UW Climate Partnership
Montlake Landfill Methane Capture Study

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Introduction:

The University of Washington, as both an environmental steward in its community and as a hub of scientific and engineering solutions for complex environmental problems, naturally comes to mind as a pioneer of reducing greenhouse gas emissions (GHG) and its own 'carbon footprint'. Normally combustion of fossil fuels is considered the culprit, however a major contributor of atmospheric Carbon Dioxide (CO_2) and methane (CH_4) are municipal landfills. Generally landfills passively vent landfill gas (LFG) uncontrolled, composed of roughly 55% methane and 40% carbon dioxide by volume[1]. This is the case for the Montlake Landfill, formerly the Ravenna Landfill, which much of the eastern portion of the UW campus is built upon. The landfill is bound by 45th Ave NE to the north, the east border of Laurel Village to the East, Montlake Blvd to the west, and Canal Road & the Intramural Activities (IMA) building to the south.

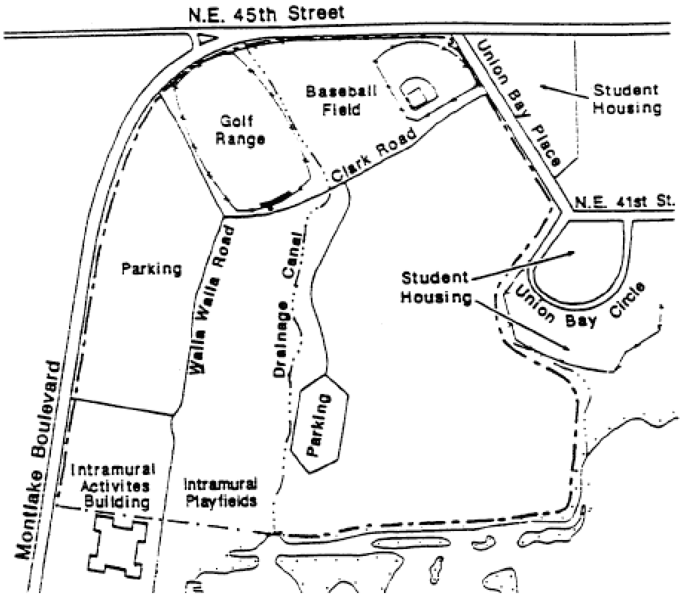

Figure 1: Map of Montlake Landfill Border (dashed line)[2]

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[1] EPA AP-42 5th Ed., Chapter 2, Section 2.4

[2] *Montlake Landfill Information Summary*, 1/99, Montlake Landfill Work Group

Historically, this portion of campus was underwater prior to 1911 when the Ship Canal was constructed and surface of Lake Washington was lowered. Between 1926 and 1971, the City of Seattle operated the landfill that accepted municipal solid waste (MSW) and debris. The landfill was a primary dump for the waste and debris from the 1961 construction of the I-5 freeway. Upon closure of the landfill in the early 1970's, the flaring system was dismantled and removed from the site. Revisiting the possibility of a new flaring system, the 1999 Montlake Landfill Workgroup determined that the LFG emissions had methane concentrations that were to low to support flaring or any other sort of combustion.

In late 2000, responding to community concern primarily of a safety nature after a 1999 earthquake, extensive methane release monitoring was performed overseen by the UW Environmental Health & Safety (EH&S) at 41 sites throughout the former landfill. Several monitoring wells indicated methane concentrations at or above the Lower Explosive Limit (LEL) of 5% methane in air by volume. A passive collection and ventilation system of perforated pipes were installed have been venting since.

The Montlake Landfill represents a significant source of UW's GHG emissions and a potential source of untapped energy. Methane emissions are of particular concern, as they represent both a safety hazard and as a GHG in the troposphere have a relative radiative efficiency of between 62 and 7 times that of carbon dioxide when spread over varying atmospheric residence times[3]. This study will determine the financial and technical barriers of installing an active collection system and either a flaring system to convert all methane emissions to carbon dioxide or an energy capture device (internal combustion engine, microturbine, etc.).

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[3] UN Intergovernmental Panel on Climate Change's (IPCC) *2001 Third Assessment Report*

Analysis

In determining the technical feasibility of a flaring or energy capture system, the LFG fuel stream must first be well characterized. Generally, the limiting factor of whether or not a landfill site can support a flaring system or energy capture device is the energy content of the fuel. The UW EH&S Dept. does perform regular monitoring of the methane concentrations for its 21 vents on the IMA parking lot and the remaining 20 vents along the site perimeter, however it does not keep record of the volumetric rate at which the LFG is emitted. The frequency of the monitoring varies greatly, generally in conjunction with whether or not the vent has increasing concentrations, ranging from daily to quarterly. As this study seeks to provide guidance for future development, the most recent data will be applied for each of the 41 vents. At the time of this report, the perimeter wells were last monitored during the 4th quarter of 2006 and the IMA parking lot vents were last monitored during January 2007 (see attached maps for locations of wells and concentrations reported). In the absence of LFG exit velocities, which determine the size of required collection systems (blowers, ducting, etc.), several conservative assumptions will have to be made.

The 'fuel' portion of the LFG will be approximated as just the methane, the trace organic species and other constituents will be treated as inert species along with the CO_2 and N_2. The combustion of methane, in either scenario, can be approximated as the following:

$$CH_4 + 2\square_{AF}(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_20 + 7.52N_2 + 2(\square_{AF}-1)O_2$$

where $\square_{AF}$ represents the equivalence ratio, or the ratio of air supplied to air required for complete combustion (molar, not mass basis). The $O_2 + 3.76N_2$ grouping represents air as 21% O_2 and 79% N_2. In general, absent of exhaust temperature requirements, combustion systems operate best with a $\square_{AF}$ greater than one (with excess air). For flaring, this won't be an issue, as flares operate as diffusion flames where fuel and oxidizer meet at the flame front.

However, energy capture devices such as engines, require tightly controlled $\square_{AF}$'s to control performance and emissions such as oxides of nitrogen, carbon monoxide, and particulate matter. Additionally, several of the species in the LFG treated as 'inerts' from an energy density standpoint cause internal corrosion and damage when burned in the engines or turbines, such as sulfur compounds, heavy metals, and excess moisture. These species will have to be removed from the LFG prior to running through either device but are not a problem for flaring. The following values for methane are to be used: lower heating value (LHV) of 21,520 Btu/lbm and a density at STP of 0.0447 lbm/ft^3.

Initially, we will consider the best case scenario, where all of the vents emit methane concentrations at the average between perimeter and parking lot maxima. The most recent monitoring shows a maximum concentration of 92.5% and 42.1% by volume for the perimeter and parking lot respectively, yielding an average of 67.3% methane by volume. Using the values stated above, this corresponds to an LFG energy density of 648 Btu/ft^3.

Flaring

The EPA requires that flares operating on a fuel with an energy content between 300 and 1,000 Btu/ft^3 have an exit velocity of no greater than 400 ft/s[4]. Additionally, flares may not operate with fuels less than 300 Btu/ft^3. Thus the fuel stream that reaches the flare can have a maximum air concentration of 53.7% by volume using the LFG energy density calculated above and the methane concentration will be 31.2% by volume after dilution. With air at a density of 1.2 kg/m^3, the resulting $\square_{AF}$ for the inlet stream will be 0.77, which is less than 1; however this does not prevent the feasibility of flaring due to open air burning.

To provide a cost estimate of flaring per ton CO_2 mitigated, an annual volume of LFG flared will need to be estimated. Assuming a 75% collection efficiency, per EPA

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[4] 40 CFR 60.18

guidance, and a flare geometry of 30 ft. tall, 6 in round diameter, and 200 ft/s exit velocity (1/2 the maximum allowed). This corresponds to a flare volumetric flow demand of 39.27 ft^3/s.

Additionally, the annual rate of LFG must be estimated. The closing weight waste in the landfill is unknown, thus instead of an estimate based upon depth of waste, the mass of waste at a landfill of a similar size and class will be used. The size of the landfill will be estimated as 1,800,000 tons of MSW upon closure. Using a rough run of the EPA's LANDGEM model, version 3.02, which estimates methane emissions from MSW landfills, a rough conservative number for fugitive methane emissions is calculated. All assumptions are default (mainly in regard to landfill gas composition and MSW decomposition rates) and the 1,800,000 tons of waste are sealed off in 1971. This year, the model estimates a methane release of 4,727,000 m^3 per year (167,879,405 ft^3/year). Using the collection efficiency and the resultant methane concentration of 31.2% (after maximum dilution), this becomes 39,283,780 ft^3/year of methane captured. Using the flare volumetric flow demand, we find the flare will operate for 278 hours of the year (at full blast). Assuming a 99% destruction efficiency of methane to carbon dioxide and the density stated above, this corresponds 868 tons CH_4 destroyed per year. Using a Global Warming Potential for methane of 21 times that of CO_2[5] this can be thought of as 18,240 tons CO_2 avoided/year. Extrapolating an estimate for Capital and O&M costs from EPA data for a 1,800,000 ton (1,636,363 metric tons) site, a collection and flare system will have a $581,000 Capital cost and an annual $70,800 O&M cost[6]. To annualize the Capital cost, we compute a Capital Recovery Factor (CRF):

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[5] *US Methane Emissions 1990-2020: Inventories, Projections, and Opportunities for Reductions*, EPA

[6] Ibid

$$CRF = \frac{I*(1+I)^n}{(1+I)^n - 1} \qquad \text{Where I = Interest = 10\%, and n = Equipment life = 10 years}$$

$$CRF = 0.1627$$

The combined annualized Capital and O&M costs total to $165,328.70/year. Adjusted from the report's 1996 dollars to 2007 dollars, by an annual 2.75% inflation rate, yields a total annual cost of $211,049.70. Using the equivalent 18,240 tons CO_2 avoided/year, this results in $12/ton CO_2. It is worth mentioning that this represents the absolute best case scenario. The methane emission rates will be lower than this estimate, thus reduced the equivalent tons CO_2 avoided, and significantly increase the $/ton CO_2.

Energy Capture

The potential for the LFG emissions to support operation of an internal combustion engine (ICE) or a microturbine for energy production is enticing, however these systems are quite sensitive to the energy density of the fuel and the resultant $\square_{AF}$ when compared to the less picky flaring system.

Consulting a leading manufacturer of industrial engines, namely those run on gaseous and alternative fuels, Waukesha, the ICE that would run off of the LFG emissions would be restricted to an input of no less than 400 Btu/ft^3 for its 'low calorific' systems[7]. Using a similar analysis as that of the flaring system, this corresponds to a maximum dilution of 38.3% by volume and an inlet methane concentration of 41.5% by volume. The same governing chemical reaction applies as flaring, yielding $\square_{AF} = 0.42$. Again this is lower than 1, which represents rich (fuel wasting) combustion.

Similarly, a leading manufacturer in microturbines that run on alternative gaseous fuels, Capstone[8], states that the device demands a fuel energy density inlet 350 Btu/ft^3.

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[7] *2006 Power Ratings,* www.waukeshaengine.com

[8] http://www.capstoneturbine.com/

Similar analysis yields a maximum dilution rate of 45.9% by volume, methane concentration by volume of 36.3%, and $\square_{\text{AF}} = 0.567$.

Unlike flaring where a $\square_{\text{AF}}$ of less than one was not a problem, this does represents a problem for the devices, as the combustion does not take place in open air and any additional dilution provided to increase the $\square_{\text{AF}}$ will lower the fuel inlet energy density to below the minimum acceptable level. This means that in order for the devices to run properly and under warranty, supplemental fuel will have to be provided (most likely natural gas). However, as more fuel is added, the $\square_{\text{AF}}$ will further decrease as there is less air that can fit in the unit per ft^3. This represents a sunk cost, as further fuel is required for sound operation that will either produce a more fuel rich environment in the ICE/microturbine or require a turbocharger (subsequently a parasitic load on the device). While it may be possible to run either unit and achieve nominal power production (both units in question provide 115 kWe and 65 kWe respectively), even under these extremely ideal situations the units cannot run safely without significant additional fuel costs. In addition to supplemental fuel, the LFG will require significant conditioning, removal of the moisture and other impurities. For reference and as calculated with flaring, the annual Capital and O&M cost combined for energy capture (either system) will be $672,515.90[9], over three times that of flaring. This cost does not include supplemental fuel requirements.

Results/Recommendations

For the next step for the UW to take will naturally to be to continue research on the subject, however it appears that energy capture will not prove to be cost effective and flaring may be cost effective, but previous reports have deemed it infeasible and there are numerous political/aesthetic barriers to flaring in proximity to the parking, sports complex, and

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[9] *US Methane Emissions 1990-2020: Inventories, Projections, and Opportunities for Reductions*, EPA

shopping/residential parcels. To reiterate, the flaring system in the best case scenario would cost \$12/ton CO_2 mitigated and either energy capture device would be at least three times that (energy production will not reach 99% methane destruction efficiency). The overall problem experienced is that the LFG emissions at this stage of the landfills 'life' have a low enough energy density that does not make either options very attractive from a cost or technical standpoint. The ICE or microturbine is certainly technically feasible, however it is not an attractive option, as the additional fuel demand will outweigh the energy produced and the costs are conservatively prohibitive.

The reader should not be discouraged, there are several aspects of these projects, which do exist throughout the country, that will aid their chances of feasibility. Local, state, and federal agencies and laws heavily favor these type of 'green energy' projects in the form of tax credits, ease in permitting/approval, and additionally foster local support. The cost of natural gas may rise drastically in the years to come due to a natural disaster, geopolitical event, or other reason, and then such alternative energy projects like this may look more attractive. Also there exists an era of change in the regard to potential carbon taxes and/or offset requirements by air pollution control authorities. This would provide additional financial incentive that this study did not quantify. Also universities are perfectly suited for pilot projects of unproven or cutting-edge technological solutions. Albeit costly, there are several technologies to capture and produce energy with LFG that in fact cannot support high volumetric flow rates or very high energy densities. Among others, the standouts are Organic Rankine cycles and modified Stirling engine systems.

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