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Environmental Action Programme Support Project
Contract DHR-0039-C-00-5034-00
United States Agency for International Development

LANDFILL GAS UTILIZATION IN RADOM, POLAND

Submitted to:
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Submitted by:
Chemonics International Inc.

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Prepared by:
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EXECUTIVE SUMMARY

The Environmental Action Programme Support (EAPS) Radom Municipal Landfill Biogas Project in Radom, Poland, is an environmentally beneficial, renewable energy project. The project seeks to control gas emitted from the landfill by installing an LFG collection system. That system will contain gas movement by putting the waste, and therefore gas generated in the landfill, under the influence of a vacuum.

The LFG collected through this process could then be used as fuel, providing additional environmental benefits. For example, an existing coal-fired furnace that lacks emissions control equipment could be replaced and decommissioned. The collected LFG could also be used for on-site electricity generation. Successful implementation of the project would have other benefits as well, among them:

- Potential use as a replicable demonstration project
- Implementation of improved landfill management techniques
- Initiation of a countrywide interproject support structure, which should encourage development of additional environment-related, renewable energy projects
- Increased crop growth in a renovated and expanded on-site greenhouse complex

A key step in implementing this project is ascertaining how much LFG can be recovered and used as fuel. Appropriate analysis can determine the volume of LFG available as a fuel source and determine the most appropriate LFG collection and utilization technologies. Osrodek Badawszo-Rozwojowy Ekologii Miast (OBREM), a local consulting firm, previously used a computer-based theoretical model to project LFG availability. The validity of this work was questioned, however, and the project has been delayed until LFG fuel supply quantity could be more confidently established. The analysis in this report resolves this issue.

In addition to analyzing LFG availability, this report contains specific design and operation recommendations or observations where they are particularly relevant to the discussion, where they involve unusual technical or operational parameters, or where they are important to successful project development. This is not intended to be a definitive design document, however.

Development of an LFG recovery project at Radom landfill is feasible, but the project will be challenging. Radom is a highly sensitive LFG recovery site. This is primarily because the landfill is shallow and recovery operations must be managed so that air is not drawn into the shallow fill as LFG is being removed. The technology and operating procedures to accomplish this are available. Experience with these techniques is limited in Poland, but project participants' skill levels appear to be substantial, and enthusiasm for the project, particularly among Radom management, is high.

Lack of basic landfill gas management experience is the principal reason for the conflict over OBREM's analytical work. The company's analysis overstates the amount of LFG recoverable from the site. Two site visits to Radom landfill determined that influencing the waste mass as assumed in the OBREM analysis is not feasible. Therefore, the power generation potential projected by OBREM is too high.

The recommended use of the LFG is as fuel for electricity generation using internal combustion engines. This method is recommended for the following reasons:

- Power generation is a proven LFG recovery technology
- Electricity is a valuable commodity in Poland's expanding society
- Power generation is a "baseload" operation, matching the continuous nature of the landfill's LFG generation

Radkom, the joint venture responsible for managing the landfill, is highly interested in expanding and modernizing its greenhouse complex. This report therefore suggests that heat recovery from the engines or some other form of greenhouse heating be incorporated into the project.

A functional analysis of Radom landfill shows that *conservatively* the site will initially support one 125 kW nominal engine, the same type used at the Bydgoszcz LPG utilization project. Following is an outline of the recommended implementation plan:

- Modify Radom landfill operating procedures to support LFG recovery. These changes should improve other aspects of Radom landfill operations.

- Install a partial LFG collection system in the landfill and stabilize LFG flow. The system will consist of eight to ten extraction wells, an interconnecting pipeline system, and a flare.

- Supply natural gas or provide diesel fuel to the powerplant. Natural gas or diesel fuel will function as a process stabilizing fuel, reducing the likelihood of stress on the collection system during start-up and while personnel are learning their jobs. These fuels will also provide backup in case the process must be shut down when fuel is needed for the powerplant or heat is needed for the greenhouse complex.

- Install one engine-generator set and start the engine on the selected process stabilization fuel. Blend in LFG as it becomes available from the stabilized and balanced collection system.

- Continue development of the landfill.

- Expand the LFG collection system and powerplant based on operational experience with the initial installation and continued development of the landfill.

The involved and unusual nature of this project, and Poland's limited experience with this type of project development, makes a strong, centralized project management essential. A project manager, such as a current EAPS staff person or an entity such as CityProf, should therefore be appointed and given as much project implementation authority as possible.

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LANDFILL GAS UTILIZATION IN RADOM, POLAND

A. Introduction

Landfill gas (LFG) is a natural byproduct of decomposing landfill waste. Without adequate controls, LFG can pollute the environment surrounding a landfill. In addition to emitting directly into the atmosphere, the gas can percolate through surrounding soils, penetrating nearby buildings and affecting vegetation growth. The Environmental Action Programme Support (EAPS) Radom Municipal Landfill Biogas Project in Radom, Poland, seeks to control LFG emissions and subsurface percolation from the Radom landfill. This control will be achieved by installing an LFG collection system. That system will contain gas movement by putting the waste, and therefore gas generated in the landfill, under the influence of a vacuum produced by equipment that would be part of the project.

The LFG collected through this process could then be used as fuel, providing additional environmental benefits. For example, an existing coal-fired furnace that lacks emissions control equipment could be replaced and decommissioned. The collected LFG could also be used for on-site electricity generation. Successful implementation of the project would have other benefits as well, among them:

- Its potential use as a replicable demonstration project
- Implementation of improved landfill management techniques
- Initiation of a countrywide interproject support structure, which should encourage development of additional environment-related, renewable energy projects
- Increased crop growth in a renovated and expanded on-site greenhouse complex

B. LFG Fuel Supply Estimation Methodology

B1. Procedural Background

A main determiner of feasibility for LFG utilization projects is the amount and stability of the potential fuel supply. The fuel supply also influences project implementation procedures, project size, technology use, economics, and other matters. Among the first tasks in evaluating an LFG project is making a baseline estimate of the fuel supply using a computerized model. Usually, this estimate will then be refined through more detailed analysis. The preparation and execution of the initial model require a disciplined compilation of core project data and information. This procedure has several benefits besides the resultant baseline estimate, including the following:

- Effectively determines key project-specific LFG model variables, such as the LFG recoverability factor, which requires a functional analysis of the landfill and its operation
- Provides information for subsequent project evaluation activities

- Offers an opportunity to identify project problems that may show up during implementation or operation

- Assists in project design, construction, installation, economic analysis, financing, etc.

Generation of a project-specific model is only the first step in a meaningful LFG fuel supply analysis. Analysis using a computer-generated model is not definitive, additional procedures are required to refine the modeled estimate based on environmental, physical, and other conditions. Osrodek Badawszo-Rozwojowy Ekologii Miast (OBREM), the local consulting firm that generated the computer model analysis for the Radom project, therefore started the process but did not finish it. The company lacked enough experience in this unique technical area to proceed with further evaluative steps. This is fully understandable, because Eastern Europe has little experience with this type of project.

B2. Analysis of the OBREM Model

The OBREM model, which is based on the Rettenberger/Tabasaran equation, is a theoretical formula that calculates ideal gas generation from basic physical parameters such as temperature, organic carbon content of waste mass, and a decomposition factor.

Since landfills are far from ideal, OBREM applied correction factors to the mathematical process to provide conservatism and make the resultant LFG projections acceptably reasonable. OBREM's correction factors were as follows:

- The gas generation rate was multiplied by 0.6. That is, the rate was decreased by 40 percent because landfill conditions were less than ideal for gas generation.

- A recovery factor of 0.6 was applied. This means that 60 percent of the gas generated (after applying the previous correction factor) would be recovered.

- A correction factor of 0.8 was applied to allow for generation equipment efficiency.

The application of these correction factors constitutes a combined impact of about 70 percent ($1 - (0.6 \times 0.6 \times 0.8)$), which calls into question the applicability of the basic model. This mathematical process provides an answer based on correction factors, rather than on an understanding of the physical and biological processes involved. As a specific example, applying even a simple energy balance would have been more appropriate than using a 0.8 equipment efficiency factor at this level of analysis.

Furthermore, experience has shown that models break down or lose their applicability when applied to low-volume waste sites like Radom. Mathematically this is a "boundary condition," or a point at which the mathematical representation fails to be representative. Physically, it means that at small volumes other factors, such as landfill operating conditions, become the determinants in LFG generation and recovery.

An alternative approach would be an empirical model incorporating parameters developed through and based on factors such as operational experience and LFG recovery tracking, then applying feedback or regression analysis. Models could be then modified based on demonstrated, functional data and parameters.

The OBREM report overstates the LFG recovery potential at Radom, given the site's current physical characteristics, even after OBREM's correction factors are applied. Further analysis is required to definitively establish a project configuration. Still, OBREM's report provides a valuable baseline estimate.

B3. Pump Test

The program initially contemplated for Radom was to attempt to verify the theoretical model for the site by conducting an LFG pump test at the landfill. The test would involve drilling a series of wells into the landfill and measuring the gas flow and quantity from these wells.

Experience has shown the difficulty of accurately correlating pump test results with long-term LFG recovery, particularly at small-volume sites. A pump test is therefore not recommended. Instead, several production wells and the supporting pipeline (header and lateral) system should be installed. The operation of this partial production system would then be routinely monitored and the data analyzed. A projection of total LFG recovery could then be extrapolated from this partial installation of the collection system. The data generated will be much more reliable than the pump test approach, and more logical, intelligent project planning decisions could be made.

Additionally, to the extent this data can be integrated with previously developed information, construction of a coherent, meaningful body of knowledge can be initiated or enhanced. This would be particularly productive if an entity currently active in this type of work, such as OBREM, were to be involved, assuming the selected organization desires to advance knowledge and skills not only for itself but for the wider community of practitioners.

B4. Functional Analysis and Recommendation

Further refinement of the model or conducting an LFG pump test program would produce little additional useful information. An alternate and potentially more productive approach would be to evaluate the feasibility of LFG recovery based on a functional analysis of the Radom site.

A functional analysis synthesizes model data with information from other sources. It requires determining functional relationships between such factors as the following:

- Physical characteristics of the landfill site
- Landfill operating practices
- Waste volumes and type deposited in the site
- Landfill design
- Implementation plan
- Conceptual recovery project operating plan
- Process configuration

A detailed knowledge of LFG recovery projects and processes is necessary for such an analysis. Unfortunately, Eastern Europe has limited relevant experience in this area. Logically, however, certain basic physical rules apply. Therefore, such an analysis based on other LFG recovery project experience will be meaningful. While time limitations did not permit a robust functional analysis, enough information was available to conduct a meaningful review and conclude that, given certain provisions, an LFG recovery project is viable at Radom.

The functional review yielded the following information:

- *Landfill size.* The landfill is small (approximately 12 hectares), shallow (approximately 10 to 12 meters deep), low tonnage (approximately 500,000 tons total, 400,000 tons of which is municipal solid waste (MSW) accumulating at approximately 50,000 tons per year)

- *Soils.* Primarily permeable (sand)

- *Landfill design.* Liner and leachate system installed, functionality unknown; liquid levels in site unknown

- *Current landfill operations.* No planned fill pattern evident; compactor used ineffectively

- *Potential operational modifications.* Implement cellular fill pattern, use compactor more effectively, reintroduce grass and leaf waste, develop effective cover program, provide better site security, discourage fires on landfill

- *Conceptual LFG collection system design.* Wells to have approximately 15 meter (m) radiuses of influence, drilled to "bottom" of the site; approximately 6–7 m solid pipe, remainder slotted; wellheads valved, set up for monitoring and pumping; dual seals, top seal incorporating geo-textile; laterals and headers buried; extend wells up as fill progresses vertically

- *Conceptual collection system operation.* Operate collection system at low vacuum, expect low LFG flow rate per well; constantly monitor for air intrusion; be prepared to pump down wells if they water out

- *Powerplant.* Use basic Bydgoszcz design: one nominal 125 kilowatt (kW) engine to start, two if further analysis justifies expansion of design; blower with variable speed motor, flare; backup powerplant with natural gas to allow collection system to recover if it should be over-stressed

The complexity and diversity of issues introduced by the foregoing discussion indicate that implementing a project at Radom will be challenging. However, executing a comprehensive, disciplined plan based on the functional analysis has a substantial probability of resulting in a viable project.

The functional analysis concludes that installation and proper operation of an eight- to ten-well LFG collection system will provide fuel for one 125 kW nominal engine.

The functional analysis can be reduced analytically as described in the following paragraphs.

Installation of eight to ten wells, properly located and constructed, with the landfill properly prepared, is expected to result in a gas flow of approximately ten cubic feet (0.283 cubic meters) per minute per well. This is based on U.S. experience as functionally adapted to the Radom site. The LFG collection system is assumed to be operating at low stable vacuum (balanced operational condition) maintaining a heat value of approximately 500 British thermal units (BTU) per cubic foot (527 $kJ/ft^3 = 18.63\ MJ/m^3$) of landfill gas. Therefore:

$$8 \text{ wells} \times 10 \text{ ft}^3/\text{min} \times 500 \text{ BTU/ft}^3 \times 60 \text{ min/hr} = \sim 2{,}400{,}000 \text{ BTU/hr}$$

or:

$$8 \text{ wells} \times 0.283 \text{ m}^3/\text{min} \times 18.63 \text{ MJ/m}^3 \times 60 \text{ min/hr} = \sim 2.532 \text{ GJ/hr}$$

Similarly, 10 wells will provide approximately 3 million BTU per hour (3.165 GJ/hr).

Heat rate for a Caterpillar model 3516 SITA, modified and operated for landfill gas application and rated at nominal 800 kilowatt electrical (kwe) output, requires a heat input of approximately 9.88 million BTU per hour (10.4 GJ/hr). Allowing for the lower efficiency of smaller engines, this results in a heat rate of approximately 13.5 million BTU per hour per megawatt (14.3 GJ/hr/MW). Therefore:

$$\frac{2.4 \text{ million BTU/hr}}{13.5 \text{ million BTU/hr}} \text{ x } 1000 \text{ kW/MW} = \sim 177 \text{ kwe}$$

or:

$$\frac{2.532 \text{ GJ/hr}}{14.3 \text{ GJ/hr/MW}} \text{ x } 1000 \text{ kW/MW} = \sim 177 \text{ kwe}$$

Similarly, 3 million BTU per hour (3.165 GJ/hr) equates to approximately 222 kwe

Relating this to a 125 kW nominally rated engine at the low end of 177 kwe system design results in a margin of about 40 percent, 77 percent at the high end of 222 kwe.

C. Technology Recommendations

C1. Electricity Generation

The proposed conceptual layout of the Radom project is based on electrical power generation. Power generation is the preferred LFG utilization technology for many reasons, among them, the following:

- Power generation is "baseload," meaning that the process is designed to operate continuously. Landfill gas is generated continuously and the collection system functions optimally if steady-state, continuous extraction is applied. So this match between biology and mechanical technology is reinforcing and supportive.
- Electricity generation using landfill gas as a fuel is a proven, demonstrated technology.
- Electricity is a valuable commodity in Poland's expanding society.
- The prime movers for power generation at Radom will be engines, the operation and maintenance of which are familiar to site personnel.
- Heat may be recovered from the process for purposes such as heating greenhouses, making the combined process highly thermally efficient.

- Using natural gas or diesel as a process stabilization fuel is functional, which is important for implementing LFG utilization projects.

Additionally, CityProf advises that project economics favor electrical power generation.

The engine-generator sets should preferably be of the same manufacturer as those used for the Bydgoszcz project. Their application to LFG utilization has been demonstrated and they are of domestic manufacture.

C2. Heat Recovery

Heat for the greenhouse complex will preferably come from engine jacket water and perhaps exhaust heat recovery. A direct-fired boiler that would draw LFG as a slipstream from the landfill on demand is an additional design consideration. The configuration at this level of detail will be resolved during final design.

C3. LFG Collection System

Fuel would be provided by an LFG collection system installed in the landfill. The recommended design of the collection system consists of vertical wells connected by lateral pipelines to a header pipeline for connection to a flare/powerplant/greenhouse complex manifold. The well design would use a 0.5 to approximately 1.0 meter bore, four- to six-inch (10- to 15-cm) well casing, annular gravel fill with dual infiltration-mitigation seals. Further design details are provided in Section B4.

Collection system design should provide for a flare. The flare blower should be designed to provide LFG fuel to the powerplant without further compression.

C4. Process Stabilization Fuel Source

The project should incorporate natural gas or diesel fuel as a process stabilization fuel source. Among the most critical aspects of managing project operation will be avoiding over-stressing the installed LFG collection system. Availability of a process stabilization fuel source should limit the tendency to pull too hard on the collection system to protect plants in the greenhouse complex, increase electrical generation, or for other reasons.

D. Radom Landfill Management Procedures

D1. Overview

Radom landfill is a sensitive site for LFG recovery. The following discussion generally describes what activities can be undertaken at the site to make it more supportive for LFG recovery.

The success of landfill gas recovery projects depends on the coordination of diverse activities. One such activity is managing the landfill to facilitate LFG recovery. This section discusses the necessary procedural changes in general terms. This discussion is neither exhaustive nor definitive. Detailed, on-site study and evaluation will be required to define the scope of this work.

First, a section of the landfill will have to be modified. The modifications will take some time and need to be in place before other construction activities can occur.

Second, operational procedures will have to be revised and attentive on-site management will have to be in place. Radkom top management is willing to undertake such an effort.

D2. Fill Sequence

A section of the landfill should be identified as the primary fill area. This could be 1.6 to 3.2 hectares, depending on topographical analysis. This area would be given priority for filling. The intent would be to fill a small area to a designated height, complete that section, or cell, and proceed to another cell.

The current practice appears to fill in "layers" across the entire site. This is disadvantageous because lack of fill sequence control makes LFG recovery planning very difficult.

D3. Operational Procedures

Consistent with the determined fill sequence, operational procedures must be modified and followed.

Municipal solid waste will be dumped, or tipped, at the working face of the active fill area. The working face area should be minimized. Waste filling should occur in approximately 10 meter "lifts" or layers as the fill progresses down a cell.

The site has good equipment, but better use could be made of the compactor. The compactor should push waste from the tipping area up onto the working face, travel up and down the face several times to compact the waste, then travel perpendicular to the face for several passes for further compaction.

Bulldozers should be used primarily for construction and cover work.

Additional changes in operational procedure will require further evaluation and coordination with Radkom management. For example, it may be necessary to enhance site security to avoid fires on the landfill and for other reasons.

D4. Landfill Construction

The original design of the landfill included a liner and leachate control system, which is commendable for environmental mitigation. The design and construction need to be reviewed for integrity of the liner and sides, particularly considering the predominantly permeable soils at the site.

Further, cover management and storm water control need to be reviewed for consistency with revised operating procedures.

E. Project Implementation Sequence Planning

E1. Phased Approach to Development

The project should be developed in phases for the following reasons:

- One section of the landfill should be prepared for recovery using techniques described in the next section. It will only be possible to prepare a portion of the site in the time available and with the waste available. This would be the Phase 1 section of the site.

- The LFG collection system should be developed in the Phase 1 section of the site. This would approximately correspond to the partial production collection system previously recommended for installation in lieu of the temporary pump test. Initial review indicates that this installation would be eight to ten wells.

- This method would permit "balancing" the collection system for optimal LFG production. Techniques specific to the site could be established and site personnel could be trained in the application of those techniques.

- The phased approach, combined with a process stabilization fuel source, would limit the tendency to stress the landfill for fuel production until operational techniques are internalized, particularly operational coordination of the collection system, powerplant, and greenhouse complex.

- Construction techniques specific to LFG projects could be established.

- The volume and quality of recovered LFG could be directly determined. This will provide firm data that can be used in designing subsequent phases of the project.

- The initial financial requirements would be lessened.

The most logical and conservative approach to implementing the project, given the project's objectives, the program of which it is a part, and basic concerns such as gas supply, would be to install a portion of the collection system and one engine-generator set. Based on experience with this installation, specifically the volume of LFG consistently recovered for fuel use, a decision regarding the manner in which to develop the succeeding phase(s) of the project can be made.

E2. Implementation Sequence

The recommended sequence for the technical implementation of this project is as follows:

- Immediately initiate modifications to Radom landfill as described in Section C.

- Install a partial collection system, including flare, and stabilize LFG flow.

- Pipe in natural gas or supply diesel fuel to the site as process stabilization fuel.

- Install one engine-generator set and start the engine on natural gas or diesel fuel. Blend in LFG as it becomes available from the stabilized collection system.

- Continue development of the landfill.
- Expand the LFG collection system and powerplant based on operational experience with the initial installation.

F. Project Management

Considering the many diverse activities that need to be effectively coordinated for this project to develop properly, identifying an authoritative local project manager is important. Local experience in implementing projects of this unusual nature is limited, making coordination and organization all the more important. The potential for improper development of any single project element is of concern because it may result in failure of or substantial damage to the entire project.

Properly managed, this position could be key to extending institutional aspects of the program of which this project is a part.

If the project outlined in this report proceeds, a project manager, preferably one with some financial control, should be appointed. CityProf has impressive capabilities and could fill this function. Alternatively, EAPS personnel are fully capable of doing the job.