LANDFILL GAS FROM SOLID URBAN WASTE - AN OPPORTUNITY EVALUATION

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"Not using the energy content
of waste is a further waste"
Ian Arbon

(Abstract)

The problems (technical, economic, social etc.) which have to be solved by municipal waste treatment, especially in Central/East European towns, are discussed in this work. Percentages of products and calorific values of the main solid organic wastes are estimated. Different urban waste utilisation methods - Landfills, Anaerobic digestion, Incineration, Refuse-derived fuels, Pyrolysis and Gasification are comment in this paper. These methods are compared using the town of Blagoevgrad (Bulgaria) as an example.

It is found that a well established landfill gas production technology offers simplicity of collection (such as is practised in most of low and moderately developed countries like Bulgaria), relatively simple operation and maintenance, improvement of the environmental protection and of the energy production (based on the local disposal and renewable energy sources) and is more feasible for the East European urban concentrations.

Key words: Solid urban waste, landfill gas.

Introduction. With rising of the life standard the objective necessity of observance of the ecological approaches accrues at the decision of municipal problems. One of these problems is a question with urban waste. Modern urban structures are similar to live organisms, i.e. they represent an open, highly no equilibrium, self-organising system (so-called dissipative structure) which must submit to the general objective laws of science on self-organising systems - synergetic. According to these laws sustainable development of the dissipative systems is possible only if two obligatory conditions are executed:

1. Feeding with high-quality energy (with low entropy)
2. Liberation of low-quality energy (waste) in the environment

Infringement any of these two conditions conducts to destruction the dissipative system. Therefore, one of the basic problems, especially strongly expressed in the large cities, is duly collecting of the waste in special storehouses eliminating their harmful consequences (sanitary depot), that requires additional investments.

Fact is that most of the waste we produce ends up at a landfill site. These sites are society's wasteland of paper, plastics, organic materials and metals. But the problem goes even deeper. Changes that take place below ground cause other changes high above the surface of the Earth. These changes could have a detrimental effect on our lives and the environment around us. Most people's mental picture of a "waste-to-energy plant" is a power station fuelled by municipal solid waste. While this is a perfectly valid example, many other types of waste are often overlooked. Indeed, it could be argued that even a truly renewable, sustainable fuel source is waste if not used.

Potential for biogas production. Table 1 [1] shows several sources of waste fuel with which there have been substantial operating experiences for power generation. This list is by no means comprehensive and one objective of this article is to stimulate thinking about what other materials currently wasted could be used as fuel for power generation. Table 1 also shows similar list renewable, sustainable biomass fuel sources. Although this article is not specifically dealing with biomass as a fuel source, many forms of biomass are also effectively waste products. For example, burning straw in the fields after harvest wastes its potential energy, pollutes, and, in many countries nowadays, is illegal.

Table 1. Definition of "renewable" and "waste" fuel sources in common use.

Renewable, sustainable biomass fuel sources	"Waste" fuel sources
Sugar cane waste (bagasse)	Sewage digester gas
Timbermill waste or sawdust	Landfill gas
Forestry and aboricultural residues	Mines gas
Short-rotation coppicing	Coke-oven gas
Straw	Refinery /process plant flare gas/ off-gas
Rice husks and coffee husks	Stripped crude gas
Peanut and other nut shells	Municipal solid waste incineration
Palm oil and coconut residues	Hazardous and chemical waste incineration
Meat and bone meal	Sewage sludge incineration
Poultry litter	Hospital and clinical waste incineration
Livestock slurry	Vehicle tyre incineration
	Refuse derived fuel

The disposal of waste is a major problem for all developed nations with the amount of waste tending to increase in proportion to the affluence of the population. Municipal waste is made up of varying proportion of most of the constituents in Table 1 and the average Gross Caloric Value (GCV) will vary also with the amount of moisture and non-combustibles present. It is also interesting to note that the GCV of municipal waste increases as the standard of living increases, due mainly to an increase in the proportion of paper and plastics. Of course the value will decrease if recycling and reclamation are introduced for combustibles such as paper. The higher figure compared with domestic waste is due in part to the much lower moisture content. Obviously, however, it is more acceptable to generate power from the disposal of waste than to not do so. As long as Mankind produces waste, it has to be disposed of and no disposal method is problem-free.

Table 2 [1] shows the typical calorific values of a variety of fossil, waste and biomass fuels.

Table 2. Calorific values for different materials used as fuel.

Material used as fuel	Gross Calorific value, GCV (MJ/kg)
Coal	23.0 – 32.0
Fuel oil	40.0 – 45.0
Natural gas	50.0 – 55.0 (38.6 MJ/m^3)
Plastic	27.0 – 34.0
Municipal solid waste	8.5 – 11.0
Hospital & clinical waste	17.5 – 22.5
Chemical waste	18.5 – 23.0
Sewage sludge	7.0 – 13.0 (depending on dryness)
Vehicle tyres	32.0 – 40.0
Sugar cane bagasse	8.0 – 12.5 (depending on dryness)
Wood	17.0 – 20.0
Rice husks, rice straw	12.0 – 18.0
Straw	14.0 – 15.5
Meat & bone meal	20.0 – 28.0 (depending on fat content)
Poultry litter	13.0 – 14.0

Figure 1 *[2] gives an overview of the different ways to convert biomass to end products.*

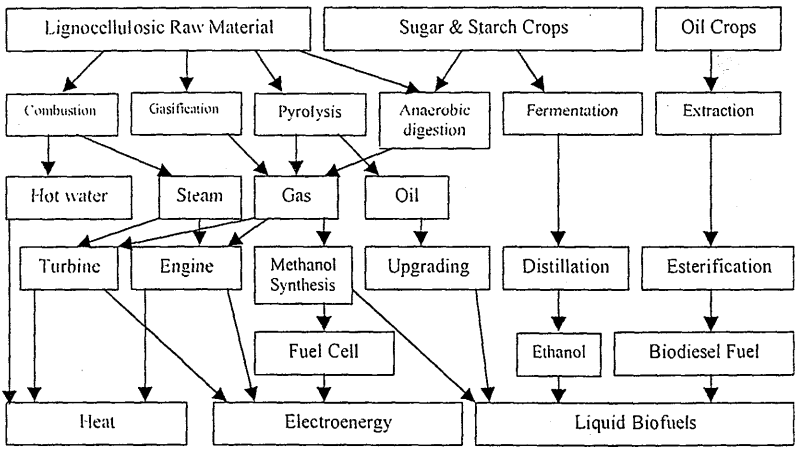

Figure 1. Possible converting of biomass to end-products

The common raw material used for biogas generation are often defined as "waste materials", e.g. human excreta, animal manure, sewage sludge, and vegetable crop residues, all of which are rich in nutrients suitable for the growth of anaerobic bacteria. Although some of these materials can be used directly as fuels and fertilizers, they could be used for biogas production to gain some additional heat value (from the biogas) while the other benefits are still retained.

Solid wastes generated from human activities include those from residential, commercial, street sweepings, institutional, and industrial categories. Table 3 [3] is a comparative analysis of solid waste characteristics of some developing and developed countries.

Table 3. Comparative solid wastes analysis (units in percentage weight)

	Bangkok, Thailand	Calcutta, India	Cairo, Egypt	UK	U.S.A.
Food wastes (organic)	39.2	36	70	17.6	9.0
Paper and cardboard	13.6	3	10	36.9	40.0
Metals	1.9	1	4	8.9	9.5
Glass	1.1	1	2	9.1	8.0
Textiles	4.8	4	2	2.4	2.0
Plastics and rubber	14.5	1	1	1.1	7.5
Miscellaneous, incombustible	3	50	10	21.9	4.0
Miscellaneous, combustible	21.9	4	1	3.1	20.0
Bulk density, kg/L	0.28	-	-	0.16	0.2-0.4

The percentage of food wastes (organic matter) were 36-70 for the developing countries (Thailand, India and Egypt) which were a few-fold higher than those of the developed countries (U.K. and U.S.A.). On the other hand, proportion of paper and cardboard were found to be higher in the solid wastes of the developed countries.

The quantity of solid waste generation is generally correlated with the per capita income and affluence, i.e. the higher the income - the greater the amount of solid waste generated. The global range of solid waste generation is 0.2-3 kg per capita daily [4]. Solid waste generation rates of less than 0.4 kg per capita daily can be applied to some cities in India, while generation rates greater than 2 kg per capita daily are applicable to several cities in the USA [5].

As the food waste portion of the solid wastes is suitable for recycling it should ideally be collected separately. But for practical reasons the food waste is collected together with other kinds of waste to be treated at a solid waste treatment plant.

Possible integrated systems of organic waste recycling are shown in Figure 2.

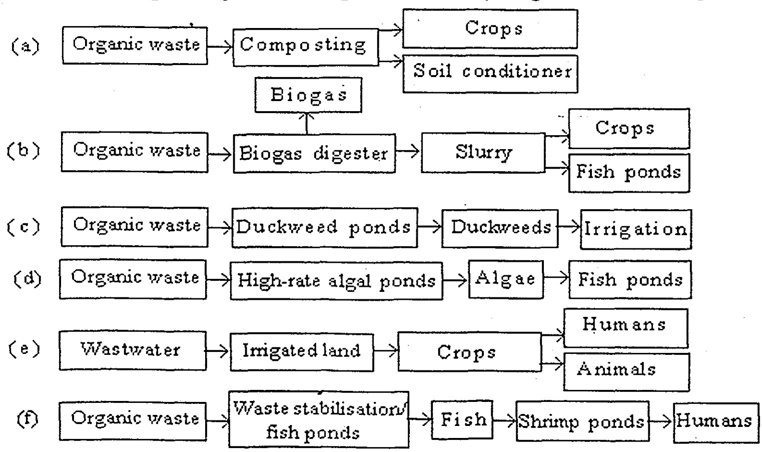

Figure 2. *Integrated systems of organic waste recycling [3].*

In scheme (a) organic waste such as excreta, animal manure, or sewage sludge is the raw material for the composting process. The composted product then serves as fertilizers for crops or as soil conditioner for infertile soil. Instead of composting scheme (b) has the organic waste converted into biogas, and the digested slurry serves as fertiliser or feed for crops or fishponds, respectively. Schemes (c) - (f) generally utilise organic waste in liquid form and the biomass yields such as weeds, algae, crops, and fish can be used as food or feed for other higher life forms, including human beings, while treated wastewater is discharged to irrigated land.

The integrated systems that combine several aspects of waste recycling at small- and large-scale operations have been tested and/or commercially implemented in both developing and developed countries.

Methods of converting of waste to power. Waste product is available in the three basic forms of matter - solid, liquid and gaseous. Table 1 includes examples of all three.
If the waste material is gaseous, it can be used, after cleaning, to fire natural gas reciprocating engines for small power outputs or gas turbines for larger. Either prime mover can be used to mechanically power other equipment in the same plant or be coupled to a generator to produce electrical power.

Liquid or solid waste, however, have traditionally been used as fuel for a combustion process, e.g., in a boiler to raise steam which can then be used for space heating in a process in the same plant or to power a steam turbine generating set. The boilers generally must be specifically designed for the combustion of waste rather than fossil fuels. The type of boiler or grate will also vary for each type of fuel. Sewage sludge is usually burned in a fluidised bed, hazardous waste in a rotary kiln, and vehicle tyres in a rotating hearth or travelling grate.

Recently several other methods of converting liquid and solid waste to electrical power have been developed. The main driver for this development has been the relatively low efficiencies of conventional steam turbine cycles. As in modern utility power stations, it is often beneficial to burn gaseous fuel in gas turbine generators, then to raise steam from the residual high temperatures in the gas turbine exhaust. Steam can then be used for space heating or elsewhere in the process flow (a combined heat and power system), or to drive a steam turbine generator as in a conventional power system (a combined cycle system). By either method the overall efficiency of the power system is greatly increased. The problem remains how to convert solid or liquid waste material into a gaseous system.
There are more than six different methods of converting municipal solid waste product to electrical power:

a) Landfill. The conventional method of dealing with this waste is to bury it in the ground. As the waste decays, the biological processes occur spontaneously, producing landfill gas (lfg). This consists of about 60 % methane (CH4) and 40 % carbon dioxide (CO4). It will be recognised that both of these gases have been defined, as among the most potent of the greenhouse gases, believed to be the primary cause of global warming. Even before the adverse effect of greenhouse gases was understood, there have been examples, particularly in warm countries, of escaping landfill gas igniting or exploding with serious consequences. For this reason the idea was mooted to recover the gas from a landfill to fuel converted diesel engines.

b) Anaerobic digestion is more commonly used with liquid and semi-liquid slurries such as animal waste. It is also used for obtaining gas from human sewage and is now being applied to a limited degree to municipal waste.

c) Incineration is preferred most in those countries that decided against further development of landfill sites. Instead of landfilling, it is burned in a suitable incinerator.

d) Refuse-derived fuels. This is a variation on the incineration theme. Not only the recyclable elements of the waste but also some of the undesirable components (e.g. mal-odorous elements) are removed prior to combustion and are then formed into briquettes that are used as fuel in a more conventional boiler grate system.

e) Pyrolysis is the thermal degradation of organic waste in the absence of oxygen to produce a carbonaceous char, oils and combustible gases.

f) Gasification differs from pyrolysis in that oxygen in the form of air, steam or pure oxygen is reacted at high temperature with the available carbon in the waste to produce a gas, ash and a tar product.

Landfill gas technology. The energy crisis in the 1980s caused economic problems for many countries, especially poor countries that depend on imported oil and gases. Perhaps the most interesting potential for biomass is in the exploitation of refuse-land fill. One of the most common methods of disposing of municipal and industrial refuse is by burying it in the ground in so-called landfill sites. When organic material such as refuse is buried then a natural process forms methane gas. Exploitation of methane from landfill sites began to be undertaken in many countries but its application has been surprisingly slow to develop.

Biogas (also called "marsh gas" or "landfill gas" - lfg); a by-product of anaerobic decomposition of organic matters has been considered as an alternative source of energy. So 1 m3 of biogas is equivalent to 0.4 kg of diesel oil, 0.6 kg petrol, or 0.8 kg of coal.
Biogas occurs in nature, but it can also be produced with process engineering from all organic materials, which are anaerobically. When organic materials such as paper, food, yard and garden waste rots, they are microbially decomposed in the absence of oxygen and produce landfill gas (eq. 1):

$$\text{(1)} \quad \text{Organic matter} \xrightarrow[\text{decomposition}]{\text{anaerobic}} CH_4 + CO_2 + H_2 + NH_3 + H_2S$$

The organic matter is initially broken down by acid-forming bacteria to give organic acids. These are in turn broken down by methane-forming bacteria. The gas finally formed contains on average about 40 % to 60 % methane with the remainder mainly carbon dioxide with small amounts of nitrogen and hydrogen sulphide. The GCV is approximately 15 to 18 MJ/m3, which compares with 38.6 MJ/m3 for natural gas.

For the production of lfg moisture content of greater than 40 % is desirable but care must be taken not to waterlog the site by extending below the natural water table, or by allowing the site to flood. A clay pit is ideal to prevent gas leakage with one metre thickness of clay topsoil (Fig. 3).

A site of area greater than 10 ha is recommended with depths of waste at least 10 m and preferably 30 m or more. The gas from a landfill site is collected by a system of pipes connected to a compressor (see Figure 3), then dried and pumped to the boiler where it can be fired using specially adapted burners. Distances of up to 8 km are possible between the site and the consumer.

The landfill cover layer (usually of clay, but dependent upon site-specific conditions) should be compacted and of approximately constant thickness (~ 1 m) to ensure that no lfg leakage occurs. If necessary, the clay layer can be supplemented by a synthetic plastic liner to ensure that the cover is more impermeable. The quantity of generated lfg usually is greater during the first some years after burying of the waste. It falls down exponentially with corresponding semi-period of time (Figure 4).

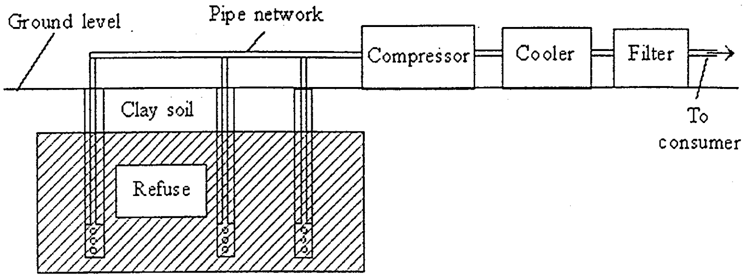

Figure 3. *Production of lfg.*

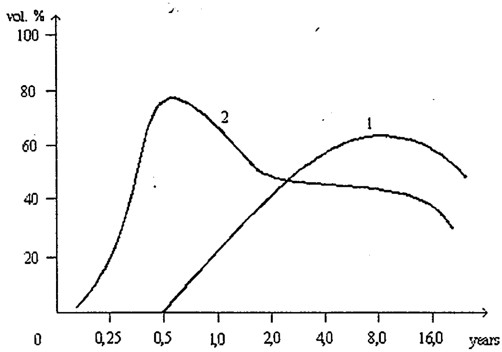

Figure 4. Content changing of the lfg during the time:
1 - Methane (CH_4), 2 - Carbon dioxide (CO_2)

Regional technical-economical survey. According to the statistics the average amount of generated urban waste in Bulgaria is about 500 kg per capita but follows some expert estimation it is considerably less (between 250 and 300 kg per capita). The total urban waste is from 1172 settlements with organised collecting and disposition of the waste where 78 % of the country population is concentrated.

Only very large municipalities could permit direct burning and if they have:

1. Sufficient in quantity and calorific value constant waste flow. To be economically efficient such installation must reprocess of 30000 t waste per year at least. For example the Blagoevgrad Municipality produce in average amount of 19000 t per year and the main part is food waste with low calorific value, so it is obviously not enough to create a plant for direct burning.

2. Serious financial sources.
3. Availability of ecological depot for incombustible ingredients and ashes.
4. Managing capacity and technical experience

These conditions practically can be implemented in the developed countries in the world only. They are not applicable in low and moderately developed countries like Bulgaria. More reasonable for Blagoevgrad at the moment is producing of landfill gas.

The economical reason to create a biogas system depends of many local factors. In Mediterranean countries and on the Balkans the urban wastes are rather different in comparison with these ones in developed countries. Most typical for them is rich content of organic matter (50-80 % of food garbage). This can be seen on the figures 5 and 6.

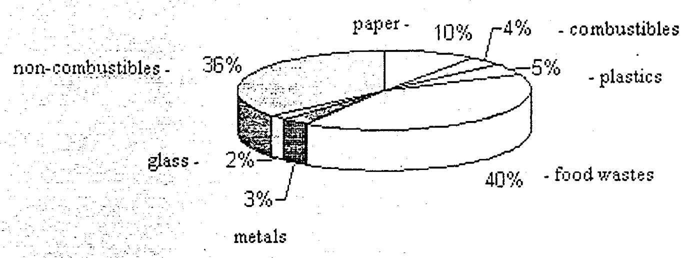

Figure 5. Household waste in the UK

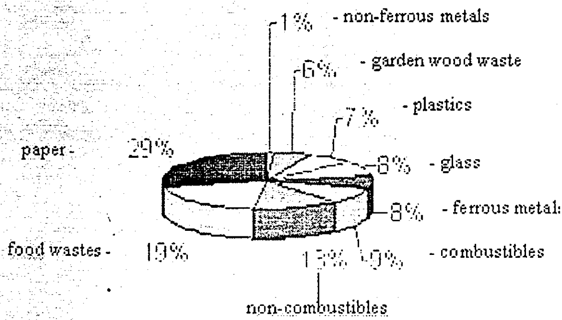

Figure 6. Analysis of household waste in Blagoevgrad, Bulgaria

Municipality of Blagoevgrad consists of the town of Blagoevgrad and 12 neighbor villages. It occupies an area of 15 km2 with 83914 inhabitants (1998) and people density of 5594 residents per km2. Urban wastes are landfill from 1977 in a sanitary depot in the village Buchino. Since 1977 till 1998 a total amount of 1 077 500 m3 urban waste is accumulated with average density of 330 kg/m3 [7].

Table 5. Average quantity of urban wastes of the Blagoevgrad municipality for the period 1996-1998

For period	daily	weekly	monthly	annual
Quantity, m^3	186	1302	5648	67775

Table 4. Ingredients and quantity of the household waste in Blagoevgrad

Type	%	1996	1997	1998	Calorific value
I. Combustibles	59	m^3/year	m^3/year	m^3/year	kJ/kg
Paper	10	6 200	5 820	8 313	14 600
Textiles	2	1 240	1 164	1 663	16 275
Plastic	5	3 100	2 910	4 156	37 000
Garbage (food wastes)	40	24 800	23 280	33 250	6 700
Vehicle tyres	2	1 240	1 164	1 662	34 700
II. Non-combustibles	41				
Metals	2,5	1 550	1 455	2 078	
Industrial	0,5	310	291	416	
Glass	2	1 240	1 164	1 662	
Other	36	22 320	20 952	29 925	
Total	100	62 000	58 200	83 125	

Origin of the urban waste of Blagoevgrad (%) is shown on Figure 7. Its daily, weekly, monthly and annual average quantity for 3-years period is given on Table 5.

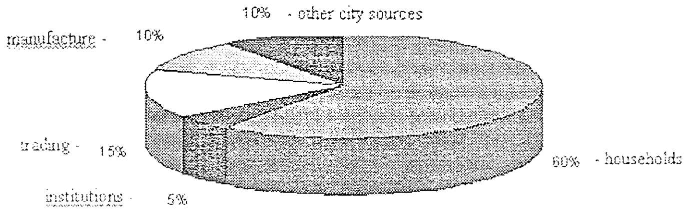

Figure 7. Origin of the urban waste of Blagoevgrad

One resident produces per day approximately (eq. 2):

(2) $$(186 \times 330) : 83914 = 0{,}73 \text{ kg/day per resident}$$

It is close to the lower limit of the life standard (0,8-2,3). Currently 85 % of domestic, commercial and urban wastes are regularly landfilled in Blagoevgrad, i.e. 57600 m3/y or 19000 t/y. A comparison with [11] shows that it is enough to obtain 760000 m3/y methane and to produce about 26600 MWh electrical energy per year.

Conclusions and future development. Utilisation of landfill gas could be made both by direct burning for producing of thermal energy only or by burning in combined thermo electrical systems for heat and electricity output. The utilisation in combined burning systems is more effective from technical and economical point of view. Given the large number of methods of converting waste to energy and the number of different types of waste which can be used for power generation, it is perhaps surprising that more such plants have been built. There is often a strong lobby against waste-to-energy plants because of the perception of unacceptable emissions and other environmental impacts. However, as long as Mankind produces waste, it has to be disposed of and no disposal method is problem-free. Obviously, however, it is more acceptable to generate power from the disposal of waste than to not do so.

REFERENCES:

[1]. I. Arbon. ***"Scope for more waste to energy"***, Renewable Energy 2001, WREN, pp. 131-133, 2001

[2]. The Future for Renewable Energy, EUREC Agency, J&J Ltd., p. 19, 1996

[3]. Chongrak Polpraset. Organic Waste Recycling, J.Willey&Sons, p. 23, 1996

[4]. Pickford J. ***"Solid waste in hot climates"***, Water, Wastes and Health in Hot Climates, Wiley, Chichester, pp. 320-344, 1977

[5]. Cook D. B. and Kalbermatten J. M. ***"Prospects for resource recovery from urban solid wastes in developing countries"***, Proceedings Regional Seminar on Solid Waste Management (ed. G. Tharun), Asian Institute of Technology, Bangkok, pp. 267-273, 1982

[6]. Hesse P. R. ***"Storage and Transport of Biogas"***, Project field document no.23, Food and Agriculture Organisation of the United Nations, Rome, 1982

[7]. P. Gramatikov, L. Direkov. ***"Evaluation of Urban Waste Utilisation Possibilities- Blagoevgrad Case Study"***, V World Renewable Energy Congress, Florence, Italy, 20-25.09.1998

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