THE “LA LA LAND” PROJECT: LITHOTROPHIC MICROBIAL ACTIVITY AND AERATION APPLICATIONS TO LANDFILLS FOR A LANDSCAPE REQUALIFICATION

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SUMMARY: Long term emissions from sanitary landfills represent one of the most crucial issue in waste management strategy. Some innovative technologies can help to reduce these emissions as, for example, the application of microbial fuel cells (MFC) and in-situ aeration. These two technologies have never been combined before; the idea of the “LA LA LAND” concept is to use them at the same time for liquid (leachate) and solid (waste) in-situ treatment. The main goal is to obtain a sustainable condition in chemical, biological and geological terms within the aftercare phase and guarantee the condition for landfill requalification and its return back to the community with a new planned use as recreational, didactic and social ones.

1. INTRODUCTION

The international scientific community commonly accepts the disposal of Municipal Solid Waste (MSW) in controlled landfill as a necessary step in the waste management strategy, even though some voices from society hold the opposite opinion (for example the “zero waste philosophy”). Landfill is the better, and in some case the only, option in the cases of:

- disposal of non-recoverable residues at low cost;
- high variability of waste composition;
- high fluctuation and seasonal peaks on the waste production (e.g. touristic areas or disposal in emergency cases);
- areas where the waste transport to other kind of plants is not feasible due to high distances (e.g. islands).

In Italy, the MSW waste production is around 29.5 million tons per year and its 26% is today disposed in landfills (ISPRA, 2016); in practice, it is roughly needed the same volume of a 30

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meters hight football pitch per week to landfill all the Italian MSW.

For these reasons, there is no doubt that landfilling is still a necessary step of waste management but the impacts that landfills may cause on the environment represent an issue.

Controlled landfills, in accordance with legislation (D.Lg. n° 36/2003), are designed and managed in order to minimize leachate and biogas emissions during both the operational and aftercare phases. Anyway, the management solution usually adopted only delay the environmental impact that could become relevant after many years (Pivato and Cossu, 2007) the end of the planned aftercare period (30 years). Modern sanitary landfills focus on preventing rain infiltration to avoid leachate production in order to have low emissions in the operational and aftercare phase, which correspond to the period of higher efficiency of landfill barriers. On the other hand, hydraulic isolation of landfills will maintain waste potential emissions. When the ageing of material reduces the efficiency of the top and bottom barriers, water infiltration, that may happen, will cause waste degradation reactions; therefore, leachate and biogas emissions will be produced, causing environmental impacts and increasing intervention costs that become higher than those budgeted in the financial plan. In Figure 1 the long term emission trend for a traditional sanitary landfill is reported and it is compared with the duration of operational and aftercare phases covered by the waste gate fee.

Economically, the cost of a landfill is quite high, mainly due to leachate and biogas management (40%), and can be assumed equal to 86.70 € per cubic meter of authorized volume of waste (Pivato et al., 2017).

Anyway, the willingness of reducing emissions, at least within the period required by legislator (30 years after the landfill closure, see Figure 1), is not only a technical, economic and environmental issue but also an ethical issue. It is inconceivable to shift environmental problems on the next generations, leaving them an environment worse than that we inherited. Such a behavior would bring us, in a short time, to an unsustainable situation and to unacceptable conditions for life.

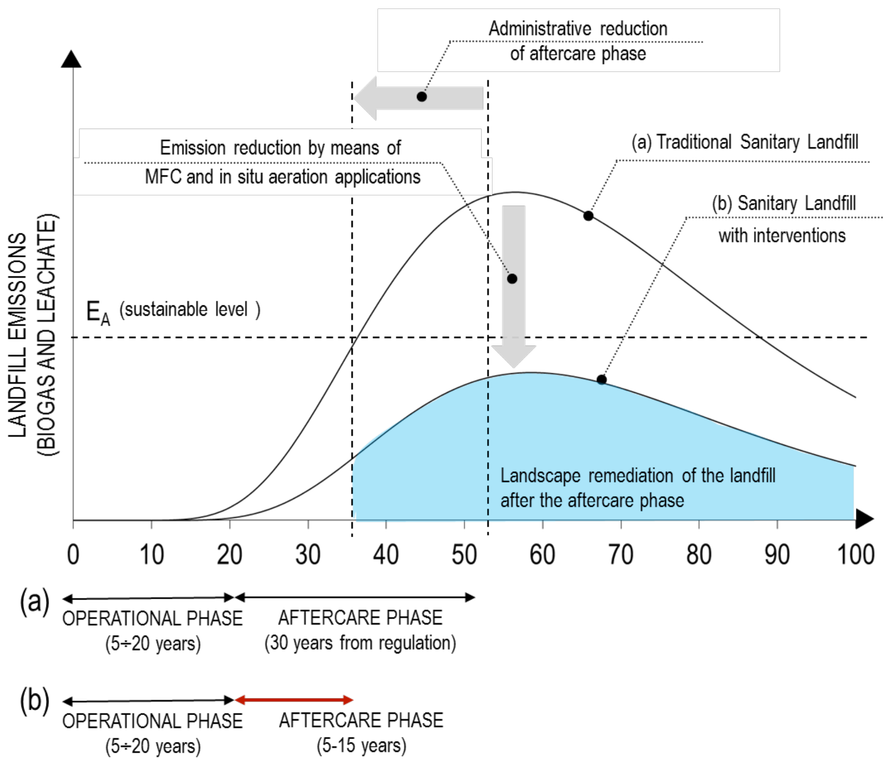

Figure 1. Long-term emissions for a traditional sanitary landfill (a) and for a sanitary landfill where new technologies for the achievement of sustainability (E_A) within the aftercare phase are

applied (b)

2. THE LEGISLATION BACKGROUND OF THE AFTERCARE IN ITALY

In Italy, the legislation regarding landfills is the Legislative Decree 13.01.2003, n° 36, derived from the Directive 99/31/EC. This Decree sets the operative and technical requirements for landfills and waste, the measures and the procedures aimed at preventing or, at least, reducing the negative impacts on health and environment. Ministerial Decree 27.09.2010, replacing M.D. 03.08.2005, gives criteria and procedures to accept waste in landfills; considering the different types of waste, it creates a distinction between landfills for inert waste, for hazardous waste and for non-hazardous waste. The manager of the landfill is the person responsible for the management of the landfill from its realization to the end of the aftercare phase (Cassazione Penale, judgement n° 32797/2013).

In accordance with art. 8 of the D.Lg. n° 36/2003, for the construction and operation of a landfill, a request for an authorization must be submitted. It includes five plans: (1) operational management plan; (2) aftercare management plan; (3) control plan; (4) financial plan; (5) environmental site restoration plan and closure of landfill. During the aftercare phase, the operator "does not have lesser responsibility than the conditions laid down in the authorization" (Council of State, judgment no. 572/2007); thus, he will have to ensure site control after closure, mainly through the management of leachate and biogas emissions. Art. 14 of D.Lg. n° 36/2003 states that the operator must provide two financial guarantees: the first for activation and operational management, including closure; the second for post-operative management. The financial guarantees for the aftercare phase are retained for at least thirty years from the date on which the competent authority informed the manager of the closure of the landfill. The term of thirty years was identified by assuming that in this timeframe the landfill will cease its emission production. If it was not, the operator should take interest in consequences; in fact, paragraph 3 of Art. 12 (D.Lg. n° 36/2003) states that "even after the final landfill closure, the operator is responsible for its maintenance, monitoring and control throughout the period during which the landfill may pose a risk to the environment". Likewise, if the emissions ceased in advance of the thirty-year term, the manager could legitimately ask for an early release of financial guarantees or at least remodeling them proportionally to risk reduction. Thus, in terms of legal and economic responsibilities, central consideration is given to a solution that reduces the risk associated with long-term emissions of landfills.

3. THE SOLUTION: THE “LA LA LAND” CONCEPT

Some innovative technologies can help in reducing long-term emissions as, for example, the application of microbial fuel cells (MFC) (Logan, 2009; Santoro et al., 2017) and in-situ aeration (Raga et al., 2015; Raga and Cossu, 2014). These two technologies have never been combined before; the idea is to use them at the same time for liquid (leachate) and solid (waste) in-situ treatment. Figure 2 represents the scheme of the concept.

The main goal is to obtain a steady condition in chemical, biological and geological terms in lower time (5 to 15 years from landfill closure) and guarantee the landfill conditions required to implement the requalification of the landfill area to return it back to the community, with a new planned use (see Figure 1).

The expected results of this new technology application are:

- Reduction of overall landfill costs (20% estimation);
- Possibility to invest saved money on on-site leachate treatment facilities (usually in Italy the

leachate is treated in an ex-situ facility);
- Possibility to speed up the in-situ leachate treatment through lithotrophic metabolism, without further energetic costs;
- Possibility to recover fertilizers from leachate implementing circular economy concepts;
- High reduction of long-term emissions with the possibility to reduce aftercare time from 30 to 5-15 years;
- Landscape requalification of the landfill site with the possibility of creating a new use for the community.

When the stability of landfill is achieved in a short time, a functional requalification is possible considering the best experiences: the realization of photovoltaic fleets, the cultivation of energy crops for biofuel production and/or ligno-cellulosic plants, the realization of parks with cycles and pedestrian paths, thematic itineraries, multidisciplinary research parks, life paths, ponds, recreational parks, golf courses, etc.

The transformation of a landfill area into a park, for example, offers a place where recreational, didactic and socialization activities can be carried out, increasing the quality of life (Figure 3).

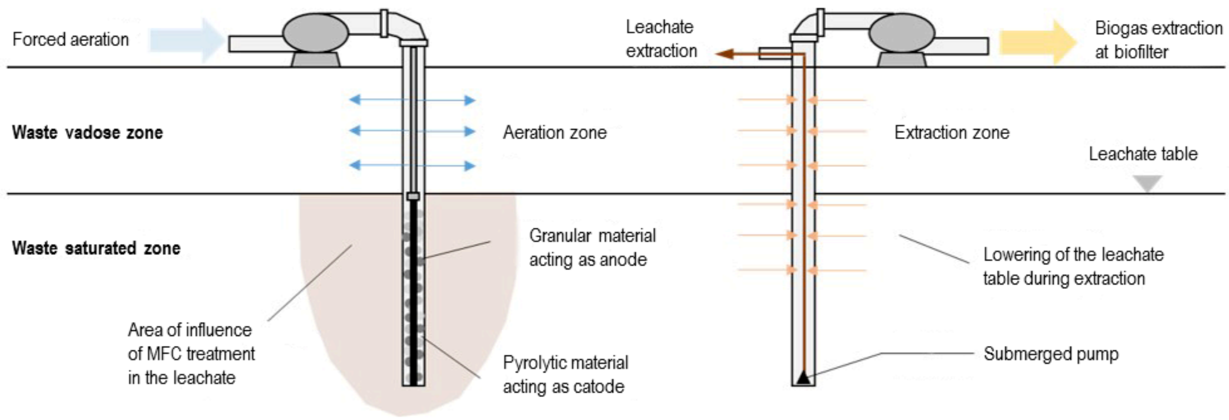

Figure 2. Representation of the scheme of application of the two technologies (microbial fuel cells and in-situ aeration) to landfill.

3.1 Microbial fuel cells (MFC) and lithotrophic metabolism

MFCs and more generally microbial electrochemical systems exploit the ability of some microorganisms to exchange electrons with conductive solid materials (lithotrophic metabolism). In the MFC there are mixed cultures of anaerobic microorganisms organized in biofilms on electro-conductive surfaces. They oxidize organic molecules in the aqueous solution and yield electrons to conductive materials that act as anodes. The circuit closes with the reduction of oxygen in cathodes exposed to air, with a total exergonic reaction. In this way, an environment containing a lot of organic substance (COD), and therefore anaerobic, is indirectly contacted with strong electron acceptors. Thus biodegradation, although in the absence of oxygen, assumes typical kinetics of aerobic biodegradation. MFCs also develop electrical currents and electro-osmotic gradients, which favor the mobility of inorganic ions in solution.

Another effect due to oxygen reduction is the rise of the pH near the cathode, due to the accumulation of hydroxyls. Given the concentration conditions of inorganic ions and pH, many ions tend to precipitate in the form of carbonate salts to cathode. Thus, while the anode takes the mineralization of the organic substance, the cathode behaves like a 'sponge' for the capture of both minerals and inorganic carbon.

The application of these technologies to the landfill would allow the in-situ treatment of leachate, with recovery of minerals and carbon. The reuse of end-of-life materials will depend on the mineral composition of the deposited salts. It will allow, however, metal removal and carbon storage, in stable form (carbonates).

3.2 In-situ aeration

In-situ aeration allows aerobic conditions to be introduced within the waste body, favoring the development of biological degradation reactions of the putrescible organic substance characterized by kinetics 10 times higher than the anaerobic ones commonly present in the landfill. This type of technique differs from others such as surface capping and perimeter isolation using diaphragms, as it directly acts on the source of gas and leachate, allowing for a definitive site remediation and avoiding further environmental issues after the intervention.

The technology system expects air to be drawn from the outside environment and low-flushed into the waste body, allowing the oxygen to propagate within the storage through convective and diffusive processes. Gaseous products of the degradation reactions are aspirated from the waste storage and sent to treatment to completely remove methane residues and other components present in the gas being released into the atmosphere. The aeration system also includes a pneumatic system that allows the reduction and control of the leachate table in the landfill. In its traditional configuration, the plant draws the energy needed to operate from the external power grid. However, the plant can use the energy produced by photovoltaic panels on the landfill surface (if provided in the final restoration project), reducing the consumption of non-renewable energy resources in favor of renewable sources, thus achieving energy self-sufficiency. The plant will not operate simultaneously throughout the landfill but on zones, alternating operation according to logic and timing that must be determined on a case-by-case basis.

Figure 3. The “La La LAND Project” for achieving sustainability

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