The number of UWDSs has been reduced to 1,300(111). 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(18).

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(134).

Table 4.8 Budget for SWM – OEP (134).

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
TOTAL	**10,614,500**	**8,165,000**	**7,430,150**	**5,715,500**	**3,184,350**	**2,449,500**

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.

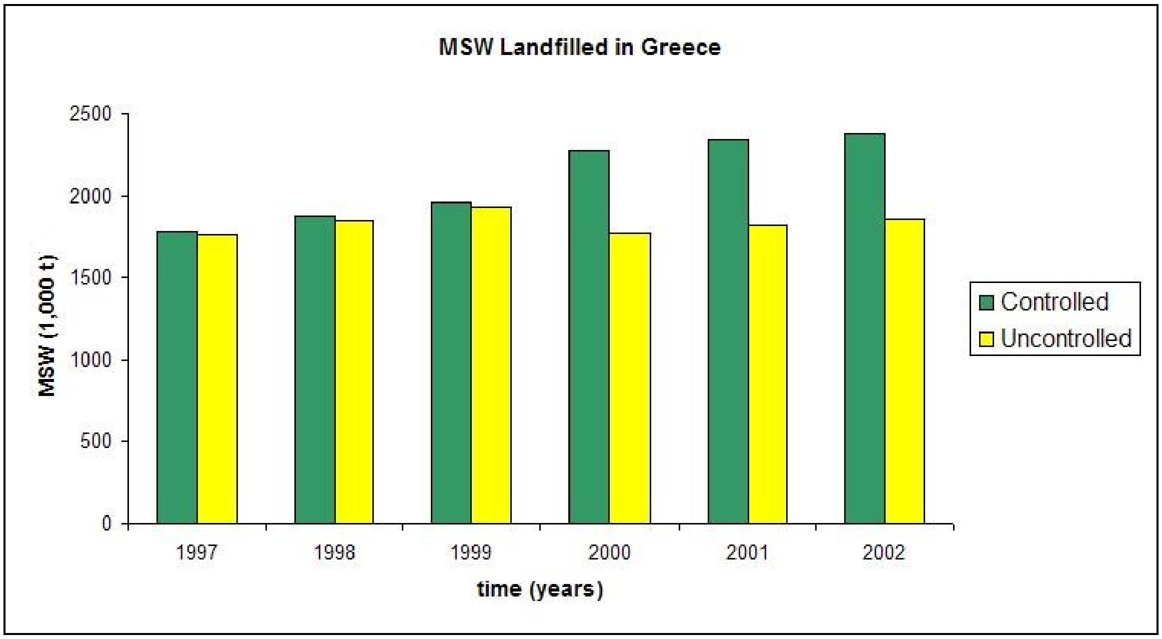


Figure 4.6 Quantities of waste landfilled (based on Reference 84)**.**

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 (CH_4) and greenhouse-gas emissions from waste landfilled in the period 1997 – 2002.

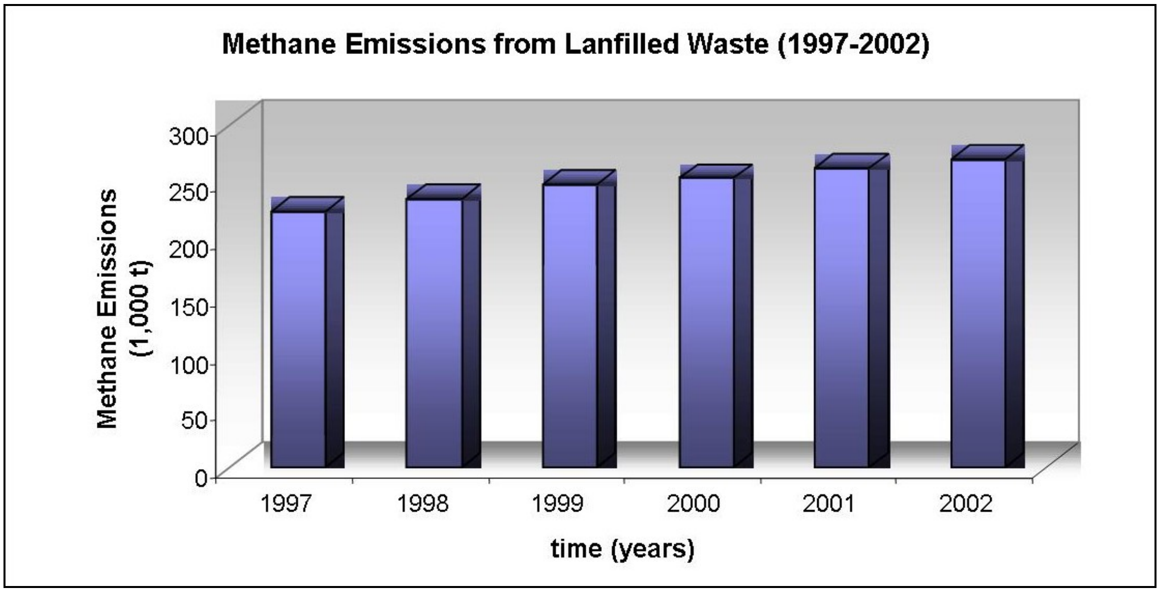


Figure 4.7 Methane emissions from waste disposal sites (based on Reference 84).

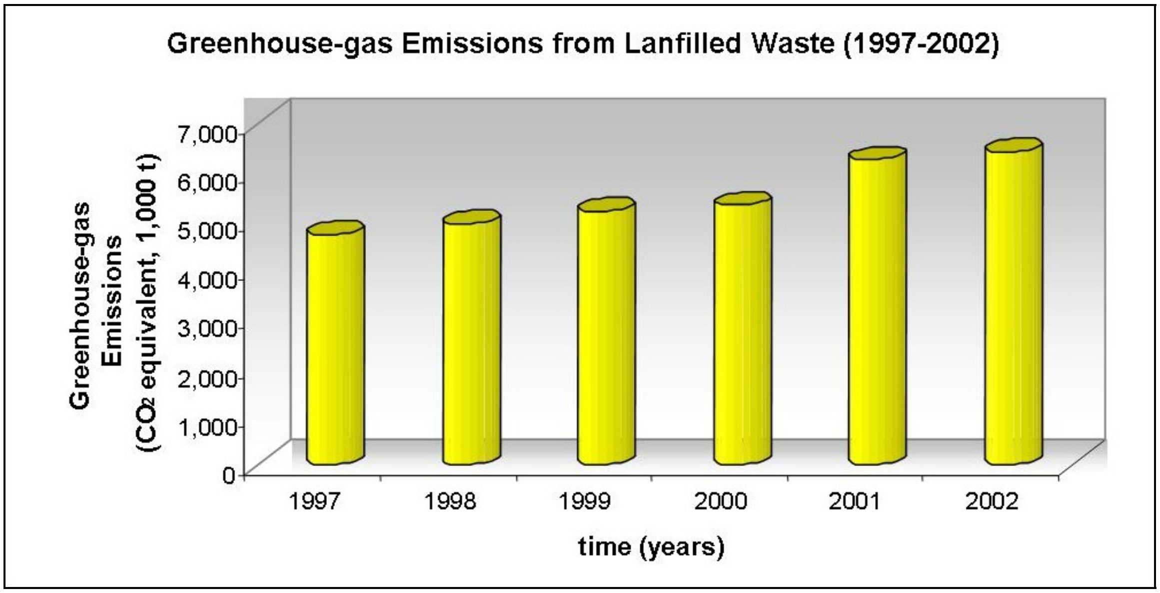


Figure 4.8 Greenhouse-gas emissions from waste disposal sites (based on Reference 84).

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^2)
2000	735	5,291
2001	703	5,098

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

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

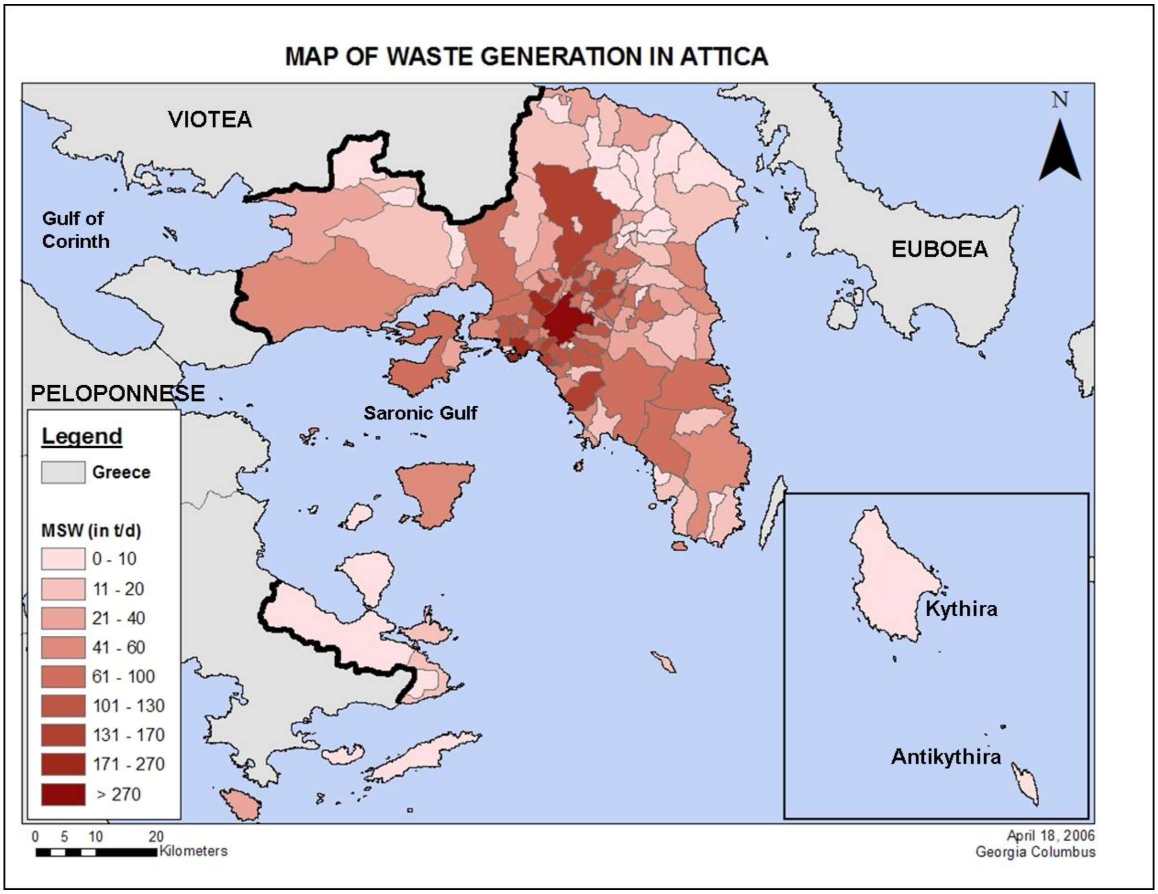


Figure 4.9 Distribution of daily waste generation in Attica Region.

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).

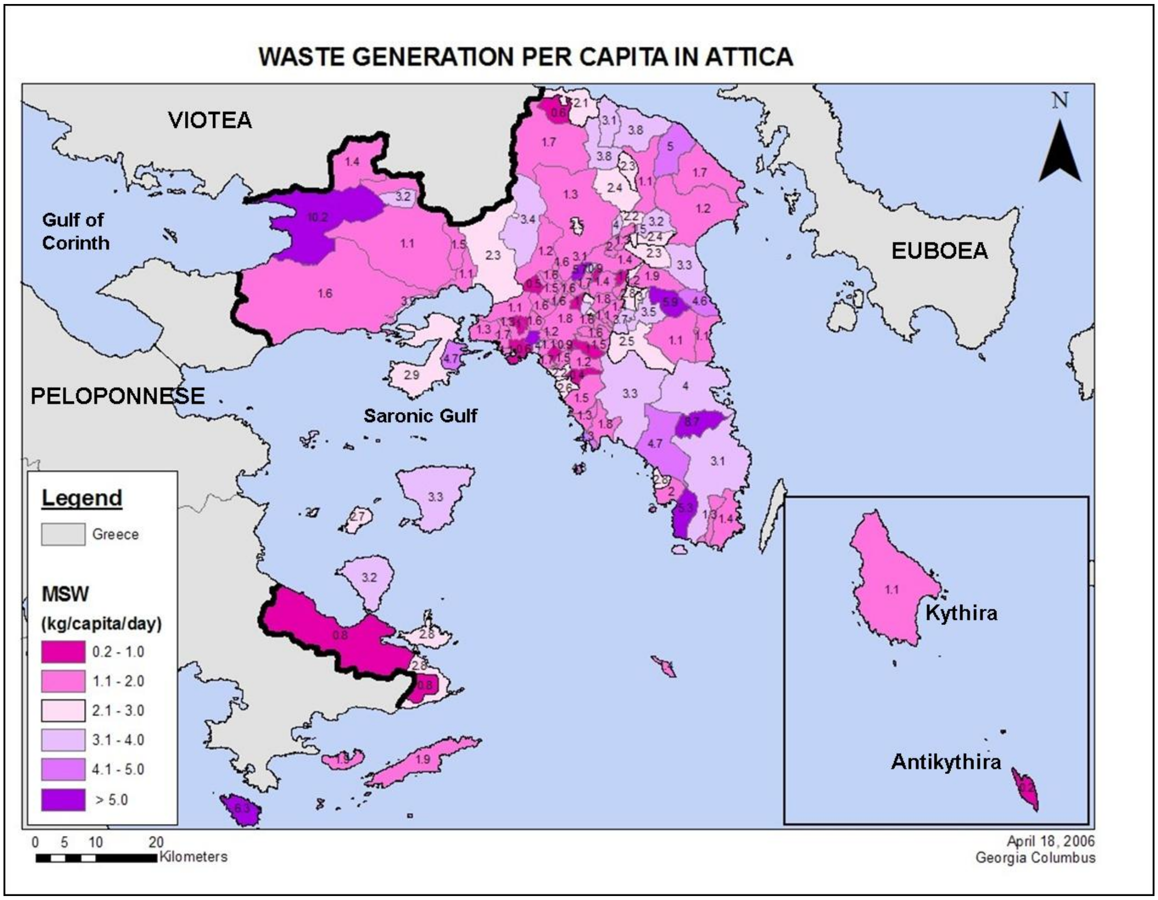


Figure 4.10 Waste generation rates per capita in Attica Region.

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(52).

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					

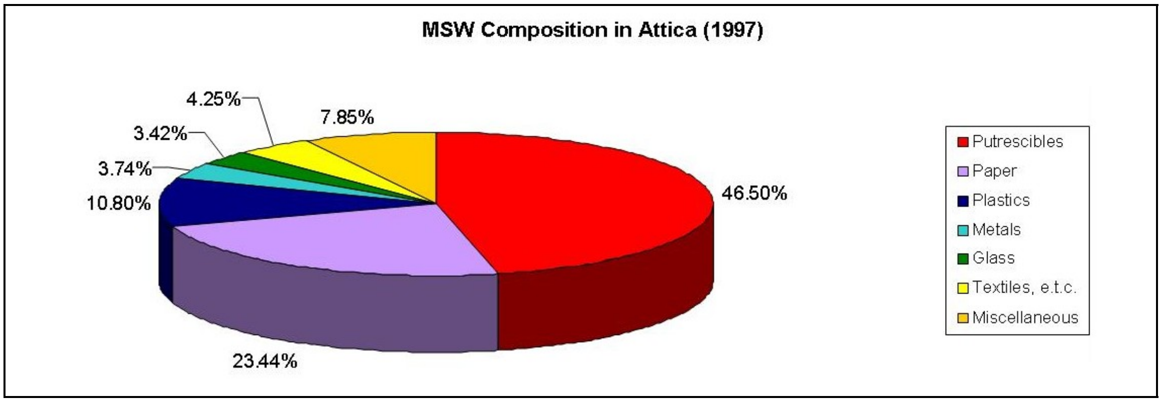


Figure 4.11 MSW composition in Attica in 1997(52).

Table 4.11 presents the composition of MSW at certain representative OLAs of Attica, their weighing coefficients (φ) 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
φ = 8.85	4.279	1.972	0.856	0.367	0.325	0.383	0.663
Aghios Ioannis Rendis	60	15	5	n/a[#]	1	10	9
φ = 1.11	0.666	0.167	0.056	-	0.011	0.111	0.100
Alimos	40	20	15	5	5	5	10
φ = 3.41	1.362	0.681	0.511	0.170	0.170	0.170	0.341
Ambelakia	50	10	20	5	5	5	5
φ = 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
φ = 0.43	0.415	0.004	-	0.004	-	-	0.004
Anixi	48.5	22	10.5	4.2	3.5	n/a	11.3
φ = 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
φ = 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
φ = 0.44	0.265	0.088	-	-	-	0.022	0.066
Galatsi	80	5	n/a	5	n/a	n/a	10
φ = 5.90	4.718	0.295	-	0.295	-	-	0.590
Hydra	25	20	20	20	10	5	0
φ = 0.19	0.048	0.038	0.038	0.038	0.019	0.010	0
Ilion	30	15	10	5	5	30	5
φ = 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
φ = 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
φ = 0.29	0.144	0.029	0.057	0.014	0.014	0.029	0
Metamorphosi	50	10	5	5	2	20	8
φ = 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
φ = 0.75	0.349	0.173	0.082	0.034	0.025	0.031	0.050
Nickaea	47	21	12	12	4	3.5	0.5
φ = 6.86	3.222	1.440	0.823	0.823	0.274	0.240	0.034
Varnava	80	2	2	2	2	2	10
φ = 0.15	0.118	0.003	0.003	0.003	0.003	0.003	0.015
ATTICA	**44.06**	**25.66**	**11.34**	**4.45**	**2.88**	**3.76**	**7.84**

[*] 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.

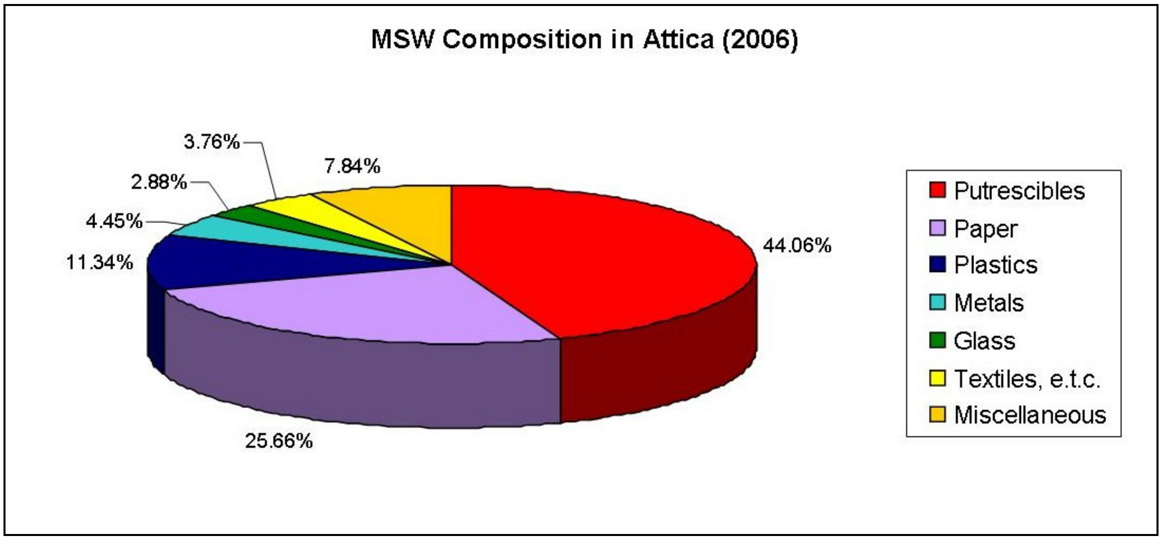


Figure 4.12 MSW composition in Attica in 2006.

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.

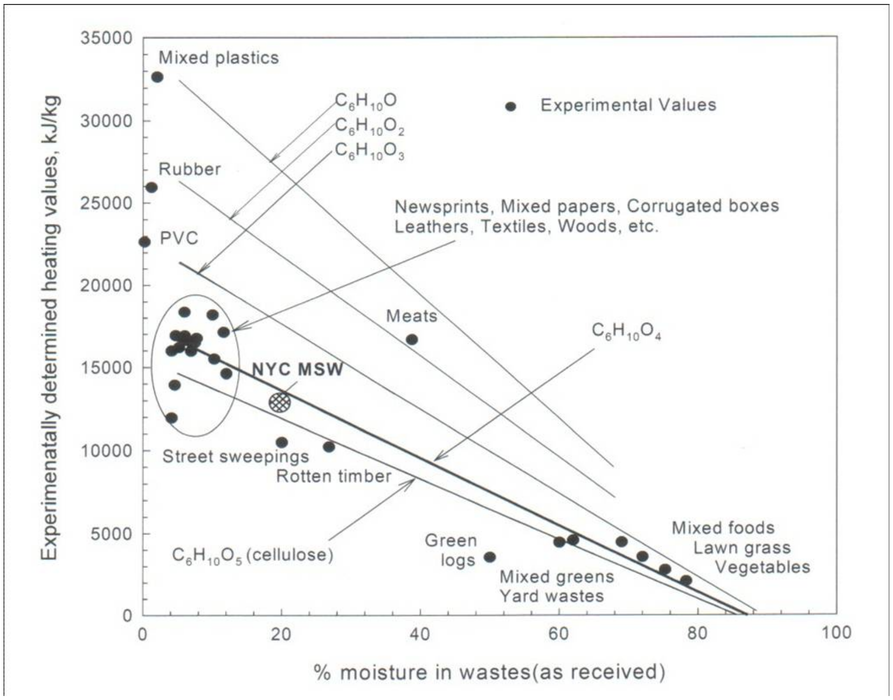
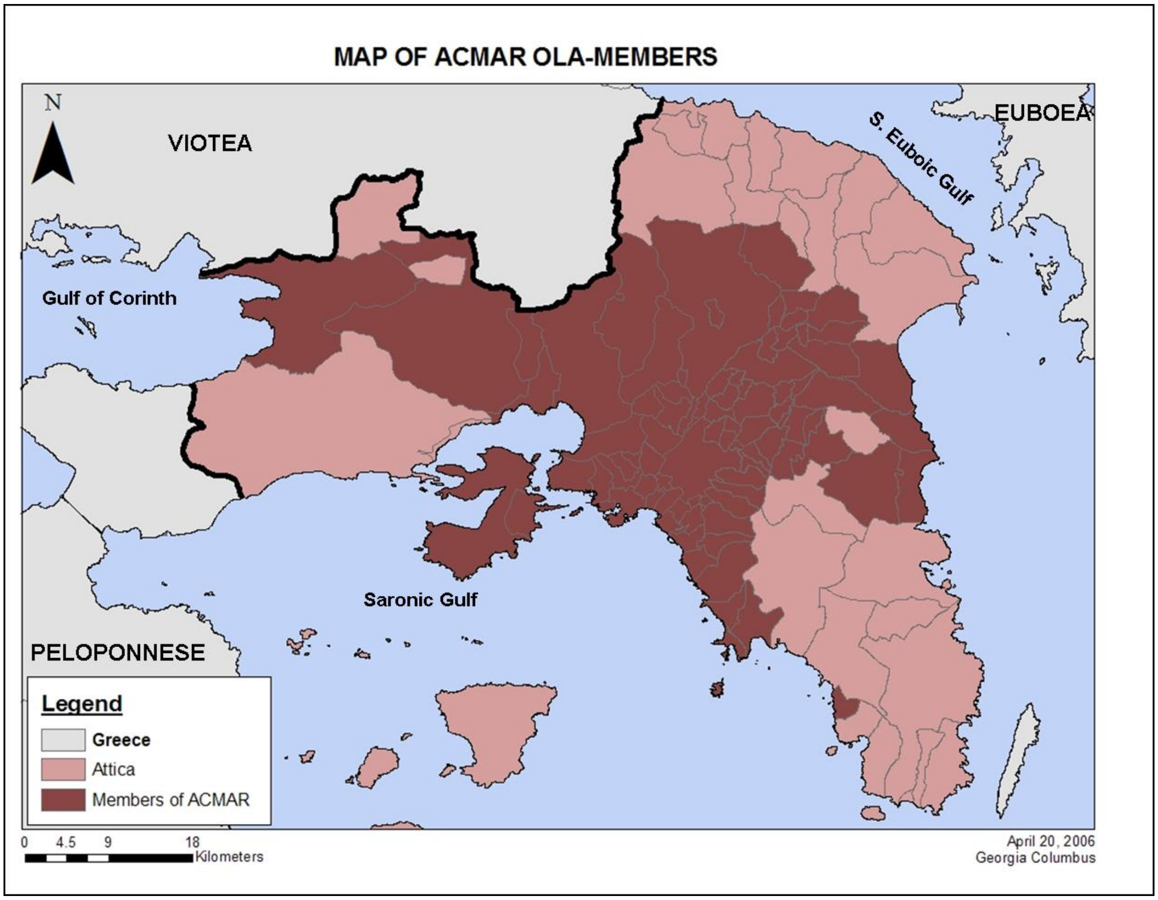


Figure 4.13 Comparison of experimental heating values of various waste materials (Hollander, Tchobanoglous, 1980). Lines show thermochemical values for respective $C_6H_{10}O_x$ materials$^{(60)}$**.**

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.



April 20, 2006
Georgia Columbus

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 (€97.3 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)(134). 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 metallic or plastic and have a capacity ranging from 0.66 to 1.10 cubic meters.

Figure 4.15 Metallic bin.

Figure 4.16 Plastic bin(147).

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.

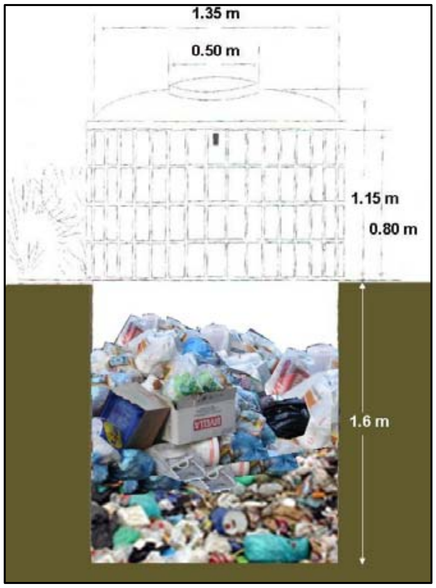


Figure 4.17 Underground Container (based on Reference 55).

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(55).

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.

(a) (b)

(c)(5) (d)(153) (e)(153)

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.

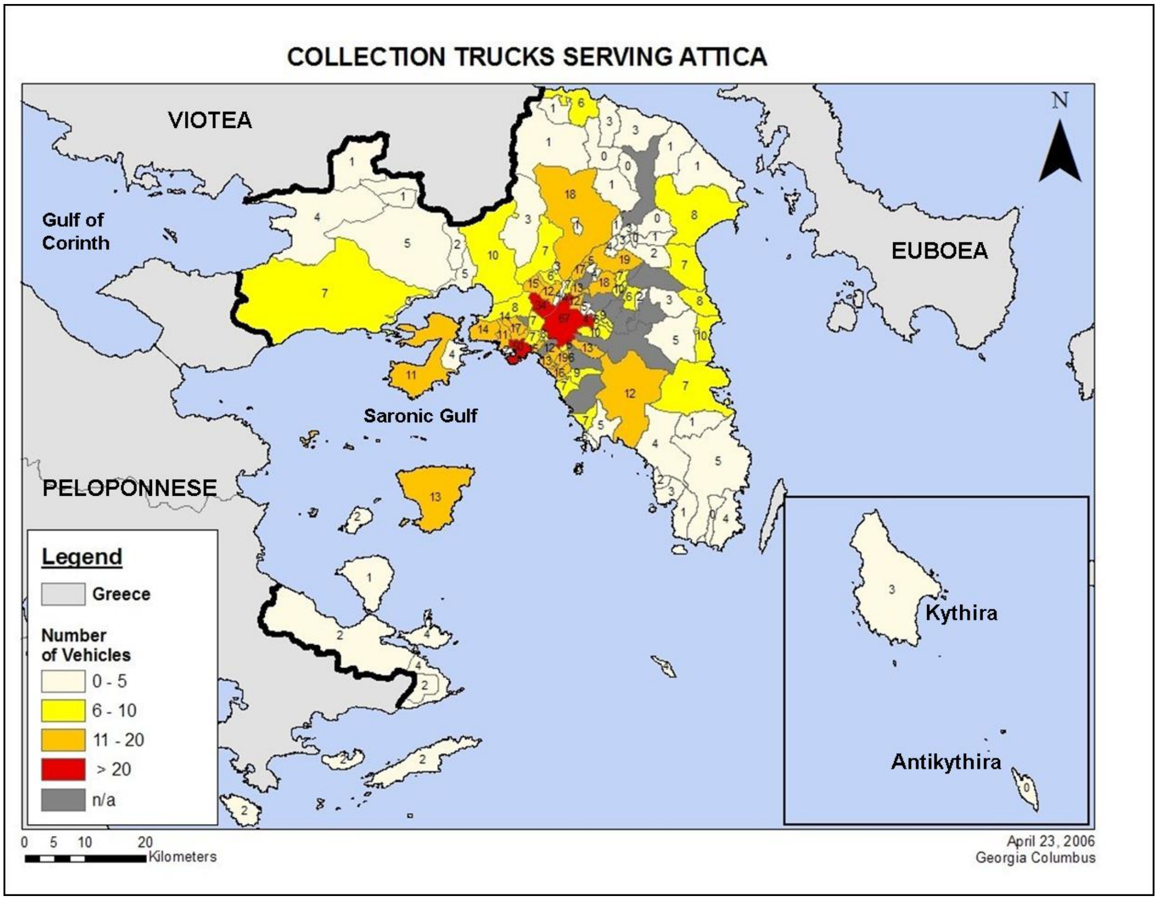


Figure 4.19 Number of collection trucks serving each OLA.

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(111).

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.

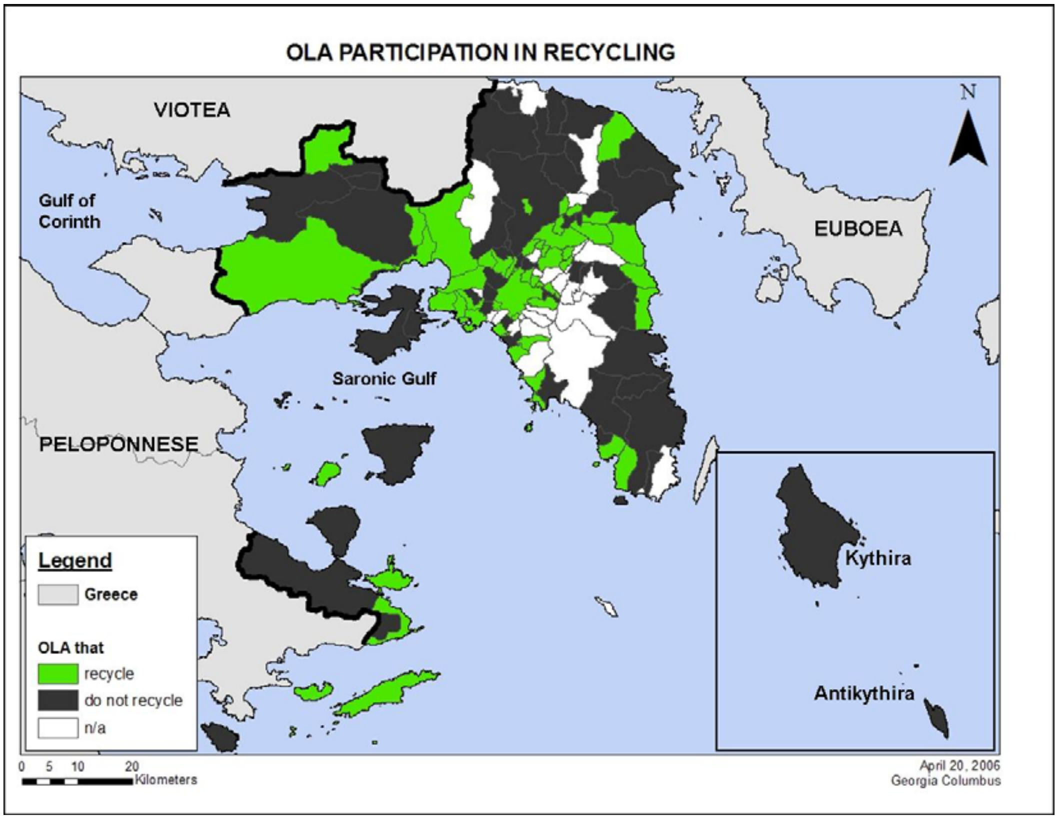


Figure 4.21 Map of OLAs that participate in recycling.

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(136).

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(154). 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(154).

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(178).

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.

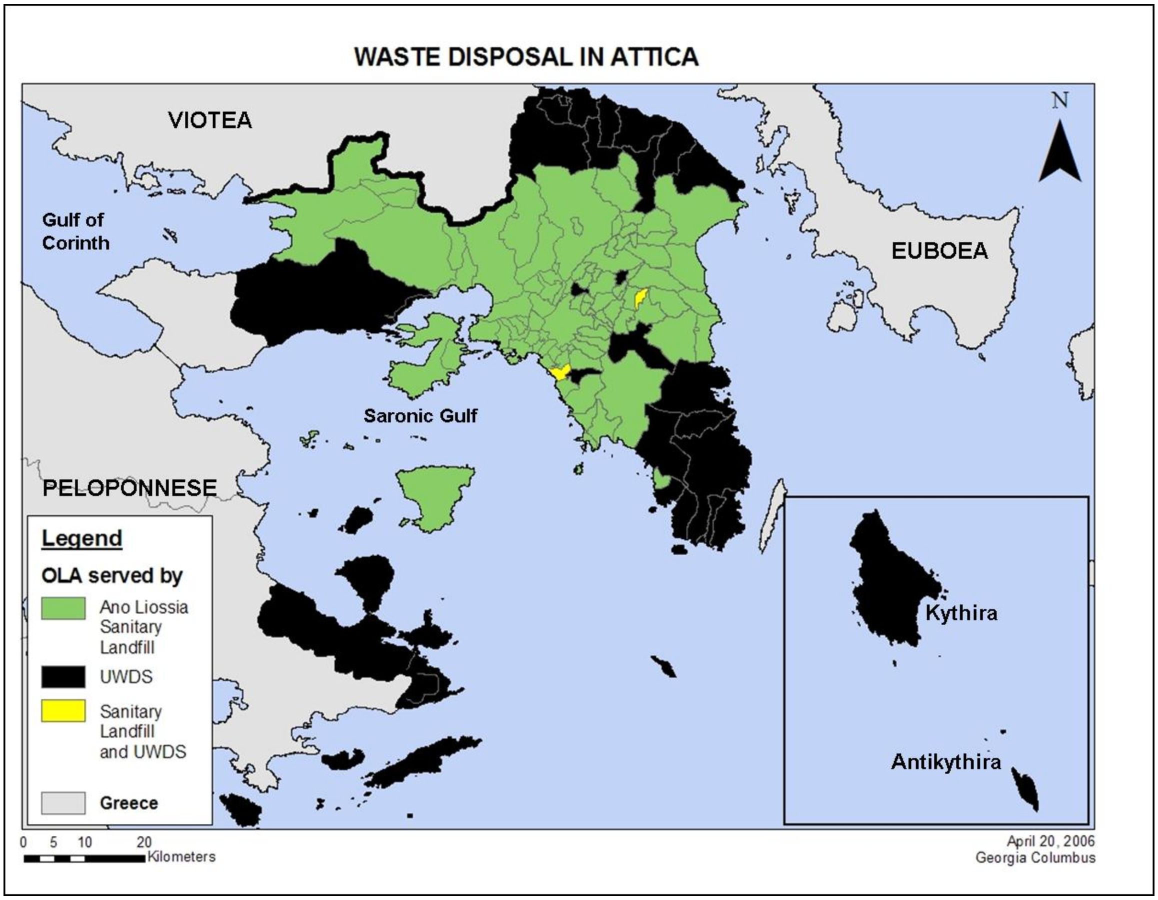


Figure 4.26 Map of OLAs served by waste disposal sites.

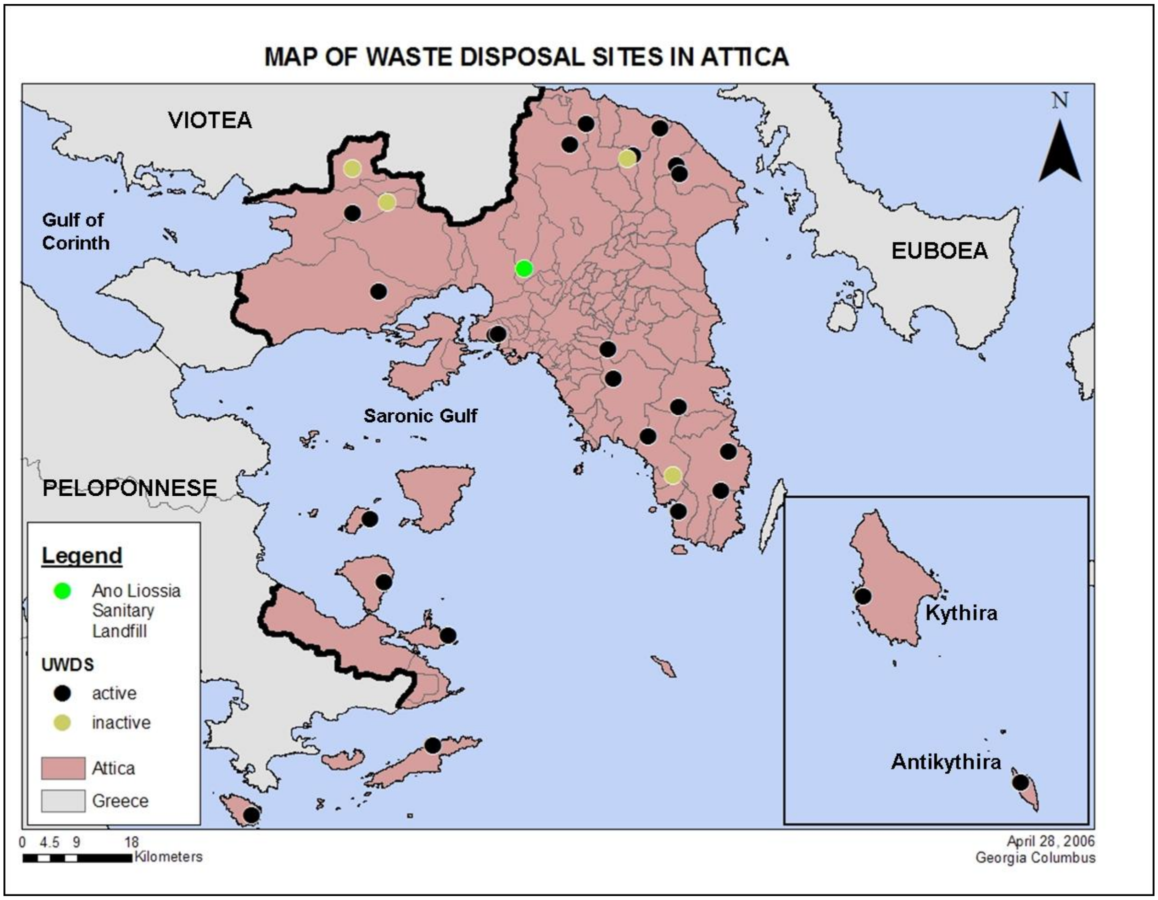


Figure 4.27 Map of waste disposal sites in Attica Region (based on Reference 45)**.**

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

4.5 EXISTING WASTE MANAGEMENT FACILITITES 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; KEΔKE in Greek). Some of the other large shareholders are(28):

- 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, Vrilissia, 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.

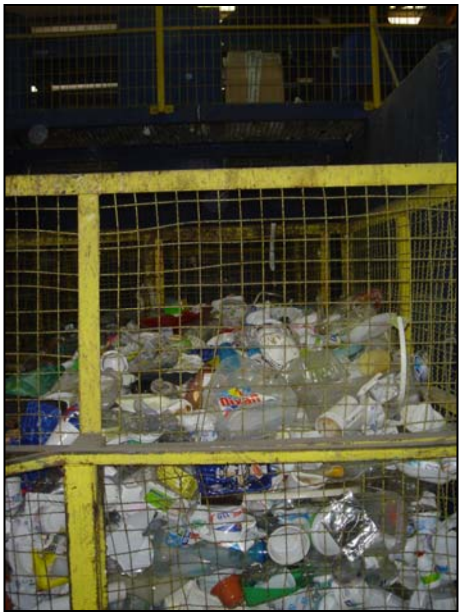


Figure 4.30 Container for mixed plastic.

Figure 4.31 Container for mixed paper.

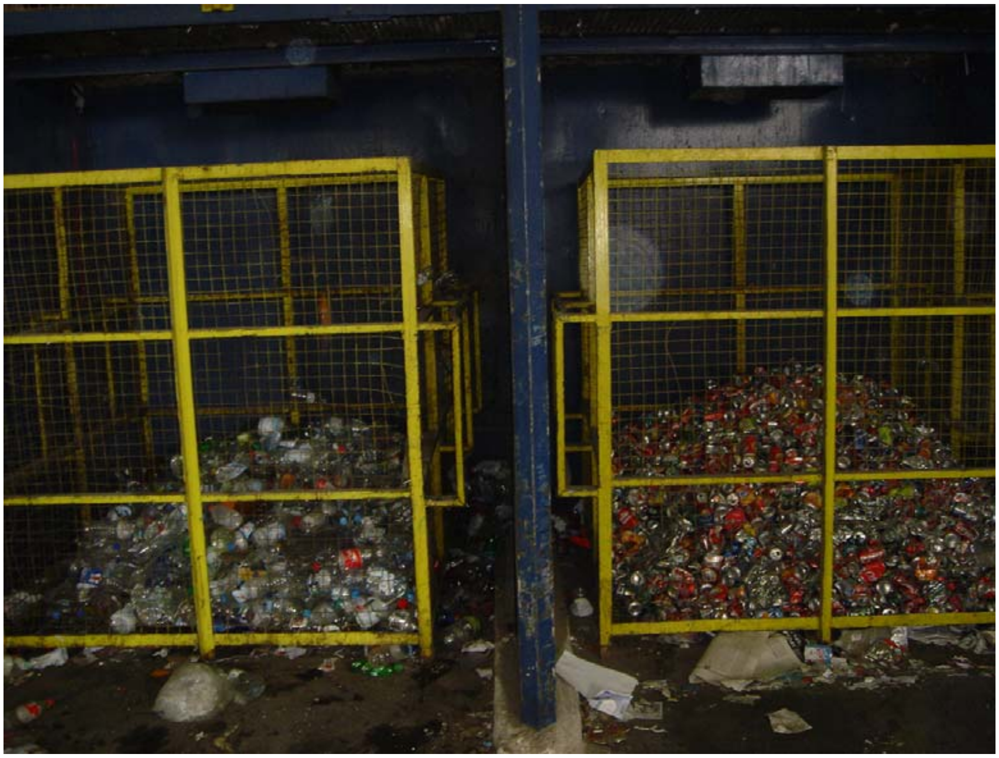


Figure 4.32 Containers for plastic bottles and aluminum cans.

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(128). 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(128).

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 (€56 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)(29).

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(136) 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.

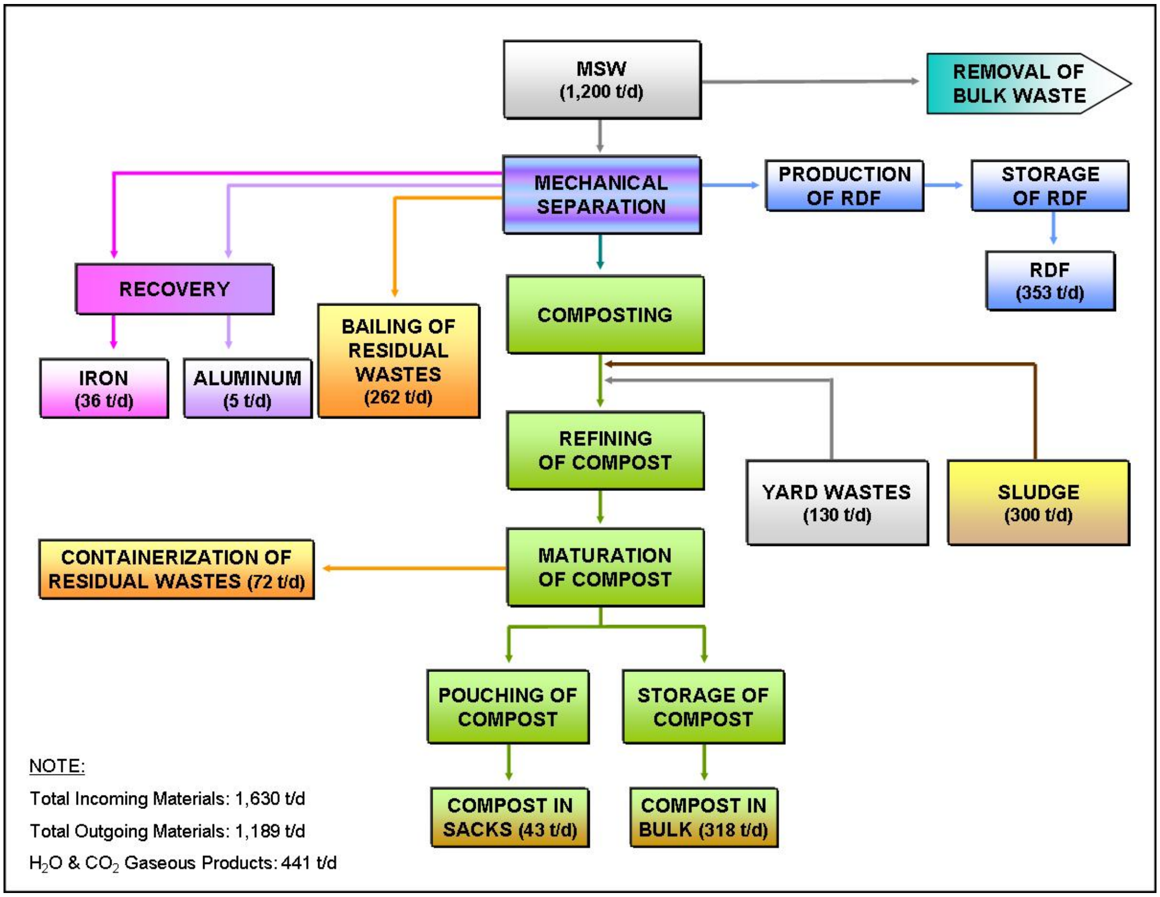


Figure 4.41 Schematic process diagram of MRCF (based on Reference 52)**.**

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(21).

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(21).

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 bailing 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$^{(21)}$**.**

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(21).

Figure 4.46 Channels in the composting unit(21).

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.

(a)(136) (b)(176)

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 (€9.3 million)(132). 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(6).

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(6).

Figure 4.49 Rotary kiln of the MWI(21).

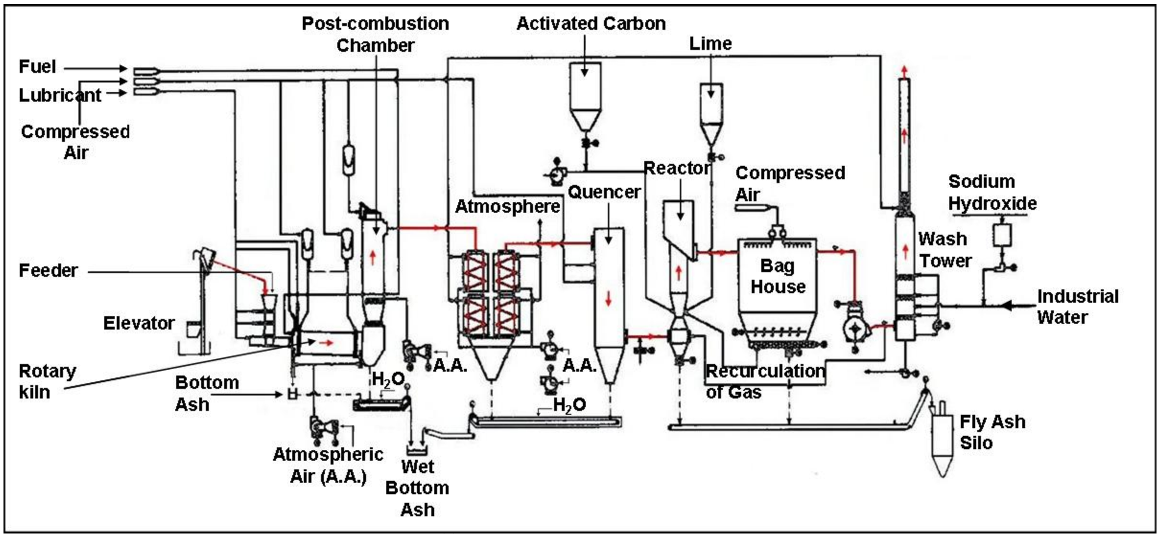


Figure 4.50 Flow diagram of the MWI(6).

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(6):

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 ($Ca(OH)_2$) injection takes place at about the same temperature. In each module, 16 kilograms of lime ($Ca(OH)_2$) per hour are injected, which is equivalent to approximately 30 kilograms of lime ($Ca(OH)_2$) 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 (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x), 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

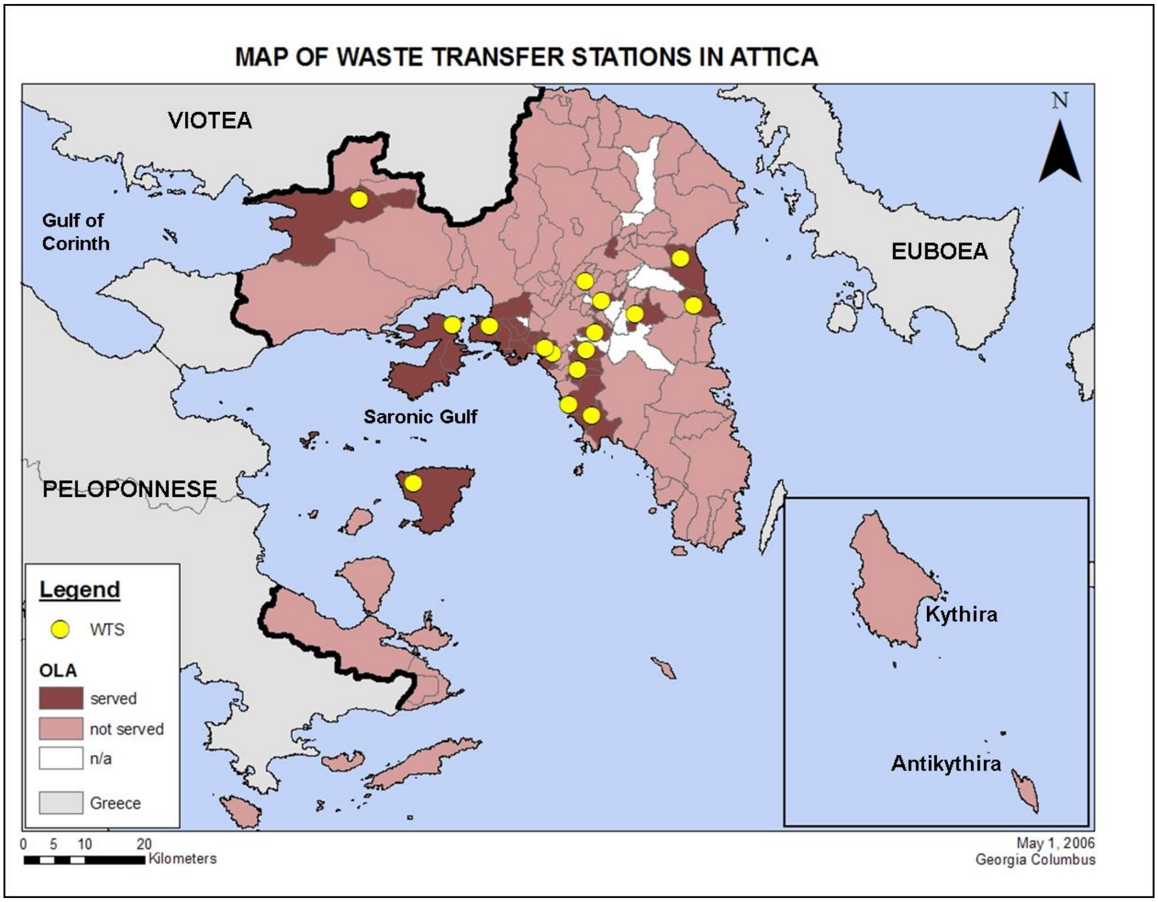


Figure 4.51 Map of WTSs in Attica.

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(136), serving 11 OLAs of the Region of Attica.

(a)(77) (b)(136)

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(136).

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(8). 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(34). 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(29).

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 (€2) 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(21).

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(27):

- 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.

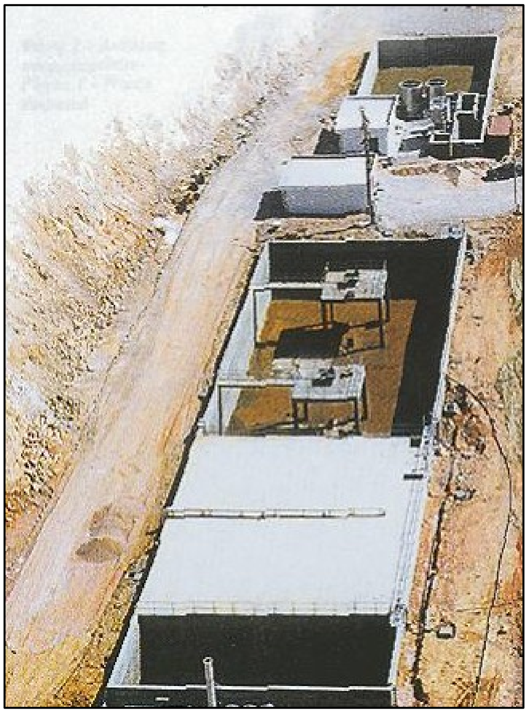


Figure 4.55 View of the LTP(136).

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.

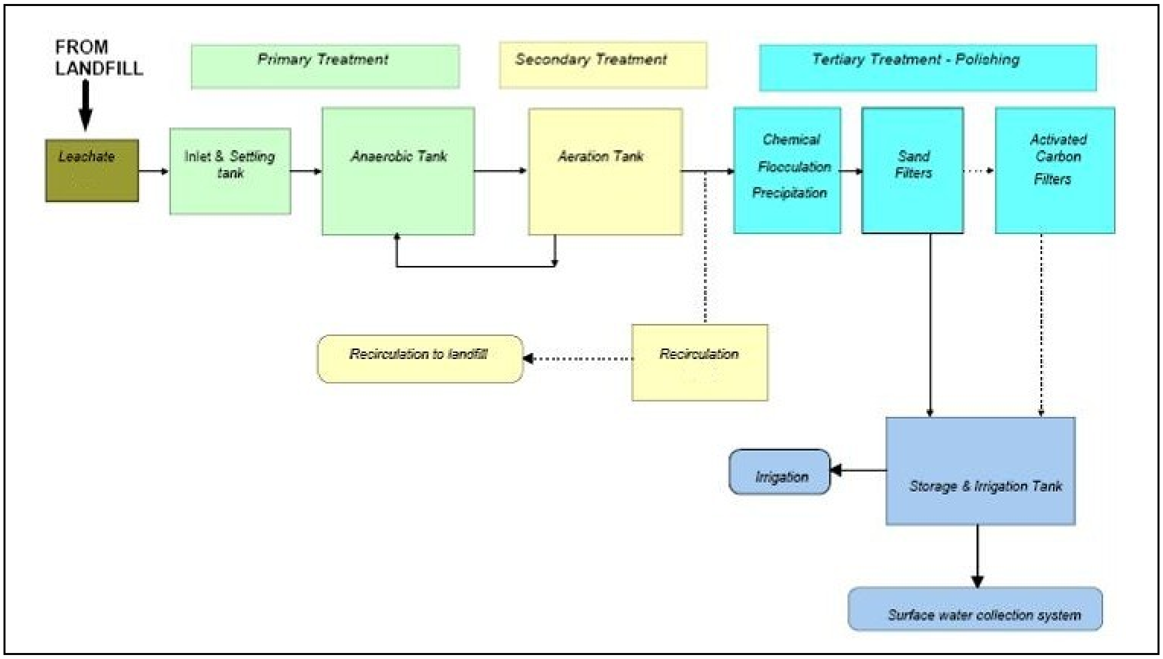


Figure 4.56 Schematic process diagram of LTP(27).

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_4) and carbon dioxide (~ 44% CO_2); as a consequence, its dispersion in the atmosphere has disastrous environmental impacts (greenhouse effect, danger of explosions and fires, negative impacts on flora)(6).

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(100).

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(121); 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(61).

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)(146).

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(100). 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.

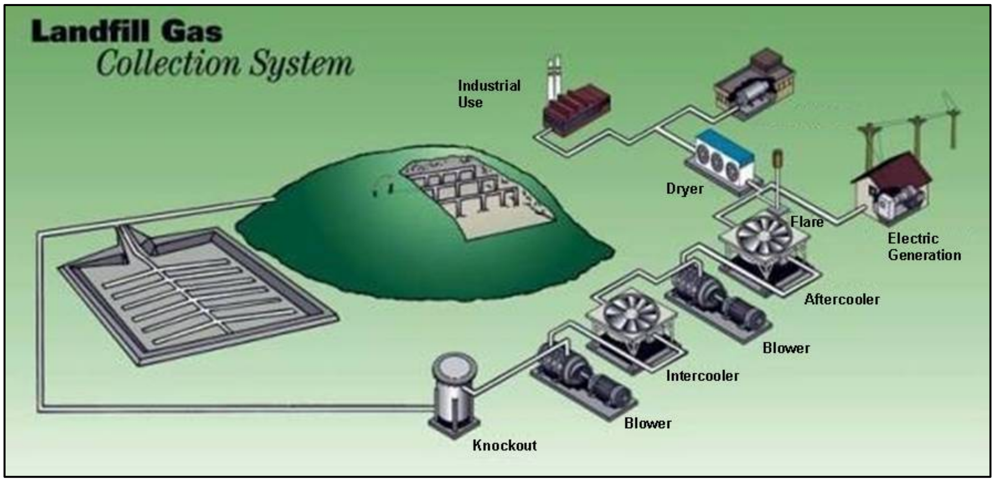


Figure 4.58 LFG collection system(50).

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(102).

Figure 4.59 Mobile energy production modules(50).

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.

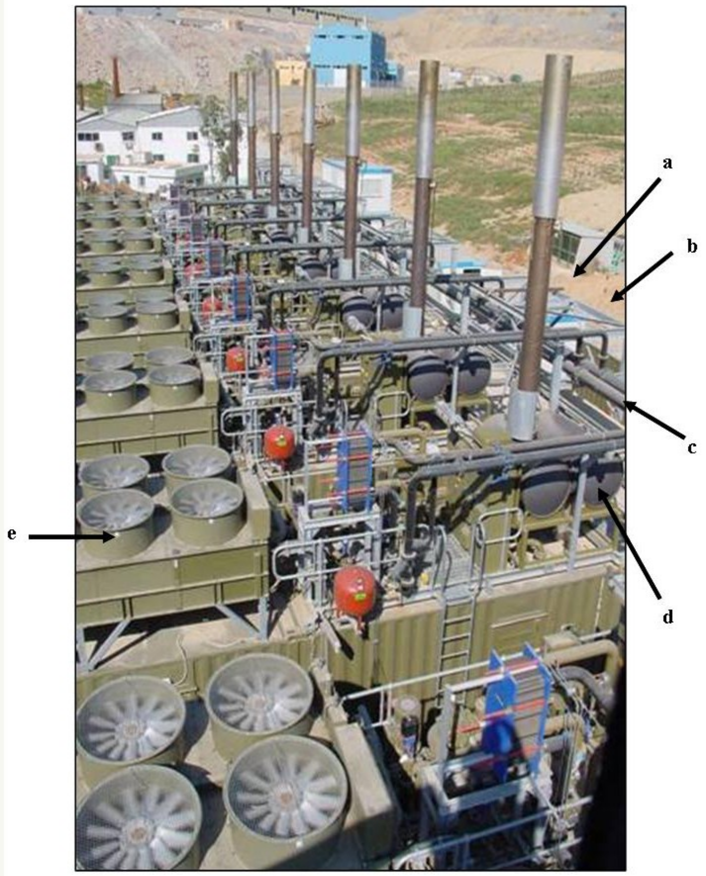


Figure 4.60 The heat recovery system(50).

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

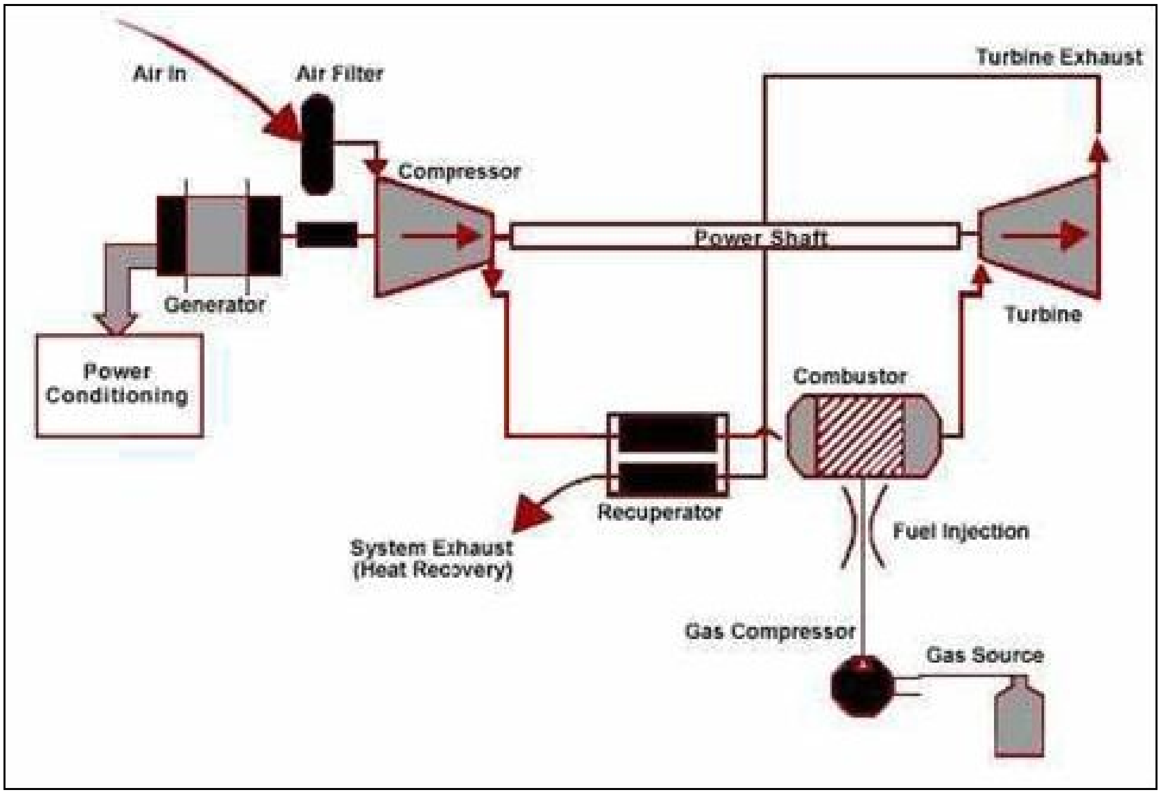


Figure 4.61 Heat recovery process schematic diagram(69).

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(45).

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	Camlia
	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(93). 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(94).

Figure 4.63 Aerial photograph of Avlona landfill(77).

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(77).

Figure 4.66 Closer view of Capandriti landfill(31).

4.5.6.1.5 *Cropia Landfill*

Figure 4.67 Aerial photograph of Cropia landfill(77)**.**

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 4.68 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(70). 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(77).

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(77)**.**

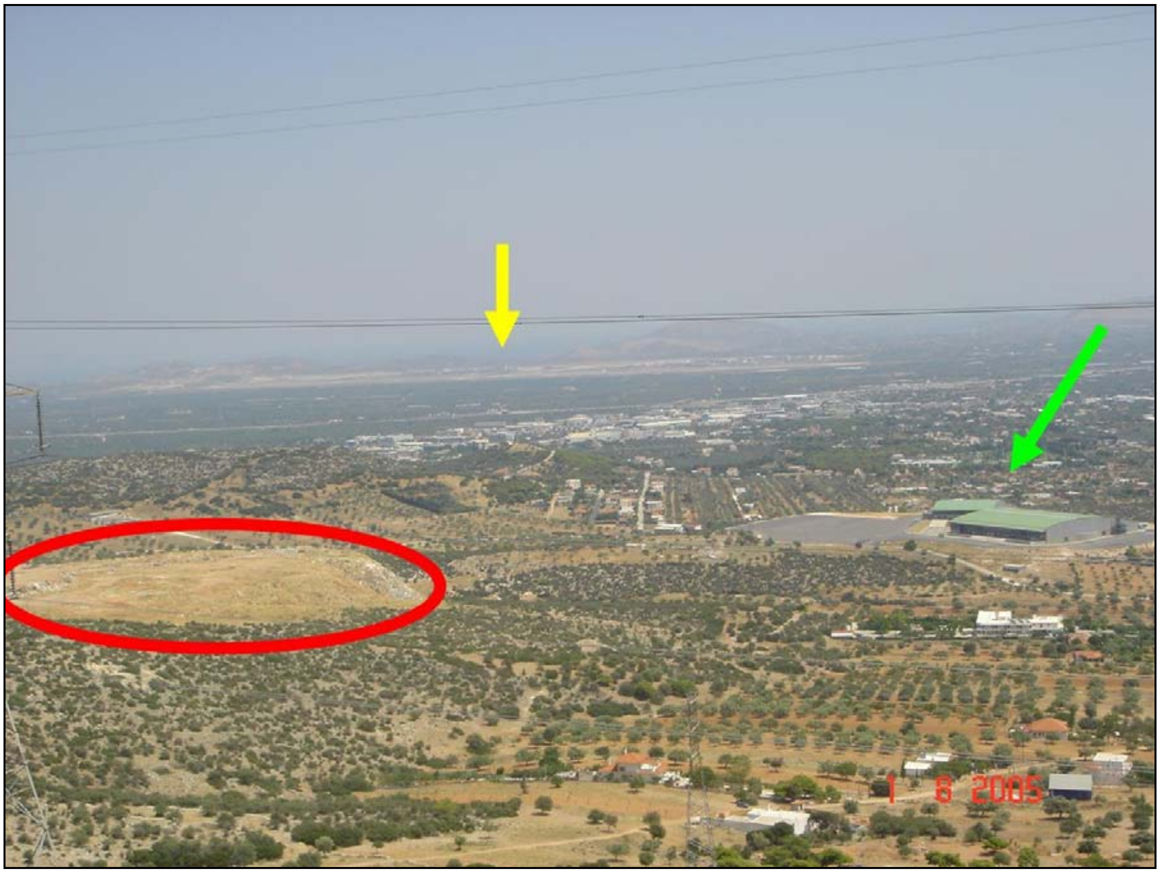


Figure 4.72 View of the western part of Paeania landfill.

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.


1 8 2005

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.

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 4.74 Aerial photograph of Varnava landfill.

Figure 4.75 View of Varnava landfill(30).

4.5.6.2 <u>Inactive Uncontrolled Landfills</u>

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(136).

Figure 4.77 View of “Schisto” site after restoration(136).

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(136).

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 FACILITITES 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)⁽⁴⁵⁾.

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)$^{(45)}$.

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.

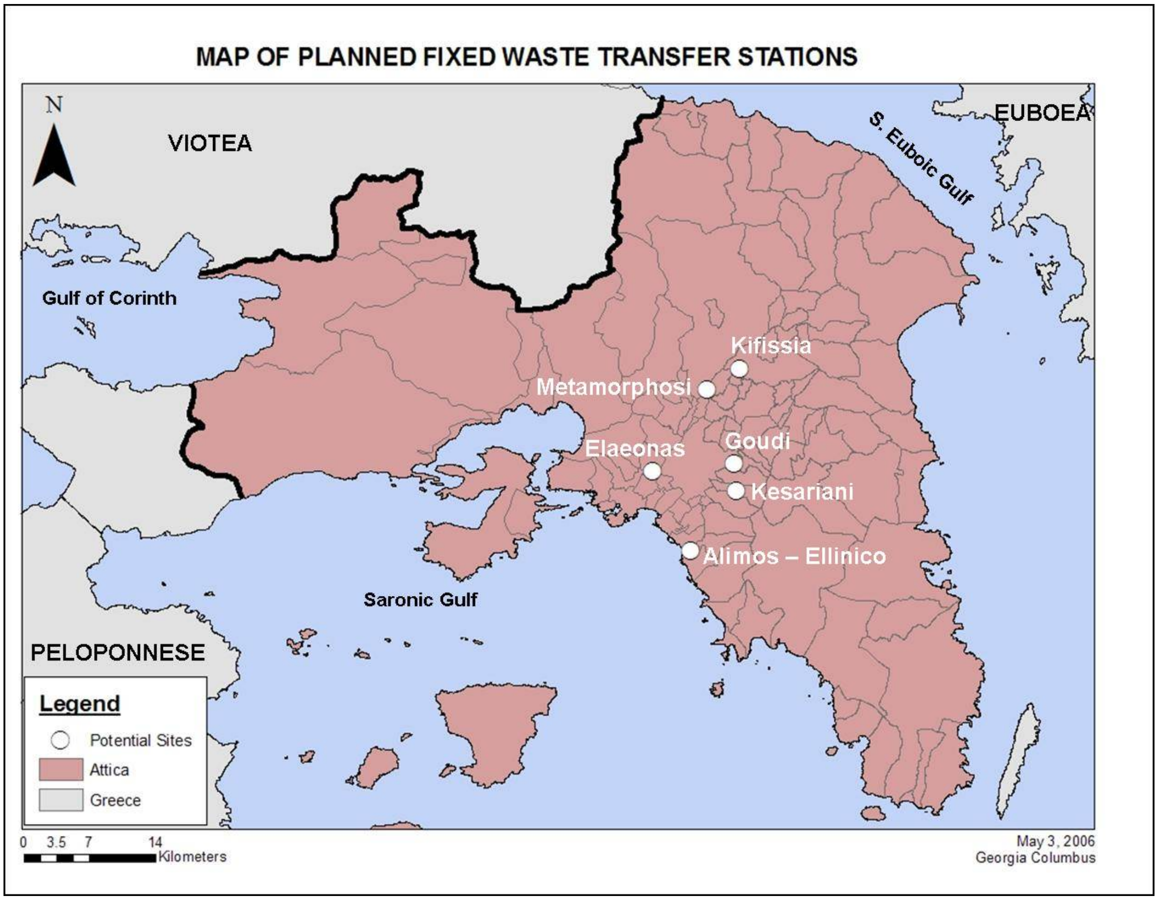


Figure 4.80 Potential Sites for fixed WTSs.

Table 4.13 Characteristics of future WTSs.

WTS	Locations	Area (m^2)	Capacity (t/d)
1	Aegalaeo (Elaeonas)	20,000[*]	1,265[#]
2	Alimos or Ellinico or Glyfada	20,000[**]	595[#]
3	Goudi or Kesariani	20,000[**]	-
4	Kifissia or Metamorphosi	20,000[**]	455[#]

[*] Reference 88
[**] Reference 93
[#] 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 Aegalaeo (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)(132) 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.

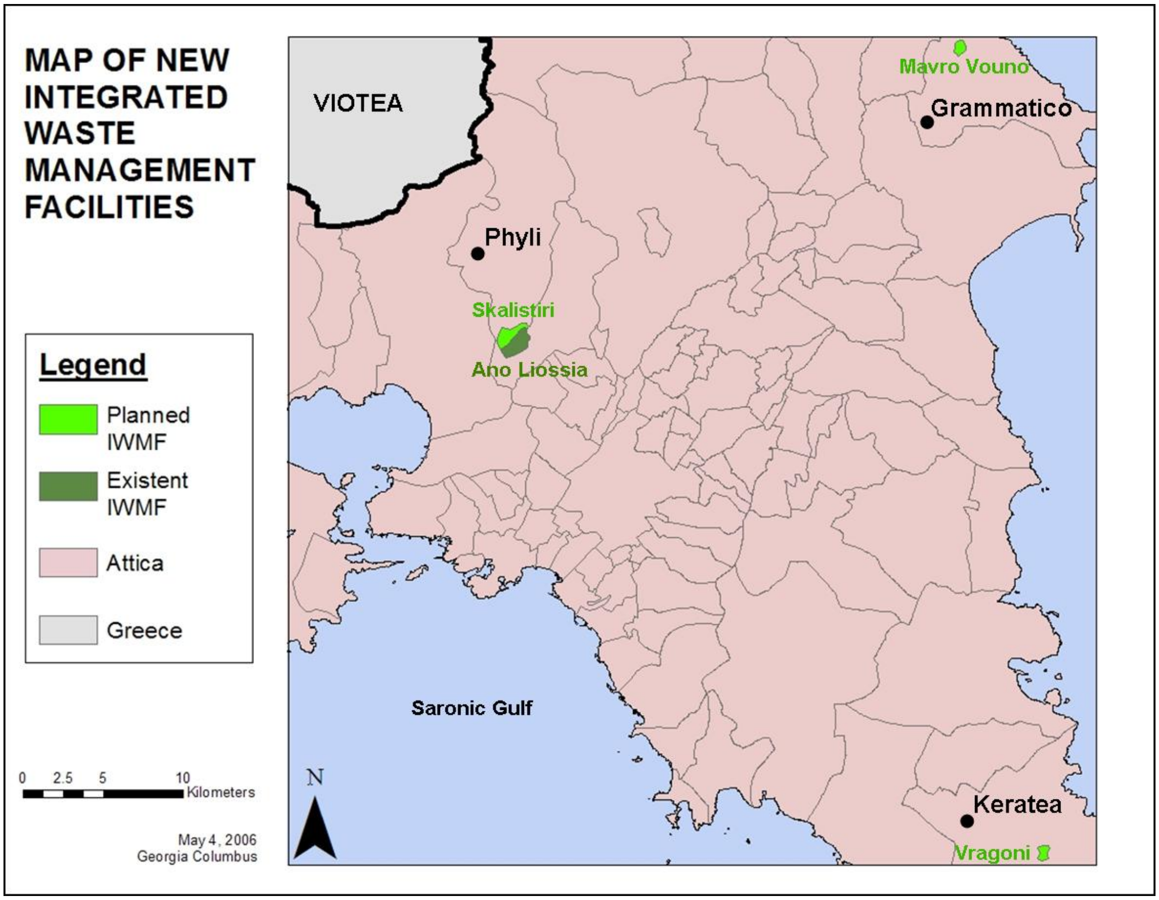


Figure 4.81 Sites of proposed IWMFs.

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$^{(45)}$**.**

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
TOTAL COSTS	**90,136,896**	**70,800,000**	

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 Phyli. 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(45).

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
TOTAL COSTS	**48,123,936**	**37,800,000**	

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(93).

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(45).

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
TOTAL COSTS	**37,684,352**	**29,600,000**	

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.

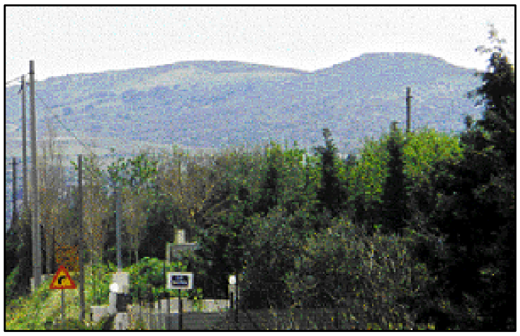


Figure 4.83 View of "Vragoni" site(93).

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)(45).

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_4), mercury (Hg), methyl mercury (CH_3Hg) – 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_2) 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)(163) 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 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.

Figure 5.1 Minato WTE facility in Tokyo(156).

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 Phyli 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 Phyli 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.

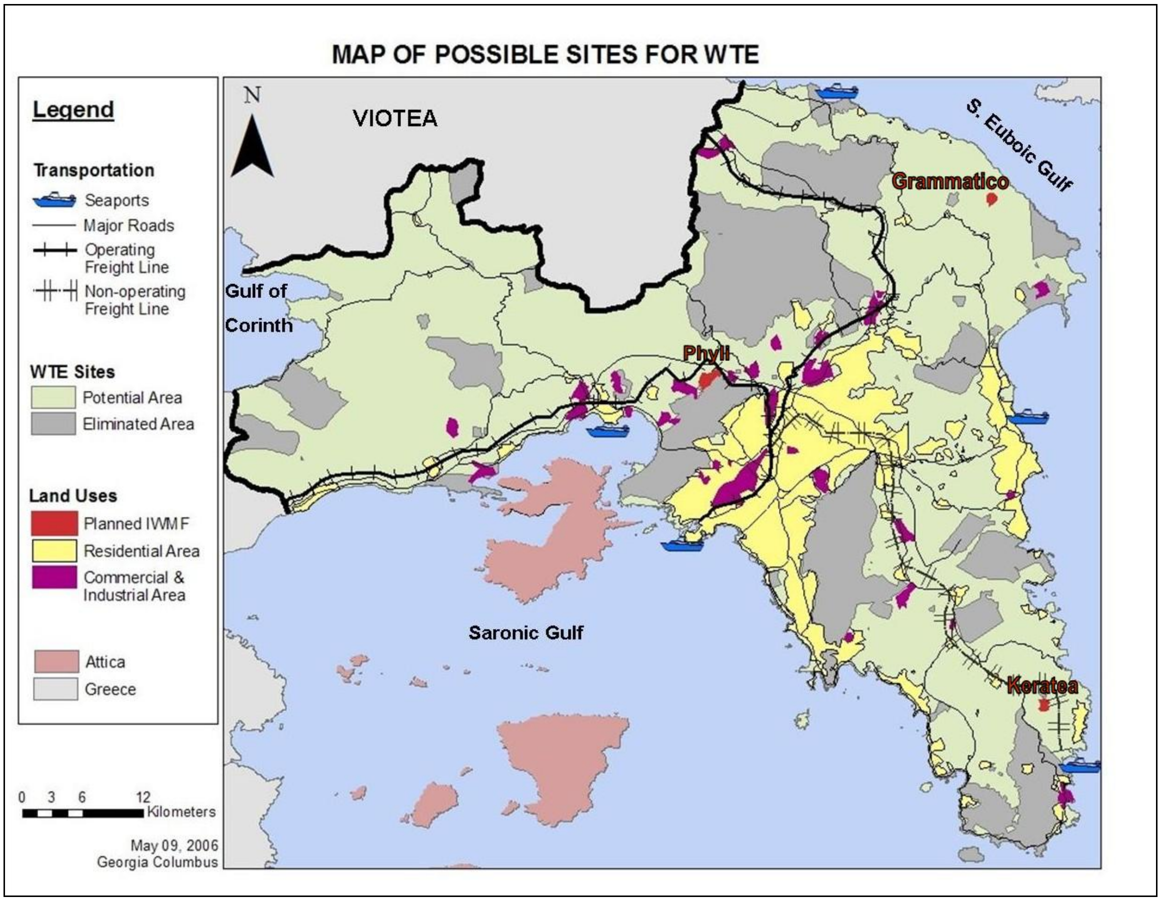


Figure 5.2 Possible sites for WTE facilities.

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(63).
- 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
TOTAL (t/d)	**3,041**	**715**	**541**	**1,294**
TOTAL (%)	**39**	**9**	**7**	**17**

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.

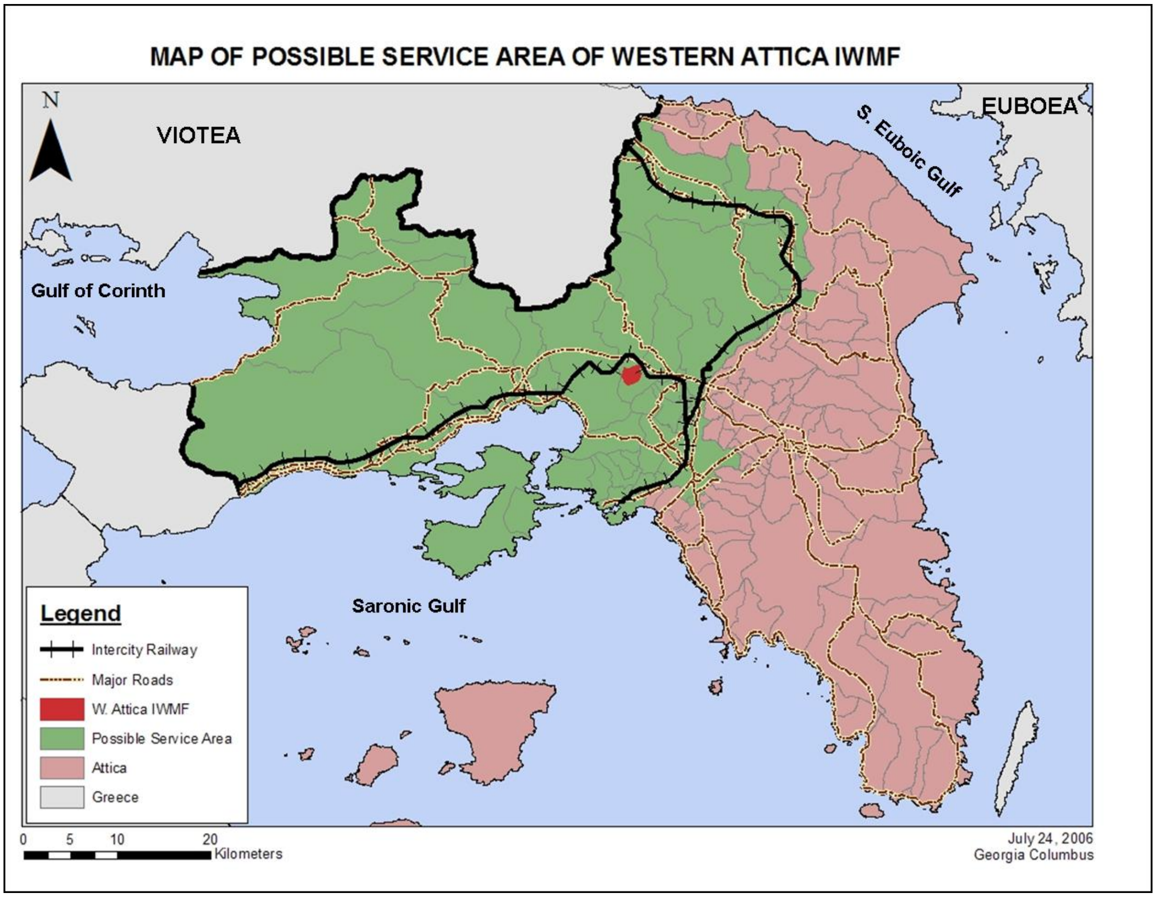


Figure 5.3 Assumed service area of Western Attica IWMF.

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	
TOTAL (t/d)	1,618	286		451	766	
TOTAL (%)	42	7		12	20	
WTE	3000*	61	666	-	689	84
TOTAL OUTGOING MATERIALS (t/d)		**347**	**952**	**451**	**689**	**84**
TOTAL OUTGOING MATERIALS (%)		**9**	**25**	**12**	**18**	**2**

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

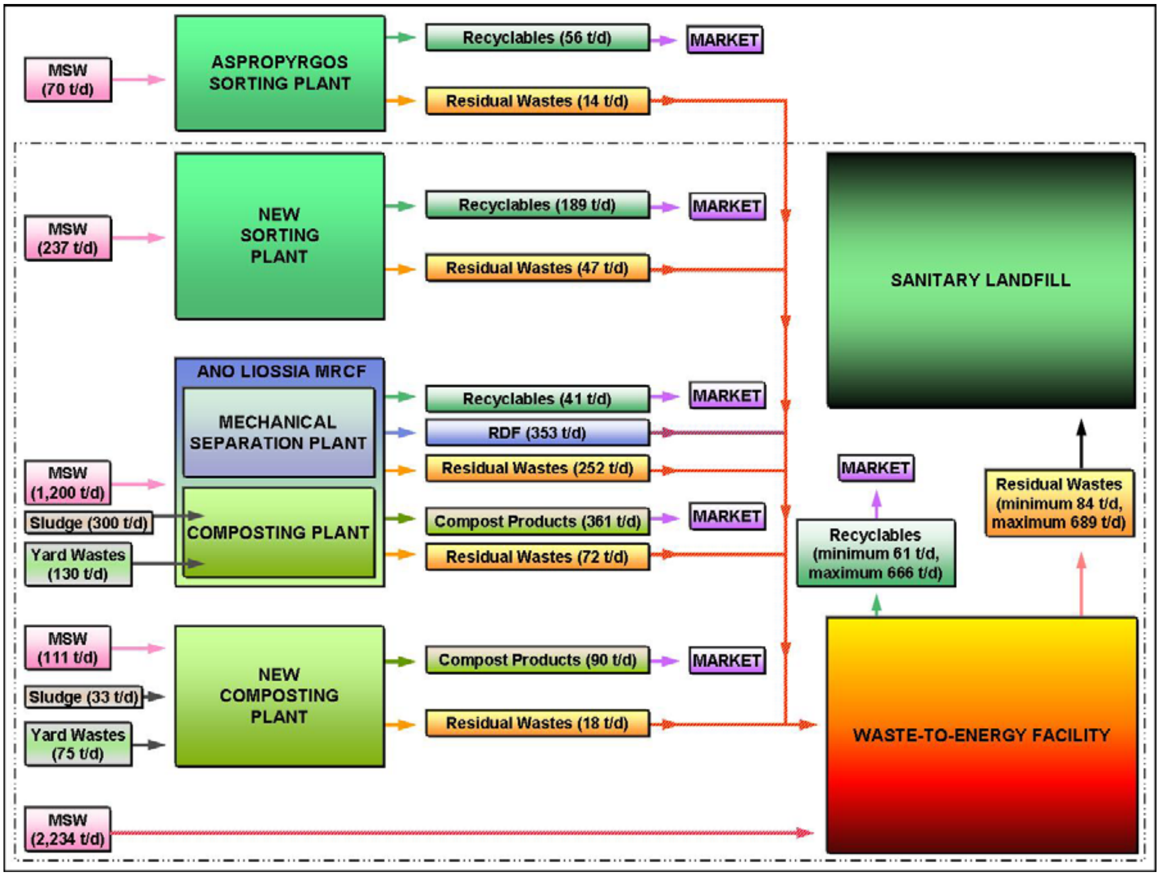


Figure 5.4 Schematic diagram of the proposed SWM system for western Attica.

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(9):

- 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(48).

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°(159).

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.

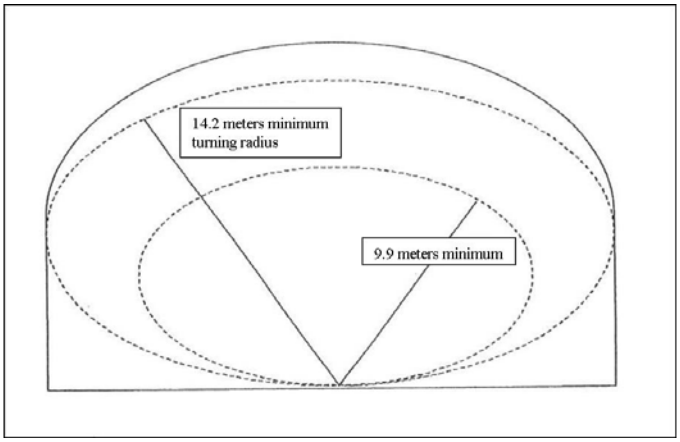


Figure 5.5 Turning path for waste collection trucks(10).

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(10).

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' windscreens (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 trough the entrance or exit of the facility without stopping(173). All the truck movements will be recorded by the TagMaster Reader and registered in a central database, which will drastically avoid potential traffic problems.

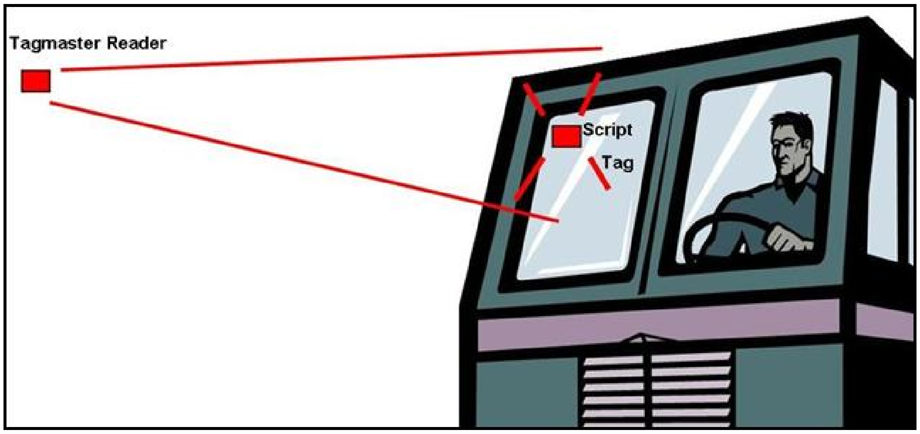


Figure 5.7 Tagmaster RFID system(10).

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(10).

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.

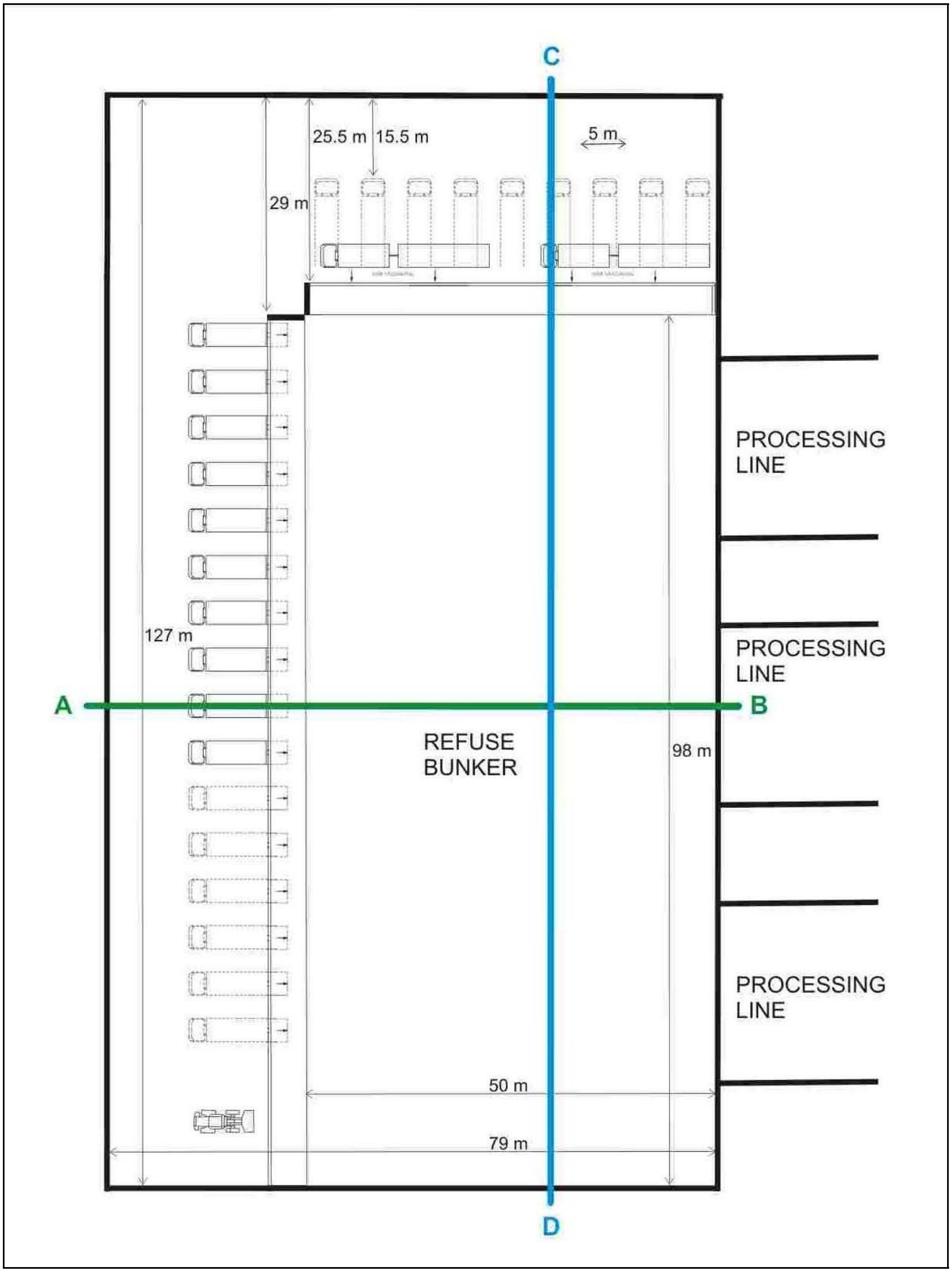


Figure 5.9 Plan of the tipping floor of the proposed plant (based on Reference 23)**.**

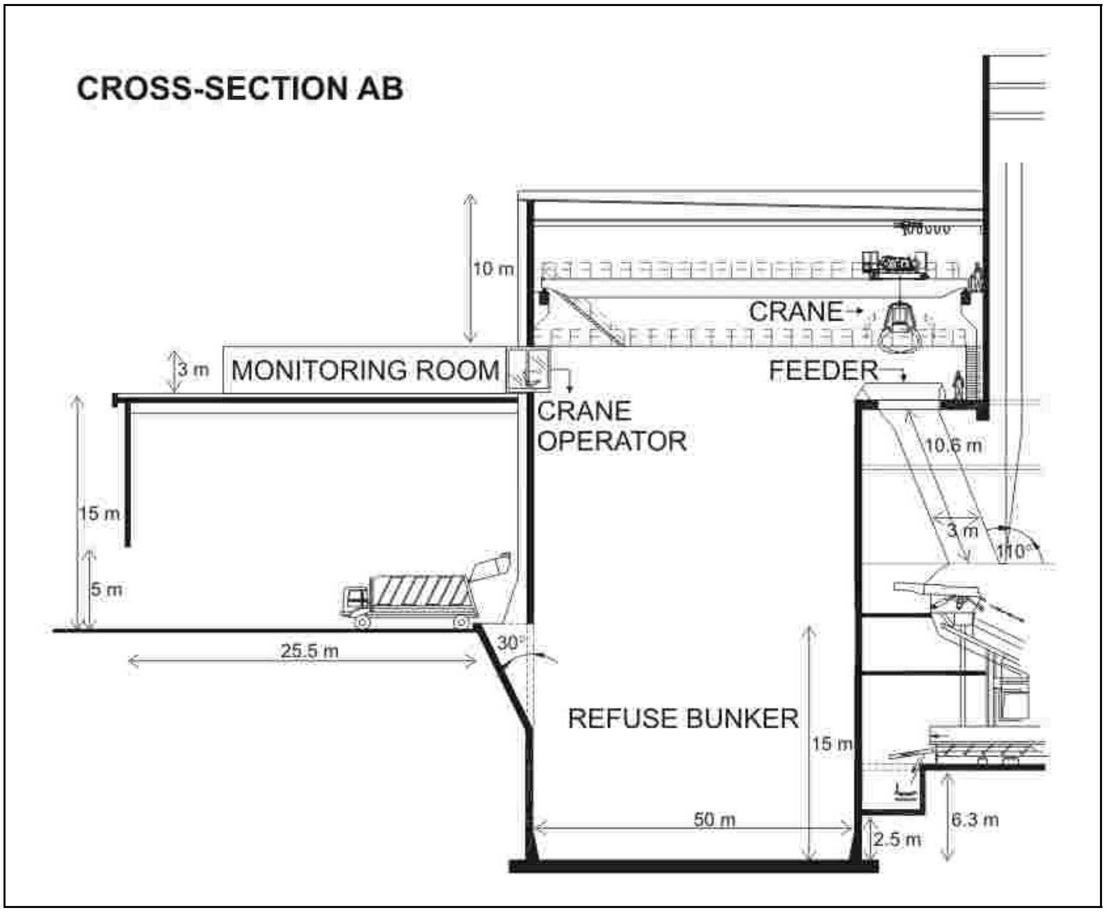


Figure 5.10 **Cross-section AB** (based on Reference 23).

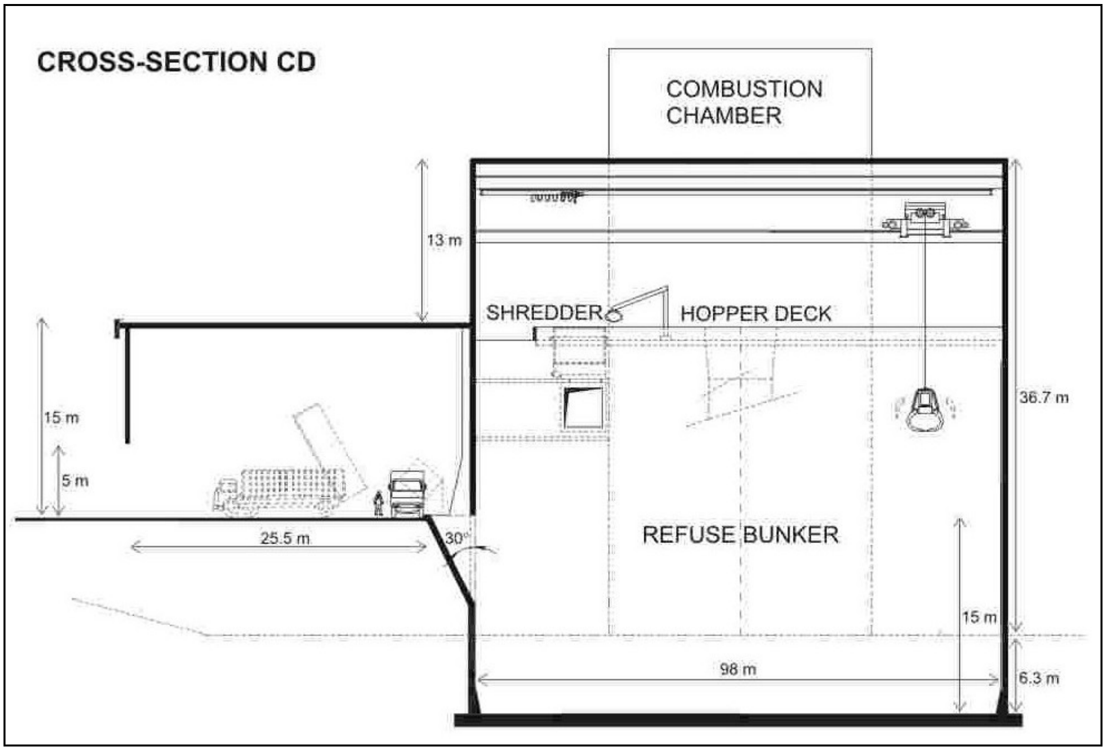


Figure 5.11 Cross-section CD (based on Reference 23).

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.

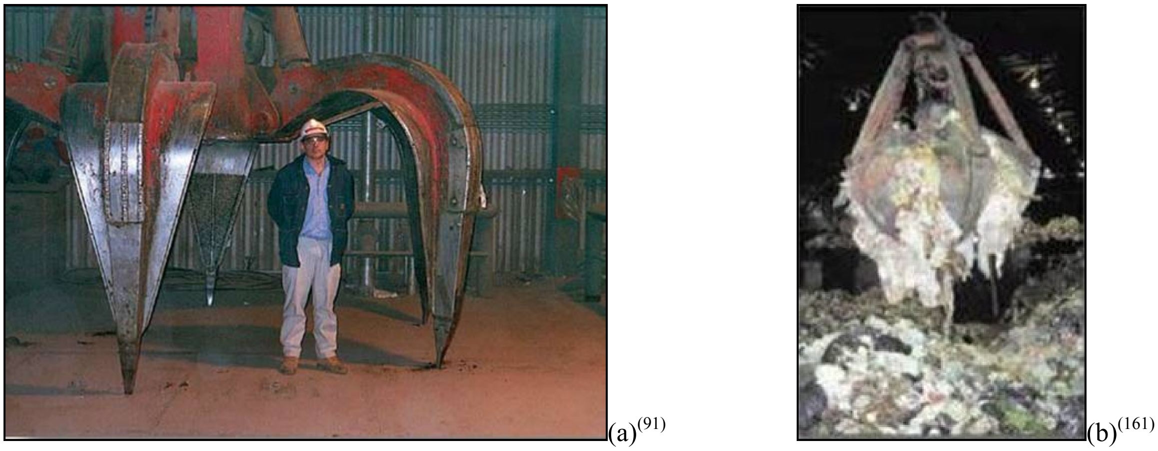

(a)(91) (b)(161)

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(51):

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

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

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

ρ: 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:

$$t = 2 \cdot (t_\kappa + t_\varepsilon + t_\delta + t_\gamma)$$

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

t_ε: 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_δ: 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_γ: 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° 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)(48). 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 (48).

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(61).

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_3) 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_2) depends on the addition of chemicals. Increased consumption of lime ($Ca(OH)_2$) can contribute to the advanced control of these three pollutants. However, a completely dry system will need lime ($Ca(OH)_2$) in excessive quantities. Also, mercury (Hg) and dioxin emissions are controlled by adding activated carbon (C) to lime ($Ca(OH)_2$).

On the other hand, an advanced ***wet system*** includes an additional wet scrubber, in which sulphur dioxide (SO_2) is reduced by reacting with a sodium hydroxide (NaOH) solution or a calcium carbonate ($CaCO_3$) suspension. Due to excess oxygen (O_2) in the flue gas, the reaction products are a sodium sulfate (Na_2SO_4) solution and a gypsum ($CaSO_4$ $2H_2O$) 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_2SO_4) solution are precipitated as gypsum ($CaSO_4$ $2H_2O$) by calcium ions. If calcium carbonate ($CaCO_3$) is used, the gypsum ($CaSO_4$ $2H_2O$) 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_2) 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 ($Ca(OH)_2$) 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_2), dust and other heavy metals are further reduced.

None of these processes, however, controls the emissions of nitrogen oxides (NO_x), 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_x) may be further controlled by injection of ammonia (NH_3) that selectively reduces the nitrogen oxides (NO_x) to elemental nitrogen (N_2) 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 (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 (NH_3). The surplus ammonia (NH_3) passes with the flue gas to the APC system. If the APC system is wet, the surplus ammonia (NH_3) is quantitatively removed as ammonium chloride (NH_4Cl), in the hydrogen chloride (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 (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.

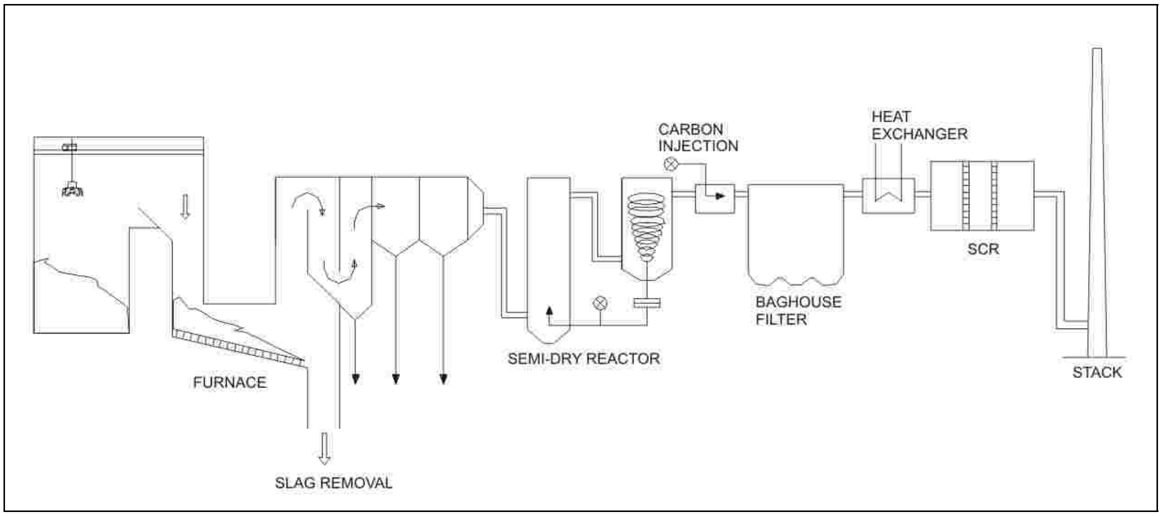


Figure 5.13 Example of a semi-dry APC system with dioxin removal and selective catalytic reduction(48).

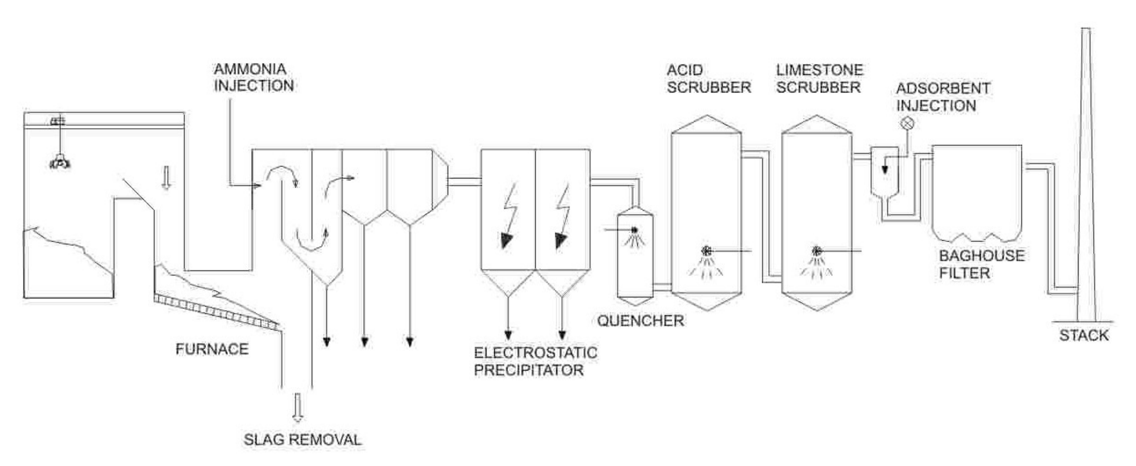


Figure 5.14 Example of a wet APC system with selective non-catalytic reduction, limestone scrubber and dioxin filter(48).

Table 5.3 Advantages and disadvantages of the semi-dry and wet APC advanced systems(48).

Advanced APC Systems	Semi-dry system with dioxin removal and SCR	Wet system with SNCR, limestone scrubber and dioxin filter
Advantages	▪ No wastewater treatment required ▪ Less prone to corrosion ▪ No visible plume	▪ Nearly stoichiometric consumption of chemicals ▪ Inexpensive NOx removal process ▪ Economic SO2 removal with CaCO3 ▪ Destruction of dioxins
Disadvantages	▪ Expensive NOx removal process ▪ High consumption of chemicals and energy ▪ More solid residues ▪ Dioxins are not destroyed, only adsorbed	▪ High investment costs ▪ Wastewater treatment required ▪ Quencher and scrubbers must be made of plastic ▪ White plume in cold and humid weather

Continuous Emission Monitoring (CEM) equipment, which typically monitors stack emissions of nitrogen oxides (NO_x), carbon monoxide (CO), oxygen (O_2), particulate via opacity meters and acid gases via monitoring hydrogen chloride (HCl) and sulfur dioxide (SO_2), 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(68).

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(165):

- 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 5.17 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(54).

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(53).

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)(83) 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(61). 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(38), 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.

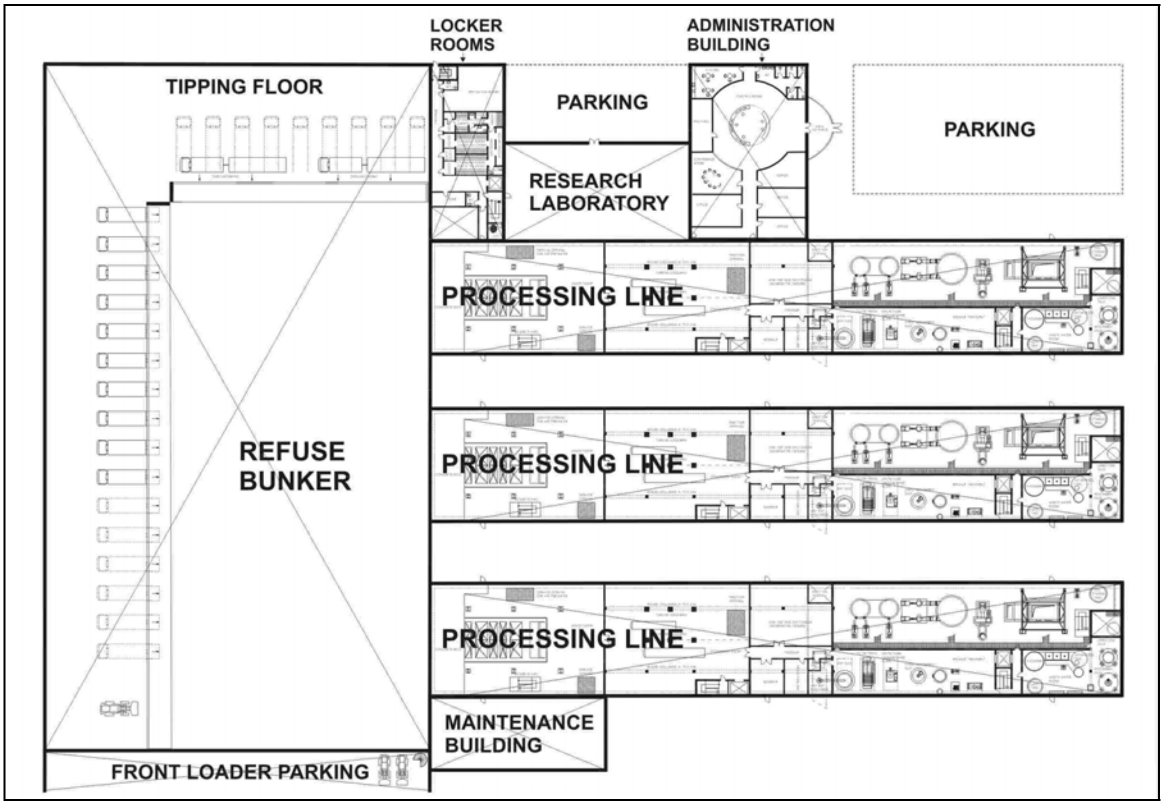


Figure 5.19 Possible plan of the proposed WTE plant (based on Reference 23)**.**

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

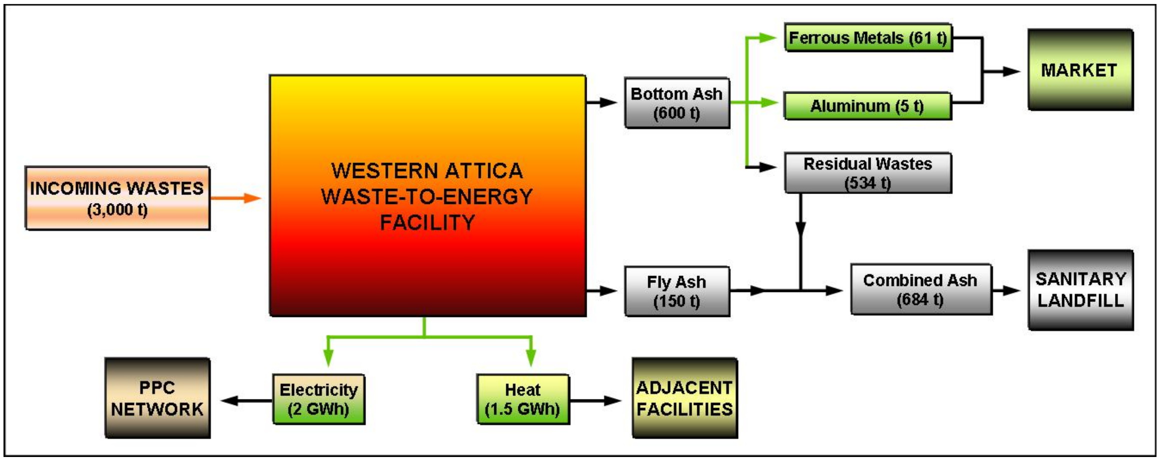


Figure 5.20 Daily material flow of the Western Attica WTE facility.

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
TOTAL					**65**	**1,414,691**	**1,111,200**

- 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
TOTAL per ton of MSW	**40.74**	**32.00**
TOTAL ANNUAL	**40,332,442**	**31,680,000**

- 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 Phyli 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 Phyli 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	**($)**	**(€)**
WTE Construction Cost	**534,710,400**	**420,000,000**
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
Subtotal	*45,047,808*	*35,383,788*	*45,948,764*	*36,091,464*	*46,867,740*	*36,813,293*
Contingency	4,504,781	3,538,379	4,594,876	3,609,146	4,686,774	3,681,329
Total	**49,552,589**	**38,922,167**	**50,543,641**	**39,700,610**	**51,554,514**	**40,494,622**
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
GRAND TOTAL	**90,353,515**	**70,970,148**	**91,932,034**	**72,210,031**	**93,524,897**	**73,461,180**

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
TOTAL	**98,361,843**	**77,260,464**	**100,537,133**	**78,969,094**	**102,694,642**	**80,663,757**

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.

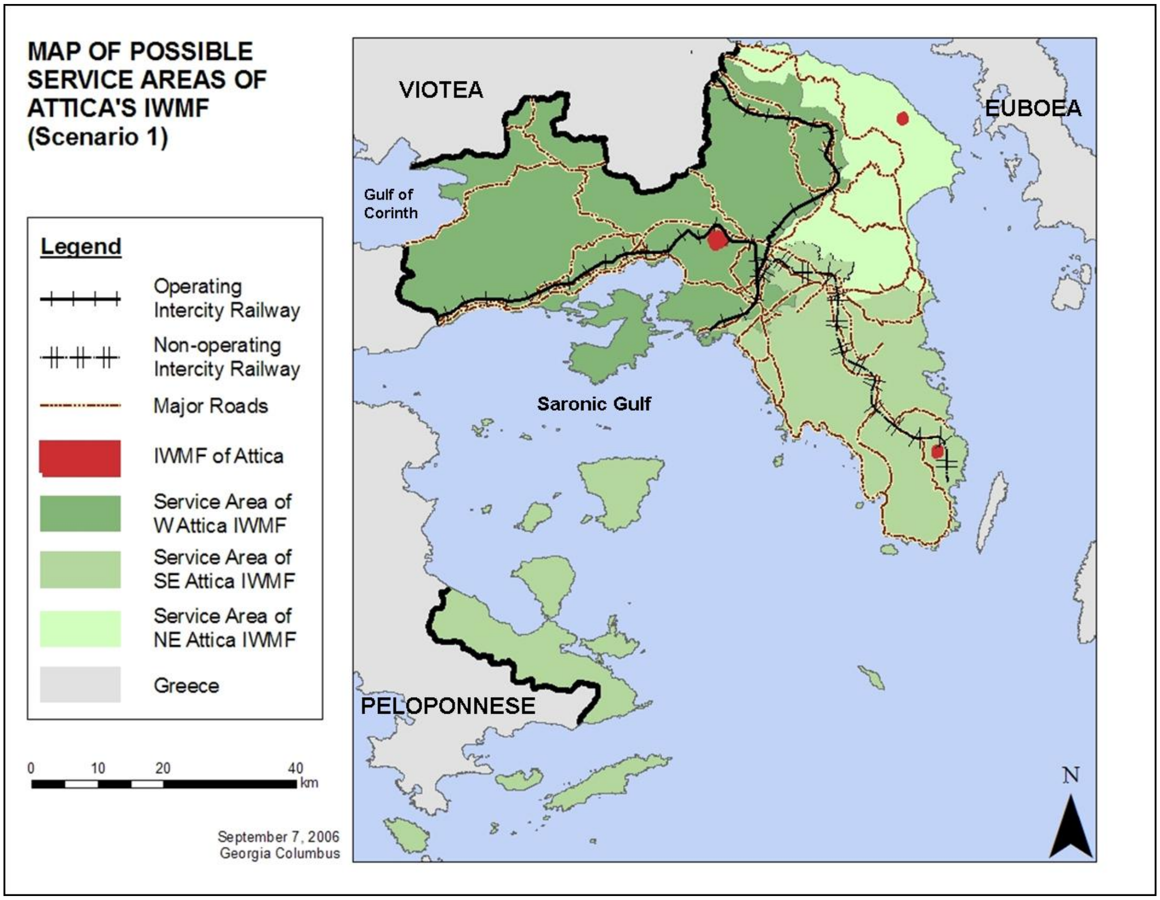
In order to completely solve the existent MSW management problem of Attica Region under the present conditions of waste generation and treatment, approximately 6,500 tons of MSW per day should be subjected to thermal treatment. This would increase material and energy recovery significantly and also reduce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

Possible service areas of the three IWMFs, according to Scenarios 1 and 2 are shown in Figures 5.21 and 5.22, respectively. The service area of the Western Attica IWMF is the same in both scenarios; it will serve approximately 2.7 million inhabitants daily producing around 3,850 tons of MSW, as mentioned in Section 5.3.1.1.

According to Scenario 1, the Southeastern Attica IWMF, where the second WTE facility will be located, will serve about 2 million inhabitants who generate about 3,150 tons of MSW daily. The Northeastern Attica IWMF, which will not include a WTE plant, will serve approximately 0.3 million inhabitants producing about 730 tons of MSW.



September 7, 2006
Georgia Columbus

Figure 5.21 Possible service areas of Attica's IWMFs – Scenario 1.

According to the Scenario 2, the Southeastern Attica IWMF will house the second WTE facility and serve approximately 1.2 million inhabitants producing 1,925 tons of MSW daily. The Northeastern Attica IWMF, which will include the third WTE facility and serve 1.1 million inhabitants generating 1,960 tons of MSW daily.

In both scenarios, the service area of the Southeastern Attica IWMF includes the OLA of Trizina and the Region's islands, except Kythira and Antikythira. According to this proposal, Marine Transfer Stations (MTSs) would be required to be constructed at these areas for waste transportation. MTSs offer significant advantages in facilitating transportation of waste towards the IWMFs without aggravating air pollution and congesting road traffic. This topic will be discussed in more detail in Chapter 6.

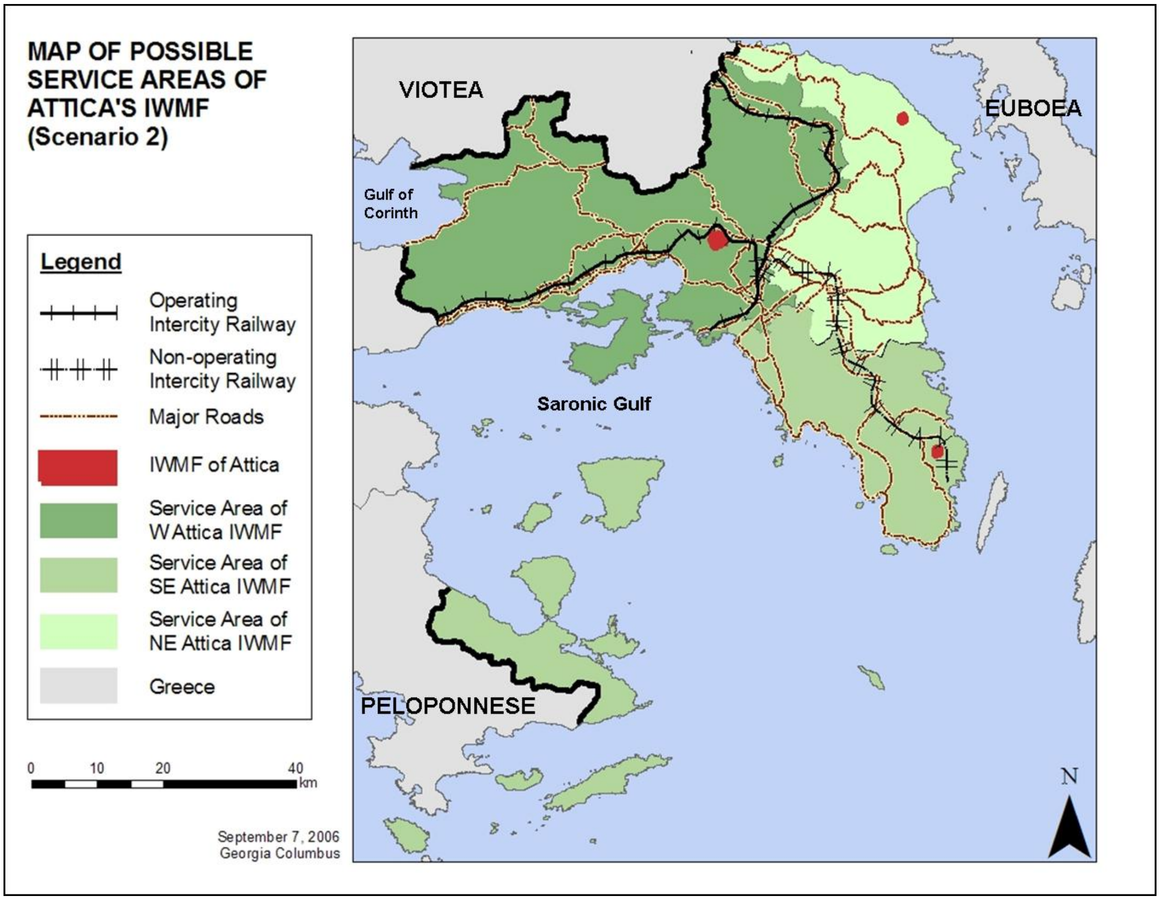


Figure 5.22 Possible service areas of Attica's IWMFs – Scenario 2.

The OLAs of Kythira and Antikythira could be served by the MSW management system proposed in this study and in particular, by the Southeastern Attica IWMF. However, due to their geographic location, it may be more practical and economically sensible that these islands be served by the new sanitary landfills proposed by Attica's Regional Plan for SWM or by the SWM system of Lakonia, Peloponnese.

The implementation of either Scenario 1 or Scenario 2 would lead to the generation of a net of 3.9 gigawatt-hours of electrical and 3 gigawatt-hours of thermal energy per day.

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
WESTERN ATTICA IWMF						
Aspropyrgos Sorting	70	56		-	14	
New Sorting	237	189		-	47	
Ano Liossia MRCF	1,200	41		361	687	
New Composting	111	-		90	18	
TOTAL (t/d)	1,618	286		451	766	
TOTAL (%)	21%	4%		6%	10%	
WTE	3,000[(1)]	61	666	-	689	84
TOTAL OUTGOING MATERIALS (t/d)		**347**	**952**	**451**	**689**	**84**
TOTAL OUTGOING MATERIALS (%)		**4%**	**12%**	**6%**	**9%**	**1%**
NORTHEASTERN ATTICA IWMF						
Maroussi Sorting	50	35		-	15	
New Sorting	229	183		-	46	
New MRF	402	14		-	206	
New Composting	56	-		45	9	
TOTAL (t/d)	687	232		45	276	
TOTAL OUTGOING MATERIALS (t/d)		**232**		**45**	**276**	
TOTAL OUTGOING MATERIALS (%)		**3%**		**1%**	**4%**	
SOUTHEASTERN ATTICA IWMF						
New Sorting	229	183		-	46	
New MRF	402	14		-	206	
New Composting	56	-		45	9	
TOTAL (t/d)	687	197		45	261	
TOTAL (%)	9%	3%		1%	3%	
WTE	3,000[(2)]	61	666	-	689	84
TOTAL OUTGOING MATERIALS (t/d)		**258**	**863**	**45**	**689**	**84**
TOTAL OUTGOING MATERIALS (%)		**3%**	**11%**	**1%**	**9%**	**1%**

[(1)] This amount includes the residual wastes from the other facilities of the Western Attica IWMF

[(2)] 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
WESTERN ATTICA IWMF						
Aspropyrgos Sorting	70	56		-	14	
New Sorting	237	189		-	47	
Ano Liossia MRCF	1,200	41		361	687	
New Composting	111	-		90	18	
TOTAL (t/d)	1,618	286		451	766	
TOTAL (%)	21%	4%		6%	10%	
WTE	3,000*	61	666	-	689	84
TOTAL OUTGOING MATERIALS (t/d)		**347**	**952**	**451**	**689**	**84**
TOTAL OUTGOING MATERIALS (%)		**4%**	**12%**	**6%**	**9%**	**1%**
NORTHEASTERN ATTICA IWMF						
Maroussi Sorting	50	35		-	15	
New Sorting	229	183		-	46	
New MRF	402	14		-	206	
New Composting	56	-		45	9	
TOTAL (t/d)	737	232		45	276	
TOTAL (%)	10%	3%		1%	4%	
WTE	1,500*	31	333	-	344	42
TOTAL OUTGOING MATERIALS (t/d)		**263**	**565**	**45**	**344**	**42**
TOTAL OUTGOING MATERIALS (%)		**3%**	**7%**	**1%**	**4%**	**1%**
SOUTHEASTERN ATTICA IWMF						
New Sorting	229	183		-	46	
New MRF	402	14		-	206	
New Composting	56	-		45	9	
TOTAL (t/d)	687	197		45	261	
TOTAL (%)	9%	3%		1%	3%	
WTE	1,500*	31	333	-	344	42
TOTAL OUTGOING MATERIALS (t/d)		**228**	**530**	**45**	**344**	**42**
TOTAL OUTGOING MATERIALS (%)		**3%**	**7%**	**1%**	**4%**	**1%**
* 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 Viotea 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)(163) was used.

CHAPTER 6: WASTE TRANSPORTATION

6.1 INTRODUCTION

The last section of this thesis provides information on alternative methods of waste transportation for the improvement of the current environmental conditions. More particularly, it refers to transportation on water and rail, as well as the usage of alternative truck fuels, which can contribute to the reduction of air pollution and/or the amelioration of the present traffic conditions.

The most obvious problem in regards to transportation is traffic congestion. One large truck takes up the highway space of almost four cars, and the average truck also is becoming longer, with the increased use of double- and triple-trailers. With little chance of increasing urban road capacity, this increase in truck volume will multiply today’s already severe congestion. Moreover, despite the training of professional drivers, higher truck volumes retard highway safety.

To control urban traffic congestion, part of the cargo movement taking place on the road network should be conveyed to water and rail. This can be relatively easily accomplished in the Region of Attica since it is surrounded by sea. As noted in Chapter 3, continental Attica has a coastline of length reaching 1,184 kilometers. Also, the railway network will be developed more in the near future.

In addition to alleviating traffic congestion, the implementation of the aforementioned concept will result in the reduction of air pollution and occurring accidents, as the number of trucks used for shipments will decrease significantly.

Furthermore, the usage of alternative truck fuels should be encouraged as it would contribute to a great extent in the effort towards a cleaner environment. The basic types of alternative fuels will be briefly described below.

6.2 TRANSPORTATION ON WATER

One of the most important assets of the area of study is the fact that it is surrounded by water, which justifies the number of existing seaports (Figure 3.52). This can be used to the area’s advantage for the reduction of the transportation flow that takes place on roads by using barges, which are cost effective in addition to being environmentally friendly.

An average barge load corresponds to the load of about 15 railcars. Also, railcar is equivalent to four semi-trailer trucks. Therefore, each barge removes 60 trucks from the local roadways (Figure 6.1).

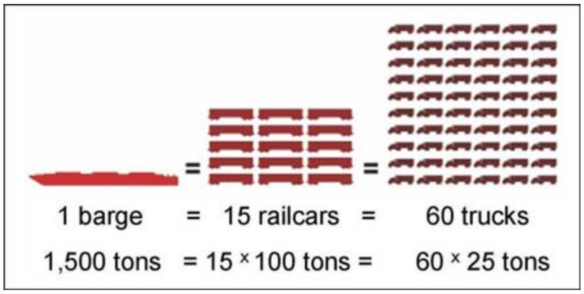


Figure 6.1 Analogy of shipping media(177).

Regarding the environmental point of view, the use of one barge saves the power required to move and eliminates the exhaust that would come from the aforementioned amounts of railcars and trucks, respectively. Table 6.1 compares the values of pollutants originating from the three aforementioned transportation media. The values are measured in kilograms produced when 1 ton of cargo is transported for 1,000 kilometers.

Table 6.1 Pollution produced by transportation media (based on Reference 144)**.**

Pollutant	Barge	Railcar	Truck
Hydrocarbons	0.25	0.13	0.18
Carbon Monoxide	0.06	0.18	52.71
Oxides of Nitrogen	0.15	50.77	2.82
NOTE: Units are kg per 1 ton for 1000 km			

Also, barge transportation is the most economical transportation method. According to studies, by using 1 liter of fuel a barge can carry 1 ton of cargo for a distance of 222 kilometers, while a railcar comes in the second place with about 87 kilometers. For the same quantity of fuel, a truck can transfer a load of 1 ton for only 26 kilometers(144). Moreover, the maintenance expenses for barges are roughly 36 times less than those resulting from the trips made by trucks(107).

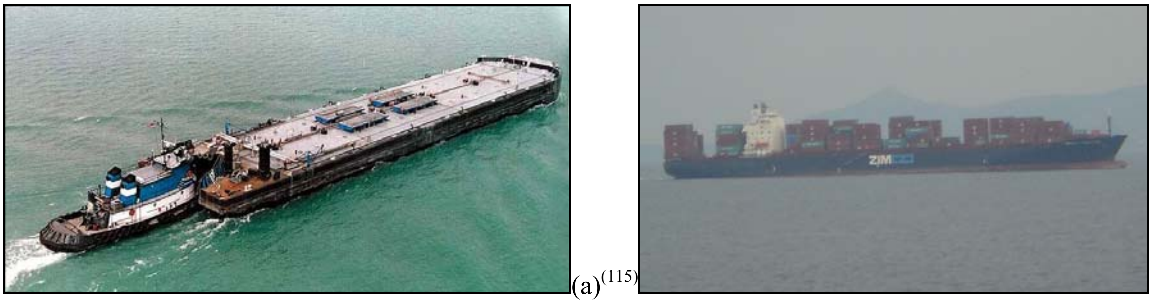

(a)(115) (b)

Figure 6.2 View of barges.

6.2.1 Marine Transfer Stations

In order to achieve transportation of waste on water in an environmentally sound manner, the construction of Marine Transfer Stations (MTSs) is required.

MTSs are facilities, where the waste collected by regular waste collection trucks is transferred and prepared for shipment by an efficient containerized system. More particularly, after the waste is deposited by the trucks on the tipping floor, it is subjected to compaction. The containerization of the compacted wastes into specially designed leak-proof, watertight containers follows. After the containers are fully packed, they are moved by crane onto a deck barge (Figure 6.3).

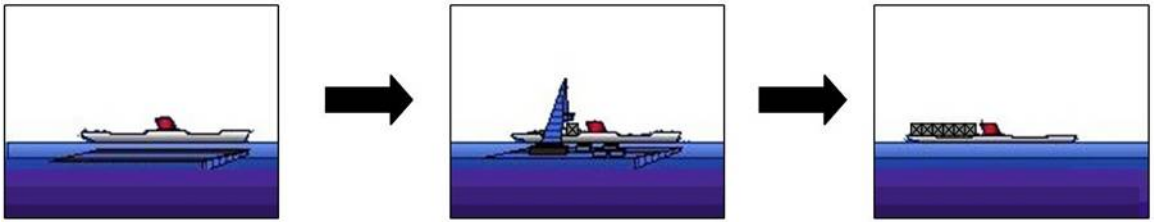


Figure 6.3 Loading containers on barge at an MTS(10).

Figures 6.4 and 6.5 are the cross-section and plan of a MTS proposed to be constructed at Queens, New York.

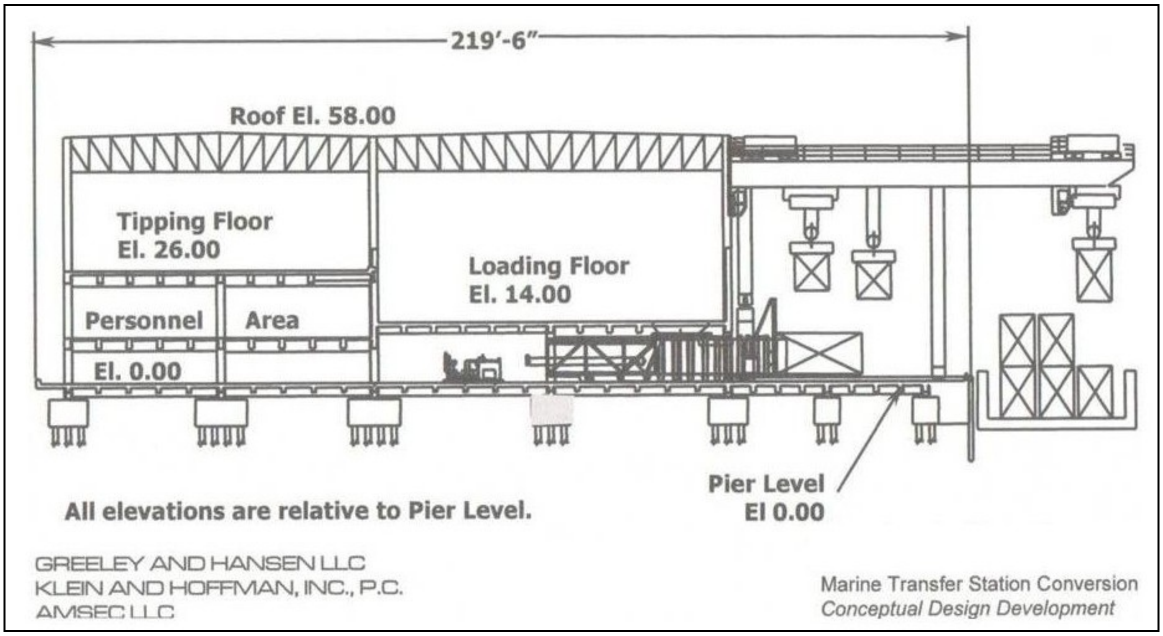


Figure 6.4 Cross-section of proposed MTS(10).

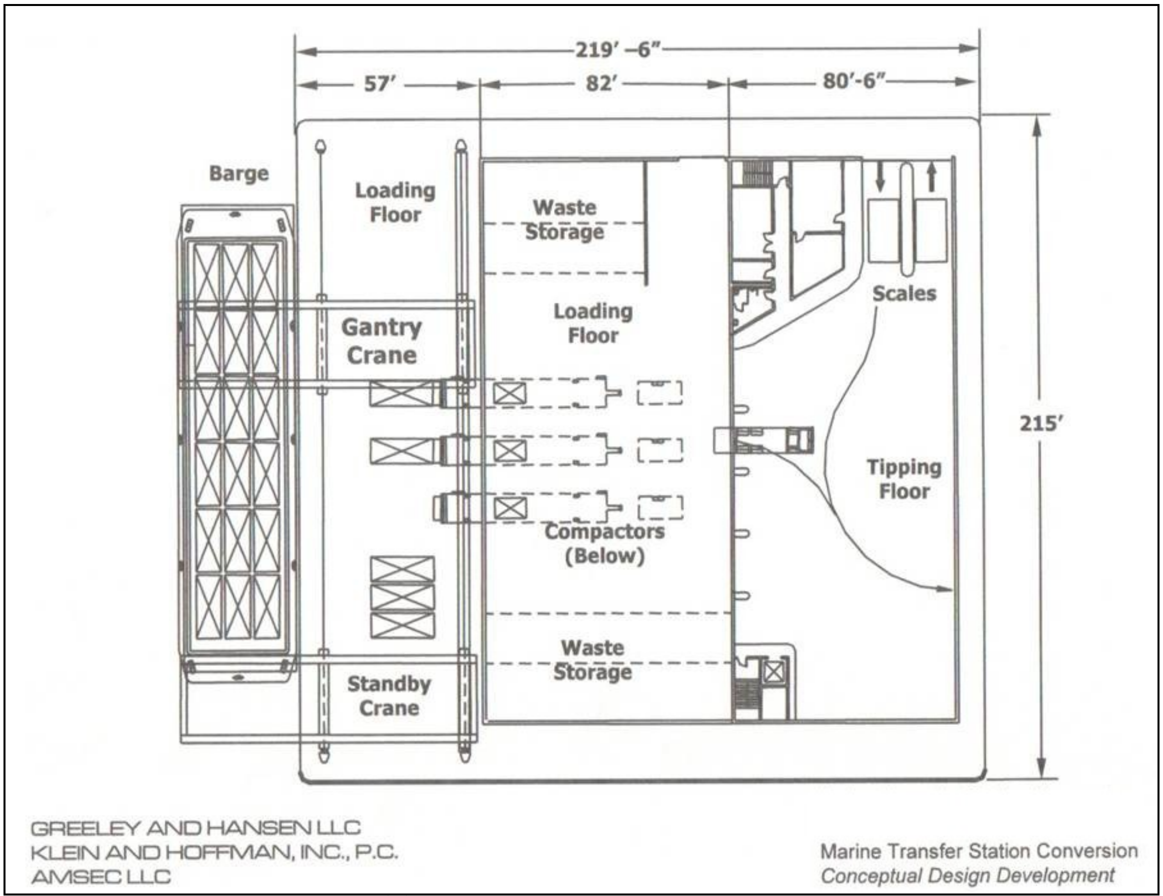
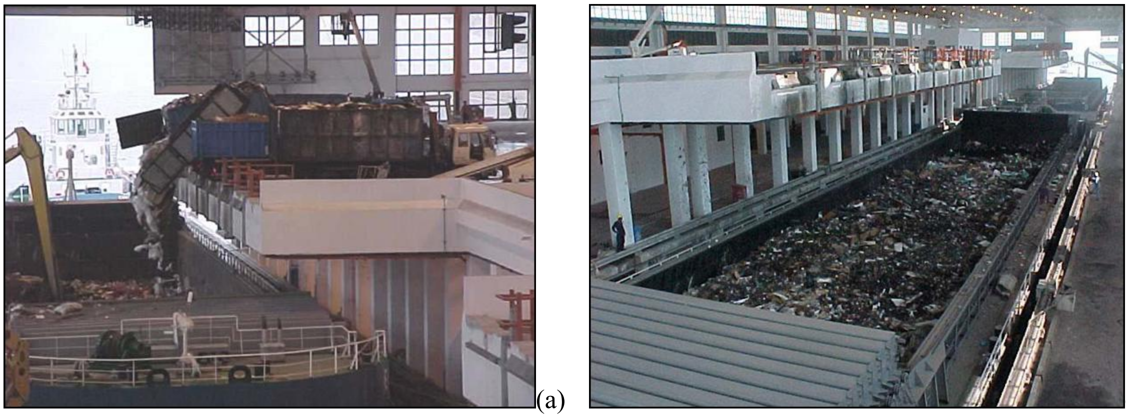
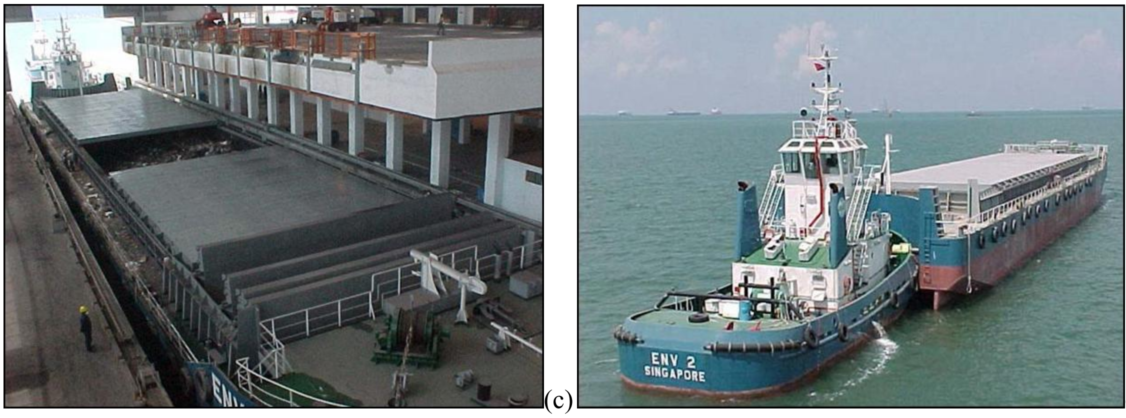


Figure 6.5 Plan of proposed MTS$^{(10)}$.

It must be noted that compaction is not necessarily included in the processes that take place at a MTS. In this case, the waste is directly discharged into specially designed barges with built-in containers. After the waste is loaded, the barges are towed to their destination. Figure 6.6 shows the processes that take place at this type of MTSs.


(a) (b)



(c) (d)

Figure 6.6 Loading waste on barge with built-in containers(171).

Regarding the Region of Attica, there are numerous potential sites for the construction of MTSs since it is surrounded by sea. In the case that the Solid Waste Management (SWM) system proposed in Chapter 5 is implemented, first priority should be given to the municipality of Trizina and the Region’s islands. The Municipal Solid Wastes (MSW) would be containerized at these areas and sent to continental Attica.

6.3 TRANSPORTATION ON RAILS

Moving freight by rail is the second best answer to traffic congestion, pollution and costs, as one can conclude from the data provided in the previous paragraph.

Furthermore, according to studies conducted on freight movement in USA by Wendell Cox, shifting to 25% of the New York City and northeastern New Jersey freight from trucks to trains would reduce drivers’ commutes by an average of 52.9 hours per peak hour per traveler in the next 20 years. In addition, at today’s prices, such a shift would save each commuter about $734 (€577) per household in costs caused by congestion. The annual air pollution would be better by saving 78,250 tons of emissions, since the projected truck traffic congestion would be alleviated by the removal of approximately 297,000 trucks by each daily peak period(145).

Consequently, the transportation on rail of the MSW generated in continental Attica should be encouraged. In order to materialize this in the proposed SWM system for Attica Region, the new station at Elefsina Plain for freight transportation should be used, and the non-operating part of railroad, located in the Prefecture of Eastern Attica, should be included in the modernization plan of the intercity railroad system.

6.4 ALTERNATIVE TRUCK FUELS

Since using trucks for the transportation of cargo is inevitable, the use of trucks that can consume alternative fuels should be preferred in order to minimize air pollution caused by their emissions. Regarding the heavy-duty vehicles, alternative fuels that can be used are(124):

- ***Natural Gas***: Natural gas, which is already used by some of the buses operated by ETHEL, is a clean burning fuel and produces significantly fewer harmful emissions than reformulated gasoline or diesel. Commercially available medium- and heavy-duty natural gas engines have demonstrated over 90% reductions of carbon monoxide (CO) and particulate matter, and over 50% reduction in nitrogen oxides (NO_x) compared to commercial diesel engines. Natural gas can be stored either onboard a vehicle as Compressed Natural Gas (CNG) at 3,000 or 3,600 psi (Figure 6.7) or as Liquefied Natural Gas (LNG) at typically 20-150 psi (Figure 6.8); and

Figure 6.7 Truck that uses CNG(124).

Figure 6.8 Truck that uses LNG(124).

Figure 6.9 Truck that uses LPG(124).

- ***Liquefied Petroleum Gas***: Liquefied Petroleum Gas (LPG) or propane is a popular alternative fuel choice for vehicles in USA, because the infrastructure of pipelines, processing facilities, and storage for its efficient distribution already exists. Furthermore, LPG, which is a by-product of natural gas processing and crude oil refining, produces fewer vehicle emissions than gasoline. Figure 6.9 shows a truck that uses LPG.

It must be noted that certain types of heavy-duty vehicles have an engine that can use combination of alternative fuel types, such as the refuse collection truck shown in picture 6.10, which can use CNG and LNG.

Figure 6.10 Truck that uses CNG and LNG(124).

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)(163) 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.

REFERENCES

Literature

1. Αντωνίου, Β., "Οι Γεωπεριβαλλοντικές Συνθήκες του Λεκανοπεδίου Αθηνών με Χρήση Γεωγραφικών Πληροφοριακών Συστημάτων", Διδακτορική Διατριβή, Τμήμα Γεωλογίας, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών, Αθήνα, Ελλάδα, 2000.
2. Arner R., "Learning from History – So as not to repeat it", 2001.
3. Bombelly V., KOBA, "The Analysis Report of Plant No 2 – Cofiring of biomass– Evaluation of Fuel Procurement and Handling in Selected Existing Plants and Exchange of Information (COFIRING) – Part 2 – ASM Brescia S.P.A. – Italy", Altener AFB – NET V.
4. Bontoux, L., "The Incineration of Waste in Europe: Issues and Perspectives", Institute for Prospective Technological Studies, Brussels, Luxembourg, 1999.
5. Γαβριλάκης, Κ., "Απορρίμματα: Προβλήματα και η Αντιμετώπισή τους", Υπουργείο Εθνικής Παιδείας και Θρησκευμάτων, Αθήνα, Ελλάδα, 2000.
6. Γαλενιάνος, Τ., Κατσούλης, Α., Παπαδόπουλος, Δ., ΑΡΣΗ, Personal Communication, 2005.
7. Γενική Γραμματεία Περιφέρεια Αττικής, "Περιφερειακό Επιχειρησιακό Πρόγραμμα (ΠΕΠ) Αττικής 2000 – 2006", Αθήνα, Ελλάδα, 2001.
8. Christodoulou, K., Retzepis, I., "Environmental Impact Study for Project: Final Remediation of Completed Slopes of the Ano Liossia Waste Disposal Site", ACMAR, Athens, Greece, 1996.
9. Columbus, G., "Municipal Solid Waste Management in Greece and Examination of Application of Waste-to-Energy in Attica – **Work in Progress**", Industrial Ecology – Earth Resources, Department of Earth and Environmental Engineering, Columbia University, NY, USA, 2004.
10. Columbus, G., "Transportation & Waste Management at Willets Point and the Examination of Application of Waste-to-Energy", Urban Ecology Studio – Wasteland to Eco-Industrial Park, Department of Earth and Environmental Engineering, Columbia University, NY, USA, 2005.
11. Commission des Communautés Européennes, "22éme Rapport Annuel sur le Controle de l' Application du Droit Communautaire (2004) – Document de Travail des Services de la Commission Situation dans les Differents Secteurs – Annexe au COM(2005)570", Commission des Communautés Européennes, Bruxelles, Belgique, 2005.
12. Εθνικό Κέντρο Περιβάλλοντος και Αειφόρου Ανάπτυξης, "Βιώσιμη Ελλάδα & το Μεσογειακό Σχέδιο Δράσης", Κείμενα Εργασίας του ΕΚΠΑΑ, Αριθμός 9, Ελλάδα, 2001.

13. Ελευθεριάδης Χ., "Η Νέα Μονάδα Μηχανικής Διαλογής – Κομποστοποίησης Στερεών Αστικών Αποβλήτων στα Άνω Λιόσια", ENVITEC, Αθήνα, Ελλάδα, 2001.
14. Estevez P., "Management of Municipal Solid Waste in Santiago, Chile: Assessing Waste-to-Energy Possibilities", Industrial Ecology – Earth Resources, Department of Earth and Environmental Engineering, Columbia University, NY, USA, 2003.
15. Eunomia – Research and Consulting, "Economic Analysis of Options for Managing Biodegradable Municipal Waste – Final Report to the European Commission".
16. Fountoulis I., Mariolakos D., Spyridonos E., Andreadakis E., "Geological Criteria and Methodology for Landfill Sites Selection", Athens, Greece.
17. Gidarakos, E., Havas, G., Ntzamilis, P., "Municipal Solid Waste Composition Determination Supporting the Integrated Solid Waste Management System in the Island of Crete", Waste Management, In Press, 2005.
18. Gnardelli, T., "Waste Management in Greece – A General Overview on the Problem of Solid Wastes", Hellenic Court of Audit, Athens, Greece, 2005.
19. Hester R.E., Harrison R.M., "Issues in Environmental Science and Technology – Waste Treatment Disposal", Royal Society of Chemistry, Bath Press, Great Britain, 1995.
20. Hogg D., Barth J., Favoino E., Centemero M., Caimi V., Amlinger F., Devliegher W., Brinton W., Antler S., "Review of Compost Standards in Greece", WRAP, 2002.
21. Θέμελης, Ν.Ι., "Επίσκεψη του ΧΥΤΑ Άνω Λιοσίων", 2002.
22. Θέμελης, Ν.Ι., Παναγιωτακόπουλος, Δ., "Θερμική Επεξεργασία Απορριμμάτων – Μια Ανατροπή", ΚΑΘΗΜΕΡΙΝΗ, Αθήνα, Ελλάδα, 2003.
23. Kamuk, B., "Waste-to-Energy: The Environmental Perspective in Europe", North American Waste-To-Energy Conference, Florida, USA, 2005.
24. Καραλέμας, Ν.Δ., "Μηχανισμοί Λειτουργίας των Πηγών του Ανατολικού Ταϋγέτου", Διπλωματική Εργασία, Τμήμα Γεωλογίας και Γεωπεριβάλλοντος, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών, Αθήνα, Ελλάδα, 2006.
25. Καρούμπαλη, Θ., Κολόμβου, Γ., "Πάγος και Παγετώνες", Τμήμα Γεωλογίας, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών, Αθήνα, Ελλάδα, 2000.
26. Kaufmann S.M., Goldstein N., Millrath K., Themelis N.J., "State of Garbage in America – 14th Annual Nationwide Survey of Solid Waste Management in the United States", NY, USA, 2004.
27. Kolocotroni, C., Cossu, R., Gioulis, Y., Tsetsis, C., "Design and Construction of the Athens Landfill", Athens, Greece.
28. Κριτσόβα Κ., Κολοκυθάς, Ι., Τσούτσος, Employees of HERRCo Mechanical Sorting Center at Maroussi, Personal Communication, 2005.
29. Λαντζουράκης Γ., "Πρόγραμμα Διαχείρισης Στερεών Αποβλήτων Αττικής – Σχεδιασμός και Υλοποίηση", ΕΣΔΚΝΑ, Αθήνα, Ελλάδα, 2001.
30. Λέκκας, Ε., Παπανικολάου Δ., Γουλιώτης, Λ., Παπασπυρόπουλος, Κ., "Τεχνική Μελέτη Περιβαλλοντικής Αποκατάστασης Χώρου Ανεξέλεγκτης Διάθεσης Αποβλήτων – Θέση

«Δρίζες» Κοινότητας Βαρνάβα, Ν. Αττικής", Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών – Τμήμα Γεωλογίας και Γεωπεριβάλλοντος, Υπουργείο Εσωτερικών, Δημόσιας Διοίκησης και Αποκέντρωσης, Κεντρική Ένωση Δήμων και Κοινοτήτων Ελλάδας, Αθήνα, Ελλάδα, 2005.

31. Λέκκας, Ε., Παπανικολάου Δ., Γουλιώτης, Λ., Παπασπυρόπουλος, Κ., "Τεχνική Μελέτη Περιβαλλοντικής Αποκατάστασης Χώρου Ανεξέλεγκτης Διάθεσης Αποβλήτων – Θέση «Σαλαμίδι» Κοινότητας Καπανδριτίου, Ν. Αττικής", Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών – Τμήμα Γεωλογίας και Γεωπεριβάλλοντος, Υπουργείο Εσωτερικών, Δημόσιας Διοίκησης και Αποκέντρωσης, Κεντρική Ένωση Δήμων και Κοινοτήτων Ελλάδας, Αθήνα, Ελλάδα, 2005.
32. Mahoney P.F., "Solid Waste as an Economic Generator for Sustainable Development", Energy Answers Corporation – The Resource Recovery Company, NY, USA, 2001.
33. Μακεδονική, Ημερήσιος Τύπος Νομού Ημαθίας, "Τεύχος: 19-20 Αυγούστου 2006", Βέροια, Ελλάδα, 2006.
34. Μανιάτη, Μ., Καρακάσης, Π., Κρητικάκος, Μ., Engineers, Employees at Ano Liossia Sanitary Landfill, Personal Communication, 2004 – 2005.
35. Μαριολάκος, Η., Νασοπούλου, Σ., Μπαντέκας Ι., Σίσκου, Λ., Αδαμαντιάδου, Σ., Γεωργιάδης, Λ., Κατσίκας, Ν., Ταπεινάκη, Σ., Οργάνωση Μέσων Ερμηνείας Περιβάλλοντος ΕΠΕ, "Αναβιώνοντας τη Λαμπρότητα του Αττικού Τοπίου – Ανάδειξη και Προβολή του Αττικού Τοπίου με Γεωπολιτιστικές Διαδρομές και Μονοπάτια", Έκθεση Προόδου, ΥΠΕΧΩΔΕ, Αθήνα, Ελλάδα, 2001.
36. Μαυρόπουλος, Α., "Ζητήματα Διαχείρισης Στερεών Αποβλήτων… Εν Θερμώ", Εταιρεία Περιβαλλοντικών Μελετών, Αθήνα, Ελλάδα, 2005.
37. MEPPPW, "Country Profile - Greece – National Reporting to the 12th Session to the Commission on Sustainable Development of the United Nations (UN CSD 12)", Athens, Greece, 2004.
38. Mitsos, N., CEO, Managing Director of Financial Sciences Corporation, Personal Communication, 2006.
39. Murck, B.W., Skinner, B.J., "Geology Today – Understanding Our Planet", John Wiley & Sons, Inc., USA, 1999.
40. National Center for the Environment and Sustainable Development, "Environmental Signals – A Report on Sustainability Indicators", Greece, 2003.
41. Official Journal of the European Communities, "Common Position (EC) No 7/2000 Adopted by the Council on 25 November 1999 with a View to Adopting Directive 2000/…/EC of the European Parliament and of the Council of… on the Incineration of Waste – 2000/C 25/02", 2000.
42. Παναγιωτακόπουλος Δ.Χ., "Βιώσιμη Διαχείριση Αστικών Στερεών Αποβλήτων", ΖΥΓΟΣ, Θεσσαλονίκη, Ελλάδα, 2002.

43. Παπακωνσταντίνου, Α., Φώτου, Γ., “Συστήματα Διαχείρισης Απορριμμάτων για Παραγωγή και Εξοικονόμηση Ενέργειας”, Σχολή Τεχνολογικών Εφαρμογών, ΤΕΙ Χαλκίδας, Χαλκίδα, Ελλάδα, 2004.
44. Papanikolaou, D.I., Lekkas, E., Sideris, C., Fountoulis, I., Danamos, G., Kranis, C., Lozios, S., Antoniou, I., Vassilakis, E., Vasilopoulou, S., Nomikou, P., Papanikolaou, I., Skourtsos, E., Soukis, K., “Geology and Tectonics of Western Attica in relation to the 7-9-99 Earthquake”, European Center on Prevention and Forecasting of Earthquakes, Athens, Greece, 1999.
45. Πασχάλη-Μάνου, Κ., Τσομπανίδης Χ., Λώλος Φ., “Αναθεώρηση Περιφερειακού Σχεδίου Διαχείρισης Στερεών Αποβλήτων (ΠΕ.Σ.Δ.Α.)”, Περιφέρεια Αττικής, Αθήνα, Ελλάδα, 2005.
46. Perry R.H., Green D.W., Maloney J.O., “Perry’s Chemical Engineers’ Handbook”, 7th Edition, McGraw-Hill, USA, 1997.
47. Porteous A., “Incineration of Residual Municipal Solid Waste for Both Energy Recovery and Environmentally Sound Waste Disposal – A Consideration of a Selected Major Non-economic Determinants”, Journal of the Institute of Energy, The H.W. Wilson Company, 2001.
48. Rand T., Haukohl J., Marxen U., “World Bank Technical Paper No 462 - Municipal Solid Waste Incineration – Requirements for a Successful Project”, The World Bank Washington D.C., USA, 2000.
49. Rylander H., Haukohl J., “Status of WTE in Europe”, Waste Management World, International Solid Wastes Association, 2002.
50. Skodras, G., Amarantos, P.S., Papadopoulou, E., Kakaras, E., “Utilization of Landfill Gas for Energy Production – Operational Experience from a 13.8 MW_e Power Plant”, Organization for the Promotion of Energy Technologies, Greece.
51. Σκορδίλης, Α.Δ., “Η Θερμική Επεξεργασία Απορριμμάτων και RDF”, ΚΟΣΜΟΣ ΕΠΕ, Αθήνα, Ελλάδα, 1997.
52. Σύψας Κ., Αρβανίτης Γ., Members of ACMAR, Personal communication, 2004.
53. Sunk, W., “Field Trip to Resource Recycling, L.L.C., Pinellas Facility, St. Petersburg, Pinellas County, FL”, NY, USA, 2006.
54. Sunk, W., Columbus, G., “Field Trip to Montenay Dutchess County RRF, Poughkeepsie, NY”, NY, USA, 2006.
55. Τεχνική Αναπτυξιακή «Άλφα-Άλφα»,. “Σύστημα Αποκομιδής Απορριμμάτων με Κάδους Μεγάλης Χωρητικότητας Εγκατεστημένους στο Έδαφος”, Δημοτική Επιχείρηση Δήμου Αγίων Αναργύρων, Αθήνα, Ελλάδα.
56. Themelis, N.J, “An Overview of the Global Waste-to-Energy Industry”, Waste Management World, International Solid Waste Association, USA, 2003.
57. Themelis, N.J., “Industrial Ecology in Managing Solid Wastes”, USA, 2004.
58. Themelis, N.J., “Integrated Waste Management of Solid Wastes”, USA, 2004.

59. Themelis, N.J., Gregory, A.F., "Sources and Material Balance of Mercury in the NY-NJ Harbor", New York Academy of Sciences, NY, USA, 2001.
60. Themelis, N.J., Kim, Y.H., Brady, M.H., "Energy Recovery from New York City Solid Wastes", ISWA Journal: Waste Management and Research, NY, USA, 2002.
61. Themelis, N.J., Personal Communication, 2006.
62. Tsalavoutas, S., Kapoutsis, G., Zahilas, L., "Leonardo Pilot Project Recy-Occupation - Survey of the Greek Recycling Sector", Leonardo Da Vinci II, Organization for Vocational Education and Training, Athens, Greece, 2002.
63. Τσίλογλου, Employee of HERRCo Mechanical Sorting Center at Aspropyrgos, Personal Communication, 2006.
64. Tsotsos D., Crowe M., Nolan K., Collins C., Carty G., Donlon B., Kristoffersen M., Brøgger M., Carlsbæk M., Hummelshøj R.M., Thomsen C.D., "Biodegradable Municipal Waste Management in Europe – Part 3: Technology and Market Issues", European Topic Center on Waste, European Environment Agency, Copenhagen, Denmark, 2002.
65. Υπουργείο Ανάπτυξης – Διεύθυνση Υδατικού Δυναμικού και Φυσικών Πόρων, Εθνικό Μετσόβιο Πολυτεχνείο, Ινστιτούτο Γεωλογικών και Μεταλλευτικών Ερευνών, Κέντρο Προγραμματισμού και Οικονομικών Ερευνών, "Σχέδιο Προγράμματος Διαχείρισης των Υδατικών Πόρων της Χώρας", Υπουργείο Ανάπτυξης, Αθήνα, Ελλάδα, 2003.
66. Υπουργείο Οικονομίας και Οικονομικών – Διαχειριστική Αρχή του ΚΠΣ, "Εθνικό Στρατηγικό Πλαίσιο Αναφοράς 2007 – 2013 – Στρατηγικό Μέρος", Υπουργείο Οικονομίας και Οικονομικών, Αθήνα, Ελλάδα, 2005
67. Υπουργείο Περιβάλλοντος, Χωροταξίας & Δημοσίων Έργων, "Γ΄ Κοινοτικό Πλαίσιο Στήριξης – Επιχειρησιακό Πρόγραμμα «Περιβάλλον» 2000 – 2006", Αθήνα, Ελλάδα, 2001.
68. US Environmental Protection Agency, "Decision-Maker's Guide to Solid Waste Management, Volume II", USA, 1995.
69. Φελεσκούρα, Χ., Παπαϊωάννου, Ε., "Σύγχρονες Τεχνολογίες Ανακύκλωσης Απορριμμάτων – Διαχείριση και Ενεργειακή Αξιοποίηση Απορριμμάτων", Σχολή Τεχνολογικών Εφαρμογών, ΤΕΙ Χαλκίδας, Χαλκίδα, Ελλάδα, 2004.
70. Φραντζής, Ι., "Καταγραφή Χώρων Ανεξέλεγκτης Απόρριψης στην Περιφέρεια Αττικής και Εξυγίανσή τους με Βάση τις Προδιαγραφές που Θέτουν οι Αντίστοιχες Κοινοτικές Οδηγίες – Τεύχος Α'", Ι. Φραντζής και Συντελεστές ΕΠΕ, Αθήνα, Ελλάδα, 1995.
71. Vesilind, P.A., Worrell, W., Reinhart, D., "Solid Waste Engineering", Brooks/Cole, Thomson Learning, Inc., CA, USA, 2002.
72. Weinstein, P. E., "Waste-to-Energy As a Key Component of Integrated Solid Waste Management for Santiago, Chile: A Cost Benefit Analysis", MS Thesis, Department of Earth and Environmental Engineering, Columbia University, NY, USA, 2006.
73. Winrock International Institute for Agricultural Development, "A Report of the Office of Energy, Environment and Technology Center for Environment Bureau for Global

Programs, Field Support and Research Unites States Agency for International Development – Mining the Urban Waste Stream for Energy: Options, Technological Limitations, and Lessons from the Field", Report No. 96-02, VA, USA, 1996.

Resources from the Internet

74. http://aix.meng.auth.gr/
75. http://biodiversity.eionet.eu.int/
76. http://dggsl.geol.uoa.gr/
77. http://earth.google.com/
78. http://earthquake.usgs.gov/
79. http://eedsa.duth.gr/
80. http://emidius.mi.ingv.it/
81. http://en.wikipedia.org/wiki/
82. http://enviro.accessbrownsville.com/
83. http://euro.recycle.net/
84. http://europa.eu.int/
85. http://linuxweb.internet.gr/
86. http://marianna.4t.com/
87. http://msw.cecs.ucf.edu/
88. http://news.kathimerini.gr/
89. http://org.eea.eu.int/
90. http://plato_dialogues.org/
91. http://preview.citect.com/
92. http://search.eb.com/
93. http://ta-nea.dolnet.gr/
94. http://tovima.dolnet.gr/
95. http://udec.org.ua/
96. http://uk.encarta.msn.com/
97. http://users.in.gr/
98. http://users.otenet.gr/
99. http://vangelakas.blogspot.com/
100. http://websrv5.sdu.dk/
101. http://wte.cbll.net/
102. http://www1.greece.gr/
103. http://www1.industry.gov.au/
104. http://www.acci.gr/
105. http://www.aia.gr/
106. http://www.ametro.gr/
107. http://www.ams.usda.gov/

108. http://www.ansaldoenergia.com/
109. http://www.aodos.gr/
110. http://www.asda.gr/
111. http://www.athensnews.gr/
112. http://www.athens-trolley.gr/
113. http://www.aviation.gr/
114. http://www.barlowprojects.com/
115. http://www.boatnerd.com/
116. http://www.boldeco.com/
117. http://www.boldrocchi.it/
118. http://www.cia.gov/
119. http://www.co.frederick.md.us/
120. http://www.drgeorgepc.com/
121. http://www.ecop.ucl.ac.be/
122. http://www.ecorec.gr/
123. http://www.edrasis.gr/
124. http://www.eere.energy.gov/
125. http://www.ekby.gr/
126. http://www.elefsina.gr/
127. http://www.elot.gr/
128. http://www.elval.gr/
129. http://www.empedos.gr/
130. http://www.energyanswers.com/
131. http://www.energydevelopments.com/
132. http://www.enet.gr/
133. http://www.enostos.net/
134. http://www.epper.gr/
135. http://www.eranet.gr/
136. http://www.esdkna.gr/
137. http://www.ethel.gr/
138. http://www.eubionet.net/
139. http://www.evrytanika.gr/
140. http://www.eydap.gr/
141. http://www.gec.jp/
142. http://www.gein.noa.gr/
143. http://www.ggde.gr/
144. http://www.gicaonline.com/
145. http://www.gorail.org/
146. http://www.helector.gr/

147. http://www.helesi.com/
148. http://www.herrco.gr/
149. http://www.iapws.jp/
150. http://www.industrialairsolutions.com/
151. http://www.isap.gr/
152. http://www.istoselides.gr/
153. http://www.kaoussis.gr/
154. http://www.kathimerini.gr/
155. http://www.maps.com/
156. http://www.martingmbh.de/
157. http://www.mem.gr/
158. http://www.minenv.gr/
159. http://www.modus.gr/
160. http://www.moneymarket.gr/
161. http://www.montenay.com/
162. http://www.nce-ltd.co.jp/
163. http://www.oanda.com/
164. http://www.oasa.gr/
165. http://www.oeaaa.faa.gov/
166. http://www.olp.gr/
167. http://www.ose.gr/
168. http://www.p2pays.org/
169. http://www.proastiakos.gr/
170. http://www.roadtraffic-technology.com/
171. http://www.seas.columbia.edu/
172. http://www.statistics.gr/
173. http://www.tagmaster.com/
174. http://www.teknikon.gr/
175. http://www.tomh-ae.gr/
176. http://www.tomi.gr/
177. http://www.tva.gov/
178. http://www.uest.gr/
179. http://www.unep.or.jp/
180. http://www.usconsulate.gr/
181. http://www.virtualtourist.com/
182. http://www.wcities.com/
183. http://www.wte.org/
184. http://www.ypes.gr/

APPENDICES

APPENDIX A

Area and Population of the OLAs of the Region of Attica

OLA	Area (km^2)	Population 2001	Population Density 2001 (inhabitants/km^2)	Population 2006	Population Density 2006 (inhabitants/km^2)
Attica	**3,806**	**3,761,810**	**988**	**4,929,695**	**1,295**
ATHENS-PIRAEUS PREFECTURE					
Municipality of Aegalaeo	6.5	74,046	11,347	74,046	11,347
Municipality of Aegina	88.8	13,552	153	13,000	146
Municipality of Aghia Paraskevi	8.3	56,836	6,870	69,033*	8,344
Municipality of Aghia Varvara	2.1	30,562	14,586	37,121*	17,716
Municipality of Aghii Anargyri	3.3	32,957	10,066	32,957	10,066
Municipality of Aghios Dimitrios	5.1	65,173	12,905	79,159*	15,675
Municipality of Aghios Ioannis Rendis	4.5	15,060	3,318	15,060	3,318
Municipality of Alimos	5.9	38,047	6,427	46,212*	7,806
Municipality of Ambelakia	14.9	7,060	475	8,500	572
Municipality of Argyroupoli	8.0	33,158	4,145	50,000	6,250
Municipality of Athens	38.9	745,514	19,158	772,072	19,840
Municipality of Callithea	4.6	109,609	23,696	133,131*	28,781
Municipality of Camatero	5.9	22,234	3,796	31,000	5,293
Municipality of Chaidari	23.1	46,276	2,003	62,500	2,705
Municipality of Chalandri	9.5	71,684	7,543	87,067*	9,162
Municipality of Cholargos	3.8	32,166	8,403	70,000	18,287
Municipality of Corydallos	4.5	67,456	14,953	105,000	23,275
Municipality of Daphne	1.4	23,674	16,910	26,000	18,571

* Estimated Values.

OLA	Area (km^2)	Population 2001	Population Density 2001 (inhabitants/km^2)	Population 2006	Population Density 2006 (inhabitants/km^2)
Municipality of Drapetsona	1.7	12,944	7,422	13,699	7,854
Municipality of Ellinico	7.6	16,740	2,195	17,500	2,294
Municipality of Galatsi	4.2	58,042	13,771	80,000	18,980
Municipality of Glyfada	25.6	80,409	3,145	97,665*	3,820
Municipality of Hydra	65.5	2,719	41	2,581	39
Municipality of Hymettus	1.1	11,139	10,126	13,529*	12,299
Municipality of Ilion	9.3	80,859	8,729	98,211*	10,603
Municipality of Ilioupoli	12.7	75,904	5,978	92,193*	7,260
Municipality of Irakleo	4.7	45,926	9,767	55,782*	11,863
Municipality of Keratsini	8.0	76,102	9,564	76,102	9,564
Municipality of Kesariani	7.8	26,419	3,387	32,089*	4,114
Municipality of Kifissia	26.1	43,929	1,683	60,000	2,299
Municipality of Kythira	278.6	3,354	12	4,074*	15
Municipality of Lycovryssi	2.0	8,116	4,103	10,400	5,258
Municipality of Maroussi	13.0	69,470	5,341	120,000	9,225
Municipality of Melissia	3.9	19,526	4,964	30,000	7,627
Municipality of Metamorphosi	5.5	26,448	4,851	26,448	4,851
Municipality of Methana	50.1	2,057	41	2,498*	50
Municipality of Moschato	2.6	23,153	9,047	30,000	11,723
Municipality of Nea Chalkidona	0.8	10,112	13,436	10,112	13,436
Municipality of Nea Eryhtraea	5.1	15,439	3,032	22,000	4,321
Municipality of Nea Ionia	4.4	66,017	14,873	90,000	20,276
Municipality of Nea Philadelphia	2.8	24,112	8,699	40,000	14,431
Municipality of Nea Smyrni	3.5	73,986	21,217	130,000	37,280

OLA	Area (km^2)	Population 2001	Population Density 2001 (inhabitants/km^2)	Population 2006	Population Density 2006 (inhabitants/km^2)
Municipality of Neo Psychiko	1.1	10,848	10,120	16,000	14,926
Municipality of Nickaea	6.7	93,086	13,986	93,000	13,974
Municipality of Palaeo Phaliro	4.8	64,759	13,615	90,000	18,922
Municipality of Papagos	3.3	13,207	3,988	18,000	5,435
Municipality of Pefki	2.1	19,887	9,429	28,000	13,276
Municipality of Perama	14.8	25,720	1,743	35,000	2,373
Municipality of Peristeri	10.7	137,918	12,898	167,515*	15,666
Municipality of Petroupoli	6.8	48,327	7,125	75,000	11,058
Municipality of Philothei	2.2	7,310	3,268	8,879*	3,969
Municipality of Piraeus	11.2	175,697	15,651	450,000	40,085
Municipality of Poros	48.8	4,348	89	5,281*	108
Municipality of Psychiko	2.7	10,901	3,967	10,500	3,821
Municipality of Salamina	81.2	30,962	381	30,000	369
Municipality of Spetses	20.6	3,916	190	4,756*	231
Municipality of Tavros	2.3	14,963	6,498	50,000	21,714
Municipality of Trizina	192.1	6,507	34	7,903*	41
Municipality of Vrilissia	3.6	25,582	7,157	40,000	11,190
Municipality of Vyronas	9.3	61,102	6,558	115,000	12,342
Municipality of Zografou	8.7	76,115	8,792	76,115	8,792
Community of Aghistri	13.5	920	68	1,117*	83
Community of Antikythira	20.1	44	2	40	2
Community of Ekali	4.4	5,190	1,178	5,378	1,221
Community of Nea Pendeli	3.1	6,156	2,002	7,477*	2,432
Community of Pendeli	24.7	4,829	196	5,865*	238
TOTAL	**1,284**	**3,206,280**	**2,497**	**4,207,569**	**3,276**

WESTERN ATTICA PREFECTURE					
OLA	**Area (km^2)**	**Population 2001**	**Population Density 2001 (inhabitants/km^2)**	**Population 2006**	**Population Density 2006 (inhabitants/km^2)**
Municipality of Ano Liossia	38.1	26,423	694	32,093[*]	843
Municipality of Aspropyrgos	101.6	27,741	273	40,000	394
Municipality of Elefsina	18.6	25,863	1,393	30,000	1,616
Municipality of Erythrae	60.9	3,326	55	3,519	58
Municipality of Mandra	206.9	12,792	62	18,000	87
Municipality of Megara	325.0	28,195	87	34,246[*]	105
Municipality of Nea Peramos	5.0	7,480	1,486	9,085[*]	1,805
Municipality of Phyli	69.1	2,947	43	5,000	72
Municipality of Vilia	144.6	3,215	22	3,905[*]	27
Municipality of Zephyri	1.4	8,860	6,229	9,000	6,327
Community of Inoe	14.3	765	54	929[*]	65
Community of Magoula	18.1	4,005	222	4,864[*]	269
TOTAL	**1,004**	**151,612**	**151**	**190,642**	**190**
EASTERN ATTICA PREFECTURE					
Municipality of Acharnae	145.6	75,341	517	120,000	824
Municipality of Aghios Stephanos	7.8	9,451	1,215	11,479[*]	1,476
Municipality of Artemida (Loutsa)	22.0	17,391	792	32,500	1,480
Municipality of Avlona	107.4	5,184	48	6,296[*]	59
Municipality of Calyvia Thorikou	66.1	12,202	184	14,821[*]	224
Municipality of Cropia	110.0	25,325	230	26,000	236
Municipality of Dionyssos	20.1	4,987	248	6,000	298
Municipality of Glyka Nera	9.7	6,623	685	8,044[*]	832
Municipality of Kerataea	129.2	13,246	103	16,089[*]	125
Municipality of Lavraeotiki	36.2	10,612	293	10,620	294

OLA	Area (km^2)	Population 2001	Population Density 2001 (inhabitants/km^2)	Population 2006	Population Density 2006 (inhabitants/km^2)
Municipality of Marathon	95.2	8,882	93	10,788*	113
Municipality of Marcopoulo Mesogaeas	82.8	15,608	189	18,957*	229
Municipality of Nea Makri	36.9	14,809	401	18,000	488
Municipality of Paeania	43.3	13,013	301	15,806*	365
Municipality of Pallini	18.5	16,679	899	20,258*	1,092
Municipality of Rafina	18.8	11,909	633	12,048	640
Municipality of Spata	51.9	10,203	196	11,000	212
Municipality of Vari	18.7	10,998	588	10,500	562
Municipality of Voula	9.3	25,532	2,751	40,000	4,310
Municipality of Vouliagmeni	6.2	6,442	1,044	6,440	1,043
Municipality of Yeracas	8.0	13,921	1,745	25,000	3,133
Community of Aghios Constantinos	10.6	687	65	1,500	142
Community of Anavyssos	14.6	7,189	493	8,500	583
Community of Anixi	4.1	5,397	1,317	6,736	1,643
Community of Anthoussa	4.0	3,024	751	3,050	757
Community of Aphidnae	35.7	2,543	71	2,500	70
Community of Calamos	44.5	5,468	123	6,641*	149
Community of Capandriti	38.0	2,937	77	3,567*	94
Community of Couvaras	25.1	1,704	68	2,070*	82
Community of Cryoneri	4.6	2,721	596	6,000	1,315
Community of Drossia	2.3	5,865	2,546	7,000	3,039
Community of Grammatico	57.0	1,486	26	1,805*	32
Community of Malakassa	29.7	1,788	60	2,172*	73
Community of Marcopoulo Oropou	23.5	3,894	166	3,894	166

OLA	Area (km^2)	Population 2001	Population Density 2001 (inhabitants/km^2)	Population 2006	Population Density 2006 (inhabitants/km^2)
Community of Oropos	30.6	8,674	283	10,535*	344
Community of Palaea Fokaea	23.0	3,123	136	3,793*	165
Community of Pikermi	20.6	2,931	142	3,560*	173
Community of Polydendri	12.7	1,438	113	1,747*	138
Community of Rodopoli	10.8	2,090	194	2,082	193
Community of Saronida	6.3	2,102	332	2,500	395
Community of Stamata	18.9	2,475	131	2,467	131
Community of Sykamino	17.4	1,522	87	1,849*	106
Community of Thracomakedones	3.5	4,780	1,369	4,870	1,395
Community of Varnava	37.1	1,722	46	2,000	54
TOTAL	**1,518**	**403,918**	**266**	**531,484**	**350**

Mountains of the Region of Attica(45)

Mountains and Hills		Maximum Elevation (in m)	Mountains and Hills		Maximum Elevation (in m)	Mountains and Hills		Maximum Elevation (in m)
1	Parnitha	1,413	14	Skarpa	573	27	Aghios Dimitrios	356
2	Kitheronas	1,409	15	Agriliki	558	28	Prophetis Helias	356
3	Yerania	1,369	16	Velatouri	532	29	Condra	335
4	Pateras	1,132	17	Olympus	487	30	Mavrovouni	335
5	Pendeli	1,108	18	Aegalaeo	463	31	Tsackiri	334
6	Hymettus	1,026	19	Caterini	458	32	Kitsou	333
7	Pastra	1,025	20	Pikilo	452	33	Tourkovounia	321
8	Dionyssovouni	651	21	Charvati	414	34	Ovriocastro	313
9	Mavrovouni	648	22	Mavrinora	405	35	Stavrocoraki	313
10	Paneo	648	23	Pyrgari	378	36	Perati	308
11	Mavrinora	646	24	Ribari	373	37	Bourani	300
12	Merenda	614	25	Cotroni	366			
13	Camari	588	26	Placa	359			

Caves of the Region of Attica(45)

Caves and Sinkholes		Regions or Mountains	Notes
1	Dardiza	Agriliki	cave
2	Agriliki		sinkhole
3	Agriliki		cave
4	unnamed		cave
5	Panas	Aegalaeo	cave
6	Osios Patapios	Yerania	cave
7	Soussaki Volcano		
8	Aghios Ierotheos		cave
9	Cacki Skala		cave
10	Dionyssos	Dionyssovouni	cave
11	Calamos	Camari	cave
12	Vergoutiani	Kitheronas	cave
13	Lookisthi		cave
14	Lookisthi		cave-sinkhole
15	Drakospilia		cave
16	Unnamed	Mavrinora	cave
17	Sykia		cave
18	Rachi		sinkhole
19	Choni Laghi	Merenda	sinkhole
20	Couvaras		cave
21	Thrakia Pliaka		cave
22	Thrakia unnamed		cave
23	Thrakia Majuni		cave
24	unnamed		sinkhole
25	Keratea	Paneo	cave
26	Megali Thrakia of Calyvia		cave
27	unnamed		cave
28	Cokinovrachos		sinkhole
29	Cokinovrachos		cave
30	Round Cave of Cokinobrachos		cave
31	Panas	Parnitha	cave
32	Keramidi		sinkhole
33	Tamiltheo		sinkhole
34	Goura		sinkhole
35	Moni Cliston		sinkhole

Caves and Sinkholes		Regions or Mountains	Notes
36	Dekelia	Parnitha	cave-sinkhole
37	Daveli		cave-sinkhole
38	Aghia Triada		cave
39	Mastoras		cave
40	unnamed Cave of Arma		cave
41	Caloyeros		cave
42	Alogopetra		cave
43	Premis		cave
44	Unnamed Cave of Goura		cave
45	Sahris		cave
46	Batakas		cave
47	Platy Vouno		cave
48	Corpis		cave
49	Vilia		cave
50	Ayeladitsa		cave
51	Charadros		cave
52	Aghia Marina		cave
53	Trypio Lithari		cave
54	Camariza		cave
55	Lykorachi		cave
56	Cakorema	Pastra	cave
57	Askitario		cave
58	M. Vathychori	Pateras	cave
59	Lykorachi		cave
60	Psatha		cave
61	Drambala		cave
62	Davelis	Pendeli	cave
63	Prophetis Helias		cave
64	unnamed		cave
65	Pyrna		cave
66	Thalossi		doline
67	Aghii Asomati		sinkhole
68	Nympaeo		cave
69	Nymphes of Pyrna		cave
70	Leondari	Hymettus	cave
71	Corakovouni		sinkhole
72	Corakovouni		cave

Caves and Sinkholes		Regions or Mountains	Notes
73	Asterio	Hymettus	sinkhole
74	Coryfogrammi		sinkhole
75	Coutouki		cave
76	Yidospilia		cave
77	Big Sinkhole of Pyrgos		sinkhole
78	Small Sinkhole of Pyrgos		sinkhole
79	Bibessis (Trypios Vrachos)		cave
80	Prophetis Helias		cave
81	Prophetis Helias		sinkhole
82	Prophetis Helias		cave-sinkhole
83	Thrakia Stavrou		cave
84	Stavros		sinkhole
85	Davelis Stavros		cave
86	Big Cave of Mavrovouni		cave
87	Small Cave of Mavrovouni		cave
88	Round Cave of Mavrovouni		cave
89	Big Sinkhole of Mavrovouni		sinkhole
90	Trypia Spilia		natural bridge
91	Mitromaras		cave
92	Cakavoula		cave-sinkhole
93	Thrakia Sykias at Vari		cave
94	Nympholiptos		cave
95	Trypa Zastani	Pikilo	doline
96	Chavossi (Chaos)	Charvati	doline
97	Vredos	Other	cave
98	Dragonera		cave
99	Nyphi of Cokinovouni		cave
100	Daveli Cave of Cokinovouni		cave
101	Kitsos		cave
102	Retsina		sinkhole
103	Siraghio		cave
104	Aretoussa		cave
105	Perachora		cave
106	Inoe		cave
107	Sounio		cave
108	Thoriko		sinkhole
109	Acropolis		cave-sinkhole
110	Cave of Phoebus at Acropolis		cave

Caves and Sinkholes		Regions or Mountains	Notes
111	Panas Cave at Acropolis	Other	cave
112	Panas Cave at Marathon		cave
113	Voula		cave-sinkhole
114	Prophetis Helias Cave at Rizoupoli		cave
115	Trypia Coryfi Cave at Palaea Fokaea		cave
116	Catafyi Cave at Palaea Fokaea		cave
117	Cave of Phoebus at Acropolis		cave
118	Tourkovounia		cave
119	Vouliagmeni		sinkhole
120	Megara		cave
121	Stavros Cave at Paeania		cave
122	Vraona		cave-doline
123	Lykos (Myrteza)		cave
124	Philiati		cave
125	Chavara		cave

Plains of the Region of Attica(45)

Plains and valleys	
1	Avlona
2	Marathon
3	Mesoghia Valley
4	Thoricou
5	Basin of Athens
6	Elefsina Valley (Thriassio Pedio)
7	Scourta
8	Megara
9	Inoe

Rivers of the Region of Attica(45)

Rivers and Streams	
1	Ilissos
2	Iridanos
3	Atticos Kifissos
4	Part of Assopos of the Viotea Region
5	Sarandapotamos
6	Gouras-Yannoulas
7	Coulouriotico

Rivers and Streams	
8	Zoerezas
9	Mavrorema
10	Charadros
11	Prossalessi
12	Rapendossas-Vrana
13	Valanaris-Megalo Rema
14	Proi Stiri
15	Vathyrema-Rema Chalandriou-Podoniftis

Lakes of the Region of Attica(45)

Lakes and Wetlands	
1	Assopos Estuary
2	Schinias Marsh
3	Parnitha (artificial)
4	Marathon (artificial)
5	Mavrolimni
6	Vouliagmenis
7	Vouliagmenis (Heraeou)
8	Coumoundourou

Bays of the Region of Attica(45)

Bays and Gulfs			
1	Chalcoutsi	17	Passa
2	Oropos	18	Sounio
3	Aghii Apostoli	19	Legrena
4	Aghia Marina	20	Anavyssos
5	Draconeras	21	Vari
6	Marathon	22	Vouliagmeni
7	Raphina	23	Cavouri
8	Loutsa	24	Phaliro
9	Vravrona	25	Piraeus
10	Porto Rafti	26	Keratsini
11	Avlaki	27	Elefsina
12	Cakis Thalassas	28	Megara
13	Dascalio	29	Calamaki
14	Tourkolimano	30	Schinos
15	Thorico	31	Psatha
16	Lavrio	32	Aegosthena

APPENDIX B

European legislative framework regarding the management of solid waste(178)

Directive 75/442/EOC	With regard to solid waste
Decision 76/431/EOC	With regard to the establishment of committee of management of waste
Resolution 90/518/EEC	With regard to the policy for management of waste
Regulation 93/259/EEC	Follow-up and control of the transportation of waste in the interior of Community as well as at the entry and their egression
Decision 94/774/EC	Decision with regard to the standardized document of follow-up that is reported in regulation 93/259
Decisions 94/741/EC and 97/622/EC	Questionnaires of reports of state - members that concern in the application of certain directives in the sector of waste
Resolution 97/311/EC	Community strategy for the management of waste
Directive 99/31/EC	With regard to the landfilling of waste
Decision 99/412/EC	Questionnaire on the obligations of report of states - members in virtue of article 41 paragraph of 2 regulation 93/259/EOC
Directive 2000/76/EC	Incineration of waste
Decision 2000/532/EC	Establishment of catalogue of waste (replacement of decision 94/3/EC)
Decision 2000/738/EC	Questionnaire with regard to the reports of states - members with regard to the application of directive 99/31/EC
Regulation 2002/2150/EC	Waste statistics
Decision 2003/33/EC	Determination of criteria and processes for the acceptance of waste in landfills according to article 16 and annex II of the directive 99/31/EC
Decision 2001/118/EC	Modification of 2000/532/EC
Directive 94/62/EC	Packaging and packaging waste
Decision 97/129/EC	Determination of system for the recognition of package materials according to directive 94/62/EC
Decision 97/138/EC	Determination of tables of the database system according to the directive 94/62/EC
Decision 2001/524/EC	With regard to the publication of report datum of standards EN 13428/13432:2000 at the Official Newspaper of European Communities in the framework of application of the directive 94/62/EC
Directive 91/156/EEC	Modification of directive 75/442/EEC
Decision 96/350/EC	Adaptation of annexes II A and II B of directive 75/442/EEC

National legislation regarding the management of urban solid waste(178)

Common Ministerial Decision 69728/824/1996	Measures and terms regarding the management of solid waste
Common Ministerial Decision 113944/1997	National plan in framework of the management of solid waste.
Common Ministerial Decision 114218/1997	Constitution of specifications framework and general programs for the management of solid waste.
Law 2939/2001	Packaging and alternative management of packaging and other products. Establishment of National Association for the alternative management of packaging and other products
Common Ministerial Decision 29407/3508/2002	Measures and terms for the landfilling of waste

Status of harmonization of National and European legislative frameworks regarding the management of solid waste(178)

Directive 75/442/EEC	Common Ministerial Decision 69728/824/1996
Decision 76/431/EEC	Instant validity in the National legislative framework
Resolution 90/518/EEC	Instant validity in the National legislative framework
Regulation 93/259/EEC	Common Ministerial Decision 29407/3508/2002
Decision 94/774/EC	Common Ministerial Decision 29407/3508/2002
Decisions 94/741/EC and 97/622/EC	Instant validity in the National legislative framework
Resolution 97/311/EC	Instant validity in the National legislative framework
Directive 99/31/EC	Common Ministerial Decision 29407/3508/2002
Decision 99/412/EC	Instant validity in the National legislative framework
Directive 2000/76/EC	
Decision 2000/532/EC	Common Ministerial Decision 69728/824/1996
Decision 2000/738/EC	Instant validity in the National legislative framework
Regulation 2002/2150/EC	Instant validity in the National legislative framework
Decision 2003/33/EC	
Decision 2001/118/EC	Instant validity in the National legislative framework
Directive 94/62/EC	Law 2939/2001
Decision 97/129/EC	
Decision 97/138/EC	
Decision 2001/524/EC	Instant validity in the National legislative framework
Directive 91/156/EEC	Common Ministerial Decision 69728/824/1996
	Common Ministerial Decision 113944/1997
	Common Ministerial Decision 114218/1997
Decision 96/350/EC	Common Ministerial Decision 69728/824/1996

APPENDIX C

Information regarding the municipal solid waste management system in the Region of Attica

OLA	Population 2006	MSW generation (t/d)	MSW generation (kg/capita/d)	Recycling	Disposal	ACMAR Member
Attica	**4,929,695**	**7,733**	**1.6**			
ATHENS-PIRAEUS PREFECTURE						
Municipality of Aegalaeo	74,046	121	1.6	no	ALSL(1)	yes
Municipality of Aegina	13,000	43	3.3	no	ALSL	no
Municipality of Aghia Paraskevi	69,033	100*	1.4	n/a#	ALSL	yes
Municipality of Aghia Varvara	37,121	38*	1.0	n/a	ALSL	yes
Municipality of Aghii Anargyri	32,957	52	1.6	yes	ALSL	yes
Municipality of Aghios Dimitrios	79,159	115*	1.5	n/a	ALSL	yes
Municipality of Aghios Ioannis Rendis	15,060	100	6.6	no	ALSL	yes
Municipality of Alimos	46,212	100*	2.2	no	UWDS(2), ALSL	yes
Municipality of Ambelakia	8,500	40	4.7	no	ALSL	yes
Municipality of Argyroupoli	50,000	20	0.4	yes	UWDS	yes
Municipality of Athens	772,072	1,400	1.8	yes	ALSL	yes
Municipality of Callithea	133,131	140*	1.1	n/a	ALSL	yes
Municipality of Camatero	31,000	50	1.6	no	ALSL	yes
Municipality of Chaidari	62,500	68	1.1	yes	ALSL	yes
Municipality of Chalandri	87,067	160*	1.8	n/a	ALSL	yes
Municipality of Cholargos	70,000	78	1.1	yes	ALSL	yes
Municipality of Corydallos	105,000	110	1.0	no	ALSL	yes

* Values of 2004 – National Technical University of Athens

\# n/a: not answered

(1) ALSL: Ano Liossia Sanitary Landfill

(2) UWDS: Uncontrolled Waste Disposal Site

OLA	Population 2006	MSW generation (t/d)	MSW generation (kg/capita/d)	Recycling	Disposal	ACMAR Member
Municipality of Daphne	26,000	35	1.3	yes	ALSL	yes
Municipality of Drapetsona	13,699	15	1.1	yes	ALSL	yes
Municipality of Ellinico	17,500	45	2.6	yes	ALSL	yes
Municipality of Galatsi	80,000	80	1.0	yes	ALSL	yes
Municipality of Glyfada	97,665	150*	1.5	n/a	ALSL	yes
Municipality of Hydra	2,581	5*	1.9	yes	UWDS	no
Municipality of Hymettus	13,529	5*	0.4	n/a	ALSL	yes
Municipality of Ilion	98,211	150	1.5	yes	ALSL	yes
Municipality of Ilioupoli	92,193	114*	1.2	n/a	ALSL	yes
Municipality of Irakleo	55,782	95*	1.7	n/a	ALSL	yes
Municipality of Keratsini	76,102	130	1.7	yes	ALSL	yes
Municipality of Kesariani	32,089	48*	1.5	n/a	ALSL	yes
Municipality of Kifissia	60,000	82	1.4	yes	ALSL	yes
Municipality of Kythira	4,074	5	1.1	no	UWDS	no
Municipality of Lycovryssi	10,400	32	3.1	yes	ALSL	yes
Municipality of Maroussi	120,000	170	1.4	yes	ALSL	yes
Municipality of Melissia	30,000	30	1.0	yes	UWDS	yes
Municipality of Metamorphosi	26,448	150	5.7	yes	ALSL	yes
Municipality of Methana	2,498	8	3.2	no	UWDS	no
Municipality of Moschato	30,000	120	4.0	n/a	ALSL	yes
Municipality of Nea Chalkidona	10,112	18	1.8	yes	ALSL	yes
Municipality of Nea Eryhtraea	22,000	45	2.0	yes	ALSL	yes
Municipality of Nea Ionia	90,000	140	1.6	no	UWDS	yes
Municipality of Nea Philadelphia	40,000	50	1.3	no	ALSL	yes
Municipality of Nea Smyrni	130,000	120*	0.9	no	ALSL	yes
Municipality of Neo Psychiko	16,000	40	2.5	yes	ALSL	yes

OLA	Population 2006	MSW generation (t/d)	MSW generation (kg/capita/d)	Recycling	Disposal	ACMAR Member
Municipality of Nickaea	93,000	126	1.3	yes	ALSL	yes
Municipality of Palaeo Phaliro	90,000	150	1.7	yes	ALSL	yes
Municipality of Papagos	18,000	28	1.6	no	ALSL	yes
Municipality of Pefki	28,000	25*	0.9	yes	ALSL	yes
Municipality of Perama	35,000	47	1.3	yes	ALSL	yes
Municipality of Peristeri	167,515	270*	1.6	no	ALSL	yes
Municipality of Petroupoli	75,000	38	0.5	yes	ALSL	yes
Municipality of Philothei	8,879	26*	2.9	n/a	ALSL	yes
Municipality of Piraeus	450,000	250	0.6	yes	ALSL	yes
Municipality of Poros	5,281	15	2.8	yes	UWDS	no
Municipality of Psychiko	10,500	40	3.8	yes	ALSL	yes
Municipality of Salamina	30,000	86	2.9	no	ALSL	yes
Municipality of Spetses	4,756	30	6.3	no	UWDS	no
Municipality of Tavros	50,000	58	1.2	yes	ALSL	yes
Municipality of Trizina	7,903	6	0.8	no	UWDS	no
Municipality of Vrilissia	40,000	48	1.2	yes	ALSL	yes
Municipality of Vyronas	115,000	110	1.0	n/a	ALSL	yes
Municipality of Zografou	76,115	120	1.6	yes	ALSL	yes
Community of Aghistri	1,117	3	2.7	yes	UWDS	no
Community of Antikythira	40	0.008	0.2	no	UWDS	no
Community of Ekali	5,378	7	1.3	no	ALSL	yes
Community of Nea Pendeli	7,477	18*	2.4	n/a	ALSL	yes
Community of Pendeli	5,865	11*	1.9	n/a	ALSL	yes
TOTAL	**4,207,569**	**6,128**				
WESTERN ATTICA PREFECTURE						
Municipality of Ano Liossia	32,093	40	1.2	no	ALSL	yes
Municipality of Aspropyrgos	40,000	90	2.3	yes	ALSL	yes

OLA	Population 2006	MSW generation (t/d)	MSW generation (kg/capita/d)	Recycling	Disposal	ACMAR Member
Municipality of Elefsina	30,000	34	1.1	yes	ALSL	yes
Municipality of Erythrae	3,519	5*	1.4	yes	ALSL	no
Municipality of Mandra	18,000	20	1.1	no	ALSL	yes
Municipality of Megara	34,246	55	1.6	yes	UWDS	no
Municipality of Nea Peramos	9,085	35	3.9	no	UWDS	no
Municipality of Phyli	5,000	17*	3.4	n/a	ALSL	yes
Municipality of Vilia	3,905	40	10.2	no	ALSL	yes
Municipality of Zephyri	9,000	14	1.6	no	ALSL	yes
Community of Inoe	929	3*	3.2	no	ALSL	no
Community of Magoula	4,864	8	1.5	yes	ALSL	yes
TOTAL	**190,642**	**361**				
EASTERN ATTICA PREFECTURE						
Municipality of Acharnae	120,000	150	1.3	no	ALSL	yes
Municipality of Aghios Stephanos	11,479	25*	2.2	n/a	ALSL	yes
Municipality of Artemida (Loutsa)	32,500	37	1.1	yes	ALSL	yes
Municipality of Avlona	6,296	11*	1.7	no	UWDS	no
Municipality of Calyvia Thorikou	14,821	69	4.7	no	UWDS	no
Municipality of Cropia	26,000	86	3.3	n/a	ALSL	no
Municipality of Dionyssos	6,000	14	2.3	yes	ALSL	yes
Municipality of Glyka Nera	8,044	30*	3.7	n/a	ALSL	yes
Municipality of Kerataea	16,089	50	3.1	no	UWDS	no
Municipality of Lavraeotiki	10,620	14	1.4	n/a	UWDS	no
Municipality of Marathon	10,788	13	1.2	no	ALSL	no
Municipality of Marcopoulo Mesogaeas	18,957	75	4.0	no	UWDS	no
Municipality of Nea Makri	18,000	60	3.3	yes	ALSL	yes
Municipality of Paeania	15,806	40*	2.5	n/a	UWDS	no

OLA	Population 2006	MSW generation (t/d)	MSW generation (kg/capita/d)	Recycling	Disposal	ACMAR Member
Municipality of Pallini	20,258	70*	3.5	n/a	ALSL	yes
Municipality of Rafina	12,048	56	4.6	yes	ALSL	yes
Municipality of Spata	11,000	12	1.1	no	ALSL	yes
Municipality of Vari	10,500	19	1.8	no	ALSL	yes
Municipality of Voula	40,000	50	1.3	yes	ALSL	yes
Municipality of Vouliagmeni	6,440	28	4.3	yes	ALSL	yes
Municipality of Yeracas	25,000	70	2.8	no	ALSL	yes
Community of Aghios Constantinos	1,500	2	1.3	no	UWDS	no
Community of Anavyssos	8,500	17	2.0	yes	UWDS	no
Community of Anixi	6,736	10	1.5	yes	ALSL	yes
Community of Anthoussa	3,050	9	3.0	no	UWDS, ALSL	yes
Community of Aphidnae	2,500	6	2.4	no	ALSL	yes
Community of Calamos	6,641	25	3.8	no	UWDS	no
Community of Capandriti	3,567	4*	1.1	n/a	UWDS	no
Community of Couvaras	2,070	18	8.7	no	UWDS	no
Community of Cryoneri	6,000	24	4.0	yes	ALSL	yes
Community of Drossia	7,000	18	2.6	no	ALSL	yes
Community of Grammatico	1,805	3	1.7	no	UWDS	no
Community of Malakassa	2,172	8	3.8	no	UWDS	no
Community of Marcopoulo Oropou	3,894	12*	3.1	no	UWDS	no
Community of Oropos	10,535	22	2.1	n/a	UWDS	no
Community of Palaea Fokaea	3,793	20	5.3	yes	UWDS	no
Community of Pikermi	3,560	21	5.9	no	ALSL	no
Community of Polydendri	1,747	4	2.3	no	ALSL	no
Community of Rodopoli	2,082	5	2.4	yes	ALSL	yes
Community of Saronida	2,500	7	2.8	no	ALSL	yes
Community of Stamata	2,467	8	3.2	no	ALSL	yes
Community of Sykamino	1,849	1	0.6	no	UWDS	no

OLA	**Population 2006**	**MSW generation (t/d)**	**MSW generation (kg/capita/d)**	**Recycling**	**Disposal**	**ACMAR Member**
Community of Thracomakedones	4,870	12	2.5	yes	ALSL	yes
Community of Varnava	2,000	10	5.0	yes	UWDS	no
TOTAL	**531,484**	**1,245**				

APPENDIX D

Estimated construction costs of the Western Attica Waste-to-Energy facility

Construction Costs	Year 1		Year 2	
	($million)	(€million)	($million)	(€million)
Beginning Cash	**203.7**	**160.0**	**331.0**	**260.0**
EPC				
Engineering Services	8.9	7.0	15.9	12.5
Procurement	133.0	104.5	221.5	174.0
Construction	48.4	38.0	81.4	63.9
Interest Expense	12.2	9.6	12.2	9.6
Remaining Amount	1.2	0.9	0.0	0.0

Capital structure of the Western Attica Waste-to-Energy facility after refinancing

Refinancing Amount	($million)	(€million)
	274.0	**215.3**
New Capital Structure		
Equity Investment	80.2	63.0
Debt	274.0	215.3

Course of the debt of the Western Attica Waste-to-Energy facility after refinancing

Principal: €215,250,000				
Rate: 5.5%				
Years: 25				
Months (€)	**Principal (€)**	**Interest (€)**	**Payment (€)**	**Balance (€)**
1	335,261	986,563	1,321,823	214,914,739
2	336,797	985,026	1,321,823	214,577,942
3	338,341	983,482	1,321,823	214,239,601
4	339,892	981,932	1,321,823	213,899,709
5	341,450	980,374	1,321,823	213,558,259
6	343,015	978,809	1,321,823	213,215,245
7	344,587	977,237	1,321,823	212,870,658
8	346,166	975,657	1,321,823	212,524,492
9	347,753	974,071	1,321,823	212,176,739
10	349,347	972,477	1,321,823	211,827,392
11	350,948	970,876	1,321,823	211,476,444
12	352,556	969,267	1,321,823	211,123,888
TOTAL	**4,126,112**	**11,735,768**	**15,861,880**	
13	354,172	967,651	1,321,823	210,769,716
14	355,795	966,028	1,321,823	210,413,921
15	357,426	964,397	1,321,823	210,056,494
16	359,064	962,759	1,321,823	209,697,430

Months (€)	Principal (€)	Interest (€)	Payment (€)	Balance (€)
17	360,710	961,113	1,321,823	209,336,720
18	362,363	959,460	1,321,823	208,974,356
19	364,024	957,799	1,321,823	208,610,332
20	365,693	956,131	1,321,823	208,244,640
21	367,369	954,455	1,321,823	207,877,271
22	369,053	952,771	1,321,823	207,508,218
23	370,744	951,079	1,321,823	207,137,474
24	372,443	949,380	1,321,823	206,765,031
TOTAL	**4,358,857**	**11,503,023**	**15,861,880**	
25	374,150	947,673	1,321,823	206,390,881
26	375,865	945,958	1,321,823	206,015,016
27	377,588	944,235	1,321,823	205,637,428
28	379,318	942,505	1,321,823	205,258,110
29	381,057	940,766	1,321,823	204,877,053
30	382,804	939,020	1,321,823	204,494,249
31	384,558	937,265	1,321,823	204,109,691
32	386,321	935,503	1,321,823	203,723,370
33	388,091	933,732	1,321,823	203,335,279
34	389,870	931,953	1,321,823	202,945,409
35	391,657	930,166	1,321,823	202,553,752
36	393,452	928,371	1,321,823	202,160,300
TOTAL	**4,604,731**	**11,257,149**	**15,861,880**	
37	395,255	926,568	1,321,823	201,765,045
38	397,067	924,756	1,321,823	201,367,978
39	398,887	922,937	1,321,823	200,969,091
40	400,715	921,108	1,321,823	200,568,376
41	402,552	919,272	1,321,823	200,165,825
42	404,397	917,427	1,321,823	199,761,428
43	406,250	915,573	1,321,823	199,355,178
44	408,112	913,711	1,321,823	198,947,066
45	409,983	911,841	1,321,823	198,537,083
46	411,862	909,962	1,321,823	198,125,222
47	413,749	908,074	1,321,823	197,711,472
48	415,646	906,178	1,321,823	197,295,827
TOTAL	**4,864,474**	**10,997,406**	**15,861,880**	
49	417,551	904,273	1,321,823	196,878,276
50	419,465	902,359	1,321,823	196,458,811
51	421,387	900,436	1,321,823	196,037,424
52	423,318	898,505	1,321,823	195,614,106
53	425,259	896,565	1,321,823	195,188,847
54	427,208	894,616	1,321,823	194,761,639
55	429,166	892,658	1,321,823	194,332,473
56	431,133	890,691	1,321,823	193,901,341
57	433,109	888,714	1,321,823	193,468,232
58	435,094	886,729	1,321,823	193,033,138
59	437,088	884,735	1,321,823	192,596,050
60	439,091	882,732	1,321,823	192,156,958
TOTAL	**5,138,868**	**10,723,012**	**15,861,880**	

Months (€)	Principal (€)	Interest (€)	Payment (€)	Balance (€)
61	441,104	880,719	1,321,823	191,715,854
62	443,126	878,698	1,321,823	191,272,729
63	445,157	876,667	1,321,823	190,827,572
64	447,197	874,626	1,321,823	190,380,375
65	449,247	872,577	1,321,823	189,931,128
66	451,306	870,518	1,321,823	189,479,823
67	453,374	868,449	1,321,823	189,026,449
68	455,452	866,371	1,321,823	188,570,997
69	457,540	864,284	1,321,823	188,113,457
70	459,637	862,187	1,321,823	187,653,820
71	461,743	860,080	1,321,823	187,192,077
72	463,860	857,964	1,321,823	186,728,217
TOTAL	**5,428,741**	**10,433,139**	**15,861,880**	
73	465,986	855,838	1,321,823	186,262,232
74	468,121	853,702	1,321,823	185,794,110
75	470,267	851,556	1,321,823	185,323,843
76	472,422	849,401	1,321,823	184,851,421
77	474,588	847,236	1,321,823	184,376,833
78	476,763	845,060	1,321,823	183,900,070
79	478,948	842,875	1,321,823	183,421,122
80	481,143	840,680	1,321,823	182,939,979
81	483,348	838,475	1,321,823	182,456,631
82	485,564	836,260	1,321,823	181,971,067
83	487,789	834,034	1,321,823	181,483,278
84	490,025	831,798	1,321,823	180,993,253
TOTAL	**5,734,965**	**10,126,915**	**15,861,880**	
85	492,271	829,552	1,321,823	180,500,982
86	494,527	827,296	1,321,823	180,006,455
87	496,794	825,030	1,321,823	179,509,661
88	499,071	822,753	1,321,823	179,010,590
89	501,358	820,465	1,321,823	178,509,232
90	503,656	818,167	1,321,823	178,005,576
91	505,964	815,859	1,321,823	177,499,612
92	508,283	813,540	1,321,823	176,991,328
93	510,613	811,210	1,321,823	176,480,715
94	512,953	808,870	1,321,823	175,967,762
95	515,304	806,519	1,321,823	175,452,457
96	517,666	804,157	1,321,823	174,934,791
TOTAL	**6,058,462**	**9,803,418**	**15,861,880**	
97	520,039	801,784	1,321,823	174,414,752
98	522,422	799,401	1,321,823	173,892,330
99	524,817	797,007	1,321,823	173,367,513
100	527,222	794,601	1,321,823	172,840,291
101	529,639	792,185	1,321,823	172,310,652
102	532,066	789,757	1,321,823	171,778,586
103	534,505	787,319	1,321,823	171,244,081
104	536,955	784,869	1,321,823	170,707,127
105	539,416	782,408	1,321,823	170,167,711

Months (€)	Principal (€)	Interest (€)	Payment (€)	Balance (€)
106	541,888	779,935	1,321,823	169,625,823
107	544,372	777,452	1,321,823	169,081,451
108	546,867	774,957	1,321,823	168,534,585
TOTAL	**6,400,207**	**9,461,673**	**15,861,880**	
109	549,373	772,450	1,321,823	167,985,211
110	551,891	769,932	1,321,823	167,433,320
111	554,421	767,403	1,321,823	166,878,900
112	556,962	764,862	1,321,823	166,321,938
113	559,514	762,309	1,321,823	165,762,424
114	562,079	759,744	1,321,823	165,200,345
115	564,655	757,168	1,321,823	164,635,690
116	567,243	754,580	1,321,823	164,068,447
117	569,843	751,980	1,321,823	163,498,604
118	572,455	749,369	1,321,823	162,926,149
119	575,078	746,745	1,321,823	162,351,070
120	577,714	744,109	1,321,823	161,773,356
TOTAL	**6,761,228**	**9,100,651**	**15,861,880**	
121	580,362	741,461	1,321,823	161,192,994
122	583,022	738,801	1,321,823	160,609,972
123	585,694	736,129	1,321,823	160,024,278
124	588,379	733,445	1,321,823	159,435,899
125	591,075	730,748	1,321,823	158,844,823
126	593,785	728,039	1,321,823	158,251,039
127	596,506	725,317	1,321,823	157,654,533
128	599,240	722,583	1,321,823	157,055,293
129	601,987	719,837	1,321,823	156,453,306
130	604,746	717,078	1,321,823	155,848,561
131	607,517	714,306	1,321,823	155,241,043
132	610,302	711,521	1,321,823	154,630,741
TOTAL	**7,142,615**	**8,719,265**	**15,861,880**	
133	613,099	708,724	1,321,823	154,017,642
134	615,909	705,914	1,321,823	153,401,733
135	618,732	703,091	1,321,823	152,783,001
136	621,568	700,255	1,321,823	152,161,433
137	624,417	697,407	1,321,823	151,537,016
138	627,279	694,545	1,321,823	150,909,738
139	630,154	691,670	1,321,823	150,279,584
140	633,042	688,781	1,321,823	149,646,542
141	635,943	685,880	1,321,823	149,010,599
142	638,858	682,965	1,321,823	148,371,741
143	641,786	680,037	1,321,823	147,729,954
144	644,728	677,096	1,321,823	147,085,227
TOTAL	**7,545,515**	**8,316,365**	**15,861,880**	
145	647,683	674,141	1,321,823	146,437,544
146	650,651	671,172	1,321,823	145,786,893
147	653,633	668,190	1,321,823	145,133,259
148	656,629	665,194	1,321,823	144,476,630
149	659,639	662,185	1,321,823	143,816,991

Months (€)	Principal (€)	Interest (€)	Payment (€)	Balance (€)
150	662,662	659,161	1,321,823	143,154,329
151	665,699	656,124	1,321,823	142,488,630
152	668,750	653,073	1,321,823	141,819,880
153	671,816	650,008	1,321,823	141,148,064
154	674,895	646,929	1,321,823	140,473,169
155	677,988	643,835	1,321,823	139,795,181
156	681,095	640,728	1,321,823	139,114,086
TOTAL	**7,971,141**	**7,890,739**	**15,861,880**	
157	684,217	637,606	1,321,823	138,429,869
158	687,353	634,470	1,321,823	137,742,516
159	690,503	631,320	1,321,823	137,052,012
160	693,668	628,155	1,321,823	136,358,344
161	696,848	624,976	1,321,823	135,661,496
162	700,041	621,782	1,321,823	134,961,455
163	703,250	618,573	1,321,823	134,258,205
164	706,473	615,350	1,321,823	133,551,732
165	709,711	612,112	1,321,823	132,842,020
166	712,964	608,859	1,321,823	132,129,056
167	716,232	605,592	1,321,823	131,412,825
168	719,515	602,309	1,321,823	130,693,310
TOTAL	**8,420,776**	**7,441,104**	**15,861,880**	
169	722,812	599,011	1,321,823	129,970,498
170	726,125	595,698	1,321,823	129,244,372
171	729,453	592,370	1,321,823	128,514,919
172	732,797	589,027	1,321,823	127,782,123
173	736,155	585,668	1,321,823	127,045,967
174	739,529	582,294	1,321,823	126,306,438
175	742,919	578,905	1,321,823	125,563,519
176	746,324	575,499	1,321,823	124,817,195
177	749,745	572,079	1,321,823	124,067,451
178	753,181	568,642	1,321,823	123,314,270
179	756,633	565,190	1,321,823	122,557,637
180	760,101	561,723	1,321,823	121,797,536
TOTAL	**8,895,774**	**6,966,106**	**15,861,880**	
181	763,585	558,239	1,321,823	121,033,952
182	767,084	554,739	1,321,823	120,266,867
183	770,600	551,223	1,321,823	119,496,267
184	774,132	547,691	1,321,823	118,722,135
185	777,680	544,143	1,321,823	117,944,455
186	781,245	540,579	1,321,823	117,163,210
187	784,825	536,998	1,321,823	116,378,385
188	788,422	533,401	1,321,823	115,589,962
189	792,036	529,787	1,321,823	114,797,926
190	795,666	526,157	1,321,823	114,002,260
191	799,313	522,510	1,321,823	113,202,947
192	802,976	518,847	1,321,823	112,399,971
TOTAL	**9,397,565**	**6,464,315**	**15,861,880**	
193	806,657	515,167	1,321,823	111,593,314

Months (€)	Principal (€)	Interest (€)	Payment (€)	Balance (€)
194	810,354	511,469	1,321,823	110,782,960
195	814,068	507,755	1,321,823	109,968,892
196	817,799	504,024	1,321,823	109,151,093
197	821,547	500,276	1,321,823	108,329,545
198	825,313	496,510	1,321,823	107,504,232
199	829,096	492,728	1,321,823	106,675,137
200	832,896	488,928	1,321,823	105,842,241
201	836,713	485,110	1,321,823	105,005,528
202	840,548	481,275	1,321,823	104,164,980
203	844,401	477,423	1,321,823	103,320,580
204	848,271	473,553	1,321,823	102,472,309
TOTAL	**9,927,662**	**5,934,218**	**15,861,880**	
205	852,159	469,665	1,321,823	101,620,150
206	856,064	465,759	1,321,823	100,764,086
207	859,988	461,835	1,321,823	99,904,098
208	863,930	457,894	1,321,823	99,040,169
209	867,889	453,934	1,321,823	98,172,279
210	871,867	449,956	1,321,823	97,300,412
211	875,863	445,960	1,321,823	96,424,549
212	879,877	441,946	1,321,823	95,544,672
213	883,910	437,913	1,321,823	94,660,761
214	887,962	433,862	1,321,823	93,772,800
215	892,031	429,792	1,321,823	92,880,769
216	896,120	425,704	1,321,823	91,984,649
TOTAL	**10,487,660**	**5,374,220**	**15,861,880**	
217	900,227	421,596	1,321,823	91,084,422
218	904,353	417,470	1,321,823	90,180,069
219	908,498	413,325	1,321,823	89,271,571
220	912,662	409,161	1,321,823	88,358,909
221	916,845	404,978	1,321,823	87,442,064
222	921,047	400,776	1,321,823	86,521,017
223	925,269	396,555	1,321,823	85,595,748
224	929,509	392,314	1,321,823	84,666,238
225	933,770	388,054	1,321,823	83,732,469
226	938,050	383,774	1,321,823	82,794,419
227	942,349	379,474	1,321,823	81,852,070
228	946,668	375,155	1,321,823	80,905,402
TOTAL	**11,079,247**	**4,782,633**	**15,861,880**	
229	951,007	370,816	1,321,823	79,954,395
230	955,366	366,458	1,321,823	78,999,030
231	959,744	362,079	1,321,823	78,039,285
232	964,143	357,680	1,321,823	77,075,142
233	968,562	353,261	1,321,823	76,106,580
234	973,002	348,822	1,321,823	75,133,578
235	977,461	344,362	1,321,823	74,156,117
236	981,941	339,882	1,321,823	73,174,176
237	986,442	335,382	1,321,823	72,187,734
238	990,963	330,860	1,321,823	71,196,771

Months (€)	Principal (€)	Interest (€)	Payment (€)	Balance (€)
239	995,505	326,319	1,321,823	70,201,267
240	1,000,068	321,756	1,321,823	69,201,199
TOTAL	**11,704,203**	**4,157,677**	**15,861,880**	
241	1,004,651	317,172	1,321,823	68,196,548
242	1,009,256	312,568	1,321,823	67,187,292
243	1,013,882	307,942	1,321,823	66,173,411
244	1,018,529	303,295	1,321,823	65,154,882
245	1,023,197	298,627	1,321,823	64,131,685
246	1,027,886	293,937	1,321,823	63,103,799
247	1,032,598	289,226	1,321,823	62,071,201
248	1,037,330	284,493	1,321,823	61,033,871
249	1,042,085	279,739	1,321,823	59,991,786
250	1,046,861	274,962	1,321,823	58,944,925
251	1,051,659	270,164	1,321,823	57,893,266
252	1,056,479	265,344	1,321,823	56,836,787
TOTAL	**12,364,412**	**3,497,468**	**15,861,880**	
253	1,061,321	260,502	1,321,823	55,775,466
254	1,066,186	255,638	1,321,823	54,709,280
255	1,071,072	250,751	1,321,823	53,638,207
256	1,075,982	245,842	1,321,823	52,562,226
257	1,080,913	240,910	1,321,823	51,481,313
258	1,085,867	235,956	1,321,823	50,395,445
259	1,090,844	230,979	1,321,823	49,304,601
260	1,095,844	225,979	1,321,823	48,208,757
261	1,100,867	220,957	1,321,823	47,107,891
262	1,105,912	215,911	1,321,823	46,001,979
263	1,110,981	210,842	1,321,823	44,890,998
264	1,116,073	205,750	1,321,823	43,774,925
TOTAL	**13,061,862**	**2,800,018**	**15,861,880**	
265	1,121,188	200,635	1,321,823	42,653,736
266	1,126,327	195,496	1,321,823	41,527,409
267	1,131,489	190,334	1,321,823	40,395,920
268	1,136,675	185,148	1,321,823	39,259,245
269	1,141,885	179,938	1,321,823	38,117,360
270	1,147,119	174,705	1,321,823	36,970,241
271	1,152,376	169,447	1,321,823	35,817,864
272	1,157,658	164,165	1,321,823	34,660,206
273	1,162,964	158,859	1,321,823	33,497,242
274	1,168,294	153,529	1,321,823	32,328,948
275	1,173,649	148,174	1,321,823	31,155,299
276	1,179,028	142,795	1,321,823	29,976,271
TOTAL	**13,798,654**	**2,063,226**	**15,861,880**	
277	1,184,432	137,391	1,321,823	28,791,839
278	1,189,861	131,963	1,321,823	27,601,978
279	1,195,314	126,509	1,321,823	26,406,664
280	1,200,793	121,031	1,321,823	25,205,871
281	1,206,296	115,527	1,321,823	23,999,574
282	1,211,825	109,998	1,321,823	22,787,749

Months (€)	Principal (€)	Interest (€)	Payment (€)	Balance (€)
283	1,217,379	104,444	1,321,823	21,570,370
284	1,222,959	98,864	1,321,823	20,347,411
285	1,228,564	93,259	1,321,823	19,118,846
286	1,234,195	87,628	1,321,823	17,884,651
287	1,239,852	81,971	1,321,823	16,644,799
288	1,245,535	76,289	1,321,823	15,399,264
TOTAL	**14,577,006**	**1,284,873**	**15,861,880**	
289	1,251,243	70,580	1,321,823	14,148,021
290	1,256,978	64,845	1,321,823	12,891,043
291	1,262,739	59,084	1,321,823	11,628,303
292	1,268,527	53,296	1,321,823	10,359,776
293	1,274,341	47,482	1,321,823	9,085,435
294	1,280,182	41,642	1,321,823	7,805,254
295	1,286,049	35,774	1,321,823	6,519,204
296	1,291,944	29,880	1,321,823	5,227,261
297	1,297,865	23,958	1,321,823	3,929,396
298	1,303,814	18,010	1,321,823	2,625,582
299	1,309,789	12,034	1,321,823	1,315,793
300	1,315,793	6,031	1,321,823	0
TOTAL	**15,399,264**	**462,616**	**15,861,880**	

Annual Revenues and Expenditure of the Western Attica Waste-to-Energy facility (years of operation 1 – 15)

REVENUES (€ million)																
Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Tipping Fee			29.6	30.2	30.8	31.4	32.1	32.7	33.3	34.0	34.7	35.4	36.1	36.8	37.6	38.3	39.1
Renewable Electricity			39.4	40.1	40.9	41.8	42.6	43.5	44.3	45.2	46.1	47.0	48.0	48.9	49.9	50.9	51.9
Non-Renewable Electricity			3.5	3.6	3.7	3.7	3.8	3.9	4.0	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7
Ferrous Metal			2.6	2.6	2.7	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.1	3.2	3.3	3.3	3.4
Aluminum			2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.8
Interest income, mil			0.0	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
TOTAL REVENUES			**77.3**	**79.0**	**80.7**	**82.3**	**83.9**	**85.6**	**87.3**	**89.1**	**90.9**	**92.7**	**94.5**	**96.4**	**98.3**	**100.3**	**102.3**

EXPENDITURE (€ million)																	
Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Ash disposal			2.7	2.7	2.8	2.9	2.9	3.0	3.0	3.1	3.2	3.2	3.3	3.3	3.4	3.5	3.5
Chemicals			3.0	3.0	3.1	3.1	3.2	3.3	3.3	3.4	3.5	3.5	3.6	3.7	3.8	3.8	3.9
APC			8.9	9.1	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	10.8	11.0	11.3	11.5	11.7
Maintenance			17.3	17.6	18.0	18.3	18.7	19.1	19.5	19.8	20.2	20.6	21.1	21.5	21.9	22.3	22.8
Miscellaneous			2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.3
Labor			1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.5
Subtotal			35.4	36.1	36.8	37.5	38.3	39.1	39.8	40.6	41.5	42.3	43.1	44.0	44.9	45.8	46.7
Contingency			3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7
Total			**38.9**	**39.7**	**40.5**	**41.3**	**42.1**	**43.0**	**43.8**	**44.7**	**45.6**	**46.5**	**47.4**	**48.4**	**49.4**	**50.3**	**51.4**
Insurance			2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.1	3.2	3.3	3.3
Annual Interest			11.7	11.5	11.3	11.0	10.7	10.4	10.1	9.8	9.5	9.1	8.7	8.3	7.9	7.4	7.0
Depreciation (Straight-Line)			12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
Total Costs			65.8	66.4	67.0	67.6	68.2	68.8	69.4	70.0	70.6	71.2	71.8	72.4	73.0	73.7	74.2
Profit Before Taxes			8.2	9.2	10.2	11.2	12.1	13.1	14.2	15.2	16.3	17.5	18.6	19.8	21.1	22.3	23.7
Corporate Taxes			2.0	2.3	2.6	2.8	3.0	3.3	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9
Net After-Tax Profit			6.1	6.9	7.7	8.4	9.1	9.9	10.6	11.4	12.2	13.1	14.0	14.9	15.8	16.8	17.8
Add-back Depreciation			12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
Available Cash			18.7	19.5	20.3	21.0	21.7	22.5	23.2	24.0	24.8	25.7	26.6	27.5	28.4	29.4	30.4

EXPENDITURE (€ million)																	
Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Loan Principal Repayment			4.1	4.4	4.6	4.9	5.1	5.4	5.7	6.1	6.4	6.8	7.1	7.5	8.0	8.4	8.9
Dividends to Equity			7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
Retained Earnings			3.7	3.9	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL EXPENSES			**71.0**	**72.2**	**73.5**	**70.5**	**71.6**	**72.8**	**73.9**	**75.1**	**76.4**	**77.6**	**78.9**	**80.2**	**81.6**	**82.9**	**84.3**

DISTRIBUTION OF INCOME (€ million)																	
Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
SURPLUS CASH FLOW			**5.0**	**5.4**	**5.8**	**10.9**	**11.4**	**11.9**	**12.4**	**13.0**	**13.5**	**14.0**	**14.6**	**15.2**	**15.7**	**16.3**	**16.9**
Electricity Rebate to Residents			0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5
Net Surplus Cash Flow			**4.6**	**5.0**	**5.5**	**10.5**	**11.0**	**11.5**	**12.0**	**12.6**	**13.1**	**13.6**	**14.2**	**14.7**	**15.3**	**15.9**	**16.4**
Distribution to Phyli OLA			1.2	1.3	1.4	2.6	2.8	2.9	3.0	3.1	3.3	3.4	3.5	3.7	3.8	4.0	4.1
Distribution to Equity			2.3	2.5	2.7	5.3	5.5	5.8	6.0	6.3	6.5	6.8	7.1	7.4	7.6	7.9	8.2
Distribution to Sponsors			1.2	1.3	1.4	2.6	2.8	2.9	3.0	3.1	3.3	3.4	3.5	3.7	3.8	4.0	4.1

Annual Revenues and Expenditure of the Western Attica Waste-to-Energy facility (years of operation 16 – 25)

REVENUES (€ million)										
Years	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Tipping Fee	39.9	40.6	41.5	42.3	43.1	44.0	44.9	45.8	46.7	47.6
Renewable Electricity	53.0	54.0	55.1	56.2	57.3	58.5	59.7	60.8	62.1	63.3
Non-Renewable Electricity	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.5	5.6	5.7
Ferrous Metal	3.5	3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.1
Aluminum	2.9	2.9	3.0	3.1	3.1	3.2	3.2	3.3	3.4	3.4
Interest income, mil	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5
TOTAL REVENUES	**104.4**	**106.5**	**108.6**	**110.8**	**113.0**	**115.3**	**117.6**	**119.9**	**122.3**	**124.8**

EXPENDITURE (€ million)										
Years	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Ash disposal	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.2	4.2	4.3
Chemicals	4.0	4.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8
APC	12.0	12.2	12.4	12.7	12.9	13.2	13.5	13.7	14.0	14.3
Maintenance	23.2	23.7	24.2	24.7	25.2	25.7	26.2	26.7	27.2	27.8
Miscellaneous	3.3	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.9	4.0
Labor	1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.8
Subtotal	47.6	48.6	49.5	50.5	51.5	52.6	53.6	54.7	55.8	56.9
Contingency	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7
Total	**52.4**	**53.4**	**54.5**	**55.6**	**56.7**	**57.8**	**59.0**	**60.2**	**61.4**	**62.6**
Insurance	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.9	4.0	4.1
Annual Interest	6.5	5.9	5.4	4.8	4.2	3.5	2.8	2.1	1.3	0.5
Depreciation (Straight-Line)	12.6	12.6	12.6	12.6	12.6	0.0	0.0	0.0	0.0	0.0
Total Costs	74.8	75.4	76.0	76.6	77.1	65.1	65.6	66.1	66.6	67.1
Profit Before Taxes	25.0	26.5	27.9	29.4	31.0	45.2	46.9	48.6	50.4	52.3
Corporate Taxes	6.3	6.6	7.0	7.4	7.7	11.3	11.7	12.2	12.6	13.1
Net After-Tax Profit	18.8	19.8	20.9	22.1	23.2	33.9	35.2	36.5	37.8	39.2
Add-back Depreciation	12.6	12.6	12.6	12.6	12.6	0.0	0.0	0.0	0.0	0.0
Available Cash	31.4	32.4	33.5	34.7	35.8	33.9	35.2	36.5	37.8	39.2
Loan Principal Repayment	9.4	9.9	10.5	11.1	11.7	12.4	13.1	13.8	14.6	15.4
Dividends to Equity	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
Retained Earnings	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL EXPENSES	**85.8**	**87.2**	**88.7**	**90.3**	**91.9**	**96.6**	**98.3**	**100.0**	**101.7**	**103.5**

DISTRIBUTION OF INCOME (€ million)										
Years	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
SURPLUS CASH FLOW	**17.5**	**18.1**	**18.7**	**19.3**	**19.9**	**17.4**	**18.0**	**18.7**	**19.3**	**20.0**
Electricity Rebate to Residents	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
Net Surplus Cash Flow	**17.0**	**17.6**	**18.2**	**18.8**	**19.4**	**16.9**	**17.5**	**18.1**	**18.8**	**19.4**
Distribution to Phyli OLA	4.3	4.4	4.5	4.7	4.9	4.2	4.4	4.5	4.7	4.8
Distribution to Equity	8.5	8.8	9.1	9.4	9.7	8.4	8.7	9.1	9.4	9.7
Distribution to Sponsors	4.3	4.4	4.5	4.7	4.9	4.2	4.4	4.5	4.7	4.8

NOTE: The conversion of the monetary values from euros (€) to dollars ($) and vice-versa, the equivalence of May 7, 2006 (€1 = $1.27312)(163) was used.