Universität Rostock

Traditio et Innovatio

Waste-to-Energy: Landfill Gas Recovery

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Outline

- Introduction
- Basics on Landfill Gas
- Landfill Gas Generation
- Landfill Gas Collection System
- Landfill Gas Utilization
- Safety and Preventive Measures
- Study Case: Oued Smar Landfill in Algeria
- Conclusion

“Landfills are to be considered as dynamic stocks of resources (materials, energy, land,…) that can be integrated into the economy.”

Introduction

Difference between Dump and Landfill

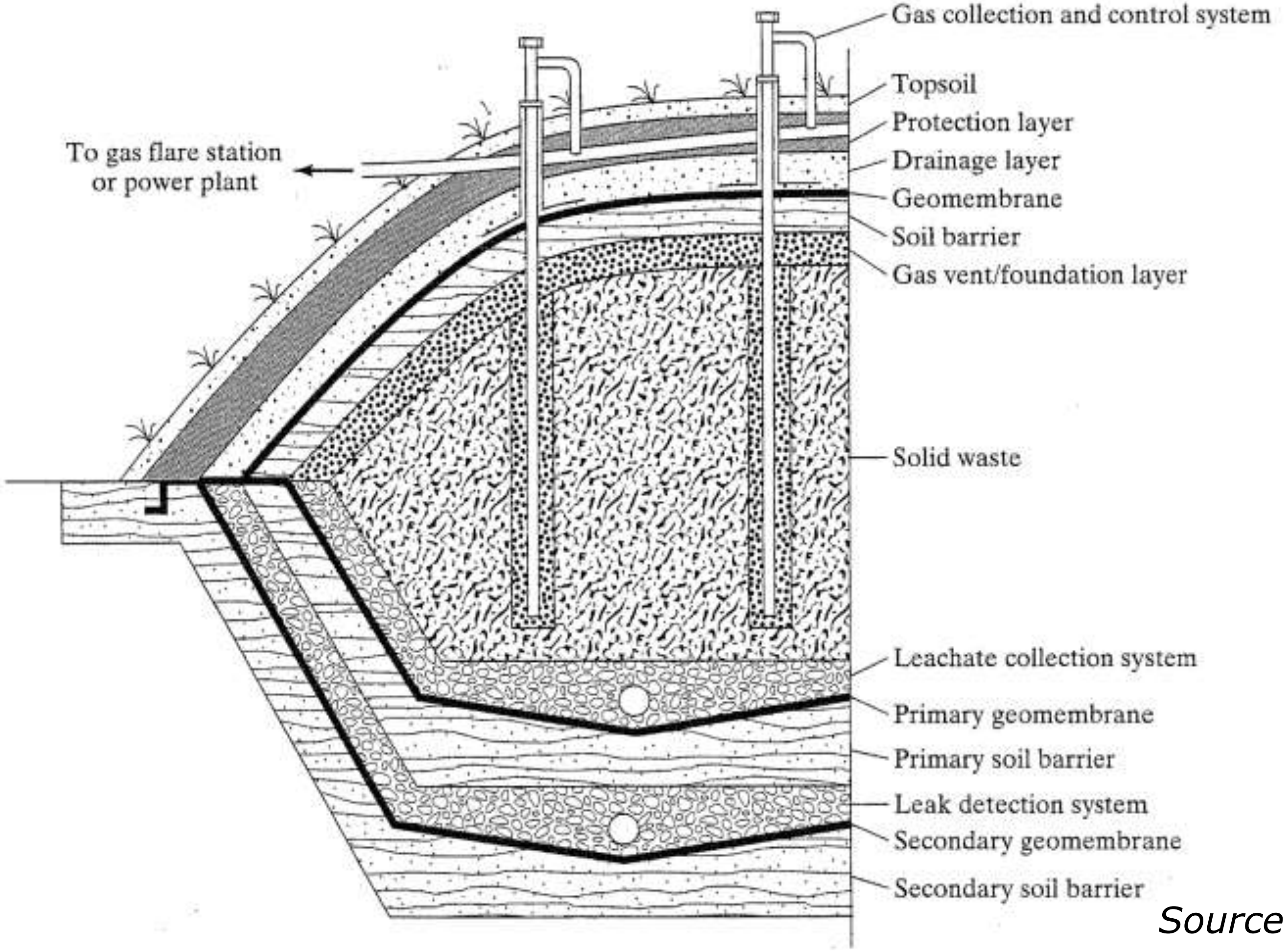
Dump is a location where waste materials are discarded or deposited without proper waste management and environmental controls.

Landfill is an engineered site where waste is isolated from the environment below the ground or on top until it is safe and completely degraded biologically, chemically and physically.

Source: ***Lome Infos***

Introduction

Typical Landfill Schematic



Source: ***Bergado and Abuel-Naga, 2005***

Introduction

Issues Related to Closed & Non Sanitary Landfills

1.Health issues

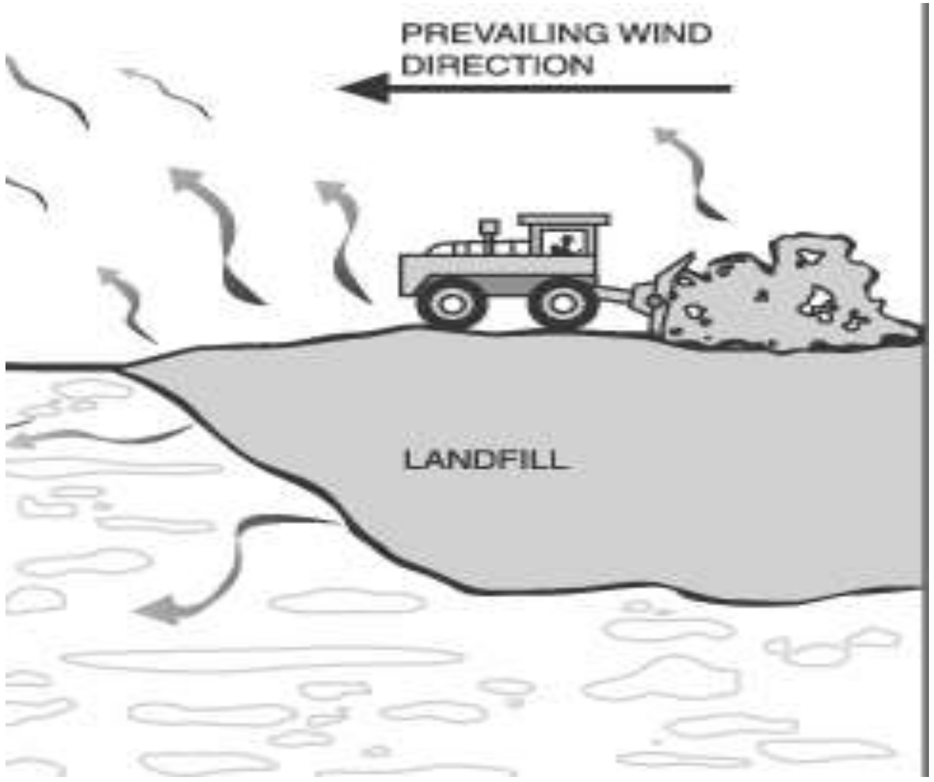
Fires (toxic vapours), Leachate in drinking water wells, direct contact with waste

2. Safety issues

Explosions, suffocation, waste slides (mechanical stability)

3. Environmental issues

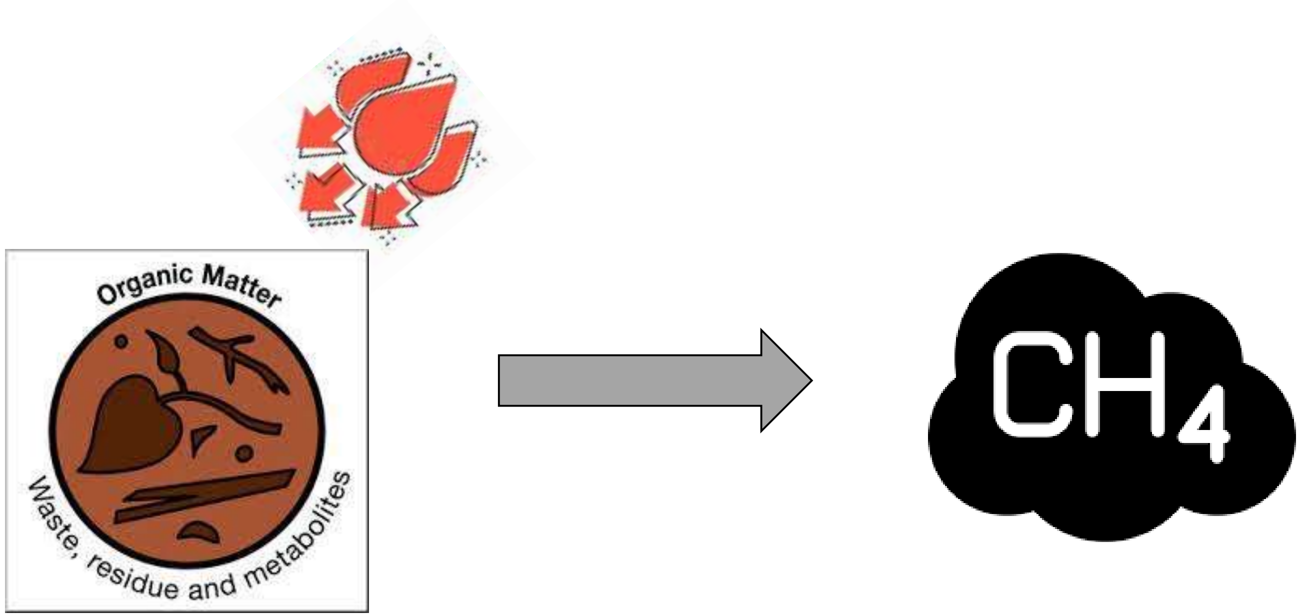
Contamination of ground and surface water, littering, CH_4 Emissions (Global Warming)



Source: ***ATSDR***

Basics on Landfill Gas

Theoretical potential of landfill gas from organic matter



under standard conditions:

1 mol C in organic matter = 22,4 l gas (CH_4 + CO_2)

on weight basis:

1 g C in organic matter = 1,868 l gas (CH_4 + CO_2)

Basics on Landfill Gas

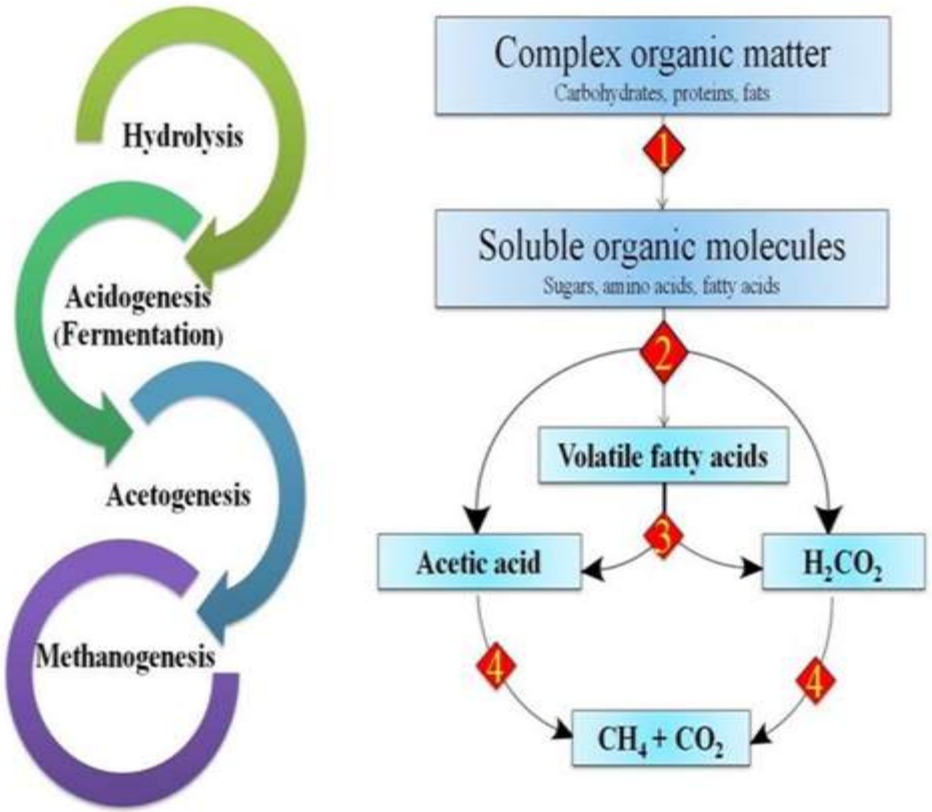
Theoretical quantity of landfill gas production

$Ge = 1{,}868 * C_{org}$

with

Ge: Total mass off landfill gas [Nm^3/Mg_{waste}]

C_{org}: biodegradable organic carbon [kg_C/ Mg_{waste}]



Basics on Landfill Gas

Favorable waste to LFG production

Household waste (MSW), with much moisture

Garden and park waste, decomposable

Basics on Landfill Gas

Unfavorable waste to LFG production

Wood is organic matter but will not produce gas!

Industrial waste, plastics, metals, no gas at all!

Building rubble, concrete blocks

Model of Weber:

$$Q_{a,t} = 1{,}868 * M * TC * f_{AO} * f_A * f_0 * f_s * k * e^{-k*t}$$

with:

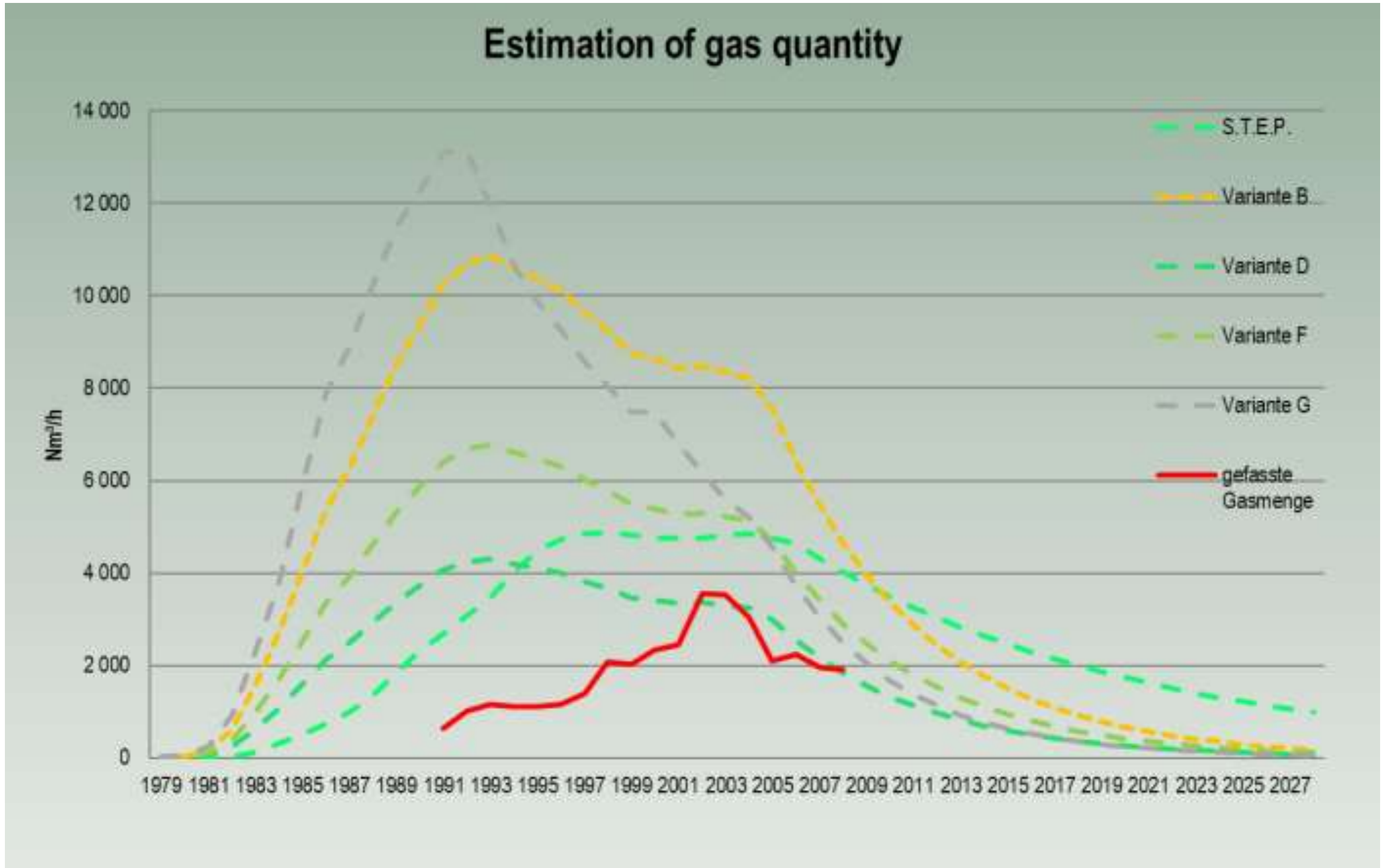
$Q_{a,t}$	real recoverable quantity of landfill gas at a certain time t [m³/a]
M	dumped quantity of waste [Mg]
TC	average content of carbon of the waste [kg_C/Mg_{waste}]
f_{AO}	starting time factor (regards carbon losses from aerobic metabolism processes **0,8...0,9**)
f_A	degredation factor (regards parts of nonbiodegradable organic materials **0,6...0,9**)
f_0	optimization factor (regards effects from landfill operations **0,6.....0,7**)
f_s	factor regards nonrecoverable parts of landfill gas by the gas venting system (**0,3...0,9)**
k	depletion constant, $k = \ln 0{,}5 * T_{1/2}$
$T_{1/2}$	time for depletion of 50 % of carbon quantity

Landfill Gas Generation

Real estimation of LFG Quantity Production

Testing extraction by suction

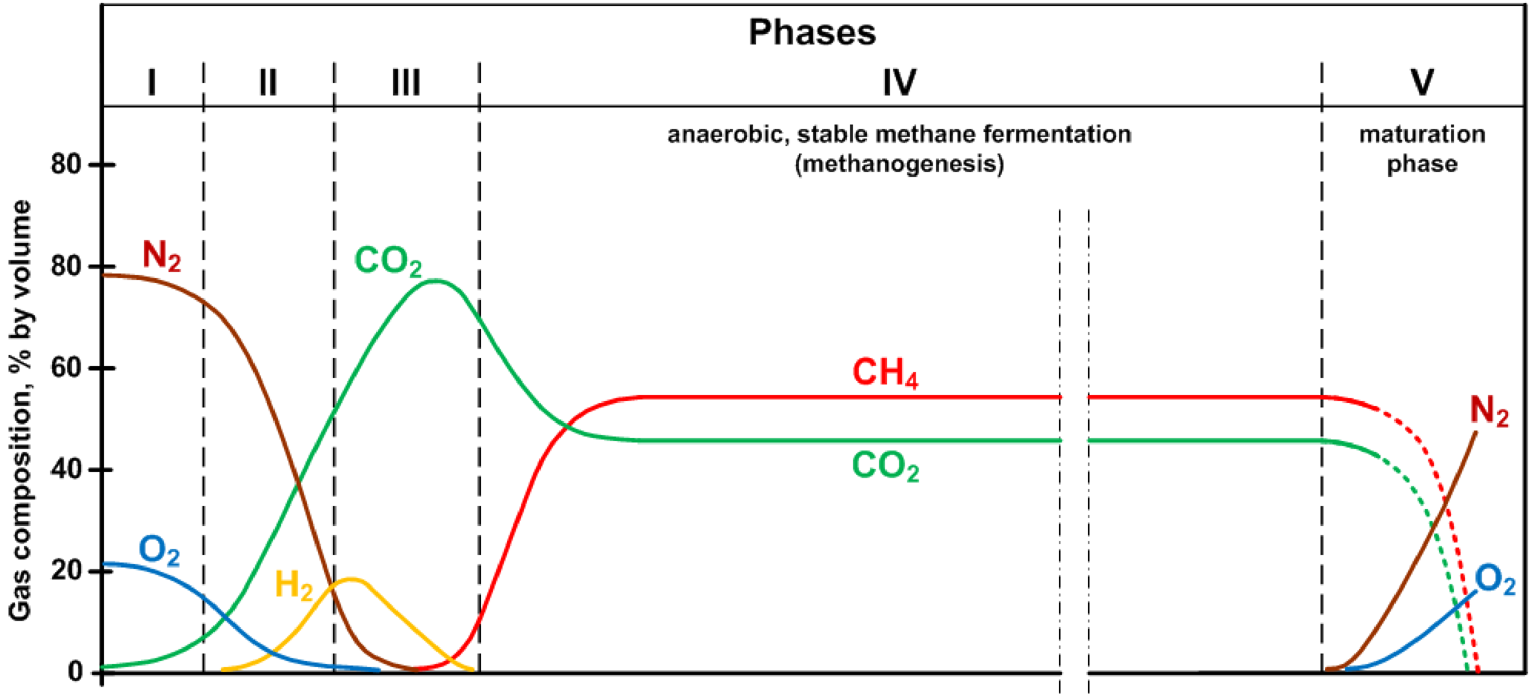
Installation of detached gas wells and operation of suction for **3 – to 6 month** including daily measurements of gas composition and gas quantity



Source: ***Licht & Nelles- Rostock University***

Landfill Gas Generation

Formation Stages of LFG



I = Initial adjustment, aerobic conditions

II = Transition phase, begin of anaerobic decomposition

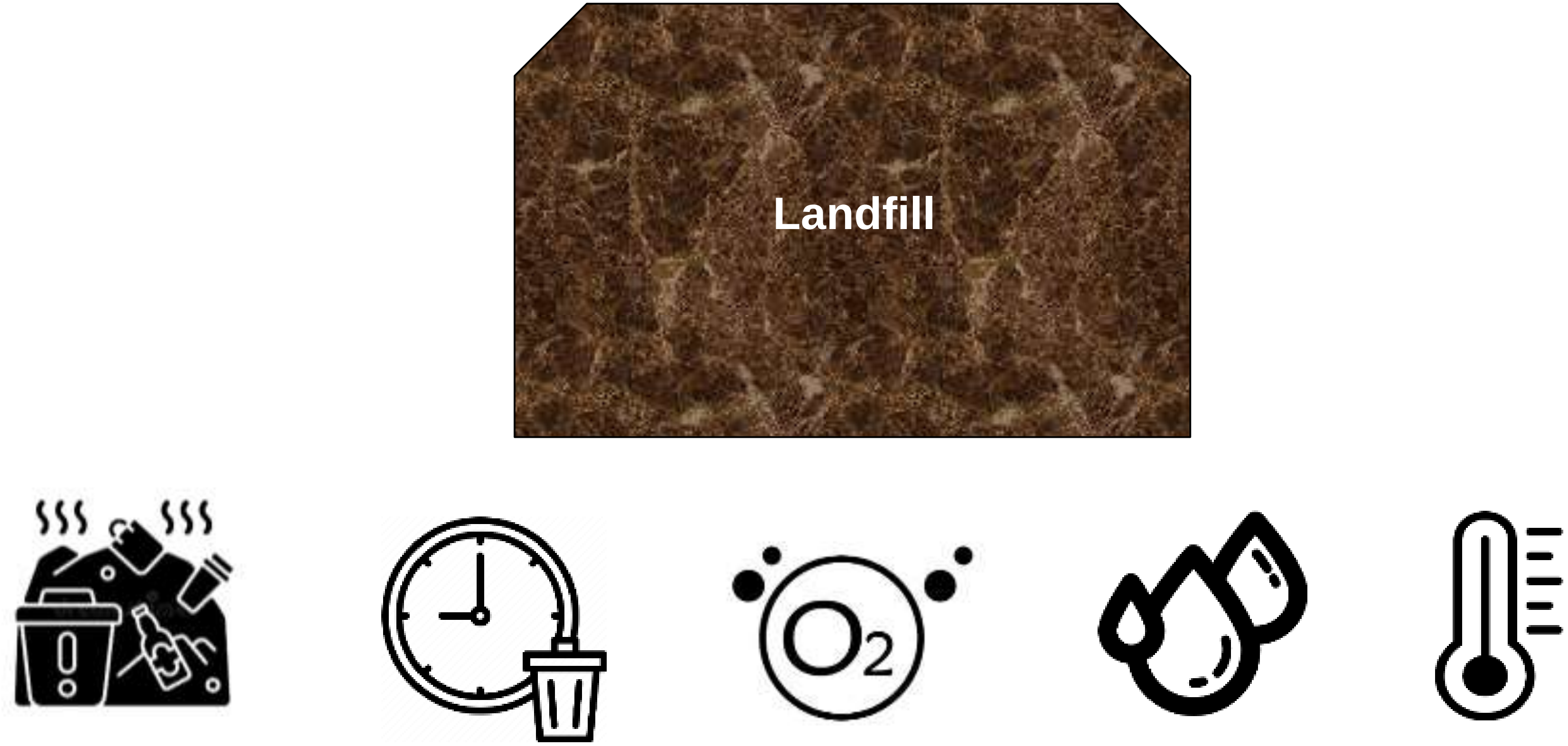
III = Acid phase, hydrolisis and acidogenesis

IV = Metane fermentation phase, strictly anaerobic, methanogenesis

V = Maturation phase: air intake, methane oxydation to CO_2 and air phase

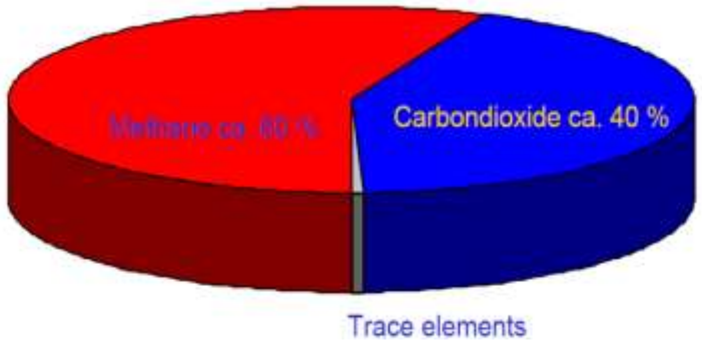
Landfill Gas Generation

Factors influencing gas generation



Landfill Gas Generation

Landfill Gas composition



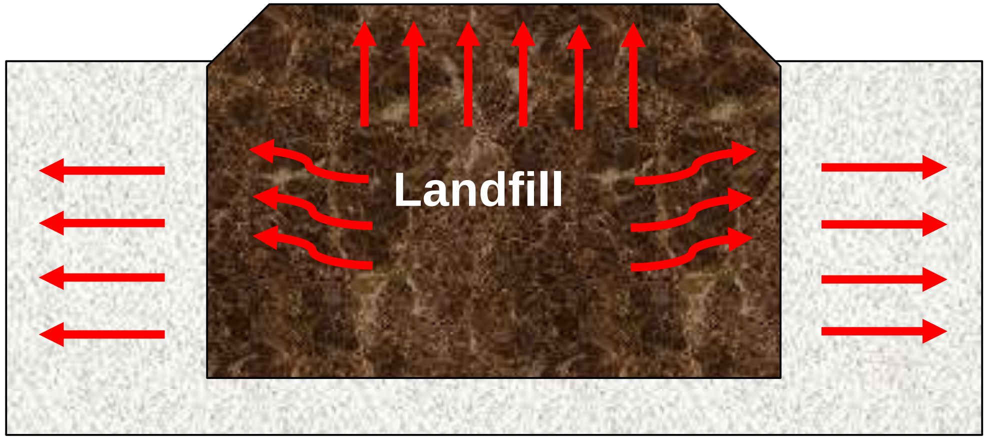
- Flammable
- Toxic
- Greenhouse gas
- Explosible

Property	Unit	Landfill Gas	Biogas *)
Methane (CH_4) Content	Vol-%	35-60	60-70
Carbon Dioxide (CO_2) Content	Vol-%	30-45	25-35
Nitrogen (N_2) Content	Vol-%	1-15	0-5
Oxygen (O_2) Content	Vol-%	0-2	0-2
Sulfur (S) Content	$mg/m_n^3{}_{CH4}$	0-2000	0-5000
Fluorine (F) Content	$mg/m_n^3{}_{CH4}$	5-10	0-5
Chlorine (Cl) Content	$mg/m_n^3{}_{CH4}$	5-50	0-5
Silicon (Si) Content	$mg/m_n^3{}_{CH4}$	5-100	0-150
Hydrocarbons (C_xH_y) Content	$mg/m_n^3{}_{CH4}$	0-500	0-100
Relative Humidity	%	100	100
Lower Heating Value (LHV)	MJ/m_n^3	12-22	22-26

*) including sewage gas

Landfill Gas Collection System

Factors influence the migration of LFG



Diffusion: Gases in a landfill move from areas of high gas concentrations to areas with lower gas concentrations.

Pressure: Gases accumulating in a landfill create areas of high pressure in which gas movement is restricted by compacted refuse or soil covers,

Permeability: Gases tend to move through areas of high permeability (e.g., sand or gravel) rather than low permeability (e.g., clay or silt).

Landfill Gas Collection System

Landfill Surface Cover Guidelines

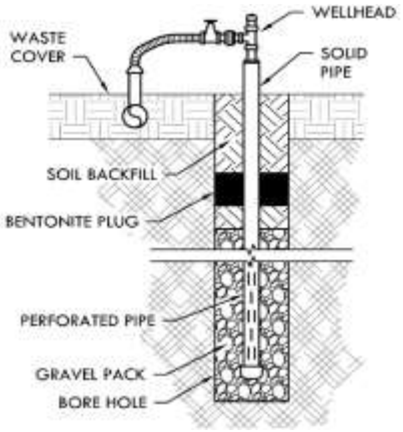
EU Landfill Directive (**1999/31/EC**)
Vegetative (d ≥ 1 m)
Water Drainage (d ≥ 0,3 m) (Kf ≥ 1 * 10^{-3} m/s)
Barrier **Geomembrane** (d ≥ 2,5 mm)
Mineral (2 Lines; d ≥ 0,5 m) (K_f < 5 * 10^{-9} m/s)
Gas Drainage (d ≥ 0,5 m)
Waste

US Environmental Protection Agency (**40 CFR Part 258**)
Vegetative (d ≥ 0,6 m)
Water Drainage (d ≥ 0,3 m) (Kf ≥ 1 * 10^{-4} m/s)
Barrier **Geomembrane** (d ≥ 3,5 mm)
Clay (d ≥ 0,6 m) (K_f < 1 * 10^{-9} m/s)
Gas Drainage (d ≥ 0,3 m)
Waste

Landfill Gas Collection System

Gas Collection System (GCS) Components

1. Gas well

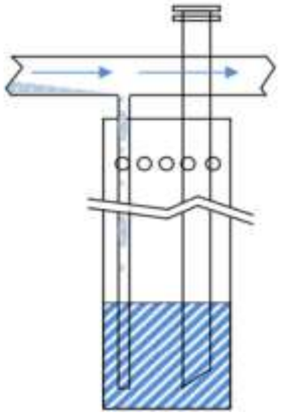


Vertical/Horizontal Well

2. Collecting Pipes

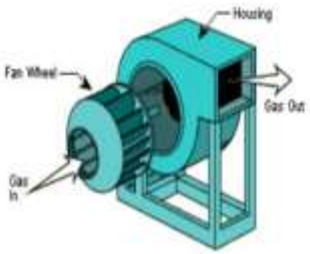
D=100 mm Laterals
D= 300-500 mm Headers
Slope (3%)

3. Condensate Drains



Barometric/J-trap

4. Blower



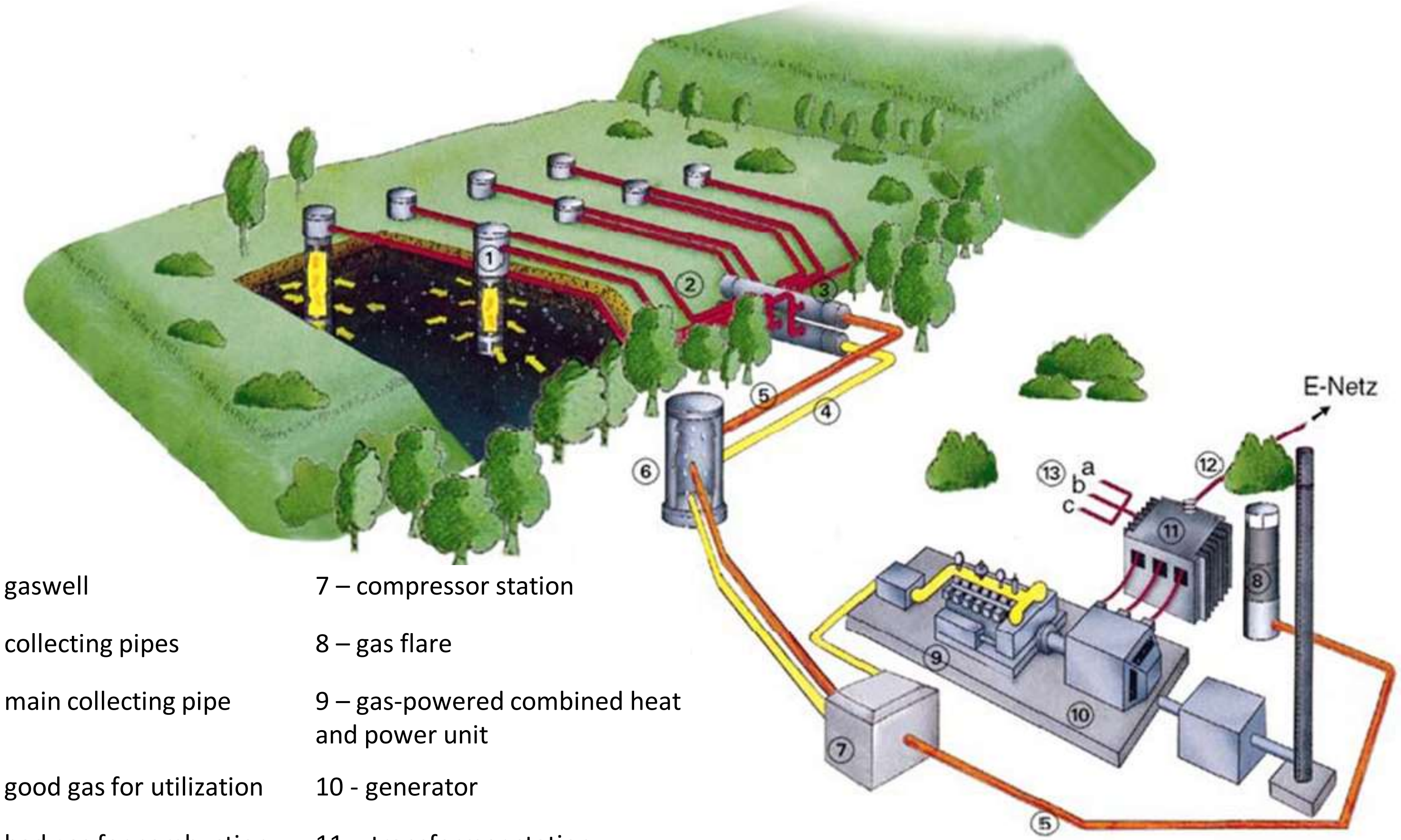
Centrifugal Fans (280mb – 300mb)

5. Flare

Open/Enclosed Flares

Landfill Gas Collection System

Diagram of landfill gas collection system

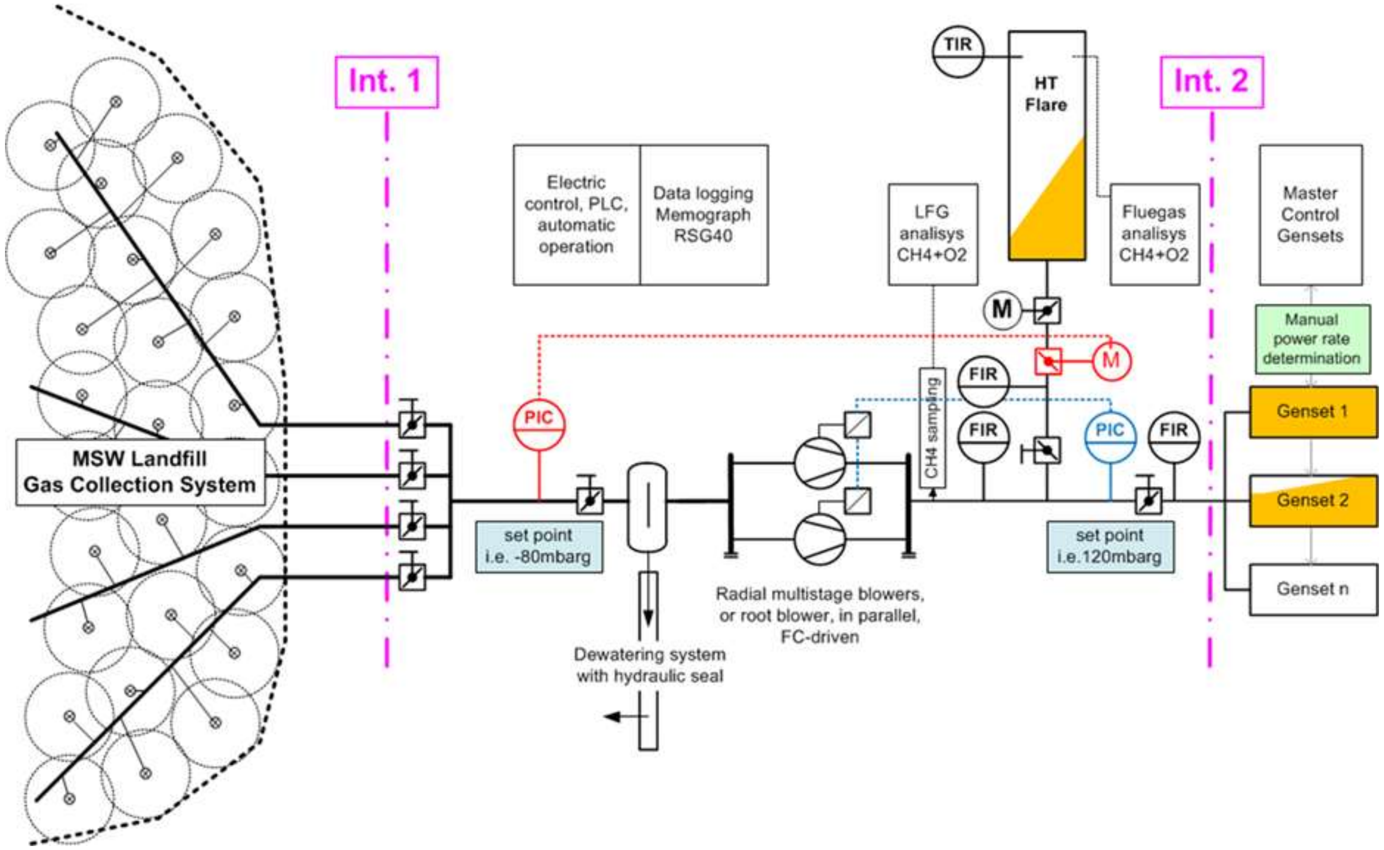


1 - gaswell	7 – compressor station
2 - collecting pipes	8 – gas flare
3 - main collecting pipe	9 – gas-powered combined heat and power unit
4 - good gas for utilization	10 - generator
5 - bad gas for combustion	11 – transformer station
6 - demister	12 – energy supply

Source: ***Licht & Nelles- Rostock University***

Landfill Gas Collection System

Conception of active degassing system

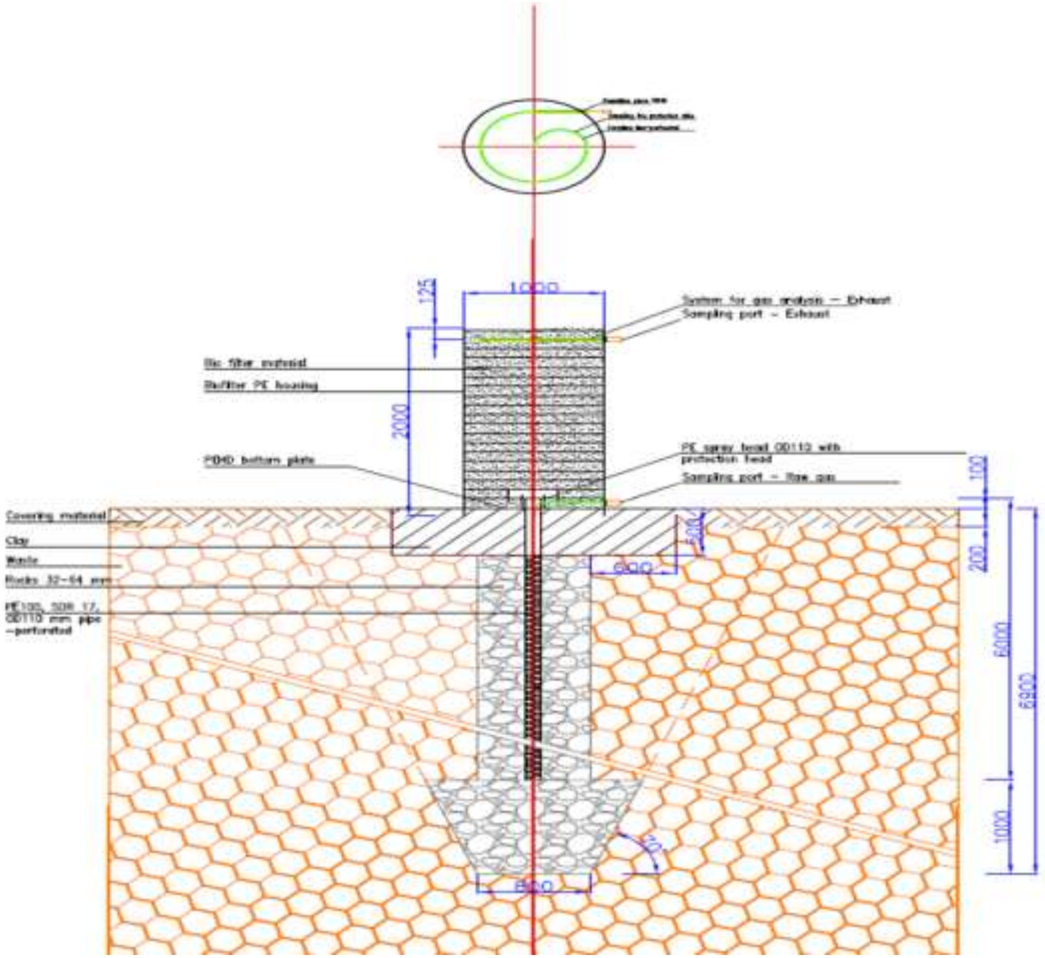


Active systems of landfill gas collection generate a vacuum inside extraction wells in order to extract landfill gas from inside the system

Source: ***Hofstetter Gastechnik AG***

Landfill Gas Collection System

Conception of passive degassing system



A passive system collects gas simply by inserting vents into the landfill and allowing LFG to travel ambiently up through the vents

Source: ***Hofstetter Gastechnik AG***

Landfill Gas Collection System

Facts of O2 in LFG

When extracting gas from the Landfill O_2 is usually available in more or less quantities !

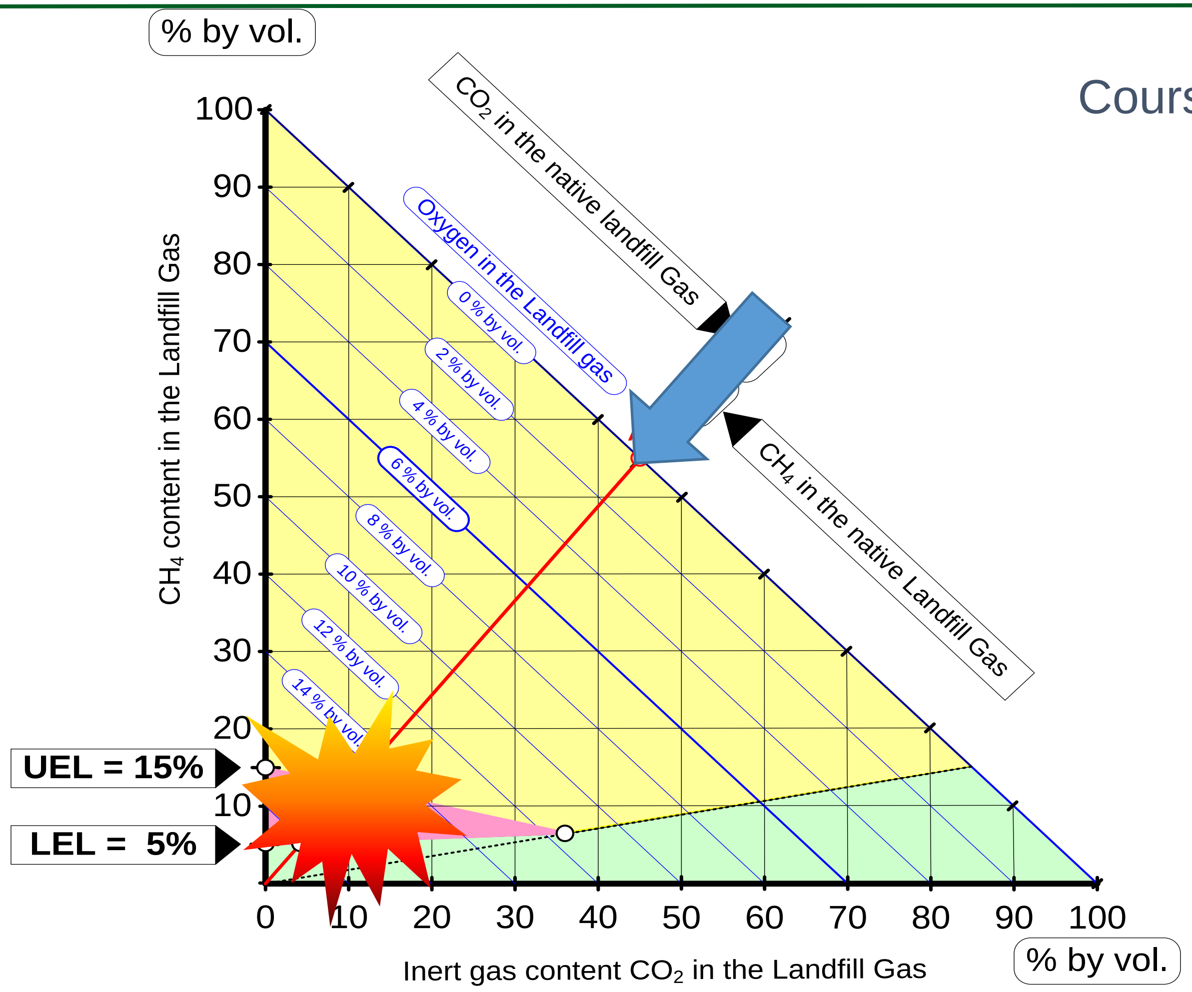
- When the gas extraction is done correctly, low concentrations of O_2 less then 2 % can be considered as normal, safety is granted
- O_2 concentrations of near 3% are indicator for a malfunction of the gas extraction, the system is still safe but corrective measures are to be done
- When O_2 is reaching 6%, then a potential danger of explosion is given. In such a case safety of the system is not any more fulfilled!

  This is a potentially dangerous situation!

Landfill Gas Collection System

Flammability diagram for LFG

Course of inflammation of a LFG/air mix



Source: ***Hofstetter Gastechnik AG***

Landfill Gas Collection System

Reasons for having O2 in LFG

- Gas piping is damaged (mechanically)
- Gas wellhead is damaged or bent
- Bad sealing of wellhead, clay filling dried out
- Bad landfill cover, fissures washed out by rain
- Hydraulic seals of gas system are faulty
- Aspiration of air through leachate system
- Suction at the gas wells too strong, “overpull”
- Incorrect operation of the gas plant, wrong regulation of flow/pressure at the gas wells

Landfill Gas Collection System

Other harmful matter in LFG

Furthermore Landfill Gas will carry along other matter hindering and damaging components, like:

- Condensate water
- Dust
- Solid particles (e,g,, sand, stones, plastic chips, etc)

Therefore a degassing plant need to be outfitted with

Pre-Dewatering unit

Gas Filter Unit

at the entry of the gas station!

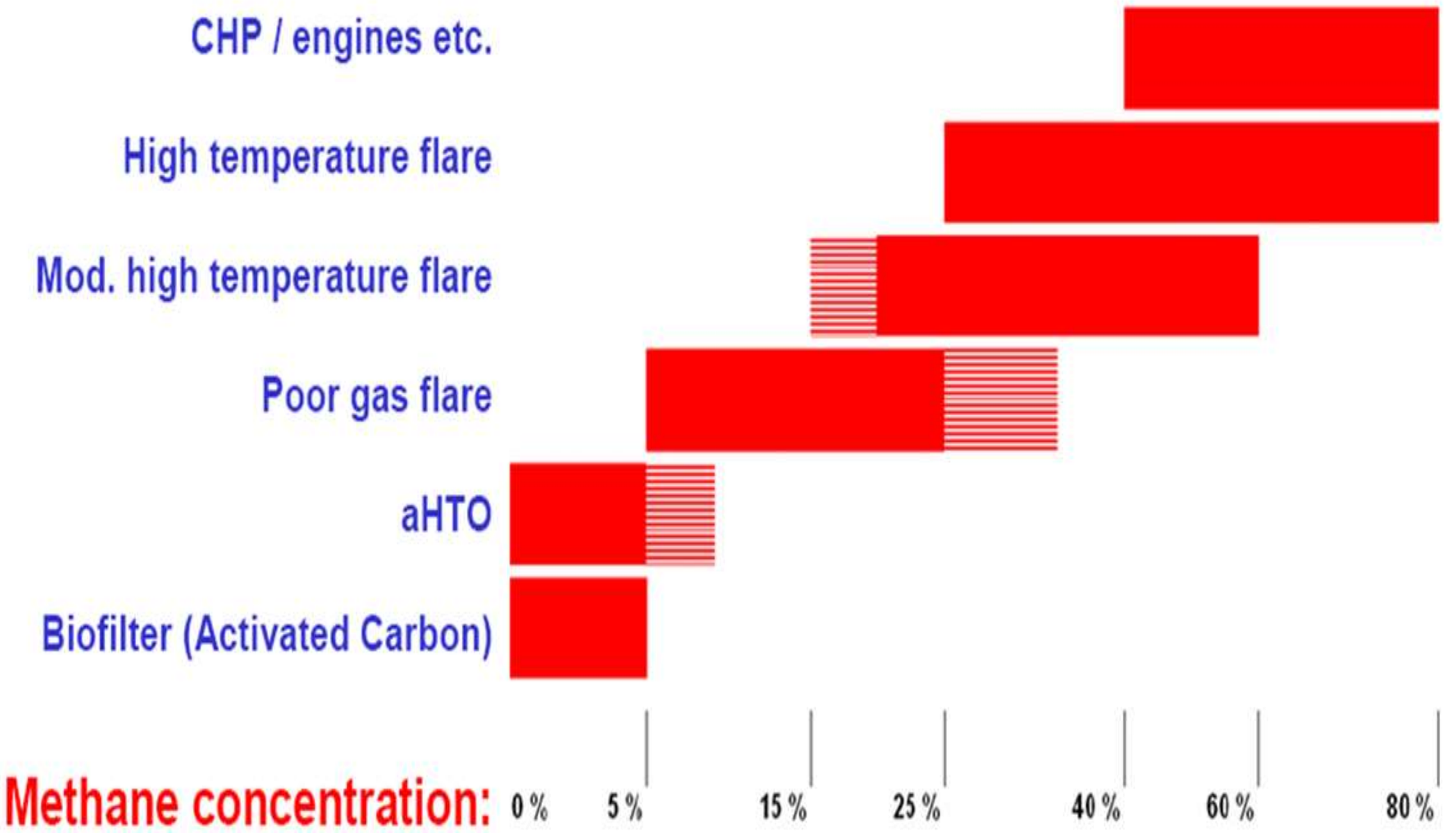
Landfill Gas Collection System

Gas pre-dewatering and filtering

Source: ***Hofstetter Gastechnik AG***

Landfill gas Utilization

Utilization Options



Landfill gas Utilization

Direct-Use LFG-Energy Projects

- Boiler applications –replace natural gas, coal, fuel oil
- Direct thermal (dryers, kilns)
- Greenhouses
- Leachate evaporation

Source**: SCS Engineers.**

Landfill gas Utilization

Electricity Generation: Reciprocating Engines (CHP)

Advantages:
- Better heat rate (more efficient)
- Moderate capital cost
- Lower fuel pressure

Disadvantages:
- Higher air emissions
- Maintenance intensive
- Require minimum 40% to 45% methane

1.6 MW CAT 3520C genset needs **1000 m3/hr** of LFG

Source: **US EPA**.

Landfill gas Utilization

Electricity Generation: Turbines

Advantages:

- Lower air emissions
- Moderate capital cost
- More tolerant of low methane content
- Higher power density

Disadvantages:

- Worse heat rate
- Requires high fuel pressure

Source: **US EPA**.

Landfill gas Utilization

High-BTU: Pipeline Gas & Vehicle Fuel (LNG/CNG)

Advantages:

- Inject treated LFG into gas pipeline
- Reduces use of fossil fuels
- Reduces local pollutant emissions

Disadvantages:

- Product gas must meet pipeline specifications
- Costly technology (capital and O&M)

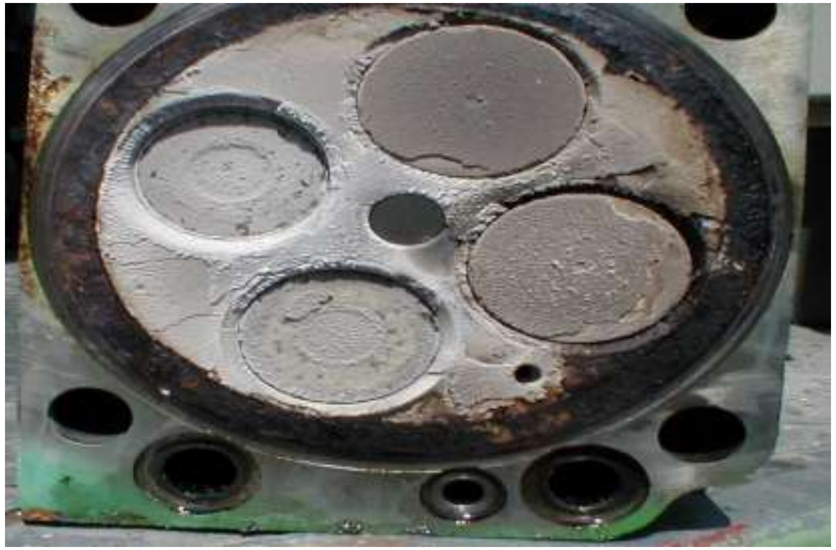
Source: **US EPA**.

Utilization Options

Issues from Siloxane

In gas engines, siloxanes are oxidised to silicon dioxide forming solid, hard and abrasive crystals.

SiO_2 will deposit on cylinders, pistons and valves. Engine maintenance will rise abruptly and often cause breakdown of the engine. Many cases of destroyed engines are known!



Source: ***Hofstetter Gastechnik AG***

Safety and Preventive Measures

Preventive measures

Basic measures to prevent accidents by asphyxiation and intoxication:

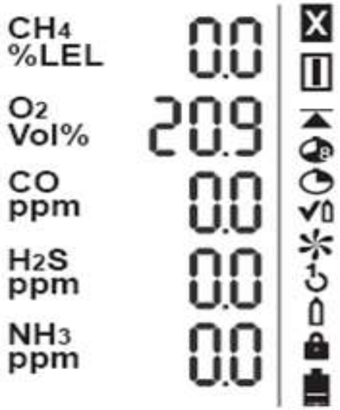
- Landfill gas must be collected from all landfills, must be flared in HT flares and, if possible, utilised.
- The Management of a landfill must release instructions for working at a gas collection system.
- When working in confined spaces, it is vital to check the atmosphere with an individual gas detector.
- Confined spaces should never be accessed when the inside atmosphere is not proved to be safe.
- Safe is: CH_4<0.5%; O_2>20%; CO_2<0.5%; H_2S<5ppm

Safety and Preventive Measures

Preventive measures

Checking the atmosphere before accessing a confined space.

Carry individual gas detector, i.e. Dräger X-am 5000 Ex.

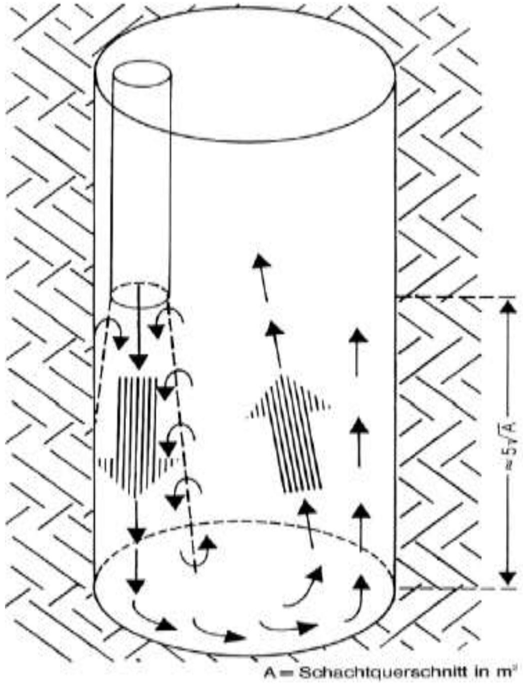


Source: ***Hofstetter Gastechnik AG***

Safety and Preventive Measures

Rescue equipment

If a confined area is not safe, then ventilation has to be carried out until a safe situation is reached.



Ventilation of shafts

Source: ***Hofstetter Gastechnik AG***

Study Case: Oued Smar Landfill – Algeria

Overview

Historical Information

- Surface: 40 Hectares
- Duration Period: 1978 to 2011
- Closed Date: 07/2012
- Rehabilitation into a Park: 2020
- Waste Quantity Estimated: 6,8 Mio T
- Type of Waste: MSW + Non HW

LFG System

- 127 Gas Wells (20 to 50 m depth)
- 1 Central Gas Station
- 12 Gas Regulation System
- 2 Flares (Capacity of 5000 m^3/h)
- 1 Cogeneration Unit (Capacity of 637 Kw)

Leachate System

- Treatment Capacity: 720 m^3/d
- Technology Used: heterogeneous catalysis with a TiO_2 catalyst
- 2 Water Tanks of 150 m^3
- Irrigation System of 20 hectares.

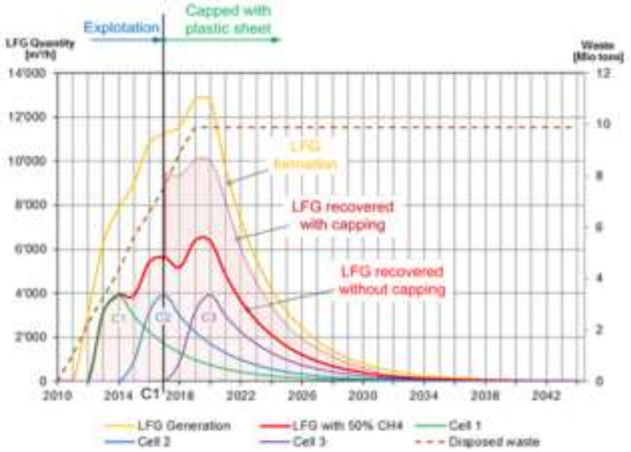
Study Case: Oued Smar Landfill – Algeria

Assessment Methodology

Methodology

LFG Potential Calculation
(Based on Tabasaran Model)

Inspection Activities
(including measurements and consultation of the LFG System)



Source: ***Envero GmbH***

Study Case: Oued Smar Landfill – Algeria

Landfill Gas Generation Prognosis

Landfill Gas Quantity Calculation

Project: **Oued Smar** Calculation No.: **001**

- Start of waste depositing: 1978 year
- Organic carbon in the MSW: DOC 210 kg/to
- Methane Correction Factor: MCF 90 %
- Temperature in the Landfill mass: T_{LFM} 35 °C
- Methane generation rate k: k 0.035 -
- Assumed methane content in the LFG: 50 vol%
- Assumed calorific value of the LFG: 5 kW

Degree of gasification after:
- 20 years 80 %
- 30 years 91 %
- 50 years 98 %

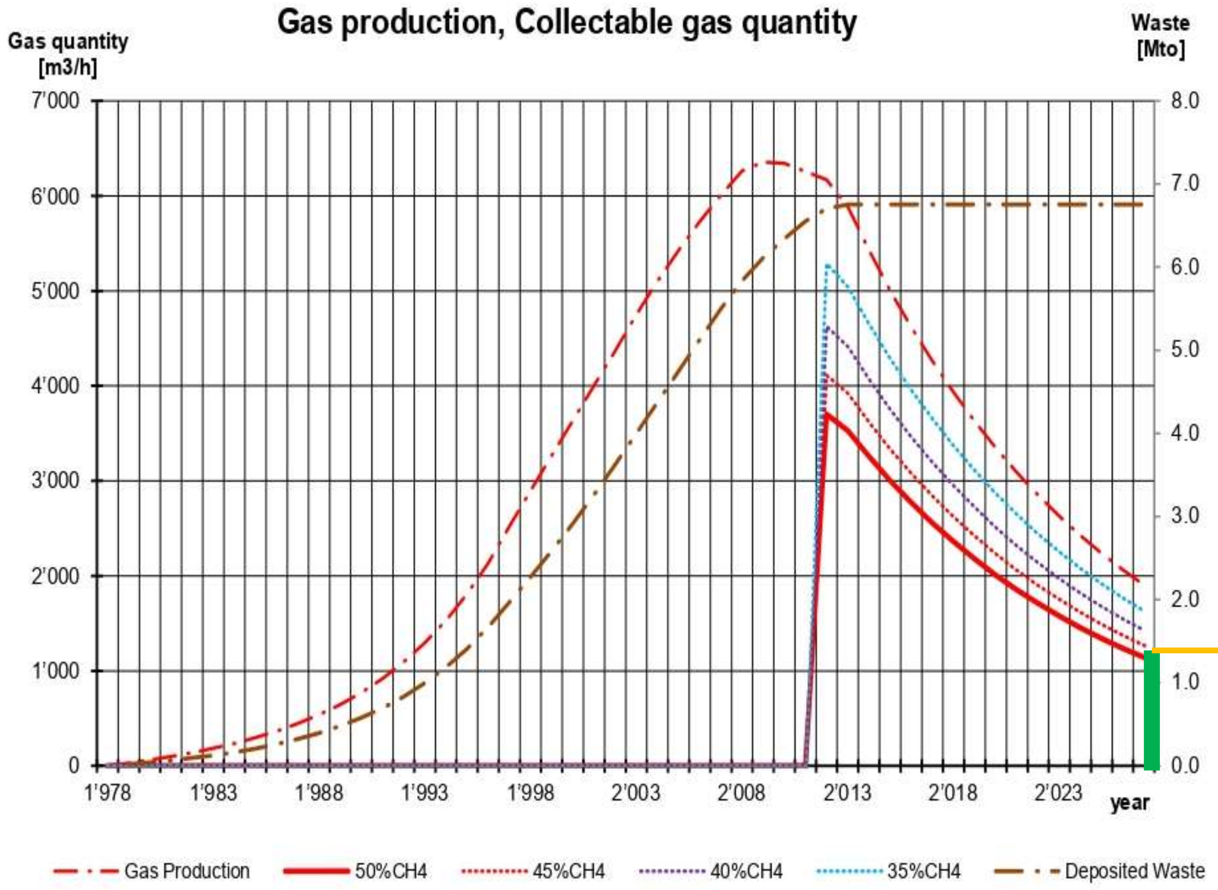
Year	Deposited waste to	Part of MSW %	Degree collect. %	Quantity degass waste to	Produced gas quantity m^3/h	Collectable gas quantity m^3/h	Cumulated gas $m^3 \times 10^6$	Power potential kWh/h	Energy potential GWh
1978	15332	80	0	12'266	0	0	0	0	0
1979	18038	80	0	14'430	29	0	0.0	0	0.0
1980	21221	80	0	16'977	62	0	0.0	0	0.0
1981	24965	80	0	19'972	98	0	0.0	0	0.0
1982	29371	80	0	23'497	138	0	0.0	0	0.0
1983	34554	80	0	27'643	184	0	0.0	0	0.0
1984	40652	80	0	32'522	236	0	0.0	0	0.0
1985	47826	80	0	38'261	296	0	0.0	0	0.0
1986	56266	80	0	45'013	365	0	0.0	0	0.0
1987	66195	80	0	52'956	445	0	0.0	0	0.0
1988	77876	80	0	62'301	538	0	0.0	0	0.0
1989	91619	80	0	73'295	646	0	0.0	0	0.0
1990	107787	80	0	86'230	772	0	0.0	0	0.0
1991	126809	80	0	101'447	919	0	0.0	0	0.0
1992	149187	80	0	119'350	1'092	0	0.0	0	0.0
1993	175514	80	0	140'411	1'294	0	0.0	0	0.0
1994	206487	80	0	165'190	1'531	0	0.0	0	0.0
1995	242926	80	0	194'341	1'810	0	0.0	0	0.0
1996	285795	80	0	228'636	2'137	0	0.0	0	0.0
1997	297566	80	0	238'053	2'521	0	0.0	0	0.0
1998	309885	80	0	247'908	2'897	0	0.0	0	0.0
1999	323025	80	0	258'420	3'269	0	0.0	0	0.0
2000	336439	80	0	269'151	3'637	0	0.0	0	0.0
2001	350400	80	0	280'320	4'002	0	0.0	0	0.0
2002	375263	80	0	300'210	4'365	0	0.0	0	0.0
2003	375263	80	0	300'210	4'749	0	0.0	0	0.0
2004	375263	80	0	300'210	5'102	0	0.0	0	0.0
2005	375263	80	0	300'210	5'429	0	0.0	0	0.0
2006	375263	80	0	300'210	5'730	0	0.0	0	0.0
2007	375263	80	0	300'210	6'007	0	0.0	0	0.0
2008	300000	80	0	240'000	6'264	0	0.0	0	0.0
2009	250000	80	0	200'000	6'355	0	0.0	0	0.0
2010	210038	80	0	168'030	6'344	0	0.0	0	0.0
2011	206105	80	0	164'884	6'256	0	0.0	0	0.0
2012	100000	80	60	80'000	6'168	3'701	32.4	18'505	162.1
2013	0	80	60	0	5'883	3'530	63.3	17'648	316.7
2014	0	80	60	0	5'427	3'256	91.9	16'282	459.3
2015	0	80	60	0	5'007	3'004	118.2	15'021	590.9
2016	0	80	60	0	4'619	2'772	142.5	13'858	712.3
2017	0	80	60	0	4'262	2'557	164.9	12'785	824.3
2018	0	80	60	0	3'932	2'359	185.5	11'795	927.6
2019	0	80	60	0	3'627	2'176	204.6	10'882	1'023.0
2020	0	80	60	0	3'346	2'008	222.2	10'039	1'110.9
2021	0	80	60	0	3'087	1'852	238.4	9'262	1'192.0
2022	0	80	60	0	2'848	1'709	253.4	8'545	1'266.9
2023	0	80	60	0	2'628	1'577	267.2	7'883	1'336.0
2024	0	80	60	0	2'424	1'455	279.9	7'273	1'399.7
2025	0	80	60	0	2'237	1'342	291.7	6'710	1'458.4
2026	0	80	60	0	2'063	1'238	302.5	6'190	1'512.7
2027	0	80	60	0	1'904	1'142	312.5	5'711	1'562.7
Total	6'753'456 to		Total	5'402'765 to					

Total gas quantity per ton of waste: **302** m^3 per 1 ton decomposable waste

Source: ***Envero GmbH***

Study Case: Oued Smar Landfill – Algeria

Landfill Gas Generation Prognosis

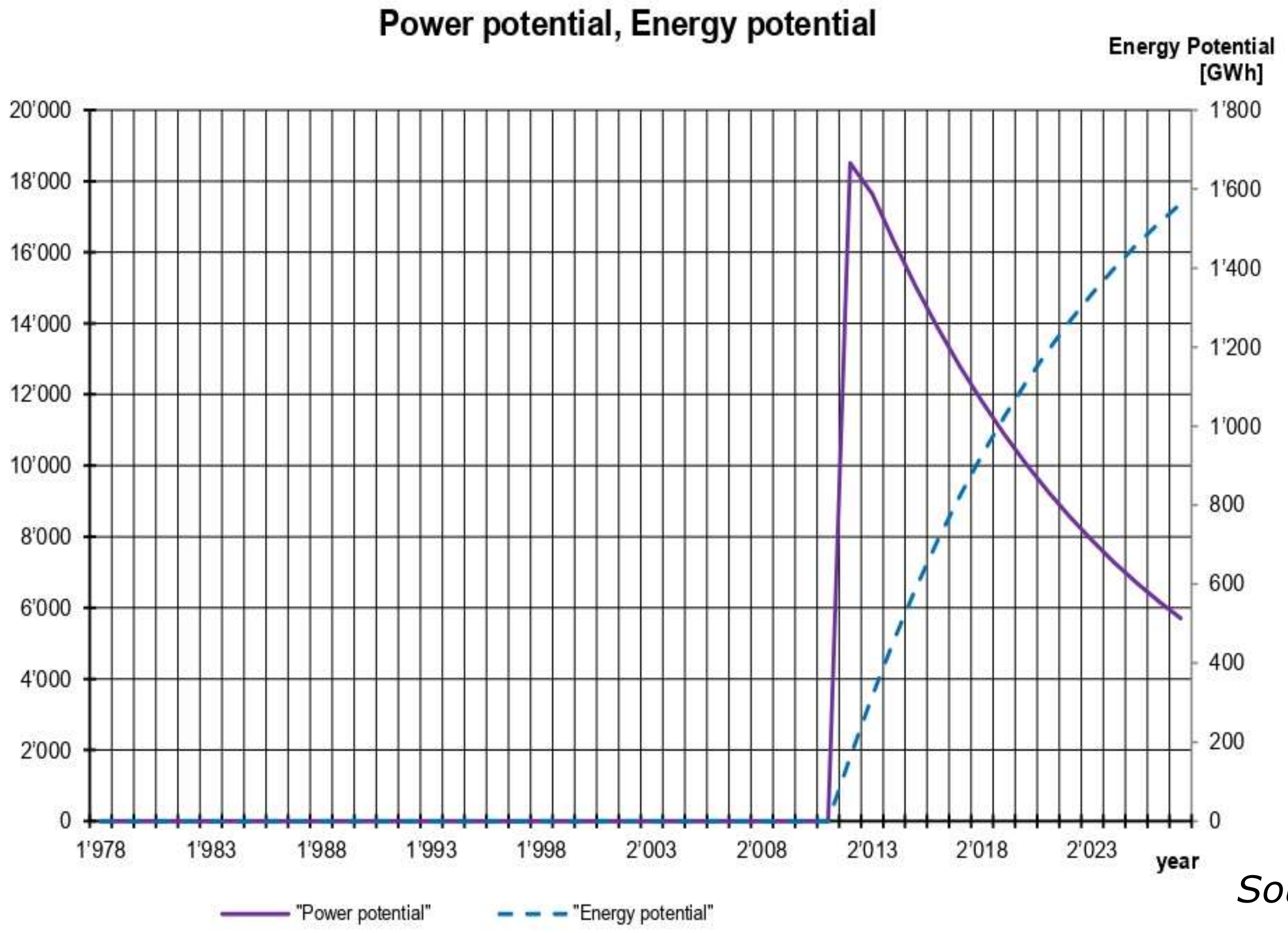


Higher than **1000 m^3/h** with **50 % of CH_4** for the next **3-5 years**.

Source: ***Envero GmbH***

Study Case: Oued Smar Landfill – Algeria

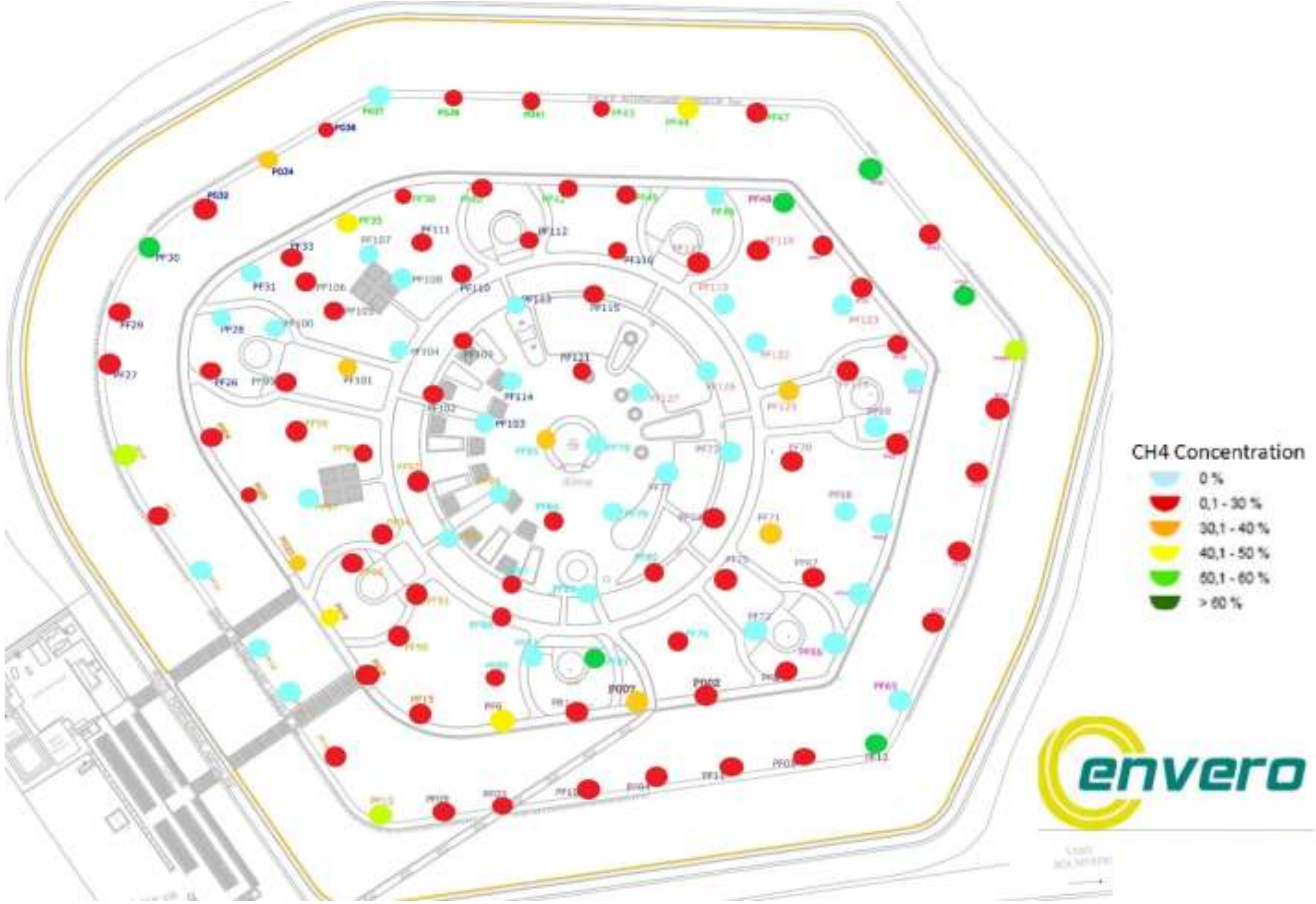
Landfill Gas Generation Prognosis



Energy Potential Estimation is higher than **600 GWh per year**

Source: ***Envero GmbH***

Study Case: Oued Smar Landfill – Algeria
Landfill Gas Composition in Gas Well-Heads



Conclusion

Rule of thumb

- ✓ Landfill with: 1’000’000 tons MSW
- ✓ Filling period: 10 years
- ✓ Peak gas extraction: 1’000 m^3/h
- ✓ Long term gas yield: 400 m^3/h
  (over 10 years)
- ✓ Energy content of 400m^3/h: ~2’000 kWh (50%CH4→5kWh/m3)
- ✓ Electricity production: ~750 kW_{el}
  (during a period of 10 years)

➢ 1 Mio tons of waste to produce 0.75 MW

➢ 1.3 Mio tons waste to produce 1 MW

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Thank you for your attention!

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Photo: **Grand Prairie Landfill – Texas- USA**