Capture and Utilisation of Landfill Gas

What is the potential for additional utilisation of landfill gas in the USA and around the world? By Nickolas Themelis and Priscilla Ulloa, Columbia University.

In his 2003 review of energy recovery from landfill gas, Willumsen[1] reported that as of 2001, there were about 955 landfills that recovered biogas. The largest number of such landfills were in the USA, followed by Germany and the UK (see Table 1). Willumsen also provided[2] detailed information on 21 landfills in Denmark that in total captured 5,800Nm^3 of biogas per hour, equivalent to 276.4MW of contained thermal energy, or 20,000 tonnes of methane (CH_4) per year.

LANDFILLING OF MUNICIPAL SOLID WASTE IN THE USA

The USA is the biggest operator of regulated landfills in the world. There are about 2000 operating in the USA. In 2003, the Earth Engineering Center (EEC) of Columbia University conducted a nationwide survey of waste management in the USA in collaboration with BioCycle Journal. The landfill data in this survey were supplied by the waste management department of each state, and the results are shown in Table 2[3]. An interesting finding of the survey was that the amount of municipal solid waste (MSW) landfilled annually was 211 million tonnes, nearly 100 million tonnes higher than that reported by the US Environmental Protection Agency (EPA).

PRODUCTS OF BIOCHEMICAL REACTION OF BIOMASS IN MSW

It has been estimated[6] that biomass materials such as paper, food and wood, constitute about 70% of the MSW, and petrochemicals constitute another 15%. The rest is made up of inorganic materials such as metals, glass, gypsum and other minerals. The biomass fraction of MSW can be approximated[8] by the molecular formula $C_6H_{10}O_4$. The gaseous product of the predominant anaerobic bioreaction of MSW in landfills consists of about 54% methane and 46% CO_2. Theoretically, complete bioreaction of one tonne of dry biomass will generate nearly 210 standard cubic metres (Nm^3) of methane[7]. Experimental tests by Barlaz et al[10] on the complete bioreaction of biomass contained in MSW are in good agreement with this projection.

The dry biomass concentration in MSW may be only 40-60% of its weight. Therefore, the corresponding generation of methane would range from 80-120Nm^3 per tonne of MSW. Also, some of the biomass within the landfill may not be subjected to biodegradation for lack of moisture that is required to sustain bacterial growth; this would reduce the amount of methane generated per ton of MSW.

Country	Approx. number of Plants
USA	325
Canada	25
Germany	150
France	10
Holland	60
UK	135
Spain	10
Italy	40
Austria	15
Switzerland	10
Norway	20
Denmark	21
Sweden	70
Finland	10
Poland	10
Czech Republic	5
Hungary	5
China	3
Australia	25
Brazil	6
Total	**955**

Table 1: Energy recovering landfills (Willumsen[2])

	14th SOG survey[4]		USEPA 2001 survey[6]	
	million tonnes/year	%	Million tonnes/year	%
Amount generated	336	100	211	100
Amount recycled and composted	90	26.7	65	30.8
Amount to waste-to-energy	26	7.7	27	12.8
Amount landfilled	220	65.6	119	56.4

Table 2: Generation and fate of MSW in the USA[3]

US DATA ON GENERATION OF BIOGAS AT LANDFILLS

Eileen Berenyi, a Research Associate of EEC, compiles the Methane Recovery from Landfills Yearbook[9]. The data presented in Table 3 is from the 1999 Yearbook. This data included tonnages of MSW landfilled since the opening of each landfill, but not the annual rate of landfilling. This last is important because it has been shown experimentally[7] (Figure 1) that most of the bioreaction of the biomass in MSW may occur in the first year of landfilling.

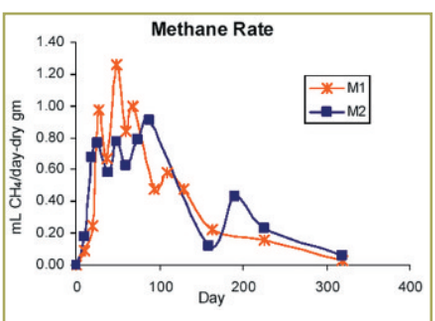

Figure 1. Generation methane in experimental apparatus simulating landfill bioreactions (M1 and M2 denote two different tests; reference 9)

The 42 states reported in Table 3 captured a total of 6.8 billion Nm³ of biogas and represent 89% of the US population. However, it should be noted that the MSW tonnages in this table represent the total amount landfilled in each state while the biogas generation is for the 327 landfills that collect biogas. Therefore, it is not possible to correlate the gas generation to MSW landfilled from the above data.

As an alternative, 25 California landfills were examined where the amounts landfilled annually were reported by the California Integrated Waste Management Board[12] and the captured gas by Berenyi[9]. Their combined annual deposition rate was 16.6 million tonnes of MSW. On a yearly basis, the total methane captured in these 25 landfills corresponded to an average of 32Nm³ of methane per tonne of MSW landfilled.

State	MSW Landfilled (Solid Wastes Digest) tonnes/y	Landfill Gas generated (Berenyi) Nm³/y	Landfill Gas used (Berenyi) Nm³/y	LFG Processed %	Heating Value Untreated Gas KJ
Alabama	5,110,224	446,559	446,559	100%	580
Arizona	6,460,129	8,186,916			531
California	35,188,243	1,952,168,440	1,408,295,409	72%	500
Colorado	6,269,618	3,096,143	3,096,143	100%	514
Connecticut	257,643	55,819,881	20,497,060	37%	543
Delaware	1,587,590	38,538,046	20,675,684	54%	501
Florida	16,248,753	245,796,024	189,780,153	77%	550
Georgia	10,827,361	33,581,240	33,581,240	100%	563
Hawaii	595,119	21,702,770	21,702,770	100%	528
Illinois	17,972,421	635,117,780	486,899,870	77%	547
Indiana	6,097,251	66,983,857	21,137,128	32%	522
Iowa	1,835,254	20,675,684	20,675,684	100%	554
Kansas	2,835,889	36,179,553	36,179,553	100%	528
Kentucky	4,486,075	21,434,834			
Maryland	2,849,497	53,333,829	31,005,877	58%	543
Massachusetts	1,406,151	203,407,647	111,848,156	55%	535
Michigan	16,686,020	455,795,378	417,920,820	92%	559
Minnesota	1,978,590	135,977,230	131,065,081	96%	513
Missouri	4,066,951	56,564,146	37,213,254	66%	580
New Hampshire	1,629,321	72,238,369	72,238,369	100%	574
New Jersey	3,594,303	350,548,853	223,279,524	64%	534
New York	6,647,011	445,472,421	336,958,573	76%	543
North Carolina	6,630,681	113,296,992	85,221,081	75%	552
Ohio	12,572,802	182,970,127	124,566,158	68%	563
Oregon	4,870,725	16,954,359	16,954,359	100%	520
Pennsylvania	22,458,496	556,625,930	363,379,983	65%	545
Rhode Island	1,375,306	86,334,749	86,334,749	100%	570
South Carolina	5,271,705	14,260,119	11,163,976	78%	563
Tennessee	5,877,710	79,963,840	35,665,183	45%	591
Texas	21,501,406	312,839,422	278,768,621	89%	547
Vermont	410,052	6,981,206	6,981,206	100%	475
Virginia	12,157,307	104,078,029	77,403,568	74%	563
Washington	4,692,008	253,050,127	13,099,065	5%	464
Wisconsin	6,263,268	199,492,812	184,160,952	92%	540
Total reporting	**253,814,753**	**6,811,497,272**	**4,901,214,602**		

Table 3: Landfill gas capture by state (based on references 9, 11)

LANDFILL METHANE OUTREACH PROGRAMME

The US Environmental Protection Agency (USEPA) operates a Landfill Methane Outreach Programme that encourages landfill owners to develop gas recovery projects wherever it is feasible to do so[13]. Through this programme, USEPA works with MSW landfill owners and operators, states, utilities, industry and other federal agencies to lower the barriers to economic landfill gas energy recovery. Table 4 compares the electricity generated by landfill gas to energy plants in each state, as reported by Berenyi in 1999[9] and by USEPA in 2005[13]. The difference represents the growth in landfill gas collection projects from 231 in 1999. Electricity generation from biogas has increased by 18% since 1999 to 1.07MWe.

State	Electricity Produced kW		State	Electricity Produced kW	
	Berenyi 1999	USEPA 2005		Berenyi 1999	USEPA 2005
Alabama	4,000	n/a	Missouri	800	n/a
Arizona	18,425	10,350	Nebraska	n/a	3,200
California	237,570	255,935	New Hampshire	15,700	13,800
Colorado	800	n/a	New Jersey	48,900	45,700
Connecticut	9,840	5,000	New York	46,047	48,300
Delaware	1,500	n/a	North Carolina	10,350	11,600
Florida	19,800	39,830	Ohio	8,500	36,200
Georgia	5,400	7,400	Oregon	5,660	5,600
Hawaii	3,000	n/a	Pennsylvania	46,350	68,400
Illinois	177,766	153,934	Rhode Island	12,000	17,000
Indiana	7,525	21,585	South Carolina	n/a	8,400
Iowa	8,500	6,400	Tennessee	7,000	7,200
Kansas	3,000	n/a	Texas	15,600	57,656
Kentucky	n/a	10,400	Vermont	1,500	1,200
Maryland	7,250	8,050	Virginia	14,600	31,800
Massachusetts	27,650	37,744	Washington	15,700	15,200
Michigan	79,900	72,300	Wisconsin	29,000	47,375
Minnesota	25,800	24,200	**Total**	**911,433**	**1,071,759**

Table 4: Electricity Generation by using LFG

Direct Heating Applications	• Use for industrial boilers • Space heating and cooling (e.g.greenhouses) • Industrial heating/cofiring
Electricity Generation Applications	• Processing and use in reciprocating internal combustion (RIC) engines (stoichoimetric or lean combustion) • Processing and use in microturbines, gas, and steam turbines • Processing and use in fuel cells
Feedstock in Chemical Manufacturing Processes	• Conversion to methanol (industrial or vehicular use) • Conversion to diesel fuel (vehicular fuel)
Purification to Pipeline Quality Gas	• Utilization as vehicular fuel • Incorporation into local natural gas network
Soil remediation Heat Recovery from Landfill Flares	• Leachate evaporation system. • Using organic Rankine cycle • Using Stirling cycle engines

Table 5: Utilisation of Landfill Gas

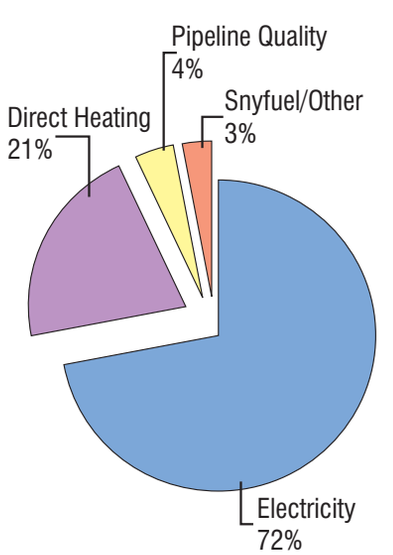

Figure 2: Distribution of uses of landfill gas in the USA

State	Number of LFG Projects	Active Area	Devoted Area CH_4 Recovery	Refuse Buried	Average Depth	Average Density Refuse
		hectares	hectares	tonnes	m	kg/m³
Alabama	2	236	16	1,306,359	14	653
Arizona	5	285	254	17,418,126	29	693
Arkansas	1	57	57	4,717,409	18	772
California	65	5,746	3,570	546,179,234	36	730
Colorado	1	36	36	27,215,821	26	
Connecticut	5	147	109	12,655,357	32	733
Delaware	2	146	53	8,527,624	23	653
Florida	12	697	530	69,971,877	25	731
Georgia	4	160	68	15,694,457	24	698
Hawaii	1	17	17	1,195,500	23	594
Illinois	43	1,743	1,087	117,968,430	26	814
Indiana	4	163	93	10,886,329	22	832
Iowa	3	210	62	11,974,961	23	761
Kansas	3	482	77	19,958,269	18	713
Kentucky	1	304	122	n/a	46	891
Louisiana	2	209	122	n/a	53	
Maryland	4	233	128	14,424,385	21	624
Massachusetts	16	345	267	20,638,665	25	752
Michigan	22	1,038	697	67,676,676	24	744
Minnesota	5	190	158	20,303,003	25	743
Missouri	2	100	37	12,185,430	46	594
New Hampshire	6	158	151	10,646,829	28	713
New Jersey	11	770	492	62,367,776	23	790
New York	20	1,050	619	152,041,187	38	812
North Carolina	15	723	435	31,942,937	24	695
Ohio	6	383	245	47,718,407	23	792
Oregon	5	531	139	14,116,847	29	812
Pennsylvania	19	1,496	572	64,773,655	32	736
Rhode Island	1	62	47	10,886,329	46	653
South Carolina	4	84	37	5,663,612	18	653
Tennessee	3	181	116	12,428,558	35	793
Texas	8	865	475	117,730,352	22	730
Vermont	2	24	13	1,327,225	25	653
Virginia	7	347	190	29,393,087	26	754
Washington	5	663	364	35,017,690	34	817
Wisconsin	12	546	289	39,335,934	25	759
Total	**327**	**20,426**	**11,742**	**1,636,288,340**		

Table 6: Characteristics of LFG projects in the USA by state

Table 5 shows how landfill gas is utilised in the USA, and Figure 2 shows the distribution of uses in graphical form.

California, with 65 plants, has the largest number of landfill gas facilities, because of state and local requirements that require collection and control of biogas[8]. Other states with a significant number of landfill gas plants include Illinois (43), Michigan (22), New York (20) and Pennsylvania (19).

Table 6 lists some of the characteristics of landfill gas projects in each state. The total active area of landfills collecting gas is about 21,000 hectares; about 57% of the active area is equipped for methane recovery. The states of California, Illinois, Michigan, New York and Pennsylvania represent approximately 50% of the total landfill area devoted to methane recovery. On the other hand, 60% of the total MSW buried in landfills equipped for gas collection is located in the states of California, New York, Illinois, Texas and Michigan.

The average landfill depth in the gas-collecting landfills range from 14 to 53m; the national US average depth is 28m. The density of the MSW buried in these landfills ranges from 594-832kg/m³, while the national average is estimated at 732kg/m³.

CAPITAL COSTS FOR UTILISING LANDFILL GAS

The California Energy Commission[13] has studied the capital costs for installing facilities for electricity generation from landfill gas, as shown in Figure 3. Reciprocating engines appear to be the best option for facilities up to 10MWe in size. For facilities in the range 10-18MWe, the use of gas turbines is more practical. Above 18MWe, steam cycles are mostly used, although combined cycles offer lower investment per kW generated.

CONCLUSIONS

On the basis of the theoretical and experimental evidence presented above, it can be assumed that under the right conditions, at least 50% of the 'latent' methane in MSW can be generated within one year of residence time in a landfill. This would correspond to about 50Nm³ of methane per tonne of a typical MSW. However, on average, the 25 California landfills that were examined in detail captured only 32Nm³ of methane per

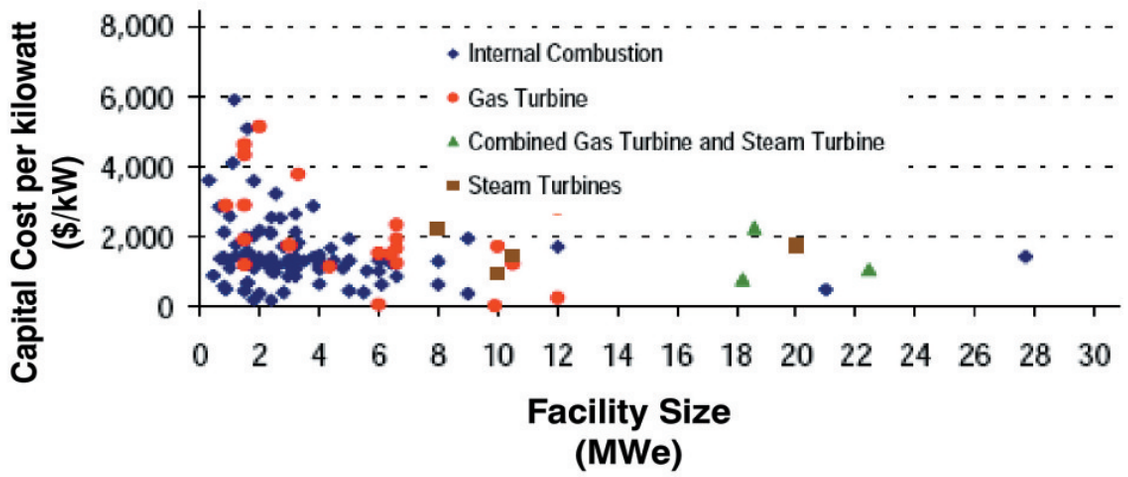

Figure 3: Capital cost vs. facility size, for landfill gas utilisation

tonne landfilled. Of course, conventional landfills are far from perfect bioreactors. In addition, there is no information regarding the effectiveness of the gas collection at the landfills.

There are nearly 330 landfills in the USA, capturing a total of 3.7 billion Nm^3 of methane, of which 70% is used to generate thermal or electric energy. The rest is flared, because it is not considered to be of economic use. There are nearly 1300 landfills that do not capture any biogas.

If it were possible to build and operate bioreactor landfills where water is added and nearly all the generated methane is captured, the methane collected in the USA, at an assumed average rate of $50Nm^3$ of methane per tonne of MSW, would be 11 billion Nm^3 of methane, ie, three times the amount that is presently captured.

With regard to the global picture, on ongoing EEC study[7] has estimated the global disposition of MSW in landfills to be 1.4 billion tons of MSW. The corresponding generation of methane is close to 50 million tons, of which only 5 million tons are currently being captured. Therefore, methane emissions to the atmosphere are about 45 million tons. Since methane has 23 times the global warming potential of carbon dioxide, global landfill emissions correspond to about one billion tons of CO_2.

If landfilling of organic materials is to be continued in some countries, future landfills must be fully controlled bioreactors where most of the methane generated is captured and used to produce energy. Landfill biogas is one of the very few sources of renewable methane. ■

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