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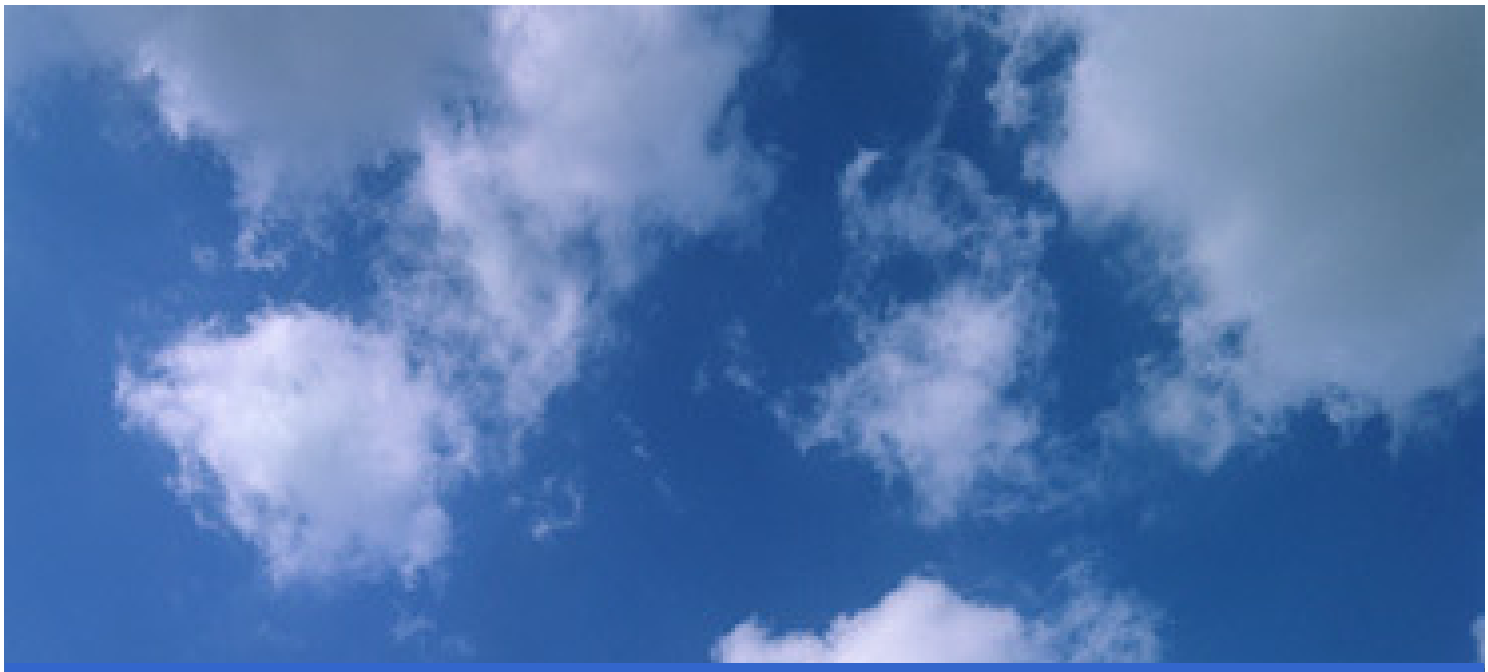


Landfill Gas Cleanup

For Engines

Ultra-Clean Biogas

Quadrogen has installed a working Integrated Biogas Cleanup System at Orange County Sanitation District in California where the ultra-clean biogas is fed to a fuel cell powerplant that also generates byproduct renewable hydrogen. Acceptable impurity levels in biogas for fuel cells are < 30 ppb.

Quadrogen's Landfill Gas Cleanup System for Engines **removes siloxanes to < 30 ppb*, drops the dew point to sub-zero Fahrenheit, and optionally removes H_2S to < 1 ppm.** It is a compact stand-alone system for applications such as Low-Btu Internal Combustion Engines that do not require Ultra-Clean biogas to reduce corrosion and maintain high availability.

* Depending upon composition

Flaring a Waste

Landfill gas must be captured and flared to avoid fugitive methane emissions, but it is a waste of good energy to utilize this renewable resource by cleaning it effectively first.

To keep engine availability above 90% the LFG must have all of its siloxanes removed and humidity minimized. With inadequate LFG cleanup, engine availability can drop below 70%.

When natural gas prices are low in a market with high electricity prices, making your own electricity from natural gas in an engine makes sense. But making electricity with landfill gas makes more sense. The reason is simple: landfill gas (LFG) is cheaper to purchase than natural gas because it is dirty and dilute. In fact, LFG is typically 20% to 50% of the cost of natural gas. This price difference provides a margin for LFG cleanup; where at minimum the siloxanes and water must be removed to reduce the corrosive conditions in the engine. The dilute nature of LFG is not a problem for specially designed low-btu engines so the extra costs of upgrading to bio-methane is not required.

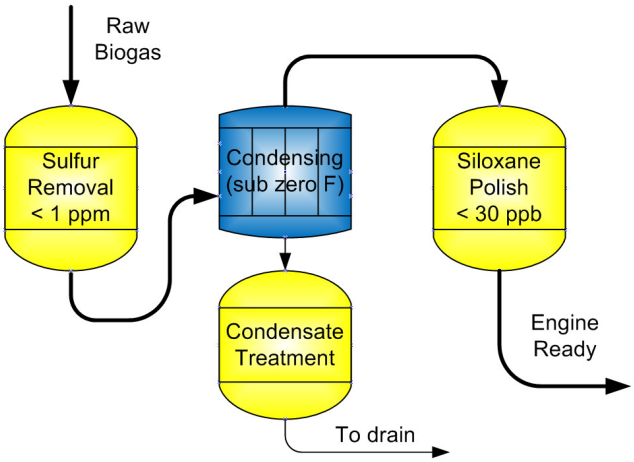
Special care and attention must be paid to the cleanup of LFG. With inadequate LFG cleanup the fuel savings are quickly eroded. Even though moderate levels of siloxanes are allowed according to low Btu engine specifications there will still be significant maintenance required to overhaul the engines regularly to remove the silicate buildup within. Not only is the maintenance costly itself, a larger impact on profitability comes from the loss of availability while these repairs are taking place. **It has been found that engine availability can drop below 70% with inadequate landfill gas cleanup.** The apparent savings from purchasing a cheaper cleanup skid are quickly eroded with the lost revenue.

To keep the engine availability high and the profits maximized the following is required from the LFG cleanup for an engine:

- **All siloxanes are removed** (< 30 ppb total, depending upon composition) so that there is no silicate buildup
- **Water is removed** (sub-zero Fahrenheit dew point) to reduce the corrosive environment in the engine
- The cleanup electrical usage is **less than 3% of generated electricity** at full power
- **Pressure drop is low** enough so that extra blowers may not be required
- There are **no fugitive emissions** of raw biogas from the cleanup skid
- Any condensate can be **disposed in a drain**
- Any adsorbent media can be **disposed in a landfill**

All of these things and more are done by Quadrogen's LFG Cleanup System for Engines.

Quadrogen's LFG Cleanup System for Engines works with a 4 step process: sulfur capture, condensing, siloxane polishing and condensate treatment. Quadrogen will supply a turn-key compact skid that combines all these functions to clean the fuel for any low-Btu engine.



LFG Cleanup System for Engines Flow Diagram

The following are 4 steps of the LFG Cleanup System for Engines:

- **Sulfur Removal (optional):** High sulfur levels in LFG can cause corrosive conditions within the engine. By removing sulfur to levels lower than 1 ppm the engine will not encounter as corrosive an environment and the oil will not need to be changed as frequently, increasing availability. Engine SO_x emissions are also reduced.
- **Condensing:** Siloxanes, water and some VOCs are removed by dropping the landfill gas to sub-zero Fahrenheit. By removing the majority of siloxanes in this way the size of the siloxane polishing media bed can be reduced. Since water is also removed corrosive conditions in the engine are reduced.
- **Siloxane Polishing:** Any remaining siloxanes are captured on a specially designed media bed while other impurities mostly pass through. Since the majority of siloxanes are already removed in the upstream condensing unit this bed is changed infrequently.
- **Condensate Treatment:** The condenser can concentrate condensable impurities in liquid form and in some cases this liquid is hazardous because of a low flash point. Therefore, the cleanup skid contains a subsystem to ensure no hazardous materials are put down the drain or back to the leachate system in the landfill.

Low Operating Costs

The media costs for the basic function of removing siloxanes and water are low because of the regenerative nature of the cold condensing subsystem, with less than 3% of the electricity generated going towards cooling. Siloxane media replacement costs are low since only polishing is done. If sulfur removal is chosen as an option then those media costs are dependent on H_2S levels.

Reducing Emissions Even More to Maximize Profits

LFG has a low price point because it is seen as a dirty and dilute fuel, but it is renewable and one of the main diluents is CO_2. There are markets for that CO_2 if it can be made to be ultra-clean. Another product offering by Quadrogen is the Integrated Biogas Cleanup System (IBCS) that can create Ultra-Clean biogas by removing *all* the contaminants in LFG. **Siloxane, halides, oxygen, heavy metals, VOCs, ammonia and sulfur are brought to levels less than 30 ppbv (parts per billion).** The CO_2 in the biogas is untouched.

Engines running on ultra-clean landfill gas will have emissions roughly equivalent to emissions while running on natural gas. With Ultra-Clean biogas it is even possible to utilize readily available engine exhaust cleanup solutions (e.g. for CO and NO_x) so that the CO_2 in the exhaust can be fed to a greenhouse to accelerate plant growth and greenhouse profits. Since there is so much CO_2 potential in landfill gas compared to NG (almost double) for such a cheap price compared to NG (less than half per Btu), the return on investment can be quite substantial. See our brochure on Ultra-Clean Biogas for more information, or contact us.

Quadrogen

Quadrogen Power Systems Inc.

#1154 – 4250 Wesbrook Mall
Vancouver, BC, Canada, V6T 1W5
604.221.7170

www.quadrogen.com