LIFE12 ENV/GR/000427 LIFE reclaim "Landfill mining pilot application for recovery of invaluable metals, materials, land and energy

TECHNICAL REPORT - ACTION B2

FOR THE POLYGYROS LANDFILL, IN THE MUNICIPALITY OF POLYGYROS, CHALKIDIKI

SUBJECT:

EXPLOITATION PLAN DEVELOPMENT

ENVECO S.A. ENVIRONMENTAL PROTECTION MANAGEMENT & ECONOMICS
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Annex A. Expert report on the Polygyros landfill mining plan

Executive Summary

The report outlines the landfill mining schemes employed and analyses the design of the landfill mining plan that is going to be used at the Polygyros Landfill site for the development of the LIFE+ Reclaim project. Major focus is paid to the design and the development of the sampling operations and at the identification of the target area to be mined.

The operational phase of a typical landfill mining (LFM) project is usually consisted of two major steps. The first is the excavation process of the waste with the use of equipment commonly employed in surface mining, while the second is the waste processing one with the sorting and screening of the waste taking place there. Of course there are also additional issues to take into account as the environmental protection of the site and the well-being of the personnel involved. Details of the above issues, are depicted in the first part of the report in which the theoretical background of LFM is given.

For the Polygyros case the initial operation will start with the development of 2 sampling trenches constructed using a backhoe loader. Their length should be at least 5 m, their depth at least 3 m, and their width of around 1 m. These trenches are to be developed in areas representing different time frames of the disposal operation, and thus allowing the assessment of differences/variations in the characteristics of the waste material. This stage will provide details for the MSW content and more importantly with allow the gathering of data for the main part of the mining operation. This, will take place in an area located at the central part of the PL's disposal site, approximately 30 m eastern from the toe area of the current working cell, at the level of +620m. This will allow for an unobscured operation to both the landfilling and mining operations that are going to take place there simultaneously. The section to be mined will have a surface area of 600-800 m^2, or dimensions about 20 x 40 m, while the depth of the cut is to be at 3-4 m, allowing for the extraction of 2000 m^3 of waste.

The PL mining scheme proposes the excavation to take place from the top (+620 m level) using a hydraulic excavator at the crest area, rather than making the extraction from the toe using front-end loaders and by scraping the waste. The extracted material will then by loaded to trucks and will be eventually channelled to the processing plant in which the screening and sorting of the materials will take place.

Finally, the outline of the environmental and safety monitoring that will be installed in the PL site is proposed, targeting the dust monitoring (especially related to mining and transport operations) and gas emissions. For this reason a number of relevant equipment are to be used (e.g. PM 10 sampling units, gas detectors, etc.) as well as personal samplers that will safeguard the personnel's safety.

1. The concept of Landfill Mining

A lot of Landfill Mining (LFM) definitions are found in the literature. According to the Oxford Dictionary of English, “landfill” means:

“the disposal of waste material by burying it” or “a place or process for a disposal of non-hazardous waste, based on burying it in the ground then compacting it to reduce the volume and finally covering it with soil and landscaping it to look like part of the surrounding land”.

The meaning of the word “mining” is, according to the same dictionary:

“the removal of minerals (such as coal, gold or silver) from the ground” or “the process of extracting solid natural resources from the shallow parts of the Earth’s crust”.

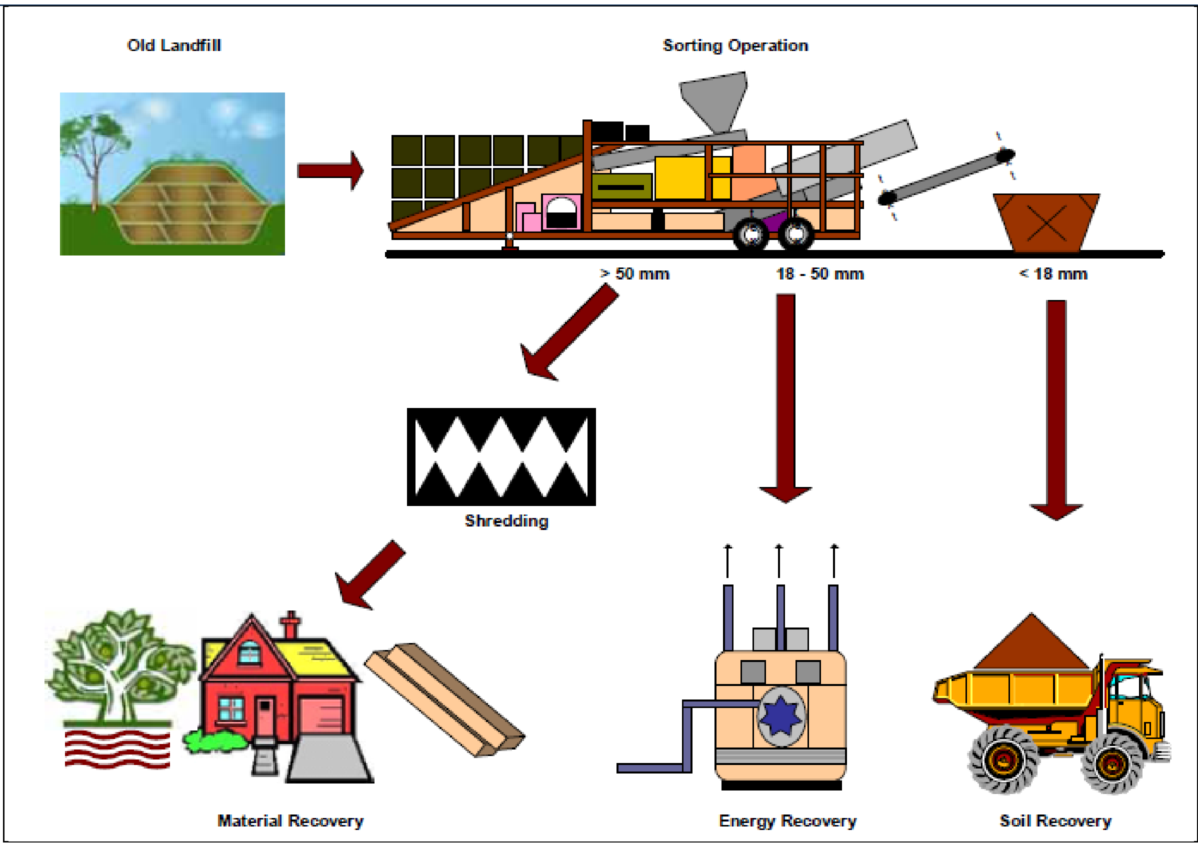
According to Krook et al. (2012), “combining these definitions, landfill mining could be described as a process for extracting minerals or other solid natural resources from waste materials that previously have been disposed of by burying them in the ground”.

Similar definitions are found in the literature by other researchers. “Landfill mining is the process of excavating from operating or closed solid waste landfills, and sorting the unearthed materials for recycling, processing, or for other dispositions” (Lee and Jones, 1990; Cosu et al., 1996; Hogland et al., 1997; Carius et al., 1999).

From a technical point of view, landfill mining is a typical open cast mining and screening process as presented in Figures 1 and 2.

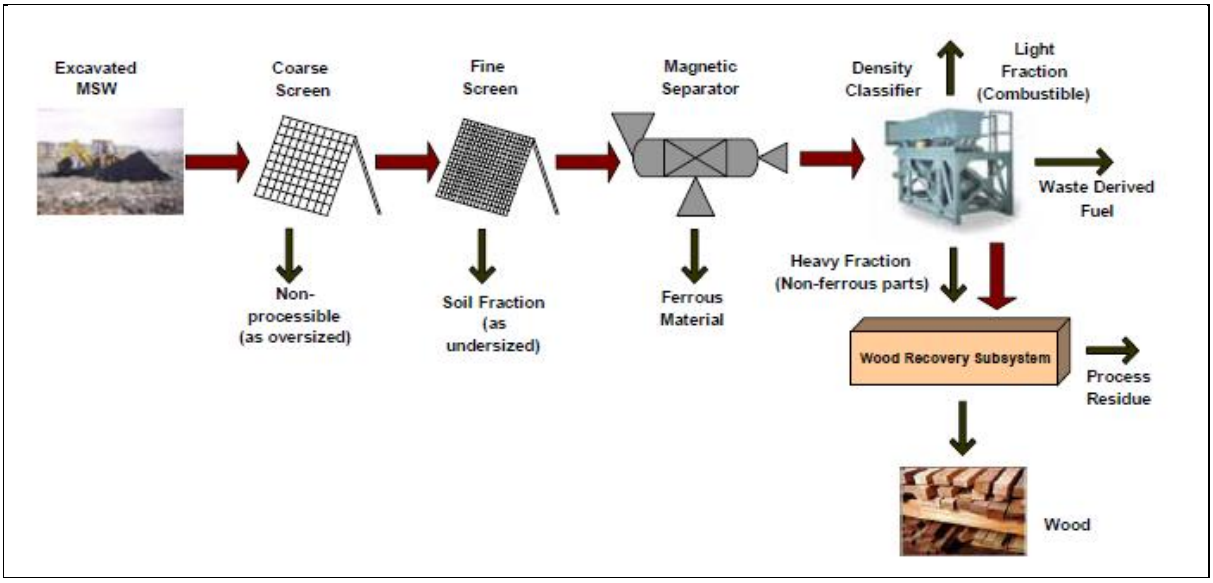
The objectives of landfill mining are summarized below (USEPA, 1997; Lee and Jones, 1990; Hogland et al., 1997):

- Conservation of landfill space.
- Reduction in landfill area.
- Elimination of potential contamination source.
- Rehabilitation of dump sites.
- Energy recovery from recovered wastes.
- Reuse of recovered materials.
- Reduction in waste management costs.
- Redevelopment of landfill sites.



Source: Carius et al., 1999

Figure 1: Schematic illustration of a landfill mining process



Source: Savage and Diaz, 1994

Figure 2: Processing scheme of a typical landfill mining plant

Examples of the LFM process have been cited since the later 1940s (Fisher, 2013). The reasons for implementing and LFM strategy are often unique to the site itself and there are specific factors that may lead to an LFM operation (ibid.).

1.1. Pros and cons of Landfill Mining

The main reasons for considering LFM operations are (Fisher, 2013):

- Extraction for recycling potential: the extraction of wastes for their recycling potential is highly likely to be driven by the material values in the market place for specific recyclates. Although metals and plastics have the highest values and the lowest level of degradation within a landfill site, there may be other materials that have a specific local value.

- Extraction for energy recovery: waste landfilled may provide a short- to medium-term resolution to energy demand; it could not be considered a 'renewable' source of energy though.

- Reclamation of land: landfill sites may be in locations that are ideal for other development purposes; may be a source of contamination that has to be removed; or there may be a need to reuse the available landfill space at the site for different kinds of wastes more suitable to long-term disposal, such as non-reactive hazardous waste. In this way the useful life of the existing landfills could be extended by many years besides avoiding the cost and time to locate, design, permit, and construction of a new landfill.

All the above reasons may be independent drivers for LFM but may also be combined to deliver wider benefits and maximise the LFM opportunity (Fisher, 2013).

On the other hand, LFM may cause significant economic and environmental impacts. The composition of wastes in historic landfill sites is not known and estimates must be made of the wastes within them and the subsequent impacts that those wastes may have. This lack of knowledge might be a limitation regarding safety issues (Fisher, 2013).

Other safety issues include physical injury from rolling stock or rotating equipment; exposure to leachate, and hazardous material or pathogens during mining or processing; subsurface fires and landfill gas emissions. Other limitations include odour and air emissions, increased traffic on roads between the landfill and resource recovery facility, extra mixing and handling of waste at the resource recovery facility, and the handling of additional inert materials.

Many of these risks are similar to traditional mining operations but are enhanced by the heterogeneous nature of the wastes in a landfill, which could result in (Joseph et al., 2004, Reno Sam, 2009):

- Poor quality of recovered materials
- Ineffectiveness of substituting recovered tin cans for scrap aluminum cans
- Poor separation of recovered materials
- Low-value and limited applications of recovered materials
- Emission of landfill gas

2. Brief History of Landfill Mining and current projects worldwide

Landfill mining projects have been used throughout the world during the last 50 years as a tool for sustainable landfilling. The first reported landfill mining project was an operation in Tel Aviv, Israel in 1953, which was then a method used to recover the soil fraction to improve the soil quality in orchards (Shual and Hillel, 1958; Savage et al., 1993). It was later employed in United States of America (USA) to obtain fuel for incineration and energy recovery (Hogland, 1996; Cossu et al., 1996; Hogland et al., 1997). Pilot studies have been also carried out in England, Italy, Sweden, Germany (Cossu et al., 1995; Hogland et al., 1995), China and India.

Until today, more than 60 Landfill Mining and Reclamation (LFMR) projects are reported in the literature (Vossen and Prent, 2011). Ford et. al. (2013) has recorded 57 of them, as shown in Table 1. The brief description of each project in Table 1 is based on the principal drivers, although frequently more, than one, drivers may exist at each site.

Table1: Principal drivers for historic and current LFMR projects worldwide

Principal project driver	Europe	North America	Asia	Total projects
Not specified	12	4	2	18
Void space recovery	3	4		7
To allow site redevelopment	5		1	6
To mitigate pollution	2	5	1	8
To improve landfill engineering (e.g. meet regulatory requirements)	4	2	1	7
Material reclamation for recycling or energy production	3	2	6	11
Total projects	29 projects across 9 countries	17 projects of which 1 in Canada and 16 in the USA	11 projects across 7 countries	57

Source: Ford et al., 2013

Given the number of landfills in existence around the world, it is evident that very few landfill mining projects have taken place since the first recorded project in 1953. The documented projects undertaken are spread around the world, while USA has undertaken the most LFMR projects.

It is also evident that although material sorting and recovery often features in a LFMR project, it is not in most of the cases the main project driver. Many of the projects reviewed involved only basic separation of wastes, principally separation of the soil fraction by screening. According to Hogland et. al (1999), the amount of recovered fine soil fraction, which could be used as cover or lining of new landfill or backfilled in a more sustainable way is the most important variable in LFM. The soil to waste ratio reported at various excavated landfills differs due to the amount of daily and final cover material employed, the size of the screens' openings, the type of landfill and waste, the degree of compaction, the age of landfill, and the local conditions like moisture content in waste and degree of composition. The average soil fraction in recovered municipal waste from landfill tends to be around 50-60%. However, it can vary between 20 and 80% as given in Table 2 depending on moisture content and decomposition rate (Hogland, 2002). Strange (1998, as mentioned in Joseph et al., 2004) suggested that a landfill needs to be 15 years old before a successful mining project can be performed.

Table2: Soil to waste ratio in landfill mining

Landfill	Soil-to-waste ratio (%)
Edinburg, New York, USA	75:25
Horicon, New York , USA	65:35
Hague, New York , USA	50:50
Chester, New York USA	25:75
Coloni, New York, USA	20:80
Sandtown, Delaware, USA	46:54
Burghof, Germany	71:29*
Schoneiche, Germany	77:23*
Döbeln-Hohenlauft, Germany	62:38*, 21:79**
Schoneiche, Germany	20-80*, 30:70**
Dresden, Germany	74:26*, 19:81**
Sengenbühl, Germany	11:89*, 45:65**
Basslitz; Germany	50:50*, 34:66**
Cagliari, Italy	31:69*
Filborna, Sweden	65:35
* Screen gauge 40 mm ** Screen gauge 8-40 mm Screen gauge is 24 mm unless otherwise indicated	

Source: Hogland, 2002

3. The Landfill Mining Process

The first step in planning a landfill mining and rehabilitation project should be a site survey to gather site-specific information such as its operating history, types of wastes present, dimensions, topography and physical characteristics (Salerni, 1995).

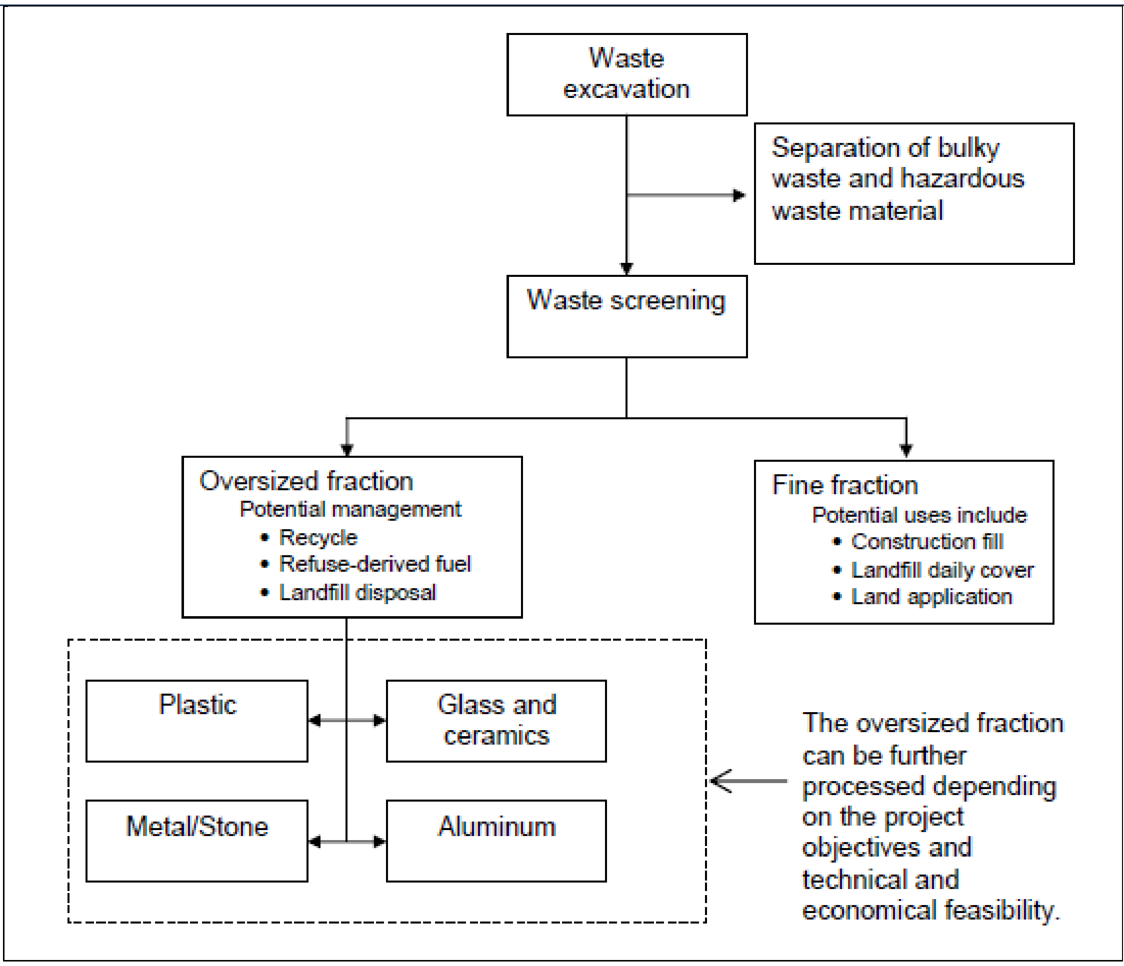
The next step of site investigation involves planning for preliminary excavation and obtaining the necessary regulatory approvals (e.g. number of pits and/or trenches to be dug; equipment and material handling procedure; analytical testing, measurements and data collection, etc.)

Some relevant factors that need to be addressed while planning dumpsite rehabilitation employing the concept of landfill mining are the proper time to begin extracting material from the landfill, the methodology that should be conducted for feasibility studies and for taking representative samples, the quantity and quality of materials that can be recovered, the variation of degradation with time, wastes and space, the environmental and health risks of landfill rehabilitation works and the enhancement of waste stabilization (Joseph et al., 2004).

The operational phase of LFM typically consists of three basic stages: excavating waste using equipment commonly employed in surface mining; processing the excavated material to meet several objectives, including separating bulky materials, sorting hazardous material and other unidentified waste, screening soils from waste, and sorting materials for recycling or use as fuel. Several common mechanical processes (such as magnets for ferrous metal and eddy current separators for aluminium) can be used (IWCS, 2009). Identifying and sorting hazardous material and other suspicious waste material has been reported by IWCS (2009) to be an integral part of most landfill mining projects. Additional processing and managing of the excavated material are guided by the project objectives, properties and conditions of the excavated material, and processing cost and time (ibid.).

According to the study of IWCS (2009), in a lot of mining projects screening of the excavated waste was the most common process used. Figure 3 presents a generalized flow chart of the process that some of mining projects employed.

As shown in Figure 3, the main part of the process is the screening, where the size and type of screen used depends on the end use of the recovered material. The non-recyclable part is typically reburied in the mined area of the landfill. If this portion is reburied without further processing, this landfill mining operation typically achieves about 70% volume reduction (Cossu et al., 1995, Hogland et al., 1995).



Source: IWCS, 2009

Figure3: Landfill Mining Process

3.1. Site investigation of landfills

Landfill and disposal site investigations aim to determine a site's conditions with respect to regulatory disposal site state minimum standards for the protection of public health and safety. One of the most important objectives of any landfill investigation is to determine the horizontal and vertical extent of waste in order to estimate a volume of waste, consider different remedial options and determine costs to clean-close the disposal site (Young, 2010).

3.1.1. Preliminary Investigation

Environmental agencies usually recommend gathering historical information and carrying out a site inspection during the preliminary investigation. Compilation of physical and historical data and all the existing information about the site need to be collected. This phase is very important for the future steps, based on the interpretation of the previous and current topography, hydrology, weather aspects, aerial photographs and historical documents with regard to the type and amount of waste. This phase could result in avoiding unnecessary tests in the next steps, so as to reduce costs without compromising the quality of the final results (Mondelli et al., 2012). A visual inspection should be also conducted during the preliminary investigation (ibid.).

3.1.2. Historical Aerial Photograph Study

The analysis of historical aerial photographs during a landfill investigation or preliminary site assessment study is one of the most important and cost-effective methods in order to determine the approximate areal (or horizontal) extents of a disposal site operation and can reduce the scope of work for intrusive field investigation work (Young, 2010).

Once the historical aerial photograph review and analysis has been performed, a scaled topographic engineering drawing should be prepared using an engineering drawing program that will allow field information to be added to develop a scaled drawing depicting the boundary of the disposal area (ibid.).

3.1.3. Geophysical Surveys

After the historical aerial photograph analysis and the development of the topographic map, a geophysical survey of the disposal site and surrounding areas should be performed to develop subsurface cross-sections that can be used to assess rock depth, changes of soil texture, groundwater level, distribution of waste, etc., so as to develop intrusive investigation (drilling, trenching, or direct push) locations (Mondelli et al., 2012). The major advantage of geophysical survey is that it allows a quick investigation of a large area avoiding direct contact with contaminants (ibid.).

Various geophysical survey methods may be employed based on site conditions. Some geophysical technologies, such as electrical conductivity, are able to directly detect the presence of contaminants by measuring the change in soil conductivities. Other technologies, such as seismic reflection are better in identifying subsurface lithologies (USEPA, 2000). It should be noted that a combination of one or more geophysical methods, e.g. resistivity (depth) and ferromagnetic (areal), may yield the most useful data (Young, 2010).

Table 3 provides a summary of the difficulties encountered and the results obtained in 11 geophysical investigations reported by USEPA (2000). In five, the geophysical technology was able to directly detect contaminants, greatly aiding the delineation of contamination at those sites. In the remaining investigations, the results described critical geological structures that influenced the migration of contaminants. This information aided site managers in identifying appropriate sampling locations for better delineation of contamination.

It should be noted that a geophysical survey is not a substitute for an intrusive investigation, and should be used to help a subsurface investigation, which will yield the most reliable information (Young, 2010).

Table 3: Methods, difficulties and results of 11 Geophysical Investigations

Site Name and Location	Geophysical Method Used	Purpose	Difficulties	Results
Marion, OH Baker Wood Creosoting Company	Ground Penetrating Radar (GPR); Electomagnetometry	Delineate source areas and soil contamination	GPR depth was limited by shallow dense clay soils; EM depth was limited by nearby structures	GPR identified buried structures that in later investigation found to be contaminated. EM delineated near-surface soil contamination
Ciba-Geigy Hamblet & Hayes Site Lewiston, ME	GPR	Characterize stratigraphy	Dense clay limited depth of penetration; swampy areas limited access	Found topographic low where later sampling found pooled DNAPL
Crystal Refinery Carson City, MI	GPR; Electrical Resistivity	Monitor groundwater contamination	No significant problems reported	Identified LNAPL mass located at water table
Kelly Air Force Base San Antonio, TX	Seismic Reflection	Map bedrock topology	Railroad noise interfered with data collection	Identified channels in bedrock where later sampling found pooled DNAPL
Kansas UST Salina, KS	Electrical Conductivity	Characterize stratigraphy	No significant problems reported	Found saddle-like formation in confining layer that acted as preferential migration pathway for LNAPL
Marshalltown FMGP Marshalltown, IA	Electrical Conductivity	Characterize stratigraphy	Probes broke when encountered cobbles and boulders; weathered bedrock was not distinguishable in logs	Clearly identified lithology, including layers not yet identified; probe able to directly detect DNAPLs
New Hampshire Plating Company Merrimack, NH	Seismic Reflection; GPR; Natural gamma; Electomagnetometry	Characterize stratigraphy; Monitor groundwater contamination	Dense clay and sediments limited depth of penetration for GPR and seismic signals	Delineated stratigraphy; identified zones of groundwater contamination
NMHSTD UST Deming, NM	Magnetometry (R); Electromagnetometry (R); Natural gamma	Characterize stratigraphy for sampling point location	No significant problems reported	Gamma logs identified clay layers that influenced vapor migration in vadose zone; logs were used to position *in situ* soil gas samplers
Tinker Air Force Base Tinker, OK	Seismic Reflection; Electromagnetometry	Characterize stratigraphy for new well installation	Muddy surface conditions interfered with data collection	Characterized stratigraphy; identified permeable layers
Trail Road Landfill Nepean, Ontario, Canada	Natural Gamma; Magnetometry; Electrical Conductivity; Density Temperature	Monitor groundwater contamination	No significant problems reported	Developed continuous lithologic logs; conductivity and temperature logs identified zones of groundwater contamination
Wurtsmith Air Force Base Oscoda, MI	GPR; Electromagnetometry (R); Magnetometry (R)	Monitor groundwater contamination	No significant problems reported	Identified unknown LNAPL plume

Note: (R) indicates that the method was used in a reconnaissance survey for buried materials that might interfere with primary technology.

Source: USEPA, 2000.

3.1.4. Intrusive Investigation of Disposal Sites

Intrusive methods such as drilling, trenching, or direct push can provide visual and physical confirmation and documentation (drilling and trenching logs) of the approximate horizontal and vertical boundaries of a disposal site (Young, 2010). Intrusive investigations should be conducted after a thorough non-intrusive investigation in order to fill data gaps or verify features of the site observed during the historical aerial photograph study and/or geophysical survey.

3.1.5. Laboratory tests for site characterization

Laboratory tests can improve the interpretation of the in-situ test results. Since a complete site investigation using current engineering practice is usually difficult to carry out because it is time consuming, expensive and normally requires authorization and multidisciplinary teams, laboratory tests can provide greater detail, but in minor scale, trying to represent the field conditions based on soil and water/gas samplings (Mondelli et al., 2012).

The more usual laboratory characterization tests to investigate municipal solid waste disposal sites include geotechnical properties (e.g. in-situ moisture content (w), natural unit weight (γ), specific gravity (Gs), etc.), Organic Matter Content (OMC), Blue Methyl Adsorption, X-Ray Diffraction (XRD), Differential Thermal Analysis (DTA) and Gravimetrical Thermal Analysis (GTA), pH and X-Ray Fluorescence (XRF) (Mondelli et al., 2012).

Laboratory tests for the estimation of pollutant transport parameters such as column, diffusion and batch equilibrium tests are also important in the more detailed phases of geo-environmental investigations (Freeze and Cherry, 1979; Rowe et al., 1988; Barone et al., 1989; Shackelford and Daniel, 1991; Yong et al., 1992; Shackelford, 1993; Yong, 2001).

3.1.6. Geotechnical investigation

Ensuring landfill stability is the major geotechnical approach during the operation and aftercare of landfills and depends on various parameters such as waste composition, waste compaction, climate conditions, landfill geometry, ground stability and pore water pressure (Koelsch, 2009).

The analysis of municipal solid waste for geotechnical purpose requires a specific procedure which is different from conventional geotechnical methods. Those methods may be useful for waste materials with geotechnical properties similar to soil (ibid.).

The first step of analysis comprises of the identification and classification of the waste. The main part of the identification is the assorting analysis regarding the kind of materials. Groups of materials are then defined corresponding with their geotechnical effect and behaviour. For geotechnical purposes, size, shape and condition of all material groups need to be determined (ibid.).

Water content and biological stability are the major parameter to identify the waste condition. In most cases, particularly when the waste analysis focus on old waste, it is sufficient to determine both parameters using the smaller waste particles (0 - 8, 8 - 40 mm). For both parameters laboratory standards are available. Water content is a basic parameter in soil mechanics as well as in other fields. Biological stability may be measured as respiration (aerobe) or as gas generation (anaerobe).

Material parameters for waste strength are available for various different waste materials. German Geotechnical Society (Koelsch, 2009) obtained results from samples in Western countries. Figure 4 provides an overview on material parameters for municipal solid waste referring on the different concepts of material testing. The figure basically classifies waste into untreated (raw) waste material and biologically stabilized material (after decay or Mechanical Biological Treatment).

Parameter	Unit	untreated MSW	MBT-waste	comments
Respiration activity AT_4	mg O_2/g TS	> 5	< 5	
dry density ρ_d	t/m^3	0.2-0.5	0.2-0.7	loose dropped
		0.5-1.0	0.8-1.5	compacted
Shear strength (anisotropic)				
Tensile angle ζ	°	25-35 dim 1+2 > 30%	10-14 dim 1+2 < 20%	
friction angle φ_{GM}	°	25-30	30-35	
Cohesion c_{GM}	kPa	<10		
Shear strength (deformation dependent)				
Friction angle $\varphi_{\varepsilon1}$	°	ε_1 = 0 %: 0 ε_1 = 10 %: 20-25 ε_1 = 20 %: 22-35		
Cohesion $c_{\varepsilon1}$	kPa	ε_1 = 0 %: 0 ε_1 = 20 %: 22-35		
modulus of stiffness E_S	kN/m^2	$E_S = -a + b*\sigma$ a: -100 bis -300, b: 10-13		

MSW: Municipal solid waste MBT: Mechanical biological treatment

Source: Koelsch, 2009

Figure 4: Geotechnical parameters for MSW and MBT-material

3.2. Planning of Landfill Mining

Once the site investigation is completed, the information gathered should be analyzed to determine whether the proposed goals could be met within the projected cost framework. The issues to be addressed in this analysis include access roads, fencing, waste reception and placement, scavenger control, slope stability, leachate management, fire control, soil cover, use of mechanical equipments, limiting the working face, environmental permit, environmental monitoring and staff training (Joseph et al., 2004).

Access road

The access road should permit the passing of two trucks travelling in either direction. The running surface should be firm and not easily disrupted by traversing trucks. The road surface should comprise of compacted earth or similar material with a top dressing of road stone. A durable, asphalt surface would be preferred, if resources are available (ibid.).

Fencing

Fencing a dumpsite is required to control access to the disposal site, manage uncontrolled scavenging by waste pickers and to protect the vegetated sites. As a minimum requirement all open dumpsites within 500 metres of communities should be fenced. Perimeter fencing is desirable around all rehabilitated open dumpsites though it may not be practical. The minimum form of fencing to control vehicular access and larger animals would be a stake-and-wire strand (barbed-wire) fence or an excavated perimeter ditch and bund planted with fast growing hedge-forming shrubs (ibid.).

Waste reception and placement

A reception area should be clearly defined to check incoming vehicles by operating staff. The reception area should have an entrance gate or barrier to regulate the flow of vehicles to and from the disposal site and a gatehouse to store waste records and documents and protect landfill staff from unfavourable weather conditions. The reception area should have sufficient space for at least two trucks to be parked and not interfere with the vehicle movements in and out of the site (ibid.).

Scavenging Control

Ideally, scavenging should not be allowed to take place, but when difficult economic circumstances prevail it is not easy to eradicate it from a disposal site. Where scavenging is tolerated, scavengers should at least be separated from the mechanical equipment emplacing waste. The usual approach is to set up a temporary scavenging area near the waste emplacement area where trucks can discharge their loads. After the scavengers have finished searching the waste it is bulldozed to the emplacement area (ibid.).

Slope stability

The final slopes of the filled portions of the site should be 2 - 8% in grade and should not exceed the upper limit so as to promote surface water runoff without ponding or water-logging or erosion of the final cover (ibid.).

Unless local geotechnical reasons prevail in the site and cannot be adjusted, the waste side slope should not be steeper than 1 in 3 and top slopes should not be more than 1 in 20 (Rushbrook, 2001). Slope stabilization activities should seek to redistribute waste within the confines of the existing dumpsite without extending the external boundaries of the fill (Joseph et al., 2004).

Leachate accumulation

If accumulated leachate is identified on the open dumpsite then a plan should be made to drain or pump the leachate into a prepared pond not liable to flooding or recirculated back into the waste. The source of the leachate should be determined and the remedial works defined to prevent leachate accumulations reoccurring in the future (ibid.).

Dumpsite fire control

A plan should be prepared to extinguish potential fires them as the mining and rehabilitation work progresses across the site. The method to be used for extinguishing fires should be presented in the plan. The use of water to extinguish fires should be avoided. Isolation and rapid natural burnout or smothering with soil is preferred (ibid.).

Soil cover

Once the landfilled areas have been sloped and all the waste compacted and covered, the site should be covered with at least 60 cm of clay-rich soil. This final cover of clay-rich soil should have an inner layer (about 30 cm for inert waste landfills or 45 cm for municipal solid waste landfills) compacted in lifts of 15 cm to minimize surface water infiltration. Compaction testing of this barrier layer may be required to ensure proper placing of the soil. An additional 30 - 45 cm of soil should be placed over the compacted clay layer to protect it from erosion, plant roots, vehicular traffic, etc. This buffer layer also provides a rooting depth for the final foliage cover (ibid.).

Mechanical equipment

The preparations for dumpsite rehabilitation should include a list of equipment to be provided to the improved site. Mechanical equipment serves three basic functions related to soil, wastes and support works at a controlled land disposal site (Joseph et al., 2004).

The required number and type of equipment varies and depends on the quantity of waste handled daily together with the available resources to operate and maintain the equipment. The most essential equipment for the full-scale operation of the disposal site are (ibid.): one bulldozer of adequate capacity to handle the daily quantity of waste arriving at the site; and one tractor with trailer to haul cover soil to the work zone and undertake other support activities.

Area of exposed waste

All exposed and uncontrolled piles of waste should be compacted into layers. All uncovered areas of waste not expected to receive new deposits of waste, or at least not in the next few months, should be covered with an intermediate or final layer of soil material. The remaining area of exposed waste will form the initial working area for the emplacement of incoming waste. This area should not exceed 0.5 ha for sites receiving up to 250 tons per day and one hectare at sites receiving 250 to 500 tons per day. Two hectares may be appropriate at large sites receiving well over 500 tons per day (Joseph et al., 2004).

Environmental permit application

The environmental permit application will be required to fully address all potential risks in advance of a LFMR operation commencing. Many of the conditions present at the landfill and its surroundings will be unique to the specific landfill, and specific to the age of the waste being excavated (Ford et al., 2013).

Environmental hazards and typical mitigation measures are discussed below. Most risks are reduced by minimising the size of the exposed working face and excavating waste in a pre-planned methodical manner.

Managing hazardous waste, that may be uncovered during reclamation operations. Hazardous wastes are likely to be more prevalent at older landfills that were in operation at a time when waste disposal practices and waste acceptance criteria were not as robust, or well regulated, as in the present day. Such wastes may be subject to special handling and disposal requirements to mitigate risk to the environment and human health of workers, nearby residents and other members of the public. The presence, nature and extent of hazardous waste could be sufficient to prevent a LFMR operation from taking place on the basis of degree of risk, or resulting expense (ibid.).

Controlling releases of landfill gases and odours. Waste excavation raises a number of potential problems related to the release of gases. Methane and other gases, generated by decomposing wastes, can cause explosions, fires, odours and risk to human health (Ford et al., 2013). The volume of gas being generated depends on the presence of gas generating wastes, the quantity and the age of the waste. Many LFMR projects have been undertaken on relatively old wastes, typically over 25 years old, since the decomposition of waste was advanced, giving rise to low levels of gas generation. Younger wastes produce higher volume of gas, resulting in a greater risk for odour issues and explosion (ibid.). However, low levels of gas can still give rise to issues, in particular the risk of accumulation to explosive or asphyxiating levels within confined structures, including beneath and within buildings. As reported in literature, gas monitors with alarms are used to monitor levels of gas, including methane, at the location of waste excavation (ibid.).

Controlling releases of liquids and leachates. Suitable containment and drainage will need to be afforded to all areas used for stockpiling and processing wastes. It is likely that any surface water runoff from these areas will either need to be collected and treated, or diverted into the landfill mass (ibid.). Consideration should be given to any damage to leachate collection and drainage systems that may result from the excavation process. Poor drainage could have waste mass stability implications. Having removed any capping materials that may be present, rainwater entry and thus leachate generation is likely to increase. For this reason, minimisation of the exposed working face can be beneficial (ibid.).

Controlling releases of dust. Dust generation is a significant, but manageable, risk at any active landfill operation, whether or not LFMR is taking place. Water bowsers to dampen roads in dry conditions, or friable wastes, is usually an effective mitigation measure. Where asbestos is, or is expected to be, encountered special measures are likely to be required, such as the use of fine spray mists. Finally, stopping operations in high winds may be necessary at times (Ford et al., 2013).

Controlling subsidence or collapse. Excavation of a landfill area can undermine the integrity of adjacent cells, which can sink or collapse into the excavated area releasing contaminants into the surrounding area and causing damage to engineered structures. Limiting the depth of excavation for any one lift is likely to be a key management method (Ford et al., 2013).

Environmental risks can be managed if considered in advance of the operation and appropriate mitigation measures designed and implemented in discussion with regulators (ibid.). Subject to location, there may be also sociological issues arising from perception of the risks from nearby residents or other stakeholders in the local environment (ibid.).

When scoping and planning a LFMR project for a specific landfill, it is necessary to fully establish the 'conceptual model' of the landfill and its surroundings. The conceptual model is the full understanding of the waste, the engineered structure of the landfill and the surroundings, including potential receptors to pollution, contamination or nuisance (ibid.).

Environmental monitoring programme

The main aim of the environmental monitoring programme is to provide the tools for a quantitative assessment of the environmental conditions and to identify solutions and measures for tackling the impacts deriving from the mining operations as well as from the whole spectrum of activities taking place in the landfill site (Joseph et al., 2004).

Staff training

The site personnel should be trained and have defined job descriptions in order to perform properly the tasks they are given. Working conditions also influence the ability and willingness of individual staff members to accept and carry out the responsibilities placed upon them. These personnel issues must be addressed during the planning stage. The minimum number of staff will vary depending on the quantity of waste received and the standard of disposal operation achieved (Joseph et al., 2004).

3.3. Available technologies in operational phase

There are a number of technologies that could potentially be employed in a LFMR operation (Table 4). Whilst most of these technologies are currently used within the waste management industry, many are unproven, or little proven, in the application of LFMR (Ford et al., 2013). In comparison to waste shortly after the point of generation, landfilled waste will often be compacted, degraded, mixed, intertwined and often wet. Furthermore, shredding and separation equipment will most likely operate at different efficiencies, and degrees of success, for waste from different landfills (ibid.).

Table 4: Available technologies for a LFMR operation

Excavation	Screens	Size Reduction/Shredding
– Trackhoe and backhoe excavators – Bulldozers – Grappling Hoes	– Trommel – Vibrating – Disc/star	– Hammermills - vertical and horizontal shaft – Shear shredder – Rotary, guillotine and scissors-type shears – Grinders - roller, disc-mill, ball mill – Flail mill – Wet pulper – Knife mill
Ferrous Metal Separators	**Non-Ferrous Metal Separators**	
– Overband magnets – Drum magnets – Head pulley magnets	– Eddy current separators	
Handling Equipment	**Air Technologies**	
– Front-end loaders – Grapples – Conveyors – Forklifts	– Windshifter – Drum separators – Air classifiers – Air knife	

Source: Ford et al., 2013

LFMR projects undertaken around the world to date have most commonly employed excavators, screeners, trommels, shredders, grinders and chippers for removing and sorting materials from landfills. More advanced separation technologies are less proven in the application of LFMR (ibid.).

A short description of some of the technologies employed in LFMR is given below (ibid.).

Excavation/ waste removal

Excavator is probably the most important piece of equipment required for waste removal and handling, for most LFMR projects. It is efficient, relatively low cost, can move high tonnages of materials quickly, and can operate over many terrain types. Following excavation, mobile or stationary grapples and/or front-end loaders and trackhoes are typically used to organise the excavated materials and separate out bulky material (Ford et al., 2013).

Landfilled wastes can be excavated from the top, working downward in “lifts” (e.g. typically 3m per lift) or from the bottom, with a front loader removing sides and faces (ibid.). The volume excavated per day will depend on the numbers of equipment used and the throughput of the waste separation processes (ibid.).

Size reduction

Size reduction typically follows excavation and is undertaken to allow ease of subsequent material handling and sorting (Ford et al., 2013). Various industrial grinders and shredders can be use for this scope (Ford et al., 2013).

Screening

Screens are used to separate wastes by size, with material passing through the screen being known as ‘undersize’, or ‘fines’, and that which does not is known as ‘oversize’, or ‘overs’. Some screen arrangements allow for sorting to a greater degree, thus creating a ‘midsize’ fraction. The most common screens used in waste management are flat vibrating screens, trommel screens and star screens (Ford et al., 2013).

Air technologies

Air technologies may include windshifters, separation drums, air classifiers and air knives. All air technologies rely on light, low density, fractions of waste being separated from heavy, high density, fractions in a stream of air (Ford et al., 2013). Whilst air technologies are widely used elsewhere in the waste management industry, they do have their limitations and their application to LFMR may be limited to certain stages in the process (ibid.).

Metal separation

Metal separation within the waste management industry includes removal of ferrous and non-ferrous metals. Removal efficiency is typically high and equipment robust. Ferrous metal removal is normally undertaken by using drum magnets or overband magnets. Ferrous metal recovery from excavated landfilled waste should be a straight forward operation. The separated metal may contain greater levels of contamination in comparison to metal extracted from non landfilled MSW (Ford et al., 2013).

4. Planning of the landfill mining pilot application in the site of the Polygyros

4.1. Introduction

The landfill mining pilot application will take place in the site of the Polygyros Landfill (PL). In this context this phase will make available the clarification of issues set in the in the objectives of the research programme. It will allow the assessment of the excavation technology available and the optimization of the design parameters, the identification and accurate characterization of the deposited waste in terms of their content in useful materials, as well as the evaluation of the space creation capabilities, through the mining process.

The details of the various parameters used in the proposed mining scheme are given in the following paragraphs. Hence, firstly a brief introduction of the PL is given along with the available alternatives for implementing the exploitation. Following that, the detailed technical plan is drawn, including the proposed siting of the mining excavation, the characteristics of the excavation in terms of geometrical characteristics, as well as with the overall planning of the surface excavation and the assessment of the required resources to complete task.

4.2. Site Location

The Polygyros Landfill is located in the Polygyros municipality, in the "Kastri" area, approximately 3.5 km northwest (NW) of the homonymous city, having a total area of about 9 ha. The centroid of the site's geographic coordinates are 40°24'11.0"N, 23°24'54.0"E. The access to the site is facilitated from a rural paved road starting from the 3rd km of the Polygyros - Thessaloniki highway (EO16A).

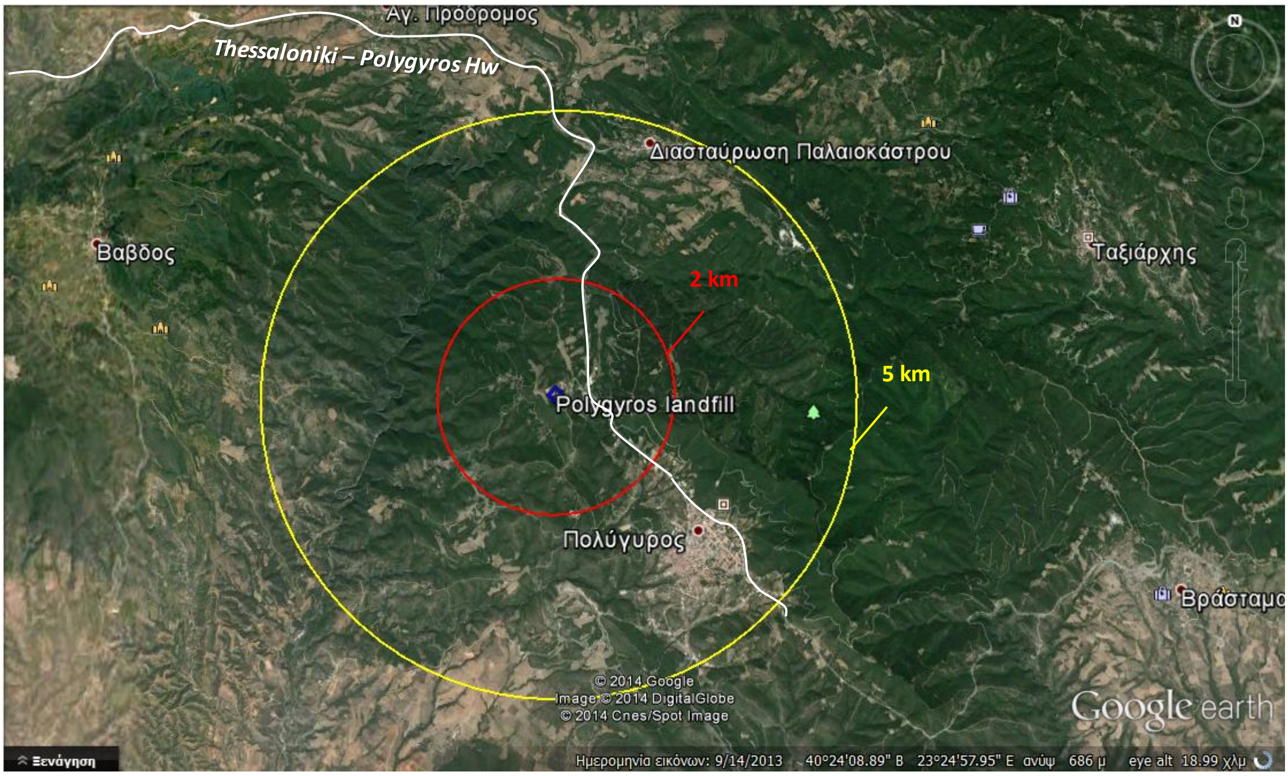


Figure 5: General view of the wider area of the Polygyros Landfill site (Google earth imaginary)

The surrounding area is characterized by the small hills found there. The PL site is developed at that hilly terrain at an elevation between +580m, at the northwestern part, and +680m, at the southern part of the area. This particular terrain is a plus to the site, as it blocks any visual contact between the Polygyros city and the main road network and the landfill, as it can be shown in the pseudo-3D representation given in Figure 6.

Figure 6: Pseudo-3D view of the PL site with respect to the Polygyros town (Google earth imaginary)

4.3. Brief Technical Description of the Polygyros Landfill

The facility is operational since 2009 and from then on it has been used for the disposal of MSW coming from the municipalities of Polygyros and Zervohoria. Since August 2011, Helector S.A. has been the operator of the site, under contract with the waste management public bodies.

The geology of the area is consisted mainly by phyllites and quartzites, while at places quartzite shales and quartzite sandstones are found. The constructional characteristics of PL include: geological barrier, synthetic (HDPE) membrane, leachate collection pipes, and leachate pond, biogas collection wells, biological treatment plant for leachate and biogas active pumping. In Figure 7 the general plan of the site is given.

The facility covers a total area of 9.3 ha, from which the disposal area is around 2.6 ha. The PL is designed to hold a total of 266,000 m^3 of municipal solid waste (MSW) that will be disposed in two phases i.e. A and B, having a maximum design capacity of 6,000 and 8,100 m^3 per annum, respectively. The main disposal area is located in the western part of the site and at the moment, the landfilling operations are taking place as part of the 1st phase, located at the lower part of the area (Figs. 8, 9). With the maximum disposal capacity of PL set at about 8,100 m^3 per annum, with a service life of around 21 years. Today, it is estimated that the remaining life of the site is about 16 years.

Figure 7: General layout of the Polygyros Landfill site

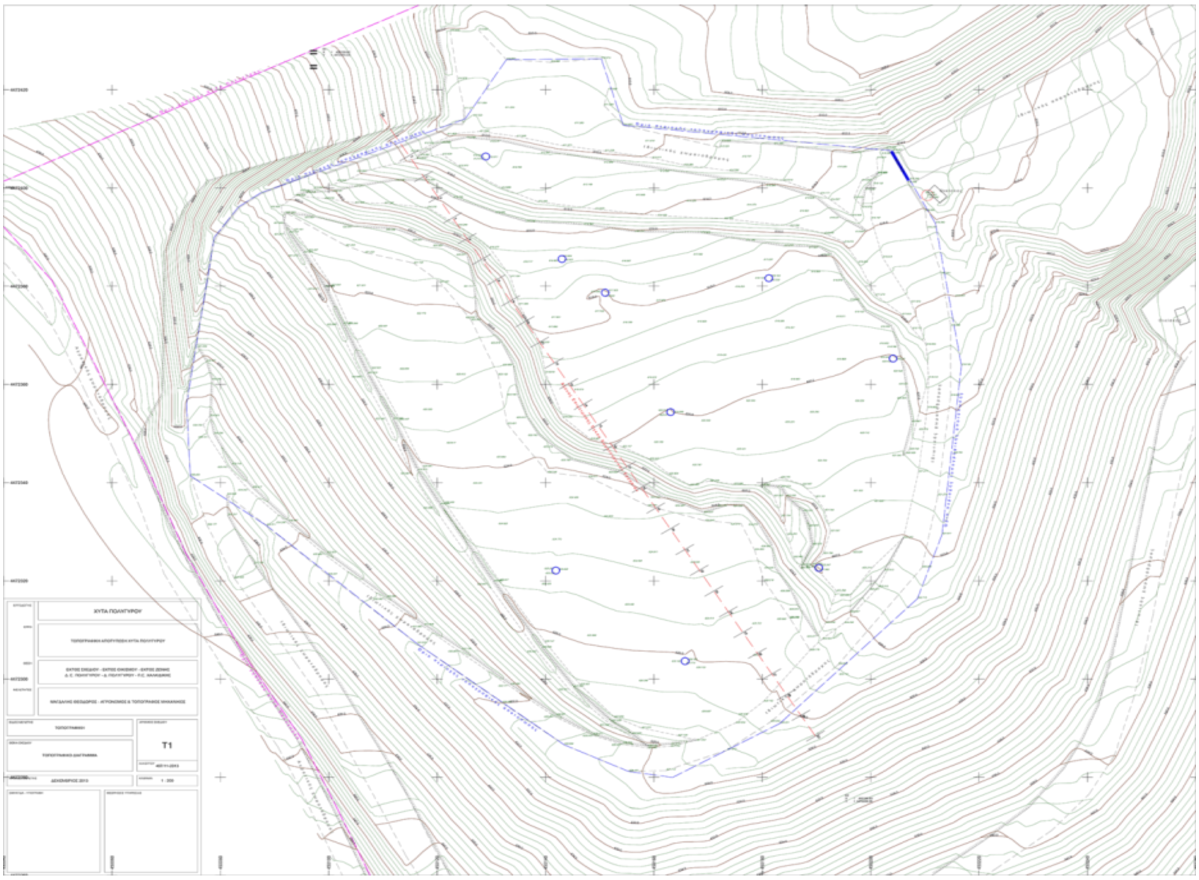


Figure 8: Sketch of the PL's MSW disposal area (not to scale)

Figure 9: View of the PL disposal area and details about the layering and compaction operations taking place at the current working cell

The disposal activities are done on a daily basis in the PL site, while in the summer time the waste quantities are reaching their peak values, as a result of the very active tourist season in the wider area.

Waste movement is usually confined to spreading the waste on the working face with compactors or dozers after loads are deposited by trucks. The waste are layered and compacted, followed by their covering with soil material. The layering of the waste is done gradually following a general direction from south to north, forming stripes (working faces) about 4-5 m in width and 0.1-0.3 m in height. Gradually the material cover the whole available area, forming the first cell of the site, up to 4-5 m in height. The next cells are constructed with the same principle, increasing the overall height of the landfill.

During these operations the leachate collection piping system is layered (in the base of the site) as well as the gas collection and management system. The leachates through a pipe network are gathered in the designated pond structure and from there they are pumped to the respective treatment facility. At the final stages of the facility the gas can be actively pumped and burned in the gas flare unit.

4.4. Mining Plan for the Polygyros Landfill Site

The mining plan should provide the necessary information regarding the extraction of the HSW material from the landfill body. The excavation procedure through which the waste is extracted from its place is usually simple and straightforward, following the principles of surface (open-pit) mining. Nevertheless, the optimization of the procedure and the organization of the whole mining cycle in conjunction with the preparation for meeting strict environmental standards and for controlling unforeseen events is crucial to achieve a cost-effective and safe operation.

The complete context of the issues that need to be addressed in the work plan were given in detail in the previous pages of the report. In this section, emphasis is given to the major assumptions and decisions taken into account for the mining activities in the PL site. These include:

- The sampling phase and methodology applied.
- The identification of the target area that the mining operations are to take place.
- The assessment of the most efficient mining scheme in terms of operation characteristics, safety and stability conditions.
- The resources required for the mining task (machinery, equipment, labor, etc.)
- The setting up of monitoring systems and measurement protocols (mining, environmental protection).

4.4.1. Sampling scheme

The sampling phase will initialize the mining of the waste. Its main purpose is to identify the type and characterisation of waste in terms of content. Furthermore, it could be used to get insight regarding the physical characteristics of the waste and assess its geotechnical properties. The available alternatives are the use of drilling boreholes and/or the development of test excavations (trenches) in order to quire the required data.

In the case of PL the most appropriate method is the development of trenches as the depth of the landfill is relatively low. Thus, the main need of the sampling is to assess the physical properties of the waste. The most suitable area for the development of these trenches is approximately at the central part of the disposal area and to the northeaster parts of the landfill. In there the area is relatively flat and can facilitate the development of the operations. The exact area of the trenches is to be decided ad hoc at the day of the sampling.

It is recommended, that at least 2 sampling trenches will be constructed using a backhoe excavator/loader. Their length should be at least 5 m, with a depth of at least 3 m, and width of at least 1 m, as shown in Figure 10, where sketches illustrating details of the sampling trenches are presented. It is also suggested that the trenches should be developed in areas representing different time frames of the disposal operation. In this manner, even though the PL is a relatively new landfill site, with a life of 6 years, it might be able to assess the difference in the characteristics of the waste material.

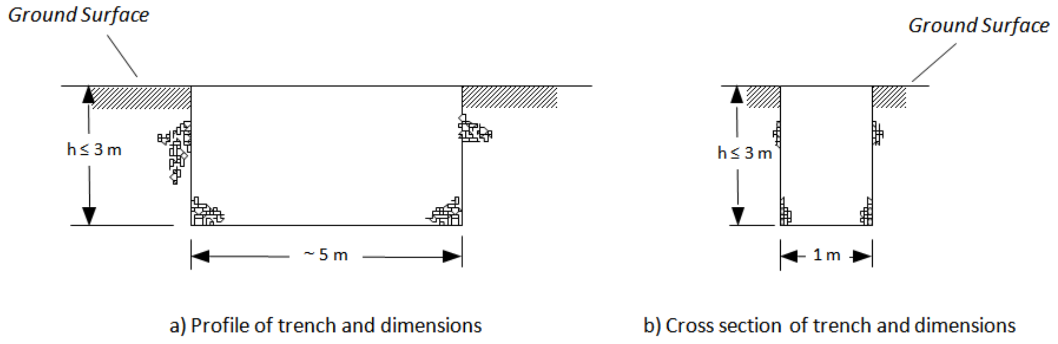


Figure 10: Sketch of the proposed trenches used for the sampling scheme

4.4.2. Target area to be mined

The purpose of the programme is to assess the performance of the mining scheme along with the beneficiation potential of the waste through the pilot application of the landfill mining. Based on the above, the large scale mining of the PL site is not an option at this stage. The required amount of waste to be mined and processed reaches a volume of 2000 m^3, over a period of around 3 months. Thus, the identification of the area that the mining activities will be focused on, is a major prerequisite for the successful completion of the project.

In the above context, the target area should be representative in terms of landfill's characteristics as well as waste content, easily accessible to the equipment and appropriately located in areas where the extraction works could not interfere with the daily waste disposal operations. The best possible arrangement, given the current state of the PL site, is to designate the mining area at the elevation of +620 m, at the central part of the disposal area, approximately 30 m eastern from the toe area of the current working cell.

There the mining could take place almost independently from the disposal operations. At the same time, the waste material found there covers a significant part of the PL's working life, from almost 2009 to 2012. Another advantage of the position is the minimization of the development works required for the setting up of the haulage road. The main internal access network of the PL will be used, while only limited new road development is required at the level of +620. The area where the processing unit will be installed is located at the entrance point of the disposal area, and thus, the total haulage length from the designated mining area to that point is almost 125 m. The proposed arrangements, the designated mining and processing areas along with the proposed haulage access road are presented in Figures 11 and 12.

The required surface area for the mining activities is a relation of the extraction depth and the volume of the waste material required. Given that at the focus area the disposal depth is ranging between 6 and 8 m and that the mining goal is set to 2000 m^3 of waste, it can be concluded that the mining area will have a surface of 600-800 m^2, or dimensions about 20 x 40 m. The above are based on the fact that the depth of the mining activities will leave at least a 2 m buffer from the base of the disposal area, limiting the excavation depth to around 4 m.

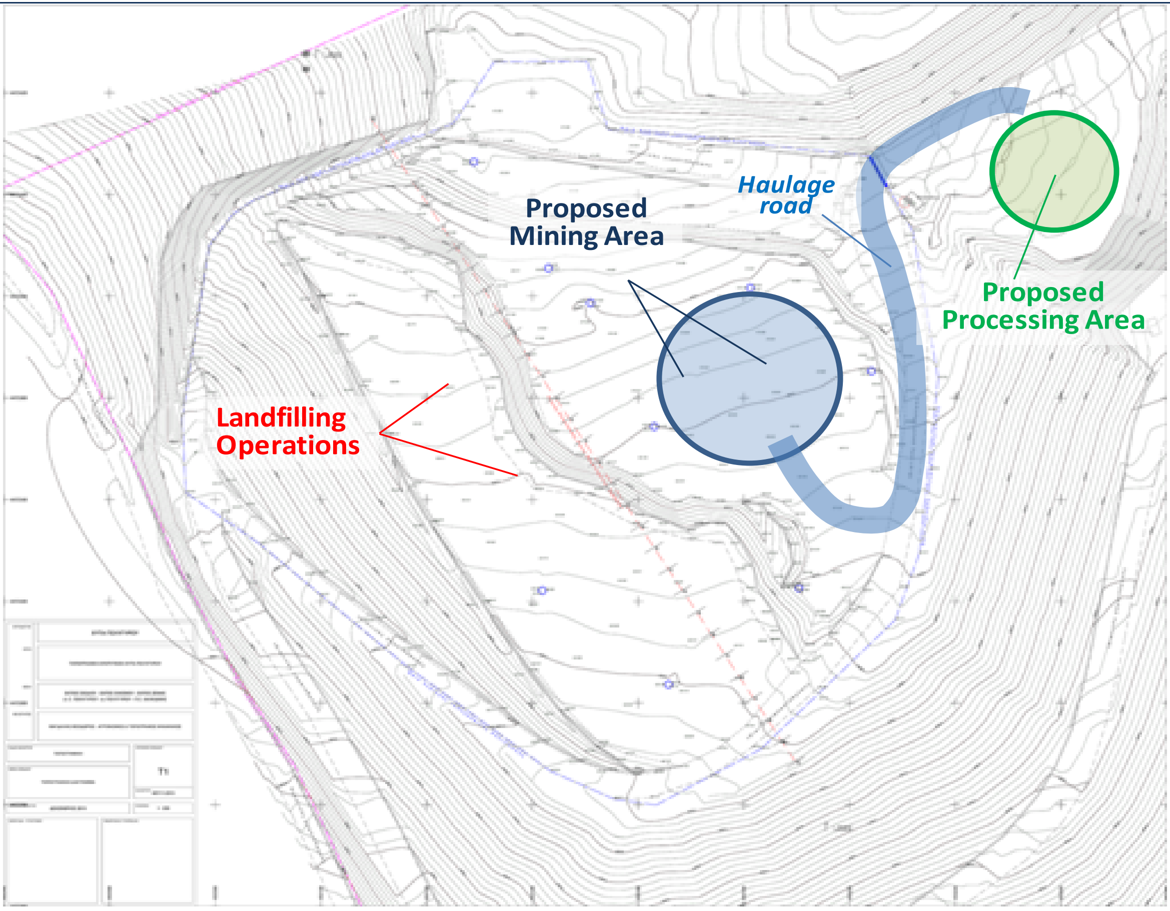


Figure 11: Proposed location of the landfill mining area, with respect to the current landfilling operations and the proposed processing area

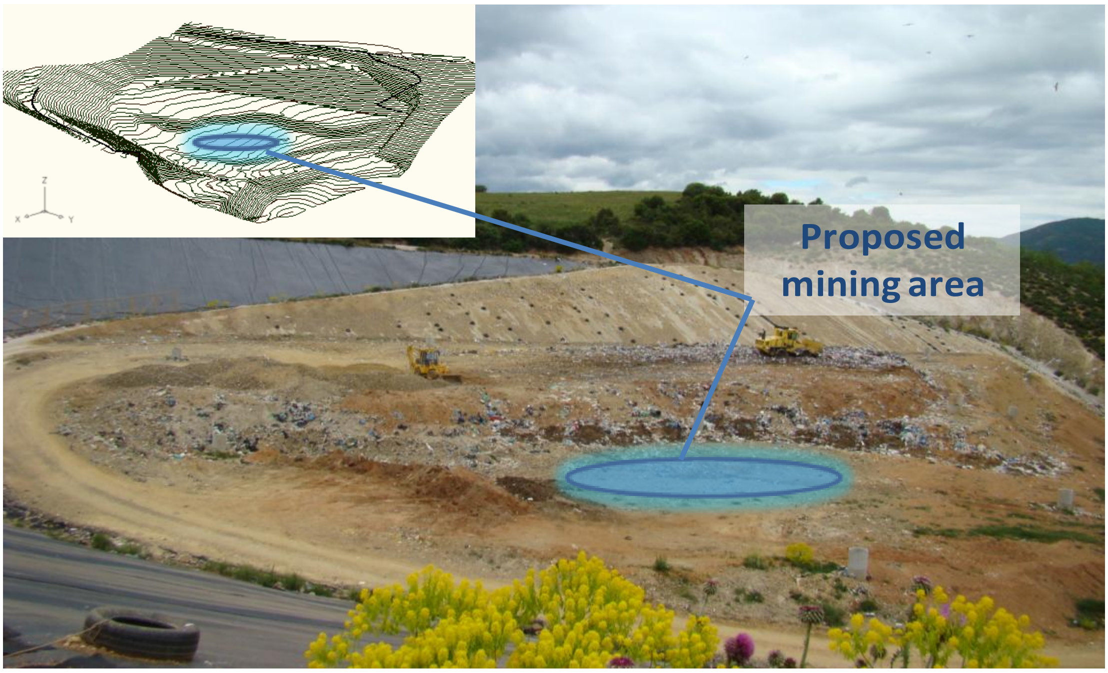


Figure 12: View of the proposed mining area in PL

4.4.3. Mining scheme and operation details

The mining of the waste will be made with conventional surface mining equipment. Usually, in relatively loose materials, as in the case of the MSW, excavators, backhoe/loaders, front-end loaders or shovels are required to make the waste extraction and to load the materials into the transport trucks.

The PL mining scheme proposes the excavation to take place from the top (+620 m level) using a hydraulic excavator at the crest area, rather than making the extraction from the toe using front-end loaders and by scraping the wastes. The excavator can perform quite well with high productivity, extracting the loose waste found below, up to a depth of 4 - 5 m (Figure 13). The other alternative would require the development of an initial trench excavation and then the moving of the equipment (front loader and bulldozers) at the lower extraction level. This method could be applied successfully to a large scale mining scheme, but in the current mining application the development of the initial trench alone would have generated almost the majority of the required waste volume. Therefore, instead of making preparatory works, the direct mining approach selected for the Polygyros pilot LFM can be simpler, straightforward and therefore less risky and more productive.

Figure 13: Typical application of top excavation in landfill mining operations using excavators and dump trucks

Based on the proposed mining plan, the waste will be mined using 3 - 5 m wide and 3 - 4 m deep trenches, aligned in the NW-SE direction. Special attention will be paid to the gas extraction wells found in the area or other fixed infrastructure so as not to disturb them. The trench excavation will start from one end (the SW - or the NE one) having a length of about 20 m. At the end of the section the next cut will start. The excavation will continue to develop towards the NE (or SW) direction, until the target volume of 2000 m^3 is reached. It is estimated that finally a "box cut" of about 20 x 40 x 4 m will be developed, at the end of the operations.

In terms of stability, the relatively shallow excavation is expected not to create strains or problems to the slope. Yet, special attention needs to be paid with a constant careful assessment of the waste conditions directly below the position of the excavator. Caution is to be paid in cases of extreme rainfalls that could deteriorate the stability conditions. In those events the possibility of the temporary suspension of the excavation is to be considered. As a general rule, the final slope of the mined area should not exceed the 1:3 limit. Furthermore, a buffer distance of around 5 to 10 m is required between the mined area and the adjacent southwestern landfilled slope. A safety distance should be kept between the loading trucks and the trench's crest, with each truck stopping at least 2 - 3 m away from the working face.

The rate of excavation will be directly linked with the feeding capacity of the processing unit, as the possible temporal stockpiling of the waste material needs to be minimized for environmental reasons. Thus, the excavation will be taking place at intervals but no apparent problems or other issues are anticipated, as long as a constant flow of materials can be maintained. Perhaps, for flexibility reasons, there is the possibility of developing a small stockpile near the processing unit. However, the proper design of the unit in terms of feeding rate can ensure the smooth operation in both the mining and the screening process. Based on preliminary estimations the whole mining and waste processing phase can be completed in about 45 working days.

At the start of the operation, the soil cover will be carefully removed and stockpiled for further reuse. The mining face need to be covered with soil so as to minimize odor issues, reduce windblown litter, etc. This can be done on a daily basis, at the end of the working shift. To facilitate the whole process, having also in mind the excavation rate, it is recommended that the exposed working face should be kept to a minimum. Further issues to take into account are the problems related to storm water and runoffs after heavy rainfalls. It is recommended that a surface water drainage system (e.g. diversion berms, grading of the surface adjacent to the excavation) could appropriately address such issues.

The haulage of the material will be performed using standard dump trucks or the excavator itself, as the distance to the pending area is probably very short. Their capacity is quite adequate to cover the capacity of the excavator and the processing unit, given the relatively small transport distance. The road network should be periodically inspected and properly maintained. Also in case where dust problems are expected, water spraying can be applied in the road surface with the use of tanker trucks.

Apart from the above given details regarding the mining plan, there is an additional task that needs to be performed. This encompasses the haulage and proper disposal of the processed waste back to the landfill site, along with the closure of the open trenches that were developed by the mining operations. The processed waste will be loaded to trucks with front loader equipment and transported for their disposal in the landfill site, while the recovered soil will be used for covering purposes. Finally, the closure of the mined space (trench) will be made upon the completion of the materials processing and the end of the pilot application. The closure will be made by the introduction of new waste material in the mined space, through standard landfilling operation. It is estimated that within a period of 7 to 10 days the mined void will be re-filled with waste and brought back to its original condition.

4.4.4. Required resources (machinery, personnel, etc.)

The mining activities require a number of equipment to be used. Helector SA, which will have the overall responsibility of the LIFE reclaim operations inside the PL, owns a small fleet of machinery already used for the landfilling activities. They include a BOMAG BC 672-RB refuse compactor and a RAM Italia 40.13 backhoe loader. Also, a truck is available for a number of workdays. Part of the above fleet will be also used for the pilot scale mining application, with the inclusion of a hydraulic excavator that will be leased for the project.

The excavator will perform the most important work relating to the development of the trenching excavation. The RAM Italia backhoe loader will be used in the initial sampling trenches, as well as in a number of supporting activities (road maintenance, grading, material loading in the processing unit, etc.). The truck will be used for the material haulage and if required its lease will be upgraded so as to have it available throughout the pilot application period. All equipment will be properly maintained so as to avoid faults during the mining operations. However, in the area there is quite high availability for the types of the required equipment and consequently even in an unfortunate even of a major breakdown the operations are expected to continue smoothly. Finally, for safety reasons, all equipment before leaving the site will be decontaminated in a pre-designated area.

The personnel employed in the mining activities is related to the partners of the programme. All employees, and especially the operators of the heavy machinery, are highly skilled with significant experience in excavation and landfilling activities. This is a plus as they have the ability to perform under difficult conditions and properly address typical working conditions and/or abnormal situations during the operations. Also, the engineers of Helector, ENVECO, NTUA and the Polygyros municipality have substantial experience in such operations. It is expected that the available personnel for the completion of the task will be comprising by:

- A site manager (Helector) responsible for the whole mining operation
- A team of at least three engineers (ENVECO, Helector, NTUA)
- A foreman
- Three operators of the heavy machinery (excavator, backhoe, truck)

Finally, all personnel will be equipped with the appropriate personal protective equipment (PPE).

4.4.5. Monitoring system

The monitoring of the operation is an essential task to document the findings of the pilot application, to assess the overall performance of the mining and processing operations as well as to evaluate the strains posed to the environment of the area.

The documentation starts with the sampling phase where the trenches are mapped and the waste's characterisation is documented. The daily progress of the main excavation operations, in meters of excavation and total volume is also to be documented and recorded through mapping and photographs. Time recordings of the excavation, loading time and total haulage will be also included in the documentation. Furthermore, data regarding the daily work hours and fuel consumption of the equipment will be stored. In addition to the above data the following specific information will also be recorded in a logbook:

- Team members and their responsibilities.
- Time of arrival and departure.
- Deviations from the operation's plan.
- Level of health and safety protection.

The environmental and safety monitoring will be consisted by a number of units and apparatuses that will be installed in the PL site and will be carried by the employees. This will allow for the assessment of the environmental conditions in the working area and for the proactive assessment of potential risks to the personnel's health. Emphasis is given to dust monitoring (especially related to mining and transport operations) and gas emissions from the waste. There will be regular air sampling which will constitute of (a) in situ automated samplers and (b) manual air sampling with suitable portable equipment (bags, tubes or passive samplers). The monitoring phase will begin before the starting of the mine operations in order to identify the background levels of the measured characteristics. The following monitoring units and apparatuses will be installed in the PL site:

- Meteorological station (already installed and running)
- PM 10, PM 2.5 and TSP sampling units
- Gas detectors
- Personal samplers and methane detectors

The majority of the equipment is owned by the project's participants. However, leased equipment could be also brought for monitoring purposes if required. The analyses of chemical characteristics and organic compounds will be made available through specialized external laboratories.

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Annex A. Expert report on the Polygyros landfill mining plan

A1. Introduction

The NTUA scientists provided the technical assistance and were responsible for providing the technical guidelines for the design of the sampling phase as well as the landfill mining scheme that will be employed at the site. In this manner the NTUA team has visited the Polygyros Landfill (PL) and inspected the area and the operations that are currently under process. Furthermore, the future operational plans of the municipal solid waste (MSW) disposal were discussed with the members of the Helector S.A. team that are responsible for the management of the PL site. This annex outlines the major findings, as well as the proposals and guidelines that should be followed for the development of the landfill mining plan.

A2. Basic Information

The Polygyros Landfill (PL) is located in the Polygyros municipality, in the "Kastri" area, approximately 3.5 km northwest (NW) of the homonymous city (Figure A1), having a total area of about 9 ha. The centroid of the site's geographic coordinates are 40°24'11.0"N, 23°24'54.0"E. The access to the site is facilitated from a rural paved road starting from the 3rd km of the Polygyros - Thessaloniki highway (EO16A). The facility is operational since 2009 and from then on it has been used for the disposal of municipal solid waste (MSW) coming from the municipalities of Polygyros and Zervohoria, with a design capacity of 266,000 m^3 MSW. Since August 2011, Helector S.A. has been the operator of the site, under contract with the waste management public bodies.

The disposal activities are done on a daily basis in the PL site, while in the summer time the waste quantities are reaching their peak values, as a result of the very active tourist season in the wider area. Waste movement is usually confined to spreading the waste on the working face with compactors or dozers after loads are deposited by trucks. The waste are layered and compacted, followed by their covering with soil material. The layering of the waste is done gradually following a general direction from south to north, forming stripes (working faces) about 4-5 m in width and 0.1-0.3 m in height. Gradually the material cover the whole available area, forming the first cell of the site, up to 4-5 m in height. The next cells are constructed with the same principle, increasing the overall height of the landfill (Figure A2).

The plan of the site that depicts the latest available data in terms of topography is given in Plan A1. In there the main area of the facility where the disposal activities are taking place is given.

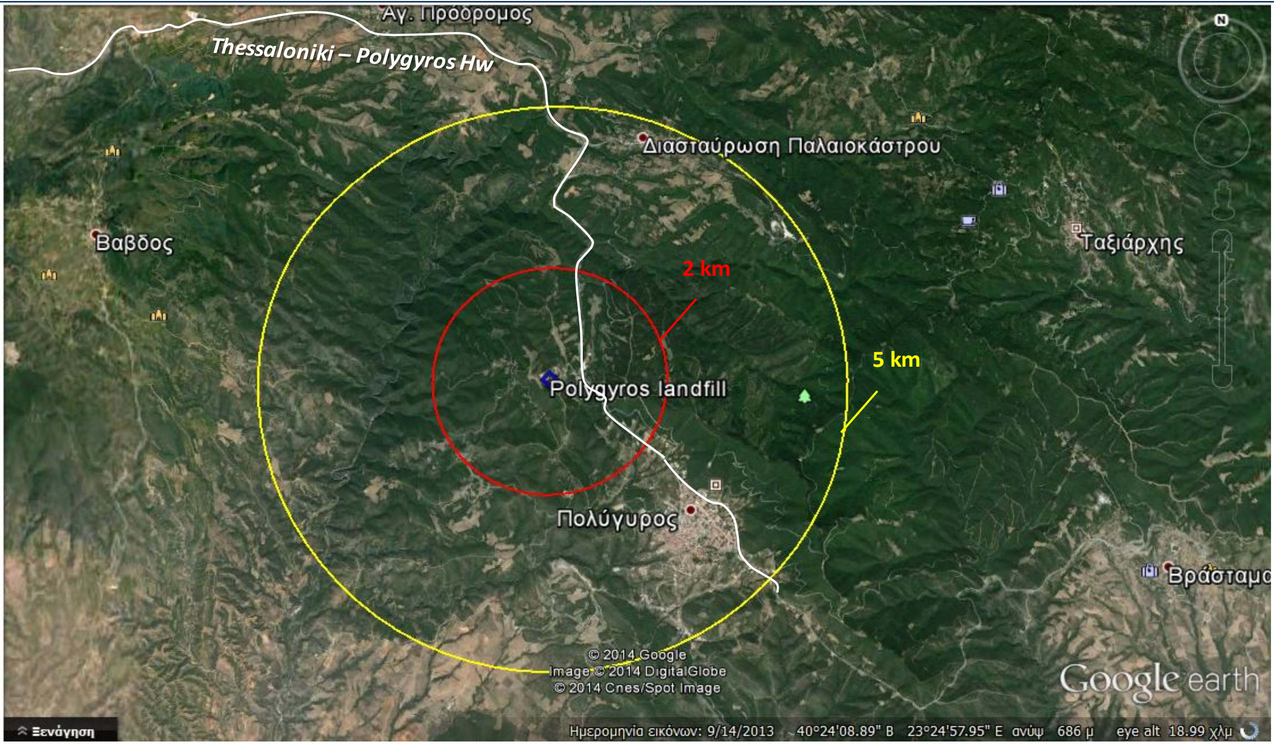


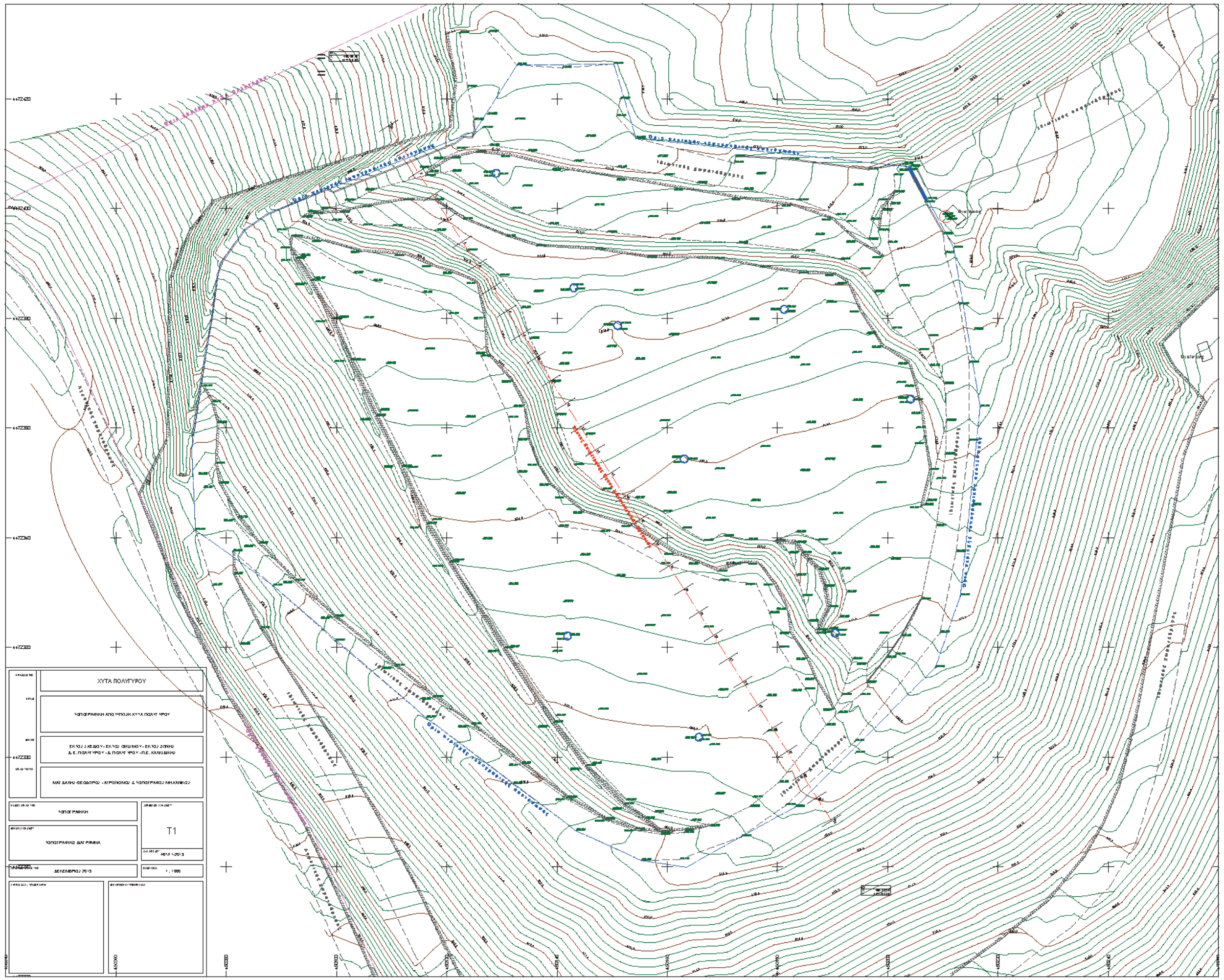
Figure A1: General view of the wider area of the Polygyros Landfill site (Google earth imaginary)

A3. Sampling and Mining Plan for the Polygyros Landfill Site

The sampling and mining plan should provide the necessary information regarding the preparatory work and the main phase of the landfill mining operations that are to take place at the PL site. The excavation procedure through which the waste is extracted from its place is usually simple and straightforward, following the principles of surface (open-pit) mining. Nevertheless, the optimization of the procedure and the organization of the whole mining cycle in conjunction with the preparation for meeting strict environmental standards and for controlling unforeseen events is crucial to achieve a cost-effective and safe operation.

The complete context of the issues that need to be addressed in the work plan were given in detail in the previous pages of the report. In this section, emphasis is given to the major assumptions and decisions taken into account for the mining activities in the PL site. These include:

- The sampling phase and methodology applied.
- The identification of the target area that the mining operations are to take place.
- The assessment of the most efficient mining scheme in terms of operation characteristics, safety and stability conditions.
- The resources required for the mining task (machinery, equipment, labor, etc.)
- The setting up of monitoring systems and measurement protocols (mining, environmental protection).



Plan A1. Site plan/Topographic map of the main disposal area of the Polygyros Landfill site

Sampling scheme

The sampling phase will initialize the mining of the waste. Its main purpose is to identify the type and characterisation of waste in terms of content. Furthermore, it could be used to gain insight regarding the physical characteristics of the waste and assess its geotechnical properties. The available alternatives are the use of drilling boreholes and/or the development of test excavations (trenches) in order to quire the required data. Furthermore, the equipment's capacity to undergo the main exploitation phase is to be tested in the sampling phase. Hence, through this phase the decisions should be made for the use of typical backhoe excavators or the selection of hydraulic shovel equipment.

In the case of PL the most appropriate method is the development of trenches as the depth of the landfill is relatively low. It is recommended, that at least 2 sampling trenches will be constructed using a backhoe excavator/loader. The target area for the development of the sampling campaign is given in Figure A2. This area is far from the operations taking place in a daily basis and it is relatively flat, facilitating the excavations.

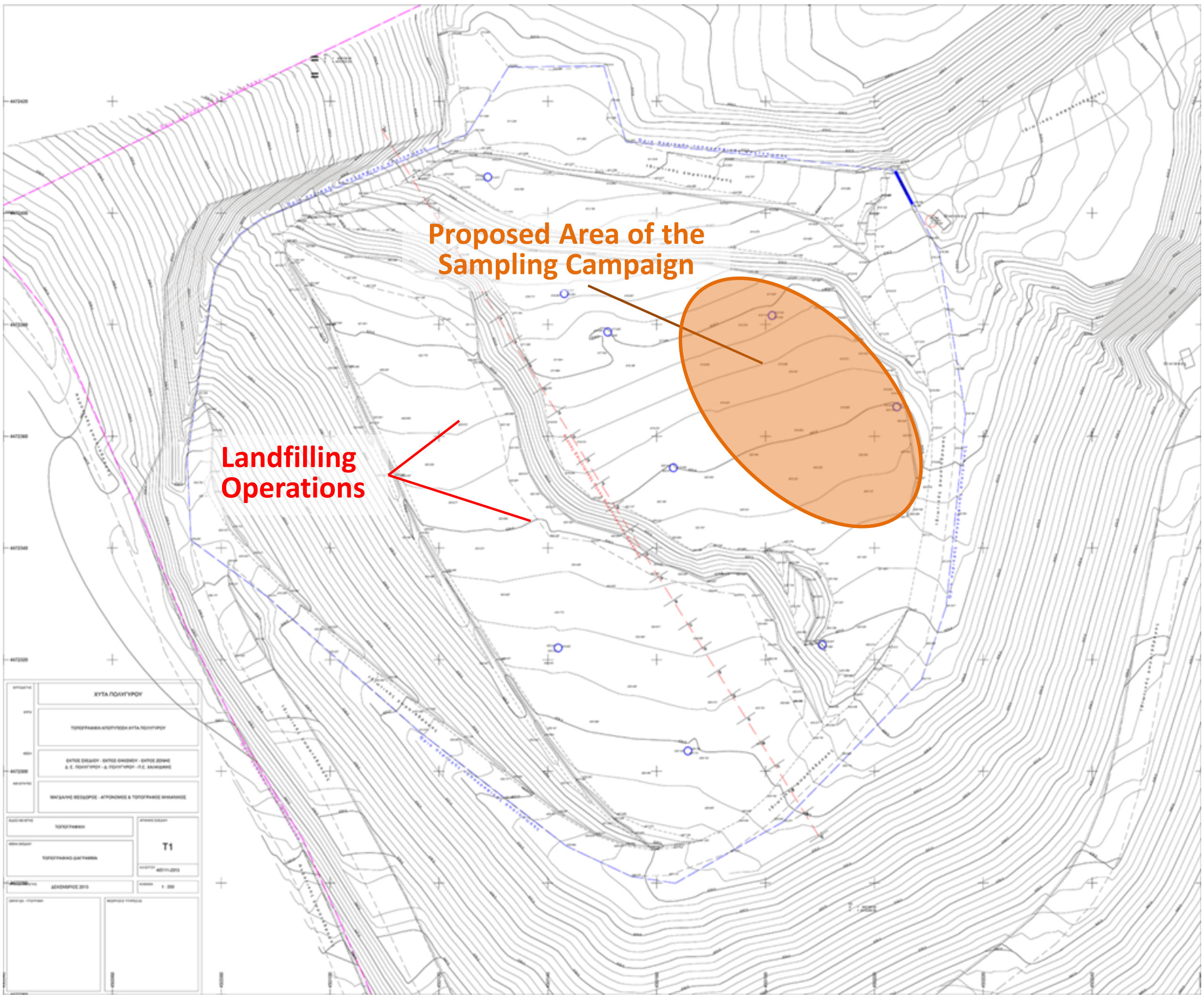


Figure A2: Proposed location of the development of the sampling campaign (trench excavations).

The exact location of the trenches and their characteristics will be decided ad hoc at the day of the commencing of the sampling campaign. However, is that recommended that their length should be at least 5 m, with a depth of at least 3 m, and width of at least 1 m, as shown in Figure A3, where sketches illustrating details of the sampling trenches are presented. It is also suggested that the trenches should be developed in areas representing different time frames of the disposal operation. In this manner, even though the PL is a relatively new landfill site, with a life of 6 years, it might be able to assess the difference in the characteristics of the waste material.

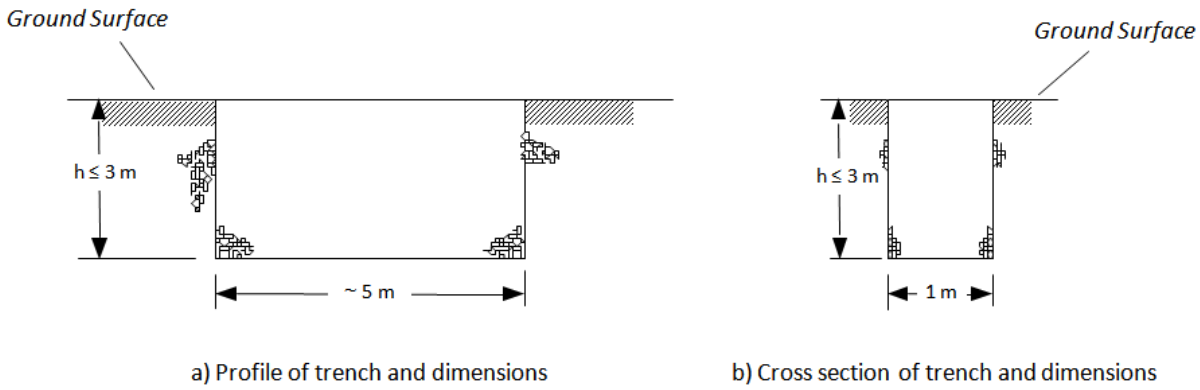


Figure A3: Sketch of the proposed trenches used for the sampling scheme

Determination of the target area to be mined

The required amount of waste to be mined and processed reaches a volume of 2000 m^3, over a period of around 3 months. Thus, the identification of the area that the mining activities will be focused on, is a major prerequisite for the successful completion of the project.

In the above context, the target area should be representative in terms of landfill's characteristics as well as waste content, easily accessible to the equipment and appropriately located in areas where the extraction works could not interfere with the daily waste disposal operations. The best possible arrangement, given the current state of the PL site, is to designate the mining area at the elevation of +620 m, at the central part of the disposal area, approximately 30 m eastern from the toe area of the current working cell.

In there, the mining could take place almost independently from the disposal operations. At the same time, the waste material found there covers a significant part of the PL's working life, from almost 2009 to 2012. Another advantage of the position is the minimization of the development works required for the setting up of the haulage road. The main internal access network of the PL will be used, while only limited new road development is required at the level of +620. The area where the processing unit will be installed is located at the entrance point of the disposal area, and thus, the total haulage length from the designated mining area to that point is almost 125 m. The proposed arrangements, the designated mining and processing areas along with the proposed haulage access road are presented in Figure A4.

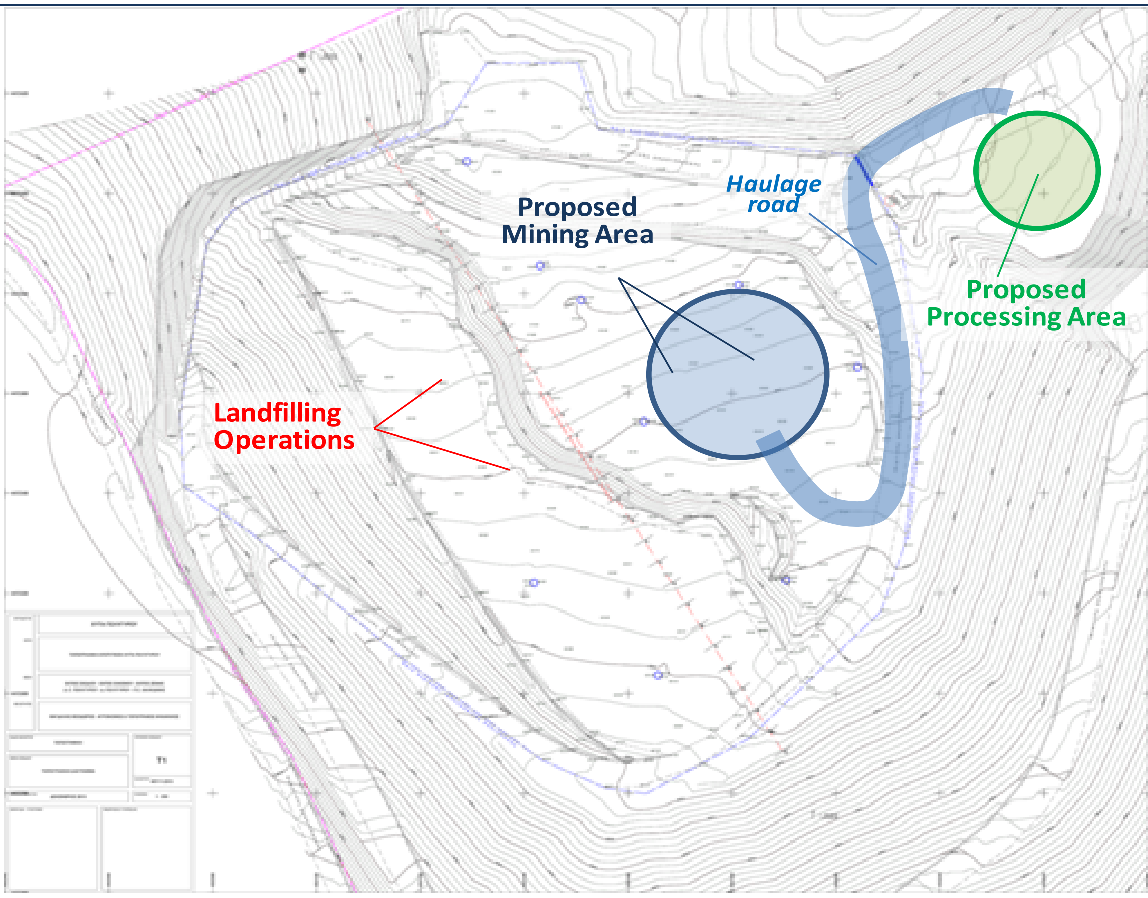


Figure A4: Proposed location of the landfill mining area, with respect to the current landfilling operations and the proposed processing area

The required surface area for the mining activities is a relation of the extraction depth and the volume of the waste material required. Given that at the focus area the disposal depth is ranging between 6 and 8 m and that the mining goal is set to 2000 m^3 of waste, it can be concluded that the mining area will have a surface of 600-800 m^2, or dimensions about 20 x 40 m. The above are based on the fact that the depth of the mining activities will leave at least a 2 m buffer from the base of the disposal area, limiting the excavation depth to around 3-4 m.

Selection of mining scheme

The mining of the waste will be made with conventional surface mining equipment. Usually, in relatively loose materials, as in the case of the MSW, excavators, backhoe/loaders, front-end loaders or shovels are required to make the waste extraction and to load the materials into the transport trucks.

The PL mining scheme proposes the excavation to take place from the top (+620 m level) using a hydraulic excavator at the crest area, rather than making the extraction from the toe using front-end loaders and by scraping the wastes. The excavator can perform quite well with high productivity, extracting the loose waste found below, up to a depth of 4 - 5 m.

The other alternative would require the development of an initial trench excavation and then the moving of the equipment (front loader and bulldozers) at the lower extraction level. This method could be applied successfully to a large scale mining scheme, but in the current mining application the development of the initial trench alone would have generated almost the majority of the required waste volume. Therefore, instead of making preparatory works, the direct mining approach selected for the Polygyros pilot LFM can be simpler, straightforward and therefore less risky and more productive.

Based on the proposed mining plan, the waste will be mined using 3 - 5 m wide and 3 - 4 m deep trenches, aligned in the NW-SE direction. Special attention will be paid to the gas extraction wells found in the area or other fixed infrastructure so as not to disturb them. The trench excavation will start from one end (the SW - or the NE one) having a length of about 20 m. At the end of the section the next cut will start. The excavation will continue to develop towards the NE (or SW) direction, until the target volume of 2000 m^3 is reached. It is estimated that finally a "box cut" of about 20 x 40 x 4 m will be developed, at the end of the operations.

In terms of stability, the relatively shallow excavation is expected not to create strains or problems to the slope. Yet, special attention needs to be paid with a constant careful assessment of the waste conditions directly below the position of the excavator. Caution is to be paid in cases of extreme rainfalls that could deteriorate the stability conditions. In those events the possibility of the temporary suspension of the excavation is to be considered. As a general rule, the final slope of the mined area should not exceed the 1:3 limit. Furthermore, a buffer distance of around 5 to 10 m is required between the mined area and the adjacent southwestern landfilled slope. A safety distance should be kept between the loading trucks and the trench's crest, with each truck stopping at least 2 - 3 m away from the working face.

The rate of excavation will be directly linked with the feeding capacity of the processing unit, as the possible temporal stockpiling of the waste material needs to be minimized for environmental reasons. Thus, the excavation will be taking place at intervals but no apparent problems or other issues are anticipated, as long as a constant flow of materials can be maintained. Perhaps, for flexibility reasons, there is the possibility of developing a small stockpile near the processing unit. However, the proper design of the unit in terms of feeding rate can ensure the smooth operation in both the mining and the screening process. Based on preliminary estimations the whole mining and waste processing phase can be completed in about 45 working days.

Details of the operational phase

At the start of the operation, the soil cover will be carefully removed and stockpiled for further reuse. The mining face need to be covered with soil so as to minimize odor issues, reduce windblown litter, etc. This can be done on a daily basis, at the end of the working shift. To facilitate the whole process, having also in mind the excavation rate, it is recommended that the exposed working face should be kept to a minimum. Further issues to take into account are the problems related to storm water and runoffs after heavy rainfalls. It is recommended that a surface water drainage system (e.g. diversion berms, grading of the surface adjacent to the excavation) could appropriately address such issues.

The haulage of the material will be performed using standard dump trucks or the excavator itself, as the distance to the pending area is probably very short. Their capacity is quite adequate to cover the capacity of the excavator and the processing unit, given the relatively small transport distance. The road network should be periodically inspected and properly maintained. Also in case where dust problems are expected, water spraying can be applied in the road surface with the use of tanker trucks.

Apart from the above given details regarding the mining plan, there is an additional task that needs to be performed. This encompasses the haulage and proper disposal of the processed waste back to the landfill site, along with the closure of the open trenches that were developed by the mining operations. The processed waste will be loaded to trucks with front loader equipment and transported for their disposal in the landfill site, while the recovered soil will be used for covering purposes. Finally, the closure of the mined space (trench) will be made upon the completion of the materials processing and the end of the pilot application. The closure will be made by the introduction of new waste material in the mined space, through standard landfilling operation. It is estimated that within a period of 7 to 10 days the mined void will be re-filled with waste and brought back to its original condition.

Overall, it is concluded that this scheme has the required flexibility to tackle possible changes in the disposal operations or to address difficulties at the mining phase or changes in the volume of the waste to be mined and processed.

A3. Assessment of the resources required

The mining activities require a number of equipment to be used. Helector SA, which will have the overall responsibility of the LIFE reclaim operations inside the PL, owns a small fleet of machinery already used for the landfilling activities. They include a BOMAG BC 672-RB refuse compactor and a RAM Italia 40.13 backhoe loader. Also, a truck is available for a number of workdays. Part of the above fleet will be also used for the pilot scale mining application, with the inclusion of a hydraulic excavator that will be leased for the project. This is to be decided upon the results obtained from the sampling phase.

The excavator will perform the most important work relating to the development of the trenching excavation. The RAM Italia backhoe loader will be used in the initial sampling trenches, as well as in a number of supporting activities (road maintenance, grading, material loading in the processing unit, etc.). The truck will be used for the material haulage and if required its lease will be upgraded so as to have it available throughout the pilot application period. All equipment will be properly maintained so as to avoid faults during the mining operations. However, in the area there is quite high availability for the types of the required equipment and consequently even in an unfortunate even of a major breakdown the operations are expected to continue smoothly. Finally, for safety reasons, all equipment before leaving the site will be decontaminated in a pre-designated area.

The personnel employed in the mining activities is related to the partners of the programme. All employees, and especially the operators of the heavy machinery, are highly skilled with significant experience in excavation and landfilling activities. This is a plus as they have the ability to perform under difficult conditions and properly address typical working conditions and/or abnormal situations during the operations. Also, the engineers of Helector, ENVECO, NTUA and the Polygyros municipality have substantial experience in such operations. It is expected that the available personnel for the completion of the task will be comprising by, a site manager (Helector) responsible for the whole mining operation, a foreman and the operators of the machinery fleet. Also, a team of engineers from ENVECO, Helector, and NTUA can assist in the details of the operation scheme and resolve issues that might come up at the period of the landfill mining activities.

A5. Photographs of the PL site

Photo A1. General view of the disposal area of the PL site

Photo A2. Details of the disposal and compacting operations at the current disposal cell

Photo A3. View of the proposed mining area with respect to the ongoing disposal operations

Photo A4. View of the proposed processing area

Photo A5. View of the north western boundaries of the PL site, the leachate collection pond and the gas flare

Photo A4. Equipment available (backhoe loader) to be used in the landfill mining operation.