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СВАЛОЧНЫЙ ГАЗ КАК ПЕРСПЕКТИВНЫЙ ИСТОЧНИК ЭНЕРГИИ
LANDFILL GAS AS A PERSPECTIVE ENERGY SUPPLY SOURCE

I. Introduction

According to the International Energy Agency (2007), the greatest part of the current global energy mix is comprised of fossil fuels. Thus, they could be seen as the main generator of modern economics. In this connection, it is quite reasonable to argue that fossil energy happens to be the key stimulator of international industries' continuous growth which is accompanied by increasing energy demand which, in its turn, leads to unprecedented rate of products' manufacturing and extreme ecological concerns. In this context, the World Bank (2001) attributes around sixty percent of the world's total waste disposal to landfills – i.e. accumulations of once produced products that ended up being out of use. Since the United States Environmental Protection Agency (USEPA) (2000) implies that most of this waste is not recycled at all, rapidly increased emissions and intensified resource depletion pose significant questions to the energy industry that accelerates product manufacturing day after day. In this connection, potential utilization of landfills for energy production could at once solve a number of problems: i.e. hamper resource depletion and decrease carbon emissions through providing a principally new power source.

In this context, landfill gas – a gas mixture produced through bacterial decomposition process taking place in organic contents of the municipal solid waste – could theoretically become such a promising energy provider capable of pulling the strain from traditional fossils and partially replacing some of the most polluting of them – e.g. coal etc. Besides, according to the World Bank (2000), such sites accumulating a large amount of anthropogenic waste happen to be a specific set of problems with off-site gas migration leading to dramatically increased groundwater contamination and explosion risks etc. Taking into consideration the continuously-growing size and number of landfills (USEPA, 2000) landfill gas deposits appear to be constantly growing which increases the number of potential risks. That is why handling landfill gas happens to be not only a promising energy development initiative, but also a perspective solution to environmental and anthropogenic problems.

II. Potential of landfill gas: Benefits and challenges

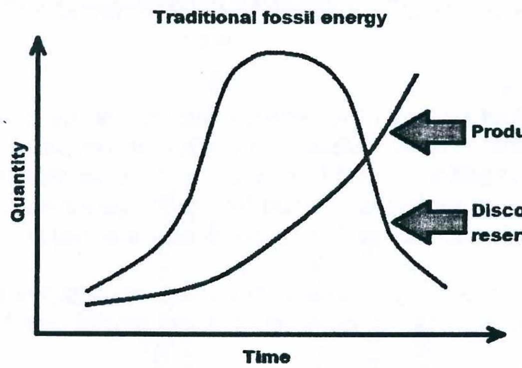
According to Jeswani, Smith and Azapagic (2013), just as any other energy supply source landfill gas represents both benefits and challenges for any perspective energy investor. In particular, relatively low primary investment costs are unfortunately opposed by increased expenditures on gas separation facilities needed to achieve the required contents' quality so that pure methane is used for power generation or as a fuel, whereas non-methane organic compounds (NMOCs) (such as carbon dioxide or water vapor etc.) are removed as potentially harmful substances.

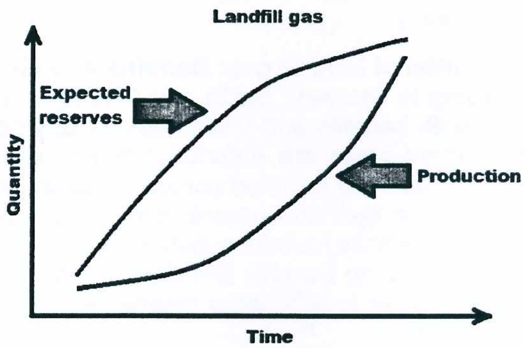
When comparing benefits and drawbacks of this energy supply source with similar advantages and disadvantages of other fossil energy means, we could clearly identify the potential that the landfill gas bears as a source of energy:

Fossil energy source	Challenges	Benefits
Landfill gas (according to Ahmed et al (2014))	Greater costs of processing due to high quantity of NMOCs	Low exploration expenditures
		Low/no depletion rate
		Low carbon emissions (in case of NMOC treatment
	High NMOC's content (up to 50%) bearing potential environmental threats if not separately processed	Relatively stable production rate (24/7 gas generation pattern)
		Almost no exploration risks
		Medium and stable EROI of approx. 10-15:1
Coal (according to Hu et al (2013))	Increasing exploration and production costs due to the decrease in number of surface mining sites	Relatively high EROI (compared to that of oil) of slowly decreasing tendency compared to those of shale oil etc.
	Decreasing production rate	Relatively low exploration expenditures
	Excessive carbon emissions	
Conventional oil (according to Downey (2009))	Increasing production costs due to the decrease in the amount of easy-extractable reserves	Currently highest average EROI possible of 40:1 (Saudi Arabia) with average being round 15-20:1 (around the globe)
	Increasing exploration risks	
	Increasing depletion rate	
	Decreasing production rate	
	Excessive carbon emissions	

Conventional natural gas (according to Downey (2009))	Increasing depletion rate	Greater deposits than those of oil etc.
		Relatively high EROI of about 15:1
		Relatively low carbon emissions
	Increasing exploration risks	Lower depletion rate
		Relatively low and stable E&P expenditures
Unconventional gas (Shale gas) (according to Downey (2009))	Higher exploration costs compared to those of the conventional gas	Excessive reserves
		Relatively low E&P expenditure
	Substantial environmental risks (groundwater contamination etc.)	Relatively low carbon emissions
		Above average EROI of 10-15:1
	High exploration risks	Low depletion rate
Unconventional oil (Shale oil and oil sands) (according to Downey (2009))	Extensive exploration and production expenditures	Potentially greater deposits than those of the conventional oil
	High exploration risks	Low depletion rate
	Greater environmental risks	
	Low EROI (round 2-5:1)	

As we see, landfill gas (alongside with both natural and shale gas) represents the most promising source of energy supplies due to its extensive reserves. In particular, according to the World Bank (2001), global amount of the landfill gas annually produced by natural means in bioreactors is estimated to be almost equal to that of industrially-produced natural gas. If we take into consideration, that the deposits of this perspective energy source are constantly growing, this poses a unique advantage unreachable by other power originators. In particular, while intensified production rate of landfill gas could go in line with its rising reserves, other fossils will most presumably reach the peak production by some time in the future (which is ultimately depicted by the bell-shaped Hubbert curve):





Additionally, natural off-site migration of landfill gas leading to groundwater and air pollution presupposes that the production benefits will be feasible not only economically, but also environmentally (Ahmed et al. (2014)). Since, according to Cora (2009, p. 58), such migration happens to be a constantly-going process evoked by instant bacterial processes stimulated by favorable temperature and humidity factors, which, in their turn, presuppose landfill gas to be unswervingly produced 24 hours a day 7 days a week. In this connection, in the opinion of Bayles (2013), landfill gas production investments will most presumably not be associated with any major traditional exploration risks since the landfill sites are generally well-known and the identification of those potentially suitable for commercial landfill gas production does not pose any major complications. In this connection, the exploration phase of the investment will allow substantial cost reduction. For example, according to the USEPA (2000), engaging half of the official 2500 US landfills in industrial methane production will bring at least 659 million tons of methane to the market with zero exploration costs. Similarly, according to the World Bank (2000), taking into consideration tremendously growing landfills of China and India will triple this amount.

On the other hand, however, some of the most important challenges posed by the landfill gas itself happen to be a hard nut to crack for investors, which may put a question on the issue of considering it a significant supply source. First, Jeswani, Smith and Azapagic (2013) state that such biological determinants as the required temperature- (usually round 5-20 degrees centigrade) and humidity-range (usually around 60-100 percent) cannot be found universally so that e.g. subarctic landfills may not be considered for biogas production. Indeed, the USEPA (2000) states that most of the Alaskan landfills are out of business focus since naturally-generated biogas does not represent any substantial commercial value. Nevertheless, this does not happen to be the key challenge – what is more important, is the significant cost of secondary gas treatment – the so-called 'gas separation' process when potentially harmful NMOCs are separated from methane and treated in an appropriate way. According to Cora (2009), the average cost of building up such gas separation facility may reach several hundred thousand Euros.

At the same time, however, even with the given drawbacks, landfill gas happens to be an important option for consideration since the average level of energy return on investment (EROI) happens to be that of 15 – i.e. nearly reaching the one of shale and even conventional gas (Cora, 2009). According to Ahmed et al. (2014), the average NPV of landfill gas projects could be compared to that of the shale gas projects. Additionally, most of the world's landfills happen to be located in mid- and south-latitudes of China, India, Brazil, Indonesia etc. so that the required temperature and humidity level is naturally created for the successful industrial production of the gas.

II.1. Prerequisites for becoming a significant energy supply source

Since we observe that landfill gas possesses a sole clear advantage over the fossil energy (which is its constantly-growing deposits) we should assume that it could potentially be used as a substitution for those power providers that will shortly be depleted. According to BP (2009), these most rapidly-exhausting resources happen to be crude oil and coal which have most presumably already reached their production peaks and thus will experience gradual production decrease in the foreseeable future. In this connection, methane in a form of conventional and unconventional gas will represent a means of substitution for those decreasing energy sources. For the landfill gas to squeeze into the growing share of natural and shale gas, it should meet some specific criteria which will determine if it could be regarded as a significant energy supply source.

The first criterion in a row happens to be the *overall* increase in the global gas price since at the current medium price level landfill gas production happens to bring the profits that cover the investment expenditures only after a several years of production (Cora, 2009). Here, even though the exploration expenditures are minimal, stable but relatively low production rate presupposes longer payback period to be considered e.g. if compared to natural or shale gas. According to Hu et al. (2013), this happens to be the reason why in China natural and shale gas development projects are more favourable than landfill gas development projects despite the world's greatest number of landfills being reported in that country.

The second criterion is the decrease in secondary gas-treatment costs – i.e. expenditures on gas separation and subsequent treatment of NMOCs. According to Cora (2009), the process of separating pure methane from non-methane substances and the consecutive processing of NMOCs, in terms of expenditures, could be compared to the investment in an average refinery's distillation facility. Alternatively, post-exploration treatment of a natural gas or shale gas happens to be a slightly less expensive procedure due to the lower content of NMOCs (Zhang and Matsuto, 2013). Indeed, according to the USEPA (2000), state subsidies on landfill gas separation facilities for the year of 2000 in the US almost equaled the expenditures on three new refinery sites.

Finally, the lack of any reliable large-scale landfill gas transportation facilities may significantly undermine its future perspectives as a potential energy supply source. Namely, Zhang and Matsuto (2013) state that stable but comparatively low production rate prevents the resource to be successfully utilized for pipeline transportation leaving only gas compression as the most economically feasible procedure. According to Cora (2009), this could be regarded as the main reason for a currently limited use of landfill gas for electricity generation since the limited length of the pipeline binding landfill site to a power-producing facility is subject to the insufficient pressure created within the pipeline itself. In particular, Zhang and Matsuto (2013) state that in China this leads to the situation when power oscillators are located at the maximum distance of 5-7 kilometers from the landfills themselves. Thus, lack of an economical gas-transportation technology will put substantial limits on the popularity of landfill gas.

II.2. Probability of becoming a significant energy supply source

Even though the variables determining whether landfill gas will become an important energy source in the future happen to be quite important, the importance of landfill gas in the future will be augmented by the following factors:

First, even though due to the unconventional oil reserves peak oil could be postponed, E&P costs of shale oil and oil sands happen to be several times more expensive than the total investments into similar landfill gas development projects (Hu et al., 2013). Following this logic, the increased oil exploration expenditures will provoke escalation of the crude oil prices. Since Downey (2009) directly binds natural gas prices to the crude oil prices, we could expect the rise of gas industry because of the rapidly increasing NPVs of gas exploration projects. Even though, potentially cheap shale gas may dilute the super-profits of the world's energy companies, according to Hu et al. (2013), the average price of methane will still be higher than that we are currently experiencing. This will actually fulfil the first condition for landfill gas to become a popular energy supply source since landfill gas production projects will get higher NPVs and thus will become more profitable.

Second, according to Cora (2009), currently-available technologies will most presumably substantially minimize landfill gas post-exploration treatment due to the significant advancements being made in the gas separation process potentially allowing NMOCs to be further split in particular gases and thus treated in different ways. My personal professional experience of working for Vireo – a Swedish bio-energy company – suggests that gas separation technologies have a tendency to cost minimization. According to Vireo (2014), the company's own annual investment in gas treatment facilities dramatically decreased in the last two years without any loss in efficiency, which signifies the rapid pace of technological development. Thus, we could assume that the landfill gas processing technologies will continue to decrease in price.

Finally, the transportation means suitable for the energy source also happen to undergo rapidly-intensified development progress. According to Downey (2009), compressed natural gas (CNG) technologies are listed among the investment priorities on most energy companies' agendas. Similarly, this presupposes gradual decrease in price as the time goes. On the other hand, however, such factors as Russia's conventional natural gas monopoly should be considered as those stimulating the development of CNG technologies while pipelines happen to be the main transportation means for the Russian hydrocarbons to be delivered to Europe (Downey, 2009). Since, according to Cora (2009), energy security plays an important role in choosing the composition of a nation's energy mix, given the price of natural gas is high, we could definitely assume that landfill gas could become a substantial alternative in Europe for the Russian import, even though the treatment costs may be significant. What is more, shale gas E&P process possesses substantially higher risks.

III. Conclusion

Thus, as we see, landfill gas has a number of advantages to be considered as a promising energy supply source in the future. In particular, according to the USEPA (2000), it is characterized by continuously growing deposits naturally increasing due to human activities, which substantially distinguishes it from traditional energy sources – e.g. fossil fuels. This feature represents its greatest benefits if we assume that the peak production of fossil energy sources is feasible in the foreseeable future. Besides, its stable production rate and minimum exploration costs highlight it against the background of such promising energy originators as shale gas, which, according to Zhang and Matsuto (2013), is associated with extreme exploration risks.

At the same time, however, such prerequisites as high average gas price and effective technology development happen to be the key determinants of the success of landfill gas. Since stable but relatively low production rate with low gas prices lead to adverse NPV values, Ahmed et al. (2014) state that landfill gas projects will not be profitable in such conditions. Besides, intensified technological development will help to eliminate such challenges as high secondary gas treatment costs and low efficiency of transportation. Since the current situation favours both of the determinants, we could expect that landfill gas will become a significant energy supply source in the future.

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