Biogas Production at Municipal Solid Waste Landfills

Table of Census® Gene Targets Related to Biogas Production and Landfill Management

Target	MI Code	Description
Methanogens	**MGN**	Targets methanogens which are responsible for methane production during anaerobic decomposition.
Acetoclastic Methanogens	**AMGN**	Targets acetoclastic methanogens which are responsible for methane production from acetate.
Fermenters	**FER**	Targets several genera of fermenting bacteria which convert soluble organic compounds from the hydrolysis phase into VFAs, alcohols, H2, and CO2.
Acetogens	**AGN**	Targets acetogens which convert longer chain VFAs and alcohols from the fermentation stage into acetate H2 and CO2.
Sulfate Reducers	**APS**	Targets the APS gene found in sulfate reducing bacteria which can compete with methanogens and cause drops in leachate pH if sulfuric acid is produced.
Ammonia oxidizers	**AMO**	Targets the ammonia monooxygenase gene (amoA) that encodes the enzyme responsible for the initial oxidation of ammonia by nitrifying bacteria that are in biological leachate treatment systems.
Methanotrophs	**SMMO**	Targets a functional gene in methanotrophs which oxidize the methane produced by methanogens to produce CO2.
Methanotrophs	**PMMO**	Targets a functional gene in methanotrophs which oxidize the methane produced by methanogens.
Iron Oxidizers	**FEOB**	Targets iron oxidizing bacteria which are involved in the corrosion of metals present within the landfill as well as methane/biogas storage systems.
Manganese Oxidizers	**MnOB**	Targets manganese oxidizing bacteria which are involved in the corrosion of metals present within the landfill as well as methane/biogas storage systems.
Sulfur Oxidizers	**SOB**	Targets sulfur oxidizing bacteria which are involved in the corrosion of metals present within the landfill as well as methane/biogas storage systems.
Iron Reducers	**IRB**	Targets iron reducing bacteria which are involved in the corrosion of metals present within the landfill as well as methane/biogas storage systems

The conversion of municipal solid waste (MSW) to landfill biogas and leachate relies on multiple chemical and biological pathways. Under aerobic conditions, aerobic bacteria convert organic matter into carbon dioxide, water, energy (heat), and a substantial amount of biomass product (1). These aerobic processes typically occur within a short period of time due to a lack of available oxygen since most modern landfills are capped with a low permeability cover which limits the amount of oxygen that can penetrate the landfill. After the initial aerobic degradation stage, anaerobic processes take over and occur in four distinct stages. The first stage is hydrolysis which involves the breakdown of insoluble biopolymers (carbohydrates, proteins, and fats) into soluble organic compounds. The next stage is acid fermentation in which fermenting bacteria convert the dissolved organic compounds from hydrolysis into volatile fatty acids, alcohols, hydrogen, and carbon dioxide. The third stage is acetogenesis where acetogenic bacteria convert the longer chain VFAs and alcohols from the fermentation stage into acetate, hydrogen, and carbon dioxide. The final stage in anaerobic degradation is methanogenesis. In this process methane gas is produced by methanogens that utilize hydrogen and carbon dioxide and a smaller group of acetoclastic methanogens which are capable of utilizing acetate (2). Overall, the anaerobic decomposition processes generate substantial amounts of methane and carbon dioxide (60%/40% ratio) as well as trace amounts of nitrogen, oxygen, ammonia, sulfides, hydrogen, and carbon monoxide, (2, 3). Trace amounts of aromatic hydrocarbons and chlorinated aliphatics are also present (2, 4).

The methane produced in landfills has been implicated as the largest anthropogenic source of atmospheric methane and thus a contributor to the greenhouse effect (5), but it can also serve as a renewable energy source. The quantity of

methane produced is influenced by the properties of the waste material and environmental factors (2, 6, 7). Higher oxygen content leads to an extension of the aerobic phase thus limiting methane production. A pH outside of the range of 6-8 has been shown to have a negative effect on methane production due to the inability of most methanogens to operate effectively outside of that pH range (8, 9). Researchers have also shown that temperatures around 40°C favor decomposition and biogas formation at landfills (10, 11). This suggests that mesophilic methanogens which operate within the temperature range of 20 to 44°C are important for this process and that maintaining a temperature around this range is necessary. However, temperature monitoring is key: heat generation during aerobic decomposition can cause the temperature to increase up to 70°C. These high temperatures can inhibit the activity of methanogens thus reducing the rate of methane production (12, 13). Studies have suggested that subsurface heating events such as this can potentially be detected by elevated CO levels (>1000 ppm) (13) due to incomplete combustion or through observed decreases in methane production possibly due to inhibition of methanogens or oxidation of methane by methanotrophic bacteria. However, more research is needed to confirm the source of CO in landfills and the cause of the decreases in methane. Due to the heterogeneous nature of the refuse composition at landfills which causes variability in environmental conditions and microbial populations (9), investigation of landfill chemistry and microbiology can be challenging. However, gaining a better understanding of the impacts of temperatures and other factors on landfill microbial community dynamics and gas emissions will lead to the development of more effective strategies for long-term landfill management.

CENSUS® qPCR: Microbial insights offers many qPCR targets related to MSW Management and biogas production. Aside from the options listed in the table, please reference the Microbial Insights document on the nitrogen cycle for additional targets.

Next Generation Sequencing (NGS): NGS is used to identify the dominant Bacteria or Archaea in leachate or solid samples. For example, monitor detection of specific genera such as *Methanosarcina* and *Methanosaeta* as a percentage of total reads over time to confirm healthy and diverse populations of methanogens or as evidence when investigating upsets.

References

1. Agency for Toxic Substances & Disease Registry (ATSDR), Chapter 2: Landfill Gas Basics, November 2001, www.atsdr.cdc.gov/hac/landfill/html/ch2.html.
2. Staszewska, E., and M. Pawlowska. 2011. Characteristics of emissions from municipal waste landfills. *Environment Protection Engineering* **37(4):**119-130.
3. Kightley, D., D.B. Nedwell, and M. Cooper. 1995. Capacity for methane oxidation in landfill cover soils measured in laboratory-scale soil microcosms. *Appl. Environ. Microbiol*. **61(2):**592-601.
4. Kjeldsen, P., A. Dalager, and K. Broholm. 1997. Attenuation of methane and nonmethane organic compounds in landfill gas affected soils. *J. Air & Waste Manage. Assoc*. **47:**1268-1275
5. Bogner, J., M. Meadows, and P. Czepiel. 1997. Fluxes of methane between landfills and atmosphere; natural and engineered controls. *Soil Use Management* **13:**268-277.
6. Gurijala, K.R., and J.M. Suflita. 1993. Environmental factors influencing methanogensis from refuse in landfill samples. *Environ. Sci. Technol*. **27:**1176-1181.
7. Lay, J.-J., Y.-Y. Li, and T. Noike. 1997. Influences of pH and moisture content on the methane production in high-solids sludge digestion. *Water Res*. **31(6):**1518-1524.
8. Kasali, G.B., E. Senior, and I. Watson-Craik. 1988. Preliminary investigation of the influence of pH on the solid-state refuse methanogenic fermentation. *J. Appl. Bacteriol*. **65(3):**231-239.
9. Staley, B.F., F.L. de los Reyes III, and M.A. Barlaz. 2011. Effect of spatial differences in microbial activity, pH, and substrate levels on methanogenesis initiation in refuse. *Appl. Environ. Microbiol*. **77(7):**2381-2391.
10. Kasali, G.B., and E. Senior. 1989. Effects of temperature and moisture on the anaerobic digestion of refuse. *J. Chem. Technol. Biotechnol*. **44:**31-41.
11. Christensen, T.H., and P. Kjeldsen. 1989. Basic biochemical processes in landfills, *Sanitary Landfilling: Process, Technology and Environmental Impact*, Academic Press.
12. Stearns, R.P., and G.S. Petoyan. 1984. Identifying and controlling landfill fires. *Waste Management & Res*. **2:**303-309.
13. Ohio EPA. 2011. Subsurface heating events at solid waste and construction and demolition debris landfills: Best management practices. *Guidance Document*.