Notice of Construction Application

A notice of construction permit is required before installing a new source of air pollution or modifying an existing source of air pollution. This application applies to facilities in Ecology's jurisdiction. Submit this application for review of your project. For general information about completing the application, refer to Ecology Forms ECY 070-410a-g, "Instructions for Ecology's Notice of Construction Application."

Ecology offers up to two hours of free pre-application assistance. We encourage you to schedule a pre-application meeting with the contact person specified for the location of your proposal, below. If you use up your two hours of free pre-application assistance, we will continue to assist you after you submit Part 1 of the application and the application fee. You may schedule a meeting with us at any point in the process.

Upon completion of the application, please enclose a check for the initial fee and mail to:

Department of Ecology
Cashiering Unit
PO Box 47611
Olympia, WA 98504-7611

For Fiscal Office Use Only: 0299-3030404-B00-216--001--000404

Check the box for the location of your proposal. For assistance, call the appropriate office listed below:

Check box	Ecology Permitting Office	Contact
☐	**Chelan, Douglas, Kittitas, Klickitat, or Okanogan County** Ecology Central Regional Office (509) 575-2490	Lynnette Haller (509) 457-7126 lynnette.haller@ecy.wa.gov
☑	**Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Stevens, Walla Walla, or Whitman County** Ecology Eastern Regional Office (509) 329-3400	~~Karin Baldwin~~ Gail Wright (509) ~~329-3452~~ 828-7933 gail.wright ~~karin.baldwin~~@ecy.wa.gov
☐	**San Juan County** Ecology Northwest Regional Office (206) 594-0000	David Adler (425) 649-7267 david.adler@ecy.wa.gov
☐	**For actions taken at Kraft and Sulfite Paper Mills and Aluminum Smelters Only** Ecology Industrial Section (360) 407-6900	James DeMay (360) 407-6868 james.demay@ecy.wa.gov
☐	**For actions taken on the US Department of Energy Hanford Reservation Only** Ecology Nuclear Waste Program (509) 372-7950	Lilyann Murphy (509) 372-7951 lilyann.murphy@ecy.wa.gov

Check the box below for the fee that applies to your application.

New project or equipment:

- ☐ **$1,904: Basic project** initial fee covers up to 16 hours of review.
- ☐ **$12,614: Complex project** initial fee covers up to 106 hours of review.

Change to an existing permit or equipment:

- ☐ **$357: Administrative or simple change** initial fee covers up to 3 hours of review. Ecology may determine your change is complex during the completeness review of your application. If you project is complex, you must pay the additional xxx before we will continue working on your application
- ☑ **$1,190: Complex** change initial fee covers up to 10 hours of review
- ☐ **$350flat fee**: Replace or alter control technology equipment under WAC 173-400-114. Ecology will contact you if we determine your change belongs in another fee category. You must pay the fee associated with that category before we will continue working on your application.

Read each statement below, then check the box next to it to acknowledge that you agree.

- ☑ The initial fee you submitted may not cover the cost of processing your application. Ecology will track the number of hours spent on your project. If the number of hours Ecology spends exceeds the hours included in your initial fee, Ecology will bill you $119 per hour for the extra time.
- ☑ You must include all information requested by this application. Ecology may not process your application if it does not include all the information requested.
- ☑ Submittal of this application allows Ecology staff to visit and inspect your facility.

Part 1: General Information

I. Project, Facility, and Company Information

1. Project Name: Gas Collection and Control System Modification
2. Facility Name: Stevens County Landfill
3. Facility Street Address:
   1257 Landfill Road, Kettle Falls, WA 99141
4. Facility Legal Description: NE 1/4 S36, T36N, R37E (Latitude N48degrees 34,768', Longitude W118degrees 5.234')
5. Company Legal Name (if different from Facility Name):
   N/A
6. Company Mailing Address (street, city, state, zip)

   1257 Landfill Road, Kettle Falls, WA 99141

II. Contact Information and Certification

1. Facility Contact Name (who will be onsite): Kevin Dionas, Solid Waste Director
2. Facility Contact Mailing Address (if different than Company Mailing Address:
   N/A

3. Facility Contact Phone Number: (509) 738-6106
4. Facility Contact E-mail: kdionas@stevenscountywa.gov
5. Billing Contact Name (who should receive billing information):
   Kevin Dionas, Solid Waste Director
6. Billing Contact Mailing Address (if different Company Mailing Address):

   N/A

7. Billing contact Phone Number: (509) 738-6106
8. Billing Contact E-mail: kdionas@stevenscountywa.gov
9. Consultant Name (optional – if 3rd party hired to complete application elements):
   Beth Fifield Hodgson
10. Consultant Organization/Company: Spring Environmental, Inc.
11. Consultant Mailing Address (street, city, state, zip):
12. Consultant Phone Number: (509) 328-7500
13. Consultant E-mail: beth@springenvironmental.com
14. Responsible Official Name and Title (who is responsible for project policy or decision making):
    Kevin Dionas
15. Responsible Official Phone: (509) 738-6106
16. Responsible Official E-mail: kdionas@stevenscountywa.gov
17. Responsible Official Certification and Signature:

    I certify that the information on this application is accurate and complete.

Signature: _____ Date: 9/10/25

Part 2: Technical Information

The Technical Information may be sent with this application form to the Cashiering Unit, or may be sent directly to the Ecology regional office with jurisdiction along with a copy of this application form.

For all sections, check the box next to each item as you complete it.

III. Project Description

- [x] Written narrative describing your proposed project.
- [x] Projected construction start and completion dates.
- [x] Operating schedule and production rates.
- [x] List of all major process equipment and manufacturer and maximum rated capacity.
- [x] Process flow diagram with all emission points identified.
- [x] Plan view site map.
- [x] Manufacturer specification sheets for major process equipment components
- [x] Manufacturer specification sheets for pollution control equipment.
- [x] Fuel specifications, including type, consumption (per hour and per year) and percent sulfur.

IV. State Environmental Policy Act (SEPA) Compliance

Check the appropriate box below.

- [x] SEPA review is complete. Include a copy of the final SEPA checklist and SEPA determination (e.g., DNS, MDNS, and EIS) with your application. See Approval Order 20AQ-E030
- [ ] SEPA review has not been conducted:
  - [ ] If review will be conducted by another agency, list the agency. You must provide a copy of the final SEPA checklist and SEPA determination before Ecology will issue your permit. Agency reviewing SEPA: _____
  - [ ] If the review will be conducted by Ecology, fill out a SEPA checklist and submit it with your application. You can find a SEPA checklist online at https://ecology.wa.gov/Regulations-Permits/SEPA/Environmental-review/SEPA-document-templates

V. Emissions Estimations of Criteria Pollutants See Attachment #3

Does your project generate criteria air pollutant emissions? [x] **Yes** [ ] **No**

If yes, please proved the following information regarding your criteria emissions in the application.

- [x] The names of the criteria air pollutants emitted (i.e., NO_X, SO_2, CO, $PM_{2.5}$, PM_{10}, TSP, VOC, and Pb)
- [x] Potential emissions of criteria air pollutants in tons per hour, tons per day, and tons per year (include calculations)
- [x] If there will be any fugitive criteria pollutant emissions, clearly identify the pollutant and quantity

VI. Emissions Estimations of Toxic Air Pollutants See Attachment #3

Does your project generate toxic air pollutant emissions? [x] **Yes** [ ] **No**

If yes, please provide the following information regarding your toxic air pollutant emissions in your application.

☑ The names of the toxic air pollutants emitted (specified in WAC 173-460-150[1])

☑ Potential emissions of toxic air pollutants in pounds per hour, pounds per day, and pounds per year (include calculations)

☑ If there will be any fugitive toxic air pollutant emissions, clearly identify the pollutant and quantity

VII. Emission Standard Compliance See Attachment #1

☑ Provide a list of all applicable new source performance standards, national emission standards for hazardous air pollutants, national emission standards for hazardous air pollutants for source categories, and emission standards adopted under Chapter 70A.15 RCW.

Does your project comply with all applicable standards identified? ☑ **Yes** ☐ **No**

VIII. Best Available Control Technology See Attachment #4 for BACT analysis from 2020 NOC Application

☑ Provide a complete evaluation of Best Available Control Technology (BACT) for your proposal.

IX. Ambient Air Impacts Analyses Not applicable

Please provide the following:

☐ Ambient air impacts analyses for Criteria Air Pollutants (including fugitive emissions)

☐ Ambient air impacts analyses for Toxic Air Pollutants (including fugitive emissions)

☐ Discharge point data for each point included in air impacts analyses (include only if modeling is required)

- ☐ Exhaust height
- ☐ Exhaust inside dimensions (ex. diameter or length and width)
- ☐ Exhaust gas velocity or volumetric flow rate
- ☐ Exhaust gas exit temperature
- ☐ The volumetric flow rate
- ☐ Description of the discharges (i.e., vertically or horizontally) and whether there are any obstructions (ex., raincap)
- ☐ Identification of the emission unit(s) discharging from the point
- ☐ The distance from the stack to the nearest property line
- ☐ Emission unit building height, width, and length
- ☐ Height of tallest building on-site or in the vicinity and the nearest distance of that building to the exhaust
- ☐ Whether the facility is in an urban or rural location

Does your project cause or contribute to a violation of any ambient air quality standard or acceptable source impact level? ☐ **Yes** ☑ **No**

To request ADA accommodation, call Ecology at (360) 407-6800, 711 (relay service), or (877) 833-6341 (TTY)

[1] http://apps.leg.wa.gov/WAC/default.aspx?cite=173-460-150

Attachment 1

Project Description

Stevens County Landfill
Gas Collection and Control System Modification – Project Description

Background:

Stevens County owns and operates the Stevens County Landfill (SCLF), a municipal solid waste (MSW) landfill, located west of Highway 25 and approximately 2 miles southwest of Kettle Falls. The facility is located at 1257 Landfill Road, Kettle Falls, Washington 99141.

The SCLF began accepting waste in the 1970s in the old landfill area. When RCRA's Subtitle D rules came into effect in the early 1990s, the old landfill area was closed (known as the "Closed Landfill Unit") and in 1993, the first modern lined landfill cell (Cell 1) was opened for waste disposal.

The Closed Landfill Unit was closed under the pre-Subtitle D regulations in accordance with WAC 173-304, *Minimum Functional Standards for Solid Waste Handling*, and is under post-closure care requirements of these standards. Landfill gas is passively vented from this unit and monitored on a quarterly basis by County staff in accordance with the Post-Closure Plan.

The SCLF currently consists of an administrative building, entrance facilities (scalehouse/scale, moderate risk waste building, recycling drop-off area), a public MSW drop-off area, a maintenance shop building, the Closed Landfill Unit, the active landfill (Cells 1 and 2, and future Cell 3), two leachate ponds, and other supporting infrastructure such as roads, buildings, and various equipment. Figure 1 provides a site map of SCLF.

SCLF submitted an NOC application in 2020 and is currently permitted under Approval Order No. 20AQ-E030 issued June 17, 2020. The approval order permits the landfill's gas collection and control system.

Project Description:

SCLF is applying for an NOC modification to address the modification of the landfill's gas collection and control system. SCLF was awarded a Landfill Methane Emissions Reduction (LMER) grant by the Washington State Department of Ecology to upgrade the existing landfill gas collection and control system (GCCS). SCLF intends to add a Parnel Biogas Inc. flare station to the facility to replace all existing flares at the facility and as a result, the collection system will be modified to account for the new flare station. Figure 2 provides the location of the flare station.

Project Timeline:

The proposed project installation is planned to begin in December 2025 and be fully implemented approximately six (6) weeks after initiation.

Operations Schedule:
The landfill gas system began operation starting when the first phase of the GCCS was installed in 2020 and will operate through the remaining life of the landfill. Landfill gas generation rates are projected to peak in 2049 (previously, the peak gas generation rate was identified as 2058). The actual closure date will depend on the amount of waste that is accepted and the in-place density of the waste. Following closure, the gas rates will then slowly decline, lasting through the post-closure care period until the landfill is functionally stable and the gas emission levels are safe.

Emissions from the proposed flare are expected to occur 24 hr/day, 365 day/yr.

Equipment List:

- Parnel Biogas Inc. 450 scfm blower, control skid, and enclosed flare with 98% destruction efficiency (See **Attachment #2)**

Fuel Specifications:

- The fuel for the flare is landfill gas
    - Typical concentrations are 50-60+% methane, 40-50% carbon dioxide, oxygen levels less than 3-5%, and balance gases of nitrogen and trace compounds such as hydrogen sulfide and volatile organic compounds

Emissions Calculations:
Emissions estimates were developed by Great West Engineering using LandGEM, a landfill gas emissions model provided by the EPA. The complete emissions inventory can be found in **Attachment #3.** The 2020 NOC application predicted peak landfill gas generation to occur in 2058, when the landfill was projected to reach its capacity. For this modification, the predicted year in which the landfill will reach capacity was updated to 2049, and the landfill gas generation rate peaked in 2049 under the updated model.

Due to the higher efficiency controls (reference **Attachments #4 and 5**), this project is estimated to decrease emissions compared to the 2020 NOC application, therefore no *de minimis* levels are estimated to be exceeded. However, this project is subject to permitting as the landfill's gas collection and control system is currently permitted.

Best Available Control Technology (BACT):
SCLF was awarded a Landfill Methane Emissions Reduction (LMER) grant by the Washington State Department of Ecology to upgrade the existing GCCS. The new flare station will replace the existing gas vent flares to meet the requirements of WAC 173-408. The flare station was previously identified on the t-BACT analysis in 2020 as a higher efficiency option (75% collection efficiency) than the gas vent flares (50% collection efficiency), but the gas vent flares were chosen due to economic reasons. As the proposed flare station was previously identified on

t-BACT and is a higher efficiency option than the current system thereby reducing emissions, a full t-BACT analysis has not been developed. See **Attachment #4** for the BACT analysis from the 2020 NOC application.

Air Dispersion Modeling:
Emission calculations for the landfill including both flare and fugitive emissions from the cells estimate that no criteria pollutants from this project exceed exemption levels and no TAPs exceed the Small Quantity Emission Rate (SQER). Therefore, no air dispersion modeling is required.

Regulatory Applicability:

- **Applicable**
  - WAC 173-400-110. No TAPs are estimated to exceed *de minimis* levels, but the gas control system is already permitted, so the proposed modification is subject to permitting.
  - WAC 173-408. As a municipal solid waste landfill, SCLF is subject to the regulations of WAC 173-408.
  - WAC 173-441. Potential greenhouse gas emissions are greater than 10,000 metric tons per year CO_2(e), so greenhouse gas reporting is applicable to this facility.
  - 40 CFR 63 Subpart A (General Provisions). Applies to all sources of HAPS.

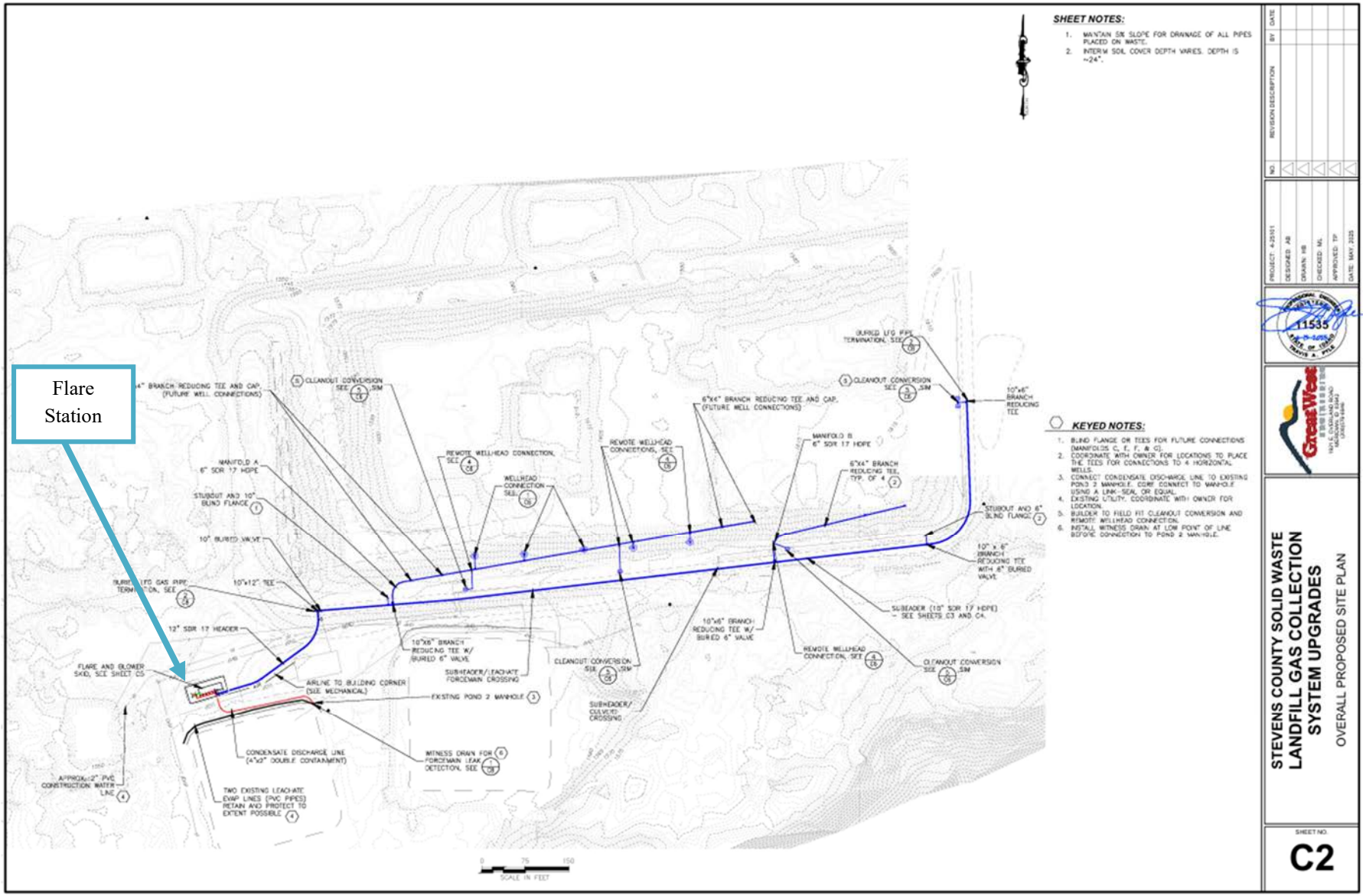
- **Not Applicable**
  - 40 CFR 60 Subpart Cc or Cf (Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills). For a municipal solid waste landfill to be regulated under the Federal Emission Guidelines (EGs), the design capacity above the volume and mass thresholds of 2.5 million cubic meters and 2.5 million megagram (Mg), respectively. SCLF is not subject to these subparts as the landfill design capacity, including closed and active landfill units, is 2.69 cubic meters and 2.18 million megagrams.
  - 40 CFR 60 Subpart WWW (Standards of Performance for Municipal Solid Waste Landfills That Commenced Construction, Reconstruction, or Modification on or After May 30, 1991, but Before July 18, 2014). For a municipal solid waste landfill to be regulated under the New Source Performance Standards (NSPS), the design capacity above the volume and mass thresholds of 2.5 million cubic meters and 2.5 million megagram (Mg), respectively. Although modified before July 2014, SCLF is not subject to this subpart as the landfill design capacity, including closed and active landfill units, is 2.69 cubic meters and 2.18 million megagrams.
  - 40 CFR 60 Subpart XXX (Standards of Performance for Municipal Solid Waste Landfills That Commenced Construction, Reconstruction, or Modification After

July 17, 2014). Modification means an increase in the permitted volume design capacity of the landfill be either lateral or vertical expansion based on its permitted design capacity as of July 17,2014. The proposed project does not include an increase in the landfill's design capacity, so the Subpart is not applicable.

- 40 CFR 63 Subpart AAAA (National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills). Since SCLF is not subject to NSPS or the EGs, it is not subject to the National Emission Standards for Hazardous Air Pollutants (NESHAP) for MSW landfills.

Figure 1. Site Map

Figure 2. Flare Station Location



Attachment 2

Manufacturer's Specifications

These records may be available upon request. To find out if there are more records for this project, contact Ecology's Public Records Office.

- Online: https://ecology.wa.gov/footer-pages/public-records-requests
- Public Records Officer email: PublicRecordsOfficer@ecy.wa.gov
- Call: 360-407-6040

Attachment 3

Emissions Inventory

Summary of Emissions

	2020 NOC	Proposed Project
Collection efficiency	50%	75%
Flare destruction rate	98%	98%
# of flares	11	1
Year of maximum emissions	2058	2049

	2020 NOC EI			Proposed Project			Change in Emissions (lb/yr)			De Minimis			SQER		
	Fugitive emissions (lb/yr)	Stack emissions (lb/yr)	Overall emissions (lb/yr)	Fugitive emissions (lb/yr)	Stack emissions (lb/yr)	Overall emissions (lb/yr)	Fugitive emissions (lb/yr)	Stack emissions (lb/yr)	Overall emissions (lb/yr)	De Minimis Value	De Minimis Period	De Minimis Exceeded?	SQER Value	SQER Period	SQER Exceeded?
Total landfill gas	6.64E+06	1.33E+05	6.77E+06	5.03E+06	3.02E+05	5.33E+06	-1.61E+06	1.69E+05	-1.44E+06						
Methane	2.34E+06	4.69E+04	2.39E+06	1.34E+06	8.06E+04	1.42E+06	-9.99E+05	3.38E+04	-9.65E+05						
Carbon dioxide	4.29E+06	8.57E+04	4.37E+06	3.69E+06	2.21E+05	3.91E+06	-5.98E+05	1.36E+05	-4.62E+05						
NMOC	1.95E+03	3.90E+01	1.99E+03	1.34E+03	8.06E+01	1.42E+03	-6.08E+02	4.16E+01	-5.66E+02						
1,1,1-Trichloroethane (methyl chloroform) - HAP	1.79E-01	3.57E-03	1.82E-01	1.23E-01	7.38E-03	1.30E-01	-5.57E-02	3.81E-03	-5.18E-02	19	24-hr	No	370	24-hr	No
1,1,2,2-Tetrachloroethane - HAP/VOC	1.76E-01	3.51E-03	1.79E-01	1.21E-01	7.26E-03	1.28E-01	-5.47E-02	3.74E-03	-5.10E-02	0.14	Year	No	2.8	Year	No
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	5.54E-01	1.11E-02	5.65E-01	3.81E-01	2.29E-02	4.04E-01	-1.73E-01	1.18E-02	-1.61E-01	5.1	Year	No	100	Year	No
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	1.77E-01	3.54E-03	1.81E-01	1.22E-01	7.31E-03	1.29E-01	-5.51E-02	3.77E-03	-5.14E-02	0.74	24-hr	No	15	24-hr	No
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	1.81E-01	3.61E-03	1.84E-01	1.24E-01	7.46E-03	1.32E-01	-5.63E-02	3.85E-03	-5.24E-02	0.31	Year	No	6.2	Year	No
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	1.79E-01	3.58E-03	1.82E-01	1.23E-01	7.39E-03	1.30E-01	-5.57E-02	3.81E-03	-5.19E-02	0.81	Year	No	16	Year	No
2-Propanol (isopropyl alcohol) - VOC	6.80E-01	1.36E-02	6.94E-01	4.68E-01	2.81E-02	4.97E-01	-2.12E-01	1.45E-02	-1.98E-01	0.3	1-hr	No	5.9	1-hr	No
Acetone	1.70E+00	3.39E-02	1.73E+00	1.17E+00	7.01E-02	1.24E+00	-5.29E-01	3.62E-02	-4.92E-01						
Acrylonitrile - HAP/VOC	1.74E-01	3.49E-03	1.78E-01	1.20E-01	7.20E-03	1.27E-01	-5.43E-02	3.72E-03	-5.06E-02	0.028	Year	No	0.56	Year	No
Benzene - No or Unknown Co-disposal - HAP/VOC	4.56E+00	9.13E-02	4.65E+00	3.14E+00	1.89E-01	3.33E+00	-1.42E+00	9.72E-02	-1.32E+00	1	Year	No	21	Year	No
Benzene - Co-disposal - HAP/VOC															
Bromodichloromethane - VOC	1.75E-01	3.51E-03	1.79E-01	1.21E-01	7.25E-03	1.28E-01	-5.47E-02	3.74E-03	-5.09E-02	0.22	Year	No	4.4	Year	No
Butane - VOC	7.07E+01	1.41E+00	7.22E+01	4.87E+01	2.92E+00	5.16E+01	-2.20E+01	1.51E+00	-2.05E+01						
Carbon disulfide - HAP/VOC	3.61E-01	7.23E-03	3.69E-01	2.49E-01	1.49E-02	2.64E-01	-1.13E-01	7.70E-03	-1.05E-01	3	24-hr	No	59	24-hr	No
Carbon monoxide	9.55E+02	1.91E+01	9.74E+02	6.57E+02	3.94E+01	6.97E+02	-2.97E+02	2.03E+01	-2.77E+02	1.1	1-hr	No	43	1-hr	No
Carbon tetrachloride - HAP/VOC	1.72E-01	3.45E-03	1.76E-01	1.19E-01	7.12E-03	1.26E-01	-5.37E-02	3.67E-03	-5.00E-02	1.4	Year	No	27	Year	No
Carbonyl sulfide - HAP/VOC	7.17E+00	1.43E-01	7.31E+00	4.93E+00	2.96E-01	5.23E+00	-2.23E+00	1.53E-01	-2.08E+00						
Chlorobenzene - HAP/VOC	1.04E+00	2.08E-02	1.06E+00	7.17E-01	4.30E-02	7.60E-01	-3.24E-01	2.22E-02	-3.02E-01	3.7	24-hr	No	74	24-hr	No
Chlorodifluoromethane	2.74E+01	5.47E-01	2.79E+01	1.88E+01	1.13E+00	2.00E+01	-8.53E+00	5.83E-01	-7.94E+00	190	24-hr	No	3700	24-hr	No
Chloroethane (ethyl chloride) - HAP/VOC	7.85E-01	1.57E-02	8.01E-01	5.41E-01	3.24E-02	5.73E-01	-2.45E-01	1.67E-02	-2.28E-01	110	24-hr	No	2200	24-hr	No
Chloroform - HAP/VOC	1.74E-01	3.49E-03	1.78E-01	1.20E-01	7.20E-03	1.27E-01	-5.43E-02	3.72E-03	-5.06E-02	0.35	Year	No	7.1	Year	No
Chloromethane - VOC	1.72E-01	3.44E-03	1.76E-01	1.18E-01	7.11E-03	1.26E-01	-5.36E-02	3.67E-03	-4.99E-02	0.33	24-hr	No	6.7	24-hr	No
Dichlorobenzene - (HAP for para isomer/VOC)	1.07E+00	2.15E-02	1.10E+00	7.39E-01	4.43E-02	7.83E-01	-3.34E-01	2.29E-02	-3.12E-01	0.74	Year	No	15	Year	No
Dichlorodifluoromethane	8.83E+00	1.77E-01	9.01E+00	6.08E+00	3.65E-01	6.44E+00	-2.75E+00	1.88E-01	-2.56E+00						
Dichlorofluoromethane - VOC	6.51E+01	1.30E+00	6.64E+01	4.48E+01	2.69E+00	4.75E+01	-2.03E+01	1.39E+00	-1.89E+01						
Dichloromethane (methylene chloride) - HAP	1.76E-01	3.52E-03	1.79E-01	1.21E-01	7.26E-03	1.28E-01	-5.48E-02	3.74E-03	-5.10E-02	490	Year	No	9800	Year	No
Dimethyl sulfide (methyl sulfide) - VOC	1.18E+02	2.36E+00	1.20E+02	8.12E+01	4.87E+00	8.61E+01	-3.68E+01	2.51E+00	-3.42E+01						
Ethane	6.52E+03	1.30E+02	6.65E+03	4.49E+03	2.69E+02	4.75E+03	-2.03E+03	1.39E+02	-1.89E+03						
Ethanol - VOC	1.68E+00	3.37E-02	1.72E+00	1.16E+00	6.95E-02	1.23E+00	-5.24E-01	3.59E-02	-4.88E-01						
Ethyl mercaptan (ethanethiol) - VOC	3.48E+01	6.96E-01	3.55E+01	2.39E+01	1.44E+00	2.54E+01	-1.08E+01	7.41E-01	-1.01E+01						
Ethylbenzene - HAP/VOC	2.27E+01	4.55E-01	2.32E+01	1.57E+01	9.39E-01	1.66E+01	-7.09E+00	4.85E-01	-6.60E+00	3.2	Year	No	65	Year	No
Ethylene dibromide - HAP/VOC	4.57E-02	9.15E-04	4.67E-02	3.15E-02	1.89E-03	3.34E-02	-1.42E-02	9.75E-04	-1.33E-02	0.014	Year	No	0.27	Year	No
Fluorotrichloromethane - VOC	2.54E+01	5.08E-01	2.59E+01	1.75E+01	1.05E+00	1.85E+01	-7.92E+00	5.42E-01	-7.38E+00						
Hexane - HAP/VOC	1.57E+01	3.15E-01	1.60E+01	1.08E+01	6.50E-01	1.15E+01	-4.90E+00	3.35E-01	-4.57E+00	2.6	24-hr	No	52	24-hr	No
Hydrogen sulfide	1.44E+02	2.89E+00	1.47E+02	9.94E+01	5.96E+00	1.05E+02	-4.50E+01	3.08E+00	-4.19E+01	0.0074	24-hr	No	0.15	24-hr	No
Mercury (total) - HAP	1.42E-02	2.83E-04	1.44E-02	9.75E-03	5.85E-04	1.03E-02	-4.41E-03	3.02E-04	-4.11E-03	0.00011	24-hr	No	0.0022	24-hr	No
Methyl ethyl ketone - HAP/VOC	3.60E-01	7.20E-03	3.67E-01	2.48E-01	1.49E-02	2.63E-01	-1.12E-01	7.67E-03	-1.04E-01	19	24-hr	No	370	24-hr	No
Methyl isobutyl ketone - HAP/VOC	4.63E+01	9.27E-01	4.73E+01	3.19E+01	1.91E+00	3.38E+01	-1.44E+01	9.87E-01	-1.34E+01	11	24-hr	No	220	24-hr	No
Methyl mercaptan - VOC	2.93E+01	5.86E-01	2.99E+01	2.02E+01	1.21E+00	2.14E+01	-9.12E+00	6.24E-01	-8.50E+00						
Pentane - VOC	5.80E+01	1.16E+00	5.91E+01	3.99E+01	2.39E+00	4.23E+01	-1.81E+01	1.23E+00	-1.68E+01						
Perchloroethylene (tetrachloroethylene) - HAP	1.70E-01	3.39E-03	1.73E-01	1.17E-01	7.00E-03	1.24E-01	-5.28E-02	3.61E-03	-4.92E-02	1.3	Year	No	27	Year	No
Propane - VOC	1.18E+02	2.36E+00	1.20E+02	8.13E+01	4.88E+00	8.62E+01	-3.68E+01	2.52E+00	-3.43E+01						
t-1,2-Dichloroethene - VOC	1.77E-01	3.54E-03	1.81E-01	1.22E-01	7.31E-03	1.29E-01	-5.51E-02	3.77E-03	-5.14E-02	3	24-hr	No	60	24-hr	No
Toluene - No or Unknown Co-disposal - HAP/VOC	1.79E+00	3.59E-02	1.83E+00	1.24E+00	7.41E-02	1.31E+00	-5.59E-01	3.82E-02	-5.21E-01	19	24-hr	No	370	24-hr	No
Toluene - Co-disposal - HAP/VOC															
Trichloroethylene (trichloroethene) - HAP/VOC	1.76E-01	3.52E-03	1.79E-01	1.21E-01	7.27E-03	1.28E-01	-5.48E-02	3.75E-03	-5.11E-02	1.7	Year	No	34	Year	No
Vinyl chloride - HAP/VOC	4.41E+00	8.82E-02	4.50E+00	3.04E+00	1.82E-01	3.22E+00	-1.37E+00	9.40E-02	-1.28E+00	0.92	Year	No	18	Year	No
Xylenes - HAP/VOC	2.17E+01	4.34E-01	2.21E+01	1.49E+01	8.97E-01	1.58E+01	-6.76E+00	4.63E-01	-6.30E+00	0.82	24-hr	No	16	24-hr	No

Greenhouse Gases	2020 NOC EI				Proposed Project					
	lb/yr	metric ton/yr	GWP[1]	CO2e (metric tpy)	lb/yr	metric ton/yr	GWP[2]	CO2e (metric tpy)	Exceeds WA GHG Threshold?	Exceeds Federal GHG Threshold
Carbon Dioxide	4.37E+06	1.98E+03	1	1,982	3.91E+06	1.77E+03	1	1,773		
Methane	2.39E+06	1.08E+03	298	322,966	1.42E+06	6.46E+02	265	171,229		
			Total	324,949			Total	173,002	Yes	Yes

1. GWP values in 2020 per Table A-1 of 40 CFR 90 Subpart A
2. GWP values per Table A-1 of 40 CFR 90 Subpart A. Note that Washington State has not adopted EPA's revised GWPs, so the potential GHG emissions are higher than presented here.

Stevens County Landfill - 2025 NOC Modification Application (2049 Emissions)

75%	Collection Efficiency
98%	Destruction Efficiency

	Uncontrolled - Total							Fugitive Emissions[1]	Flare - Controlled[2]	
Gas / Pollutant	Emission Rate							Emission Rate	Emission Rate	
	(Mg/year)	(m3/year)	(av ft3/min)	(ft3/year)	(short tons/year)	(lb/year)	(g/s)	(lb/year)	(lb/year)	(g/s)
Total landfill gas	9.15E+03	7.33E+06	4.92E+02	2.59E+08	1.01E+04	2.01E+07	2.90E+02	5.03E+06	3.02E+05	4.34E+00
Methane	2.44E+03	3.66E+06	2.46E+02	1.29E+08	2.69E+03	5.38E+06	7.73E+01	1.34E+06	8.06E+04	1.16E+00
Carbon dioxide	6.71E+03	3.66E+06	2.46E+02	1.29E+08	7.38E+03	1.48E+07	2.12E+02	3.69E+06	2.21E+05	3.18E+00
NMOC	2.44E+00	6.81E+02	4.58E-02	2.41E+04	2.69E+00	5.37E+03	7.73E-02	1.34E+03	8.06E+01	1.16E-03
1,1,1-Trichloroethane (methyl chloroform) - HAP	2.24E-04	4.03E-02	2.71E-06	1.42E+00	2.46E-04	4.92E-01	7.08E-06	1.23E-01	7.38E-03	1.06E-07
1,1,2,2-Tetrachloroethane - HAP/VOC	2.20E-04	3.15E-02	2.12E-06	1.11E+00	2.42E-04	4.84E-01	6.96E-06	1.21E-01	7.26E-03	1.04E-07
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	6.94E-04	1.69E-01	1.13E-05	5.95E+00	7.63E-04	1.53E+00	2.19E-05	3.81E-01	2.29E-02	3.29E-07
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	2.22E-04	5.49E-02	3.69E-06	1.94E+00	2.44E-04	4.87E-01	7.01E-06	1.22E-01	7.31E-03	1.05E-07
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	2.26E-04	5.49E-02	3.69E-06	1.94E+00	2.49E-04	4.98E-01	7.16E-06	1.24E-01	7.46E-03	1.07E-07
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	2.24E-04	4.76E-02	3.20E-06	1.68E+00	2.46E-04	4.92E-01	7.08E-06	1.23E-01	7.39E-03	1.06E-07
2-Propanol (isopropyl alcohol) - VOC	8.52E-04	3.41E-01	2.29E-05	1.20E+01	9.37E-04	1.87E+00	2.70E-05	4.68E-01	2.81E-02	4.04E-07
Acetone	2.12E-03	8.79E-01	5.91E-05	3.10E+01	2.34E-03	4.67E+00	6.72E-05	1.17E+00	7.01E-02	1.01E-06
Acrylonitrile - HAP/VOC	2.18E-04	9.89E-02	6.65E-06	3.49E+00	2.40E-04	4.80E-01	6.91E-06	1.20E-01	7.20E-03	1.04E-07
Benzene - No or Unknown Co-disposal - HAP/VOC	5.71E-03	1.76E+00	1.18E-04	6.21E+01	6.28E-03	1.26E+01	1.81E-04	3.14E+00	1.89E-01	2.71E-06
Benzene - Co-disposal - HAP/VOC	2.62E-01	8.06E+01	5.41E-03	2.85E+03	2.88E-01					
Bromodichloromethane - VOC	2.20E-04	3.22E-02	2.17E-06	1.14E+00	2.42E-04	4.83E-01	6.95E-06	1.21E-01	7.25E-03	1.04E-07
Butane - VOC	8.86E-02	3.66E+01	2.46E-03	1.29E+03	9.74E-02	1.95E+02	2.80E-03	4.87E+01	2.92E+00	4.20E-05
Carbon disulfide - HAP/VOC	4.52E-04	1.43E-01	9.60E-06	5.05E+00	4.98E-04	9.95E-01	1.43E-05	2.49E-01	1.49E-02	2.15E-07
Carbon monoxide	1.19E+00	1.03E+03	6.89E-02	3.62E+04	1.31E+00	2.63E+03	3.78E-02	6.57E+02	3.94E+01	5.67E-04
Carbon tetrachloride - HAP/VOC	2.16E-04	3.37E-02	2.26E-06	1.19E+00	2.37E-04	4.74E-01	6.82E-06	1.19E-01	7.12E-03	1.02E-07
Carbonyl sulfide - HAP/VOC	8.97E-03	3.59E+00	2.41E-04	1.27E+02	9.87E-03	1.97E+01	2.84E-04	4.93E+00	2.96E-01	4.26E-06
Chlorobenzene - HAP/VOC	1.30E-03	2.78E-01	1.87E-05	9.83E+00	1.43E-03	2.87E+00	4.12E-05	7.17E-01	4.30E-02	6.19E-07
Chlorodifluoromethane	3.43E-02	9.52E+00	6.40E-04	3.36E+02	3.77E-02	7.54E+01	1.08E-03	1.88E+01	1.13E+00	1.63E-05
Chloroethane (ethyl chloride) - HAP/VOC	9.83E-04	3.66E-01	2.46E-05	1.29E+01	1.08E-03	2.16E+00	3.11E-05	5.41E-01	3.24E-02	4.67E-07
Chloroform - HAP/VOC	2.18E-04	4.40E-02	2.95E-06	1.55E+00	2.40E-04	4.80E-01	6.91E-06	1.20E-01	7.20E-03	1.04E-07
Chloromethane - VOC	2.15E-04	1.03E-01	6.89E-06	3.62E+00	2.37E-04	4.74E-01	6.82E-06	1.18E-01	7.11E-03	1.02E-07
Dichlorobenzene - (HAP for para isomer/VOC)	1.34E-03	2.20E-01	1.48E-05	7.76E+00	1.48E-03	2.96E+00	4.25E-05	7.39E-01	4.43E-02	6.38E-07
Dichlorodifluoromethane	1.11E-02	2.20E+00	1.48E-04	7.76E+01	1.22E-02	2.43E+01	3.50E-04	6.08E+00	3.65E-01	5.25E-06
Dichlorofluoromethane - VOC	8.15E-02	1.90E+01	1.28E-03	6.73E+02	8.97E-02	1.79E+02	2.58E-03	4.48E+01	2.69E+00	3.87E-05
Dichloromethane (methylene chloride) - HAP	2.20E-04	6.23E-02	4.18E-06	2.20E+00	2.42E-04	4.84E-01	6.96E-06	1.21E-01	7.26E-03	1.04E-07
Dimethyl sulfide (methyl sulfide) - VOC	1.48E-01	5.71E+01	3.84E-03	2.02E+03	1.62E-01	3.25E+02	4.67E-03	8.12E+01	4.87E+00	7.01E-05
Ethane	8.15E+00	6.52E+03	4.38E-01	2.30E+05	8.97E+00	1.79E+04	2.58E-01	4.49E+03	2.69E+02	3.87E-03
Ethanol - VOC	2.11E-03	1.10E+00	7.38E-05	3.88E+01	2.32E-03	4.63E+00	6.66E-05	1.16E+00	6.95E-02	1.00E-06
Ethyl mercaptan (ethanethiol) - VOC	4.35E-02	1.69E+01	1.13E-03	5.95E+02	4.79E-02	9.58E+01	1.38E-03	2.39E+01	1.44E+00	2.07E-05
Ethylbenzene - HAP/VOC	2.85E-02	6.45E+00	4.33E-04	2.28E+02	3.13E-02	6.26E+01	9.01E-04	1.57E+01	9.39E-01	1.35E-05
Ethylene dibromide - HAP/VOC	5.73E-05	7.33E-03	4.92E-07	2.59E-01	6.30E-05	1.26E-01	1.81E-06	3.15E-02	1.89E-03	2.72E-08
Fluorotrichloromethane - VOC	3.18E-02	5.57E+00	3.74E-04	1.97E+02	3.50E-02	7.00E+01	1.01E-03	1.75E+01	1.05E+00	1.51E-05
Hexane - HAP/VOC	1.97E-02	5.49E+00	3.69E-04	1.94E+02	2.17E-02	4.33E+01	6.23E-04	1.08E+01	6.50E-01	9.35E-06
Hydrogen sulfide	1.81E-01	1.27E+02	8.57E-03	4.50E+03	1.99E-01	3.98E+02	5.72E-03	9.94E+01	5.96E+00	8.58E-05
Mercury (total) - HAP	1.77E-05	2.12E-03	1.43E-07	7.50E-02	1.95E-05	3.90E-02	5.61E-07	9.75E-03	5.85E-04	8.41E-09
Methyl ethyl ketone - HAP/VOC	4.50E-04	1.50E-01	1.01E-05	5.30E+00	4.95E-04	9.91E-01	1.43E-05	2.48E-01	1.49E-02	2.14E-07
Methyl isobutyl ketone - HAP/VOC	5.80E-02	1.39E+01	9.35E-04	4.92E+02	6.38E-02	1.28E+02	1.83E-03	3.19E+01	1.91E+00	2.75E-05
Methyl mercaptan - VOC	3.66E-02	1.83E+01	1.23E-03	6.47E+02	4.03E-02	8.06E+01	1.16E-03	2.02E+01	1.21E+00	1.74E-05
Pentane - VOC	7.26E-02	2.42E+01	1.62E-03	8.54E+02	7.98E-02	1.60E+02	2.30E-03	3.99E+01	2.39E+00	3.44E-05
Perchloroethylene (tetrachloroethylene) - HAP	2.12E-04	3.08E-02	2.07E-06	1.09E+00	2.33E-04	4.67E-01	6.72E-06	1.17E-01	7.00E-03	1.01E-07
Propane - VOC	1.48E-01	8.06E+01	5.41E-03	2.85E+03	1.63E-01	3.25E+02	4.68E-03	8.13E+01	4.88E+00	7.01E-05
t-1,2-Dichloroethene - VOC	2.22E-04	5.49E-02	3.69E-06	1.94E+00	2.44E-04	4.87E-01	7.01E-06	1.22E-01	7.31E-03	1.05E-07
Toluene - No or Unknown Co-disposal - HAP/VOC	2.25E-03	5.86E-01	3.94E-05	2.07E+01	2.47E-03	4.94E+00	7.11E-05	1.24E+00	7.41E-02	1.07E-06
Toluene - Co-disposal - HAP/VOC	4.77E+00	1.25E+03	8.37E-02	4.40E+04	5.25E+00					
Trichloroethylene (trichloroethene) - HAP/VOC	2.20E-04	4.03E-02	2.71E-06	1.42E+00	2.42E-04	4.84E-01	6.97E-06	1.21E-01	7.27E-03	1.05E-07
Vinyl chloride - HAP/VOC	5.52E-03	2.12E+00	1.43E-04	7.50E+01	6.08E-03	1.22E+01	1.75E-04	3.04E+00	1.82E-01	2.62E-06
Xylenes - HAP/VOC	2.72E-02	6.15E+00	4.13E-04	2.17E+02	2.99E-02	5.98E+01	8.60E-04	1.49E+01	8.97E-01	1.29E-05

1. Assumed 25% of emissions are fugitive
2. Assumed 75% of total emissions go to flare. 98% destruction efficiency per Parnel Biogas flare proposal

Stevens County Landfill - 2020 NOC Application (2058 Emissions)

50%	Collection Efficiency
98%	Destruction Efficiency

	Uncontrolled Emissions - Total						Fugitive Gases	Stack Emissions	Total Emissions
Gas/Pollutant	Emission Rate						Emission Rate	Emission Rate	Emission Rate
	(Mg/year)	(m3/year)	(av ft3/min)	(ft3/year)	(short tons/year)	(lb/year)	(lb/year)	(lb/year)	(lb/year)
Total landfill gas	7.000E+03	5.321E+06	3.575E+02	1.879E+08	7.700E+03	15399585			
Methane	2.130E+03	3.193E+06	2.145E+02	1.127E+08	2.343E+03	4685751	2342875	46858	2389733
Carbon dioxide	3.896E+03	2.128E+06	1.430E+02	7.516E+07	4.286E+03	8571068	4285534	85711	4371245
NMOC	1.774E+00	4.948E+02	3.325E-02	1.748E+04	1.951E+00	3902.231	1951	39.02	1990.138
1,1,1-Trichloroethane (methyl chloroform) - HAP	1.624E-04	2.926E-02	1.966E-06	1.033E+00	1.786E-04	0.357	0.179	0.004	0.182
1,1,2,2-Tetrachloroethane - HAP/VOC	1.597E-04	2.288E-02	1.537E-06	8.080E-01	1.757E-04	0.351	0.176	0.004	0.179
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	5.038E-04	1.224E-01	8.223E-06	4.322E+00	5.541E-04	1.108	0.554	0.011	0.565
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	1.609E-04	3.991E-02	2.681E-06	1.409E+00	1.770E-04	0.354	0.177	0.004	0.181
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	1.643E-04	3.991E-02	2.681E-06	1.409E+00	1.807E-04	0.361	0.181	0.004	0.184
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	1.625E-04	3.459E-02	2.324E-06	1.221E+00	1.788E-04	0.358	0.179	0.004	0.182
2-Propanol (isopropyl alcohol) - VOC	6.186E-04	2.474E-01	1.662E-05	8.738E+00	6.804E-04	1.361	0.680	0.014	0.694
Acetone	1.542E-03	6.385E-01	4.290E-05	2.255E+01	1.697E-03	3.393	1.697	0.034	1.731
Acrylonitrile - HAP/VOC	1.585E-04	7.183E-02	4.826E-06	2.537E+00	1.744E-04	0.349	0.174	0.003	0.178
Benzene - No or Unknown Co-disposal - HAP/VOC	4.149E-03	1.277E+00	8.580E-05	4.510E+01	4.564E-03	9.127	4.564	0.091	4.655
Benzene - Co-disposal - HAP/VOC									
Bromodichloromethane - VOC	1.595E-04	2.341E-02	1.573E-06	8.268E-01	1.755E-04	0.351	0.175	0.004	0.179
Butane - VOC	6.431E-02	2.660E+01	1.788E-03	9.395E+02	7.074E-02	141.488	70.7	1.415	72.159
Carbon disulfide - HAP/VOC	3.285E-04	1.038E-01	6.971E-06	3.664E+00	3.614E-04	0.723	0.361	0.007	0.369
Carbon monoxide	8.678E-01	7.449E+02	5.005E-02	2.631E+04	9.546E-01	1909.3	955	19.093	973.722
Carbon tetrachloride - HAP/VOC	1.566E-04	2.448E-02	1.645E-06	8.644E-01	1.723E-04	0.345	0.172	0.003	0.176
Carbonyl sulfide - HAP/VOC	6.514E-03	2.607E+00	1.752E-04	9.207E+01	7.166E-03	14.331	7.166	0.143	7.309
Chlorobenzene - HAP/VOC	9.466E-04	2.022E-01	1.359E-05	7.140E+00	1.041E-03	2.083	1.041	0.021	1.062
Chlorodifluoromethane	2.488E-02	6.917E+00	4.648E-04	2.443E+02	2.737E-02	54.731	27.365	0.547	27.913
Chloroethane (ethyl chloride) - HAP/VOC	7.139E-04	2.660E-01	1.788E-05	9.395E+00	7.853E-04	1.571	0.785	0.016	0.801
Chloroform - HAP/VOC	1.585E-04	3.193E-02	2.145E-06	1.127E+00	1.744E-04	0.349	0.174	0.003	0.178
Chloromethane - VOC	1.564E-04	7.449E-02	5.005E-06	2.631E+00	1.721E-04	0.344	0.172	0.003	0.176
Dichlorobenzene - (HAP for para isomer/VOC)	9.760E-04	1.596E-01	1.073E-05	5.637E+00	1.074E-03	2.147	1.074	0.021	1.095
Dichlorodifluoromethane	8.028E-03	1.596E+00	1.073E-04	5.637E+01	8.830E-03	17.661	8.830	0.177	9.007
Dichlorofluoromethane - VOC	5.922E-02	1.383E+01	9.295E-04	4.886E+02	6.514E-02	130.286	65.143	1.303	66.446
Dichloromethane (methylene chloride) - HAP	1.598E-04	4.523E-02	3.039E-06	1.597E+00	1.758E-04	0.352	0.176	0.004	0.179
Dimethyl sulfide (methyl sulfide) - VOC	1.072E-01	4.150E+01	2.789E-03	1.466E+03	1.180E-01	235.950	117.975	2.359	120.334
Ethane	5.923E+00	4.736E+03	3.182E-01	1.672E+05	6.515E+00	13030.1	6515	130.301	6645.340
Ethanol - VOC	1.530E-03	7.981E-01	5.363E-05	2.819E+01	1.683E-03	3.365	1.683	0.034	1.716
Ethyl mercaptan (ethanethiol) - VOC	3.162E-02	1.224E+01	8.223E-04	4.322E+02	3.479E-02	69.575	34.787	0.696	35.483
Ethylbenzene - HAP/VOC	2.067E-02	4.682E+00	3.146E-04	1.654E+02	2.274E-02	45.485	22.742	0.455	23.197
Ethylene dibromide - HAP/VOC	4.158E-05	5.321E-03	3.575E-07	1.879E-01	4.574E-05	0.091	0.046	0.001	0.047
Fluorotrichloromethane - VOC	2.311E-02	4.044E+00	2.717E-04	1.428E+02	2.542E-02	50.835	25.417	0.508	25.926
Hexane - HAP/VOC	1.430E-02	3.991E+00	2.681E-04	1.409E+02	1.573E-02	31.470	15.735	0.315	16.049
Hydrogen sulfide	1.312E-01	9.258E+01	6.221E-03	3.270E+03	1.444E-01	288.717	144	2.887	147.246
Mercury (total) - HAP	1.288E-05	1.543E-03	1.037E-07	5.449E-02	1.416E-05	0.028	0.01	0.0003	0.014
Methyl ethyl ketone - HAP/VOC	3.272E-04	1.091E-01	7.329E-06	3.852E+00	3.599E-04	0.720	0.36	0.007	0.367
Methyl isobutyl ketone - HAP/VOC	4.212E-02	1.011E+01	6.793E-04	3.570E+02	4.633E-02	92.656	46.33	0.927	47.254
Methyl mercaptan - VOC	2.662E-02	1.330E+01	8.938E-04	4.698E+02	2.928E-02	58.560	29.28	0.586	29.865
Pentane - VOC	5.269E-02	1.756E+01	1.180E-03	6.201E+02	5.796E-02	115.924	57.96	1.159	59.121
Perchloroethylene (tetrachloroethylene) - HAP	1.541E-04	2.235E-02	1.502E-06	7.892E-01	1.696E-04	0.339	0.17	0.003	0.173
Propane - VOC	1.073E-01	5.853E+01	3.933E-03	2.067E+03	1.181E-01	236.133	118.07	2.361	120.428
t-1,2-Dichloroethene - VOC	1.609E-04	3.991E-02	2.681E-06	1.409E+00	1.770E-04	0.354	0.18	0.004	0.181
Toluene - No or Unknown Co-disposal - HAP/VOC	1.631E-03	4.257E-01	2.860E-05	1.503E+01	1.794E-03	3.589	1.79	0.036	1.830
Toluene - Co-disposal - HAP/VOC									
Trichloroethylene (trichloroethene) - HAP/VOC	1.599E-04	2.926E-02	1.966E-06	1.033E+00	1.759E-04	0.352	0.18	0.004	0.179
Vinyl chloride - HAP/VOC	4.011E-03	1.543E+00	1.037E-04	5.449E+01	4.412E-03	8.825	4.41	0.088	4.501
Xylenes - HAP/VOC	1.974E-02	4.470E+00	3.003E-04	1.578E+02	2.171E-02	43.417	21.71	0.434	22.143

Attachment 4

2020 NOC Application BACT Analysis

Stevens County Landfill
Air Permitting – BACT/tBACT Review

PREPARED FOR:	Washington State Department of Ecology
PREPARED BY:	Travis Pyle, PE/Great West
REVIEWED BY:	Craig Sauer, PG/Great West Kevin Dionas/Stevens County Roger Kaiser/Stevens County
DATE:	March 19, 2020
PROJECT NUMBER:	4-18167
REVISION NO.:	0
APPROVED BY:	Travis Pyle, PE/Great West

1.0 Introduction

This technical memorandum presents a Best Available Control Technology (BACT) [and Best Available Control Technology for Toxic Air Pollutants (tBACT)] review for controlling fugitive gas emissions at the Stevens County Landfill (SCLF). This document has been prepared to support the 2020 NOC Application.

2.0 Background

The following background information documents the correspondences that have taken place on the BACT/tBACT review between Great West Engineering and Washington State Department of Ecology.

Great West Engineering (Travis Pyle) and Washington State Department of Ecology (Andy Kruse) met at Ecology's Eastern Regional Office in Spokane on June 11th. The purpose of the meeting was to discuss the air permitting process as it relates to the SCLF. Leading up to this meeting were several emails between the two parties discussing the current conditions of the SCLF and the need for air permitting. During the meeting, it was confirmed that the SCLF is below the 2.5 million cubic meters AND 2.5 million megagram (Mg)-thresholds for design capacity, and as such, is not subject to regulations under New Source Performance Standards (NSPS) for MSW landfills (40 CFR 60 Subpart WWW or Subpart XXX), the Federal Emission Guidelines (EGs) for MSW landfills (40 CFR Subpart Cc), the National Emission Standards for Hazardous Air Pollutants (NESHAP) for MSW landfills (40 CFR Subpart AAAA), or Title V requirements (email also from Andrew Kruse, PE/Ecology to Travis Pyle, PE/Great West on June 3, 2019). The dates for when the SCLF was constructed, reconstructed or

modified were confirmed to be before July 17, 2014, which otherwise requires compliance with the 40 CFR Part 60, Subpart XXX. At the time this document was prepared, the state plan under 40 CFR Part 60 Subpart Cf had not been prepared or a federal plan prepared and adopted. As such, the SCLF is currently regulated under Subpart XXX.

Great West Engineering (Travis Pyle and Craig Sauer), Stevens County (Wayne Cornwall, Kevin Dionas and Roger Kaiser), and Ecology (Andy Kruse and Jenny Filipy) met via a teleconference meeting on August 20, 2019. The purpose of the meeting was to review the original BACT/tBACT technical memorandum and discuss what supplemental information was needed. A supplemental BACT/tBACT review document was submitted to Ecology on September 10, 2019. A teleconference call was between Great West Engineering (Travis Pyle) and Ecology (Andy Kruse) on September 13, 2019, as part of an informal review. Following that meeting, Mr. Kruse sent an email to Travis Pyle that day with the next steps (where these have been included/addressed is provided in blue font).

- *Include this recent BACT review with additional information surrounding the justification of the smaller candlestick flare system (i.e. manufacturer quotes, etc.).*
  - Refer to the NOC Application package **Enclosure A** – Technical Information Memorandum/Attachment 4 for manufacturer's information and data. Manufacturer's quotes are provided herein as **Attachment 1**.
- *Proposed processes to ensure "up-time" of the flares, to minimize free venting.*
  - The vent flares will be maintained as recommended by the manufacturer with replacement parts on-hand to reduce the amount of downtime and minimize the amount of free venting.
- *Highlights of proposed Fugitive Dust Control Plan (FDCP) to ensure fugitive dust is being controlled. A more thorough plan will be required in the O&M manual after permit issuance.*
  - Refer to the NOC Application package **Enclosure A** – Technical Information Memorandum/Section V.A.
- *Brief summary of how the closed cell will impact the open cells and the "phase-out" plan of closed cell.*
  - The closed landfill has no measurable impacts to air quality as discussed in the NOC Application package **Enclosure A** – Technical Information Memorandum/Section III.A. The Closed Landfill Unit is currently under post-closure care until such time that Stevens County decides to request termination of post-closure.
- *If needed, cover impacts that public access to the open face of the open cells may introduce if modeling for SQER exceedance is required.*
  - The general public is not allowed on the open face of the landfill. The public is required to drop-off their refuse at the public z-wall area. Refer to NOC Application package **Enclosure D** for the air dispersion modeling approach and report.

- *Brief summary of conservative estimate surrounding the 50% collection efficiency of the smaller candlestick system.*
    - The basis for the 50% collection efficiency estimate is included in the NOC Application package **Enclosure A** – Technical Information Memorandum/Section III.H.2

Although not currently subject to the "federal" requirements (i.e., below the design capacity thresholds), the SCLF is still considered an industrial facility in the State of Washington and must comply with the state's air quality standards, namely WAC 173-400-110(5), *New Source Review (NSR) for Sources and Portable Sources – Exemptions Based on Emissions,* to determine if the potential to emit (PTE) exceeds the New Source Review (NSR) thresholds, including the fugitive dust emissions (PM-10 and PM-2.5) from the haul roads. Toxic air pollutants (TAPs) can also be generated from landfill gas, and the PTE of any TAPs cannot exceed the levels listed in WAC 173-460-150, *Controls for New Sources of Toxic Air Pollutants, Table of ASIL [Acceptable Source Impact Level], SQER [Small Quantity Emission Rate] and De Minimus Emission Values*.

Landfill gas sampling was conducted as part of this study, as presented in **Enclosure A** – Technical Information Memorandum/Section III.G.

Also, since the SCLF accepted waste before May 30, 1991 (in the old, now closed landfill unit), it is regulated under WAC 173-400-070(6)(a). As such, the control device for air emissions must be designed and operated to reduce non-methane organic compounds (NMOCs) by 98% (minimum). This is considered the minimum level for BACT.

3.0 General Site Information

Stevens County owns and operates the SCLF, a municipal solid waste landfill (MSWLF), located west of Highway 25 and approximately 2 miles southwest of Kettle Falls. **Exhibit 1** presents a vicinity map of where the SCLF is located. The landfill facility has a physical address of 1257 Landfill Road, Kettle Falls, Washington. The SCLF began accepting waste in the 1970s in the old landfill area. When the Subtitle D rules came into effect in the early 1990s, the County decided to close the old landfill area (now known as the "Closed Landfill Unit") and opened the first modern lined landfill cell (Cell 1) for waste disposal in 1993.

Exhibit 1 – Vicinity Map (courtesy of Google Earth, photo taken 8/20/2016)

The SCLF includes an administrative building, entrance facilities (scalehouse/scale, MRW facility, and public MSW drop-off area), a maintenance shop building, the Closed Landfill Unit, the active landfill (Cells 1 and 2, and future Cell 3), two leachate ponds, and other supporting buildings and infrastructure. The Closed Landfill Unit was closed under the pre-Subtitle D regulations in accordance with WAC 173-304, *Minimum Functional Standards for Solid Waste Handling*, and is under post-closure care requirements of these standards. Currently landfill gas is passively vented from this unit and monitored on a quarterly basis by County staff in accordance with the Post-Closure Plan. An overall site map of the SCLF is shown in **Exhibit 2**.

Exhibit 2 –Overall Site Map (courtesy of Google Earth, photo taken 8/20/2016)

4.0 Criteria Pollutants/Toxic Air Pollutants

Refer to the NOC Application package Enclosure A – Technical Information Memorandum/Section V for the criteria Pollutants and Section VI for the Toxic Air Pollutants (TAPs).

5.0 Control System Descriptions

This section provides a brief description of the landfill gas collection and control system (GCCS) options considered for the SCLF. The first option is a "Flare Station," which consists of an air handling unit/skid and an enclosed flare stack. An alternative system, "Gas Vent Flares," is also considered. This system includes a series of solar-powered vent flare units view to lessen the financial burden on the County. For both systems, the minimum 98%

BACT would be satisfied. Furthermore, the collection system inside the landfill waste body (horizontal collection wells, wellheads, manifolds, laterals, leachate cleanout risers, etc.) would be identical for both systems.

5.1 Option 1 – Flare Station

The general concept for this option includes the following development phases.

- **Phase 1** – This phase begins with installing the main infrastructure of the gas system, including the flare station (air handling skid and flare stack), header and sub-header pipes, manifold lines, lateral connections to wellheads on leachate line cleanouts and risers in Cells 1 and 2, followed by installing the first layer of horizontal gas wells and wellheads in Cell 2. This phase also includes installation of the condensate management system.
- **Phase 2** – This phase follows the filling of Cell 2 to the sub-interim closure grades, installing more manifolds and laterals, and horizontal gas wells with wellheads.
- **Phase 3** – This phase continues with the filling in Cells 1 and 2 up to the interim closure grade, installing more manifold lines and laterals, and horizontal gas wells with wellheads.
- **Phase 4** – This phase completes the collection system to the interim closure grades of Cells 1 and 2. Additional manifolds and lateral lines will be installed along with horizontal gas wells and wellheads.
- **Phase 5** – This phase begins with the development of Cell 3. The sub-header will be extended to service Cell 3, along with additional manifold lines, and horizontal gas wells with wellheads. Laterals will also be connected to leachate cleanout lines with wellheads connected to them. At the latter stages of this phase, the flare station will need to be completely replaced to finish out the active filling and transition into post-closure care. Flare stations typically have a service life on the order of 25 years with good maintenance and repairs.

The collection efficiency for the active gas collection system using a full blower station is assumed to be 75%, accounting for scheduled and unscheduled maintenance and anticipated coverage of the collection system inside the landfill.

5.2 Option 2 – Gas Vent Flares

This option would use gas vent flares augmented with vacuum fan kits instead of a single flare station with blowers. The Solar Spark® landfill gas vent flares are manufactured/ distributed by EPG Companies. These units are reported to have greater than 98% NMOC destruction and are widely used for odor and emissions control at landfills (refer to **Attachment 1** for manufacturer's data). The units are constructed for a long service life with very little maintenance. They are solar-powered with continuous ignitors and use an all-weather stainless-steel spark pilot, stainless-steel ball valve, and an in-line flame arrestor. Optional features include a guy wire kit, visibility shield, solar-powered vacuum fan kit (to be used by Stevens County), and cold weather insultation kit (used as needed). These units are available in two sizes. The Model CF-5 has a flow range of 2-90 CFM, and the Model CF-10 has a flow range of 5-140 CFM. These units are designed to burn methane with

concentrations ranging from 25% to 100% (expected methane concentration range of 45%-60% for the SCLF).

The collection efficiency for the alternative system using a combination of passive and solar-powered vent flares is 50%, accounting for scheduled and unscheduled maintenance, solar power availability through the year, and anticipated coverage of the collection system inside the landfill. Refer to the NOC Application package **Enclosure A/**Section III.H.2 for further information regarding the collection efficiency assumption. Furthermore, the master plan for layout of this system is presented in NOC Application package **Enclosure A** - Attachment 1.

The general concept for this control system includes the following development phases.

- **Phase 1** – This phase begins with connecting vent flare flares to the leachate line cleanouts and risers in Cells 1 and 2, followed by installing the first layer of horizontal gas wells and wellheads, laterals, and manifold line in Cell 2. This phase also includes installation of the condensate p-trap and sump connected to the manifold line at the vent flares.
- **Phase 2** – This phase follows the filling of Cell 2 to the sub-interim closure grades, installing more manifolds and laterals, horizontal gas wells with wellheads, and a vent flare. This phase also includes installation of the condensate p-trap and sump connected to the manifold line at the vent flare.
- **Phase 3** – This phase continues with the filling in Cells 1 and 2 up to the interim closure grade, installing more manifold lines and laterals, horizontal gas wells with wellheads, and a vent flare.
- **Phase 4** – This phase completes the collection system to the interim closure grades of Cells 1 and 2. Additional manifolds and lateral lines will be installed along with horizontal gas wells and wellheads.
- **Phase 5** – This phase adds horizontal gas wells in Cell 3 and completes the system to the final fill grades. Additional manifolds and laterals lines will be installed includes installation of the condensate p-traps and sump connections to the manifold line at the vent flares. Similar to Option 1, it is assumed that all vent flares will be replaced after 25 years of operation.

6.0 Average Annual Emission Estimates

The emission levels will change each year at the SCLF as more waste is placed and then will eventually decline when the landfill is closed. A 50-year window (2020-2069) was assumed for determining the average landfill gas flow and emissions from the SCFL (following the approximate 50-year timeframe for the assumed control equipment with one-time complete replacement of equipment for each option). The average landfill gas generation flow rate over this time period from the LandGEM model is approximately 283 scfm. The peak generation rate of 358 scfm occurs in 2058/2059 when the landfill closes and has the maximum amount of waste in place.

The average flow rate of **283 scfm** was used to determine the average amount of pollutants that will be emitted from the landfill (refer to **Table 1**).

Table 1 also includes the estimated tons of controlled emissions considering a typical collection efficiency of 75% for the Flare Station (Option 1) and the assumed 50% for the Gas Vent Flares (Option 2). Both control options assume a minimum destruction or removal efficiency (DRE) of 98%, to meet BACT. Ecology considers the amount of volatile organic compounds (VOCs) equal the amount of NMOCs, and the TAPs are included in the NMOCs. As such, the basis of the controlled emissions for this study uses the average NMOC concentration from the January 10, 2020, sampling event.

Table 1 – Average Annual Emissions and Control Estimates for the SCLF

Pollutant	Estimated SCLF Emissions (tons/year)	Notes
NMOCs	1.55	Source: January 2020 Sampling Event – Average NMOC concentration of 93 ppm @ 283 scfm average flow and using LandGEM output = 1.40 Mg/yr, or 1.55 U.S. (short) tons; Conversion: 1.102 U.S tons = 1.0 megagrams (metric tons)
Methane	1,858.9	Source: January 2020 Sampling Event – Average Methane concentration of 65%+; LandGEM maximum allowed of 60 @283 scfm and using LandGEM output = 1,687 Mg/yr, or 1,859 U.S. (short) tons; Conversion 1.102 U.S. tons = 1.0 megagrams (metric tons)
Total	**1,860.5**	
Flare Station:		
Amount Collected	**1,395.4**	75% assumed collection efficiency
Net Emissions Controlled	**1,367.5**	DRE 98%
Gas Vent Flares:		
Amount Collected	**930.25**	50% assumed collection efficiency
Net Emissions Controlled	**911.65**	DRE 98%

7.0 Cost Per Ton of Emissions Controlled Estimate

An Engineer's opinion of cost was prepared as part of this study to determine the estimated cost per ton of emissions controlled. These costs include operational costs and allowances for engineering design, permitting, and construction management support. This opinion of cost is considered a Class 4 ("Study of Feasibility") level of estimate with a typical accuracy range of -30% to +50%. The estimate assumes a rate of annual inflation of 2.0% on average and 2.0% interest earned on investments, which offsets the time value of money.

7.1 Option 1 – Flare Station

Table 2 presents a summary of the capital costs for installing the full GCCS in 2020 dollars (2020$). The table also shows the estimated cost on a per ton of controlled emissions. Refer to Attachment 2 for an itemized list of costs.

Table 2 – SCLF Phase Development for Option 1 – Flare Station/Cost Per Ton of Controlled Emissions

Phase	Cost Estimate (2020$)	Notes/Comments
Phase 1 (2020)	$1,341,000	Install initial infrastructure and system
Phase 2 (2022)	$213,000	Coincident with Cells 1 and 2 filling to sub-interim closure
Phase 3 (2026)	$281,000	Continue with Cells 1 and filling to sub-interim closure
Phase 4 (2032)	$202,000	Continue with Cells 1 and 2 filling to interim closure
Phase 5 (2035)	$2,165,000	Build with the development of Cell 3; includes replacing the flare station in 2045
Total Annual Cost	**$151,040**	**Annualized capital cost + annual ops costs**

7.2 Option 2 – Gas Vent Flares

Table 3 presents a summary of the capital costs for installing the alternative system in 2019$. The table also shows the cost on a per ton of controlled emissions. Refer to Attachment 2 for an itemized list of costs.

Table 3 – SCLF Phase Development for the Gas Vent Flare System/Cost Per Ton of Controlled Emissions

Phase	Cost Estimate (2020$)	Notes/Comments
Phase 1 (2020)	$296,000	Install initial infrastructure and system
Phase 2 (2022)	$243,000	Coincident with Cells 1 and 2 filling to sub-interim closure
Phase 3 (2026)	$285,000	Continue with Cells 1 and filling to sub-interim closure
Phase 4 (2032)	$244,000	Continue with Cells 1 and 2 filling to interim closure
Phase 5 (2035)	$1,509,000	Build with the development of Cell 3; includes complete replacement of all vent flares in 2045
Total Capital Investment	**$2,577,000**	
50-year Annualized Cost	**$51,540**	**Total capital costs / 50 years of service life for the system**
Est. Annual Ops Costs	**$35,000**	**Includes estimates for labor, consulting, lab testing, reporting, and materials/supplies (no utilities – solar)**
Total Annual Cost	**$86,540**	**Annualized capital cost + annual ops costs**
Emissions Controlled	**911.65 tons/year**	**Refer to Table 1 (NMOCs + Methane)**
Cost of Emissions Controlled	**$94.93/ton**	

8.0 Summary/Conclusions

The estimated cost per ton of controlled emissions (NMOCs plus methane) for the flare station (Option 1) is $110.45/ton, while the gas vent flare system (Option 2) is $94.93/ton. The difference is over $15.50/ton of controlled emissions. Not only is Option 1 less expensive on annualized, 50-year basis, it is much more economical for the County to implement in the near-term (less capital). The first phase of Option 1 is over a $1 million less expensive than the flare station. Implementing the gas vent flares will provide the County an opportunity to pay for this system out of their current operations budget rather than borrowing money or having to raise the tip fee exorbitantly high. Future phases with the alternative system can then be paid for by implementing slight increase(s), if required, in the tip fee over time and setting aside capital reserves. For these reasons, it is recommended that the SCLF move forward with the vent flares (Option 2) in order to control landfill gas emissions.

Attachment 5

EPA: Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Municipal Solid Waste Landfills

June 2011

United States
Environmental Protection
Agency

Office of Air and Radiation **June 2011**

AVAILABLE AND EMERGING TECHNOLOGIES FOR REDUCING GREENHOUSE GAS EMISSIONS FROM MUNICIPAL SOLID WASTE LANDFILLS

Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Municipal Solid Waste Landfills

Prepared by the

Sector Policies and Programs Division
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

June 2011

Table of Contents

Abbreviations and Acronyms

ADEME	French Agency for Environmental and Energy Management
ATSDR	Agency for Toxic Substances and Disease Registry
BAAQMD	Bay Area Air Quality Management District
BACT	Best available control technology
Btu	British thermal units
CCAR	California Climate Action Registry
CCTP	Climate Change Technology Program
CEC	California Energy Commission
CH_4	Methane
CHP	Combined heat and power
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
CPTR	Cost Incurred Per Metric Ton of Reduced CO_2e
DER	Distributed Energy Resource
GHG	Greenhouse gas
HAP	Hazard air pollutants
H_2	Hydrogen
H_2S	Hydrogen sulfide
kW	Kilowatts
lb	Pound
LFG	Landfill gas
LFGcost	Landfill Gas Energy Cost Model
LFGE	Landfill gas energy
LMOP	Landfill Methane Outreach Program
LNG	Liquefied natural gas
Mg	Megagrams
MSW	Municipal solid waste
MT	Metric ton
MW	Megawatts
MWh	Megawatt-hour
N_2	Nitrogen
N_2O	Nitrous oxide
NESHAP	National Emission Standards for Hazardous Air Pollutants
NMOC	Nonmethane organic compounds
NO_x	Nitrogen oxides
NREL	National Renewable Energy Laboratory
NSPS	New Source Performance Standard
O_2	Oxygen
ppmv	Parts per million by volume
PSD	Prevention of significant deterioration
psi	Pounds per square inch
RCRA	Resource Conservation and Recovery Act
scfm	Standard cubic feet per minute
SO_x	Sulfur oxides

SWICS	Solid Waste Industry for Climate Solutions
WARM	Waste Reduction Model

I. Introduction

This document is one of several white papers that summarize readily available information on control techniques and measures to mitigate greenhouse gas (GHG) emissions from specific industrial sectors. These white papers are solely intended to provide basic information on GHG control technologies and reduction measures in order to assist States and local air pollution control agencies, tribal authorities, and regulated entities in implementing technologies or measures to reduce GHG under the Clean Air Act, including, where applicable, in permitting under the prevention of significant deterioration (PSD) program and the assessment of best available control technology (BACT). These white papers do not set policy, standards or otherwise establish any binding requirements; such requirements are contained in the applicable EPA regulations and approved state implementation plans.

II. Purpose of this Document

This document provides information on control techniques and measures that are available to mitigate GHG emissions from the municipal solid waste landfill sector at this time. Because the primary GHG emitted by the municipal solid waste landfill industry are methane (CH_4) and carbon dioxide (CO_2), the control technologies and measures presented in this document focus on these pollutants. While a large number of available technologies are discussed here, this paper does not necessarily represent all potentially available technologies or measures that that may be considered for any given source for the purposes of reducing its GHG emissions. For example, controls that are applied to other industrial source categories with exhaust streams similar to the municipal solid waste sector may be available through "technology transfer" or new technologies may be developed for use in this sector.

The information presented in this document does not represent U.S. EPA endorsement of any particular control strategy. As such, it should not be construed as EPA approval of a particular control technology or measure, or of the emissions reductions that could be achieved by a particular unit or source under review.

III. Description of Municipal Solid Waste Landfills

The term municipal solid waste (MSW) landfill refers to an entire disposal facility in a contiguous geographic space where municipal waste is placed in or on land. The term does not cover land application units, surface impoundments, injection wells, or waste piles. Many MSW landfills receive other types of waste, such as construction and demolition debris, industrial wastes, and sludge. The information presented in this paper refers to landfills that primarily receive MSW, as defined in the criteria for MSW landfills under the Resource Conservation and Recovery Act (RCRA) regulations (40 CFR Part 258).

According to 2009 data, 54% of MSW in the United States was landfilled, 12% was incinerated, and 34% was recycled or composted (EPA, 2010a). There were approximately

1,800 operational landfills in the United States in 2006 (EPA, 2010b). These landfills accepted approximately 132 million tons of MSW in 2009 (EPA, 2010a).

After placement in a landfill, a portion of organic waste (such as paper, food waste, and yard trimmings) decomposes. Landfill gas is produced by microorganisms under anaerobic conditions and is comprised of approximately 50% CH_4, 50% CO_2, and trace amounts of nonmethane organic compounds (NMOC). Landfill gas generation occurs under a four phase process, as shown in Figure 1. First, CO_2 is produced under aerobic conditions. After oxygen (O_2) is depleted, CO_2 and hydrogen (H_2) are produced under anaerobic conditions. Then CO_2 production depletes in proportion to the CH_4 that is produced. Finally, CH_4, CO_2 and nitrogen (N_2) production stabilize. Significant LFG production typically begins one or two years after waste disposal in a landfill and can continue for 10 to 60 years or longer (ATSDR, 2001a).

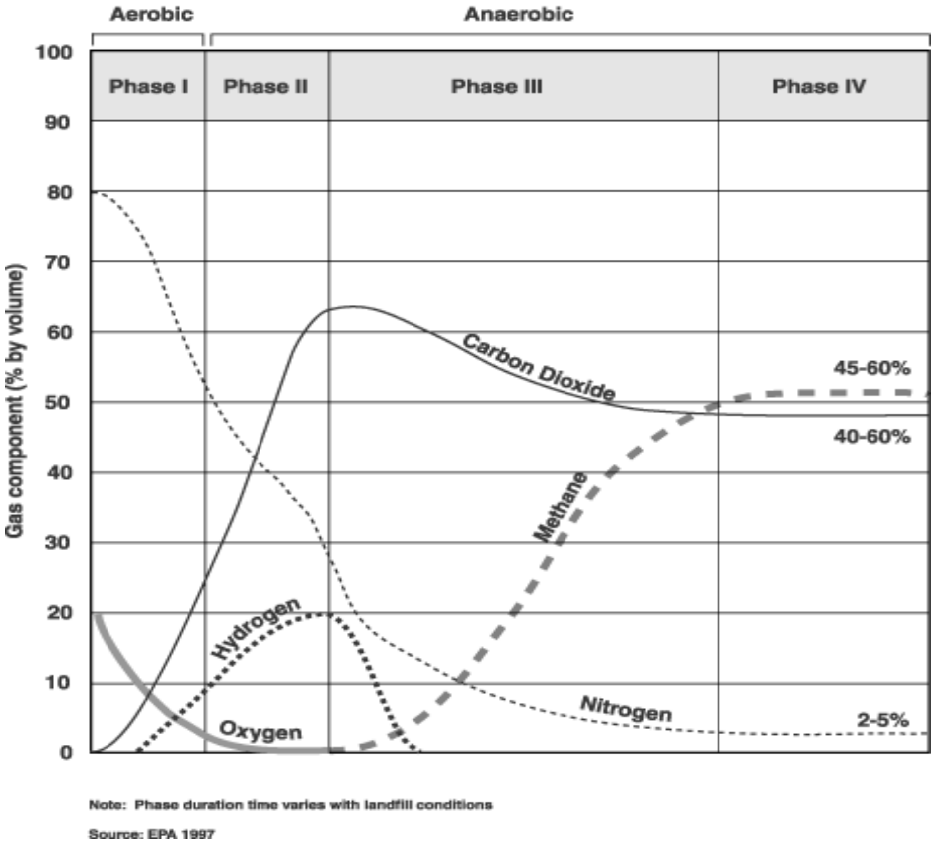


Figure 1: Production phases of landfill gas (ATSDR, 2001a)

Landfills are the second largest anthropogenic source of CH_4 in the United States; approximately 22% of total U.S. anthropogenic CH_4 in 2008 (EPA, 2010b). The global warming potential of CH_4 is 21 times that of CO_2, making CH_4 a more potent GHG than CO_2. Typically, GHG emissions are expressed in terms of carbon dioxide equivalents (CO_2e) that weigh emissions using global warming potentials. For example, a landfill emitting 1,000 metric tons of

CH_4 and 1,000 metric tons of CO_2 would have CO_2e emissions of 22,000 metric tons [= (1,000 x 21) + 1,000].

Landfills primarily use the "area fill" method which consists of waste placement on a liner, spreading the waste mass in layers, and compaction with heavy equipment. Daily cover is then applied to the waste mass to prevent odors, blowing litter, scavenging, and vectors (carriers capable of transmitting pathogens from one organism to another). Landfill liners may be comprised of compacted clay or synthetic materials to prevent off-site gas migration and to create an impermeable barrier for leachate. A final cover or cap is placed on top of the landfill, after an area or cell is completed, to prevent erosion, infiltration of precipitation, and for odor and gas control.

Methane generation in landfills is a function of several factors, including: (1) the total amount of waste; (2) the age of the waste, which is related to the amount of waste landfilled annually; (3) the characteristics of the MSW, including the biodegradability of the waste; and (4) the climate where the landfill is located, especially the amount of rainfall. Methane emissions from landfills are a function of methane generation, as discussed above, and (1) the amount of CH_4 that is recovered and either flared or used for energy purposes, and (2) the amount of CH_4 that leaks out of the landfill cover, some of which is oxidized.

IV. Summary of Control Measures

Table 1 summarizes the GHG control measures presented in this document. Where available, the table includes emission reduction potential, capital costs, operating and maintenance costs, and any important details on the applicability of the control.

Table 1. Summary of GHG Control Measures for MSW Landfills

Measure	Applicability	CH_4 Reduction[a]	Typical Capital Costs[b]	Typical Annual O&M Costs[b]	Cost Effectiveness ($/metric ton of CO_2e reduced)[e]	Notes/Issues
LFG Collection Efficiency Improvement	All landfills with gas collection systems	Varies	$24,000/acre	$4,100/acre	NA	Cost and performance varies depending on the type of cover material.
Flare	All landfills with gas collection systems	99%			$6 - $25	Emits secondary criteria pollutant emissions (e.g. NOx and CO. No revenue.
Turbine	For larger landfills with gas collection systems	99%	$1,400/kW (≥3 MW)	$130/kW	$12 - $18	Emits secondary criteria pollutant emissions (e.g. NOx and CO). Generates revenue for landfills.
Engine		96-98%	$1,700/kW (≥800 kW)	$180/kW	$12 - $16	
Microturbine		99%	$5,500/kW (≤1 MW)	$380/kW	$2 - $13	
Small Engine		96-98%	$2,300/kW (≤1 MW)	$210/kW	$11	
CHP Engine		96-98%	$2,300/kW (≥800 kW)	$180/kW	$7 - $57	
CHP Turbine		99%	NA	NA	$4 - $51	
CHP Microturbine		99%	NA	NA	$9 - $64	
Direct Use (boilers, heaters, etc.)		Varies by technology	$960/scfm[c] + $330,000/mile[d]	$90/scfm[c,d]	NA	
Biocover	All landfills	Up to 32%	$48,000/acre	NA	$745	No extensive retrofit.
Biofiltration Bed	Landfills with passive or no gas collection systems	Up to 19%	NA	NA	NA	Low cost.

[a] References provided in section V of this document for the different control measures.

[b] Costs for collection system & flare, turbines, engines, microturbines, small engines, and direct use obtained from *Chapter 4 (Project Economics and Financing)* of LMOP's *Landfill Gas Energy Project Development Handbook (*EPA, 2010c), Costs for CHP engines determined by evaluating the engine case study in the handbook as a CHP engine using LMOP's LFGcost model (EPA, 2010d).

[c] Costs for gas compression and treatment.

[d] Costs for pipeline and condensate management system (if applicable).

[e] Cost effectiveness obtained from analysis done by BAAQMD for conventional landfills with a medium compacted waste density (BAAQMD, 2008), with adjustments made to determine the costs per metric ton of CO_2e reduced from the combustion of CH_4, instead of the costs per metric ton of CO_2e avoided from displacement of power generation. See section V.D and Appendix A for additional information.

NA = not available

V. Available Control Technologies for GHG Emissions from MSW Landfills

This section describes the available technologies for controlling GHG emissions from MSW landfills. The available control technologies are divided into three categories: LFG collection efficiency improvement, LFG control devices, and increase of CH_4 oxidization. An economic analysis of the control technologies discussed is also included. It should also be noted that large landfills with emissions exceeding 50 megagrams (Mg) NMOC or more are required by New Source Performance Standards (NSPS) to control and/or treat LFG to significantly reduce the amount of toxic air pollutants released. In essentially all cases, controls required by the NSPS will co-control the GHG emissions.

A. LFG Collection Efficiency Improvement

Collection efficiency is contingent upon landfill design and the manner in which landfills are operated and maintained. Gas collection efficiency can be improved by implementing rigorous gas well and surface monitoring and leak identification and repair. Factors contributing to variability in collection efficiency are discussed below.

There are two types of LFG collection systems, active and passive. Passive systems rely on the natural pressure gradient between the waste mass and the atmosphere to move gas to collection systems. Most passive systems intercept LFG migration and the collected gas is vented to the atmosphere. Active systems use mechanical blowers or compressors to create a vacuum that optimizes LFG collection (ATSDR, 2001a).

For active gas collection systems, the collection efficiency depends primarily upon the design and maintenance of the collection system and the type of materials used to cover the landfill (BAAQMD, 2008). In the background information document for the draft updated landfill AP-42 chapter, a typical collection efficiency range of 50% to 95% is given with a suggested average of 75% (EPA, 2008a).

EPA's Office of Research and Development has completed a field test program using optical remote sensing technology (EPA's OTM-10) to quantify LFG collection efficiency. Sampling was conducted at three MSW landfills to evaluate CH_4 emissions across the landfill footprint to compare to the quantity of extracted gas (i.e., rate of fugitive CH_4 vs. rate of collected CH_4). The preliminary results suggest gas collection efficiencies from 36% to 85% reflecting a range based on landfill design and operational differences. The report is under review and is expected to be released in 2011.

Higher collection efficiencies may be achieved at landfills with well maintained and operated collection systems, a liner under the waste, and a cover consisting of a geomembrane and a thick layer of clay. Studies conducted by the Solid Waste Industry for Climate Solutions (SWICS) indicate collection systems meeting the requirements of NSPS, Subpart WWW are often more capable of achieving higher collection efficiencies than collection systems used solely for energy recovery because it is difficult to optimize gas quality while trying to attain a high level of gas collection (SWICS, 2009).

Results of gas collection efficiency studies for various cover materials using flux box measurements are documented in Spokas et al. (2005). The data were used to develop default values of percent recovery for the French environment agency (ADEME). These default collection efficiencies for active gas collection systems are listed in Table 2.

Table 2. LFG Collection Efficiencies for Various Cover Materials

Type of Landfill Cover Material	Gas Collection Efficiency
Operating cell (no final cover)	35%
Temporary cover	65%
Clay final cover	85%
Geomembrane final cover	90%

Gas collection research studies done by SWICS used flux box data, which may potentially under estimate gas collection efficiency. The resulting collection efficiencies for landfills with active gas collection systems are summarized below (SWICS, 2009):

- 50-70% (mid-range default = 60%) for a landfill or portions of a landfill that are under daily soil cover;
- 54-95% (mid-range default = 75%) for a landfill or portions of a landfill that contain an intermediate soil cover; and
- 90-99% (mid-range default = 95%) for landfills that contain a final soil and/or geomembrane cover systems.

As shown in Table 3, the mid-range default values for the three cover types identified above were adopted as the collection efficiencies listed in the GHG reporting rule for MSW landfills (40 CFR 98, Subpart HH, Table HH-3). The collection efficiency of a passive gas collection system is assumed to be zero because the pressure gradient is unknown and would likely vary in time and space.

Table 3. LFG Collection Efficiencies in the GHG Reporting Rule

Description	Gas Collection Efficiency
Area without active gas collection, regardless of cover type	0%
Area with daily soil cover and active gas collection	60%
Area with an intermediate soil cover, or a final soil cover not meeting the criteria below to achieve 95% efficiency, and active gas collection	75%
Area with a final soil cover of 3 feet or thicker of clay and/or geomembrane cover system and active gas collection	95%

As shown is Table 3, landfills with final geomembrane covers have higher collection efficiencies. Changing the final cover material can improve gas collection efficiency. This technology is applicable for all landfills. Typically, modern landfills with active gas collection systems have clay or geomembrane covers in place. An additional geomembrane or clay cover can be added to older landfills with gas collection systems to reduce LFG emissions (BAAQMD, 2008).

B. LFG Control Devices

After collection, LFG may be controlled and/or treated for subsequent sale or use as an energy source to create electricity, steam, heat, or alternate fuels such as pipeline quality gas or vehicle fuel. With approximately half the heating value of natural gas (350 to 600 British thermal units (Btu) per cubic foot), LFG is considered a medium Btu gas. Combustion of LFG is the most common method used to reduce the volatility, global warming potential, and hazards associated with LFG. Combustion methods include destruction devices (e.g., flares), electricity generation units (e.g., reciprocating engines, gas turbines), and energy recovery technologies (e.g., boilers). During the combustion process, CH_4 in LFG is converted to CO_2. Since CH_4 has 21 times the global warming potential of CO_2, combustion reduces the global warming effect of LFG significantly. Although CH_4 has 21 times the global warming potential of CO_2, combusting CH_4 reduces the global warming potential only by a factor of 7.6 because the resulting CO_2 weighs more than the CH_4 by a factor of 2.75. Combustion of LFG also reduces odors and other hazards associated with LFG emissions. However, combustion units emit secondary criteria pollutants, such as carbon monoxide (CO) and nitrogen oxides (NO_X), as well as hazardous air pollutants (HAP). Fuel cells are considered a non-combustion treatment option for LFG that converts the gas to energy.

The control devices frequently used for LFG and the associated control efficiencies are described in the following sections. It is important to note that all of the technologies discussed

below typically require treatment of the LFG prior to entering the control device to remove moisture, particulates, and other impurities. The level of treatment depends primarily on the type of control and the types and amounts of contaminants in the LFG. A list of common LFG constituents is found in Tables 2.4-1 and 2.4-2 of the landfill AP-42 chapter (EPA, 1998a). Some of the major trace contaminants in LFG that may need to be treated prior to control include sulfur compounds, such as hydrogen sulfide (H_2S), and siloxanes.

Flares

Of the combustion methods, flaring is the most commonly used. However, unlike other combustion options, flaring does not recover energy. Controlling LFG emissions by flares is technically feasible for most landfills and many landfills have flares in place. The capital and maintenance costs associated with flares are relatively low compared to other combustion technologies. Flares are often used as backup control devices for landfills that have engines or turbines to generate electricity to limit emissions while these devices are off-line or to respond to variations in LFG generation.

Two different types of flares are available, open flares and enclosed flares. Open flares employ simple technology where the collected gas is combusted in an elevated open burner. A continuous or intermittent pilot light is generally used to maintain the combustion. While open flares are thought to have combustion efficiencies similar to those of enclosed flares, data are not available to confirm this because open-air combustion makes them difficult to test. Under NSPS, Subpart WWW, open flares must meet a minimum Btu content and have a pilot light. For landfills generating LFG that is unable to meet the Btu content consistently, it may be necessary to supplement the collected gas with natural gas or another fuel source, which may create an additional cost for the landfill.

Enclosed flares typically employ multiple burners within fire-resistant walls, which allow them to maintain a relatively constant and limited peak temperature by regulating the supply of combustion air (ATSDR, 2001b). Enclosed flares can be tested for destruction efficiency of NMOC and HAP. The background information document for the draft updated landfill AP-42 chapter provides an NMOC control efficiency range of 86% to 100% for flares, with an average of 97.7% (EPA, 2008a). A report published by California's Bay Area Air Quality Management District (BAAQMD) states that flares typically have CH_4 destruction efficiencies of greater than 99.5% (BAAQMD, 2008). Under NSPS, Subpart WWW, enclosed flares are considered to be incinerators and are required to have a minimum NMOC control efficiency of 98% by weight. In California, flares are required to have minimum CH_4 destruction efficiencies of 99% (CCR, Article 4, Subarticle 6, Section 95464(b)(2)(A)(1)).

Electricity Generation

Internal combustion engines are the most widely used technology for the conversion of LFG to electricity. Advantages of this technology include: low capital cost, high efficiency, and adaptability to variations in the gas output of landfills. The operation of reciprocating engines at low pressure (12-30 pounds per square inch (psi)) also yields less condensate than operation at

higher pressure (60-160 psi) (Potas, 1993). Internal combustion engines are primarily used at sites where gas production can generate 100 kilowatts (kW) to 3 megawatts (MW) of electricity, or where sustainable LFG flow rates to the engines are approximately 50 to 960 cubic feet per minute (cfm) at 50% CH_4 (EPA, 2010d). For sites able to produce more than 3 MW of electricity, additional engines may be added.

Turbines are an alternative to internal combustion engines. Turbines using LFG require a dependable gas supply for effective operation, and are generally suitable for landfills when gas production can generate at least 3 MW, or where sustainable LFG flow rates to the turbines are over approximately 1,050 cfm at 50% CH_4 (EPA, 2010d). Typically, LFG-fired turbines have capacities greater than 5 MW. Advantages of this technology when compared to internal combustion engines include: a greater resistance to corrosion damage, relatively compact size, and lower operation and maintenance costs. When compared with other generator options, turbines require additional power to run the plant's compression system.

Microturbines can be used instead of internal combustion engines for LFG energy conversion. This technology generally works best for small scale recovery projects that supply electricity to the landfill or to a site that is in close proximity to the landfill. Single microturbine units have capacities ranging between 30 and 250 kW, and are most suitable for applications below 1 MW, or where sustainable LFG flow rates to the microturbines are below approximately 350 cfm at 50% CH_4 (EPA, 2010d). Sufficient LFG treatment is generally required for microturbines and involves the removal of moisture and other contaminants (EPA, 2010c).

In general, turbines have a higher CH_4 destruction efficiency (greater than 99.5%) than internal combustion engines (roughly 96%) (BAAQMD, 2008). For landfills subject to NSPS, Subpart WWW, control technologies are required to have a minimum control efficiency of 98% by weight NMOC reduction or an outlet concentration of 20 parts per million by volume (ppmv), dry basis as hexane at 3% O_2, of NMOC. In California, LFG control devices other than flares must achieve a CH_4 destruction efficiency of at least 99% by weight; and lean burn internal combustion engines must reduce the outlet CH_4 concentration to less than 3,000 ppmv, dry basis, corrected to 15% O_2 (CCR, Article 4, Subarticle 6, Section 95464(b)(3)(A)). Lean burn internal combustion engines are not defined within this California regulation; however, the NSPS for stationary spark ignition internal combustion engines (40 CFR 60, Subpart JJJJ) defines lean burn engines as any two-stroke or four-stroke spark ignited engine that does not meet the definition of a rich burn engine. Rich burn engines are defined as any four-stroke spark ignited engine where the manufacturer's recommended operating air/fuel ratio divided by the stoichiometric air/fuel ratio at full load conditions is less than or equal to 1.1.

Cogeneration

Cogeneration, also known as combined heat and power (CHP), is the use of LFG to generate electricity while recovering waste heat from the LFG combustion device. The thermal energy recovered is usually in the form of steam or hot water that can be used for on-site heating, cooling, or process needs. Cogeneration systems are typically more efficient and often more cost effective than separate systems for heat and power (EPA, 2008b). Combustion technologies

generally suitable for CHP include internal combustion engines, gas turbines, and microturbines. There are also boiler/steam turbine applications where LFG is combusted in large boilers for steam generation that is then used by turbines to create electricity (EPA, 2010c).

The CH_4 control efficiency for cogeneration is directly linked to the electricity generation unit combusting LFG. Landfills subject to NSPS, Subpart WWW, must meet the same requirements for cogeneration as those listed above for electricity generation.

Direct Use

Landfill gas may be used to offset traditional fuel sources such as natural gas, coal, and fuel oil used in industrial, commercial, and institutional applications. Direct use of LFG is primarily limited to facilities within 5 miles of a landfill. There are, however, facilities that have used LFG as a fuel at distances greater than 10 miles. Direct use applications for landfills include: boilers (LFG used solely or co-fired with other fuels), direct thermal technologies (e.g. dryers, heaters, kilns), and leachate evaporation. Innovative uses of LFG include heating greenhouses, firing pottery, glassblowing, metalworking, and heating water for an aquaculture (fish farming) operation (EPA, 2010c).

Control efficiencies of CH_4 for LFG direct use applications vary depending on the type of technology employed. For landfills subject to NSPS, Subpart WWW, control technologies are required to have a minimum control efficiency of 98% by weight NMOC reduction or an outlet concentration of 20 parts per million by volume (ppmv), dry basis as hexane at 3% O_2, of NMOC. In addition, if a boiler or process heater is used as the control device, the collected LFG must be routed into the flame zone.

Alternate Fuels

Purification techniques can be used to convert LFG to pipeline-quality natural gas, compressed natural gas (CNG), or liquefied natural gas (LNG). Purification of LFG for the production of natural gas typically involves the removal of inert constituents by adsorption (molecular sieve), absorption with a liquid solvent, and membrane separation. The production of pipeline-quality gas includes processing LFG to increase its energy content and pressurizing the pipeline that is connected to the gas production facility (CCTP, 2005).

The conversion of LFG to CNG and LNG require similar processes, and the resulting products can be used as vehicle fuel. First, the corrosive materials are removed through the use of phase separators, coalescing filters, and activated carbon adsorbents. Next, water and O_2 are removed. A cryogenic purifier is then used to remove CO_2, which yields high quality gas that is over 90% CH_4 (CCTP, 2005).

The type of LFG alternative fuel production and end use will affect the CH_4 control efficiency. For landfills subject to NSPS, Subpart WWW, control technologies are required to have a minimum control efficiency of 98% by weight NMOC reduction or an outlet concentration of 20 parts per million by volume (ppmv), dry basis as hexane at 3% O_2, of

NMOC. If the collected gas is routed to a treatment system, including purification and conversion devices, then vented gases from the treatment system must meet these requirements.

Fuel Cells

A fuel cell is an electrochemical cell that converts energy from a fuel into electrical energy. Electricity is generated from the reaction between a fuel supply and an oxidizing agent. The products of basic fuel cell reactions are CO_2, water vapor, heat, and electricity (Vargas, 2008). The difference between a battery and a fuel cell is that in a battery, all reactants are present within the battery and are slowly being depleted during the use of the battery. In a fuel cell, reactants (fuel) are continuously supplied to the cell (CEC, 2003). Fuel cells are used in a variety of applications to generate clean electricity without the use of combustion such as in generating transportation fuels for car, boats, and buses. Also fuel cells can serve as a power source in remote locations such as spacecraft, remote weather stations, parks, and in military applications. Fuel cells running on hydrogen are compact and lightweight and have no major moving parts.

For LFG applications, fuel cells use hydrogen from CH_4 to generate electricity (EPA, 1998b). Fuel cells have an advantage over combustion technologies in that the energy efficiency is typically higher without generating combustion by-products such as NO_X, CO, and sulfur oxides (SO_X) (EPA, 1998c). If fuel cells are used to generate electricity from landfill CH_4, then a gas cleanup system is required to ensure that the catalyst within the fuel cell is not contaminated by trace constituents that are present in LFG. Trace constituents include sulfur and chlorine compounds which can inhibit performance and poison the catalyst (NREL, 1998).

EPA's Office of Research and Development conducted a review of fuel cells for LFG applications. The phosphoric acid fuel cell was identified as most appropriate because it is commercially available and has been successfully demonstrated at two landfills. Other types of fuel cells (molten carbonate, solid oxide, polymer electrolyte membrane) may also be applicable for LFG applications as further fuel cell development is conducted. The first demonstration of a fuel cell was at the Penrose Landfill in California. The second was at a Connecticut landfill. Both demonstrations used a 200 kW phosphoric acid fuel cell manufactured by ONSI Corporation (EPA, 1998b). The energy efficiency for the demonstration at the Connecticut landfill was 37% at 120 kW and could have been higher if the waste heat had been utilized. The trace constituents removed in the gas clean up system were flared. An environmental and economic evaluation of a commercial fuel cell energy system concluded that there is a large potential market for fuel cells in this application. The major disadvantage is that the cost is higher compared to combustion technologies such as internal combustion engines and turbines.

For landfills subject to NSPS, Subpart WWW, control technologies are required to have a minimum control efficiency of 98% by weight NMOC reduction or an outlet concentration of 20 parts per million by volume (ppmv), dry basis as hexane at 3% O_2, of NMOC. If the collected gas is routed to a treatment system, including conversion devices, then vented gases from the treatment system must meet these requirements.

C. Increase of CH_4 Oxidation

The technologies to increase the CH_4 oxidation rate include biocovers and biofiltration beds. The principle of these technologies is the use of methanotrophic bacteria, which oxidize LFG, specifically CH_4, to water, CO_2, and biomass. Methanotrophic bacteria possess the CH_4 mono-oxygenase enzyme that enables them to use CH_4 as a source of energy and as a carbon source. These bacteria are usually found in agricultural soils, forest soils, and compost. These technologies are primarily in the research and development phase, rather than widespread application. The details of these two technologies are discussed below.

Biocovers

A biocover is an additional final cover that functions as a CH_4 oxidation enhancer to convert CH_4 into CO_2 prior to venting to the atmosphere. A biocover is composed of two substrate layers: a gas dispersion layer and a CH_4 oxidation layer. The gas dispersion layer is an additional permeable layer of gravel, broken glass, or sand beneath the porous media of the CH_4 metabolizing layer. This layer is added to evenly distribute the uncaptured LFG to the CH_4 oxidation media and to remove excess moisture from the gas. The CH_4 oxidation media can be made of soil, compost, or other porous media. This media is usually seeded with methanotrophic bacteria from the waste decomposition.

This control technology does not require extensive retrofit and is applicable to all landfills, including uncontrolled and older landfills with passive or active collection systems. The biocover itself is not known to affect the functionality of an existing or new gas collection and control system. In addition, it has low secondary criteria pollutant emissions. Biocovers can be used as additional final cover to improve the CH_4 oxidation rate. According to Abichou et al. (2006), biocover applications increased the average CH_4 oxidation rate up to 32%.

Biofiltration Beds

Similar to biocovers, biofiltration beds aim to further oxidize CH_4 from passively collected LFG. The collected LFG is passed through a vessel containing CH_4-oxidizing media prior to venting to the atmosphere or to a control system. This control technology is only feasible for small landfills or landfills with passive gas collection systems due to the size of the biofiltration bed required to treat an air/LFG mixture. In addition, due to the nature of passive gas collection systems, this technology lacks the ability to control and monitor the LFG collection. According to Morales (2006), a pilot project shows that the radial biofiltration bed design has a CH_4 oxidation rate of 19%.

A benefit of using a biofiltration bed compared to LFG combustion is that biofiltration beds produce only CO_2 and water vapor. Unlike other combustion-based mitigation measures, a biofiltration bed does not emit secondary pollutants such as NO_X, SO_X, and particulate matter. This technology requires few safety controls for operation, and no start up or shut down procedures.

D. Economic Analysis

The economic analysis for GHG control technologies is based on a cost effectiveness value, which is defined in this paper as the cost to remove one metric ton of CO_2e. The cost of LFG control technologies can be estimated using the Landfill Gas Energy Cost Model (LFGcost), which was developed by EPA's Landfill Methane Outreach Program (LMOP) (EPA, 2010d). This model includes direct and indirect costs associated with LFG energy (LFGE) projects. The direct costs are the costs for equipment, including basic treatment of LFG, and installation. The indirect costs include costs for engineering, design, and administration; site surveys and preparation; permits, right-of-ways, and fees; and mobilization/demobilization of construction equipment. Costs estimated by LFGcost are based on costs for average project sites. Individual landfills should adjust costs based on site-specific parameters and conditions. The types of LFG control projects included in LFGcost, Version 2.2 (EPA, 2010d) are as follows:

- LFG collection and flaring systems;
- Direct LFG utilization projects;
- Electricity generation with standard turbines (greater than 3 MW);
- Electricity generation with standard reciprocating engines (800 kW and greater);
- Processing LFG into a high Btu gas (1,000 standard cubic feet per minute (scfm) to 10,000 scfm);
- Electricity generation with microturbines (30 kW to 750 kW);
- Electricity generation with small reciprocating engines (100 kW to 1 MW);
- Leachate evaporators (500 gallons/day and greater);
- Electricity generation and hot water production with CHP reciprocating engines (800 kW and greater);
- Electricity generation and steam production with CHP turbines (greater than 3 MW); and
- Electricity generation and steam production with CHP microturbines (30 kW to 300 kW).

In 2008, California's BAAQMD published an economic analysis study on LFG control options using EPA's LFGcost software. This study was performed for MSW landfills of varying sizes (1.5, 3.0, and 5.9 million Mgs), types (conventional and bioreactor), and waste densities (low, medium, and high). The cost effectiveness values contained in the BAAQMD study for electricity generation technologies are based on CO_2e reduced due to avoided electricity production at the power plant. These values were adjusted to determine cost effectiveness values in terms of CO_2e reduced from the combustion of CH_4 and CO_2e reduced from both the combustion of CH_4 and avoided electricity generation. Appendix A contains the calculation procedures used to adjust the original cost effectiveness values in the BAAQMD report. The cost effectiveness for adding LFG combustion options to conventional landfills with a medium compacted waste density (100,000 tons of waste in place per acre) are provided in Table 4.

Table 4. Cost Effectiveness for Various LFG Combustion Technologies[a, b]

LFG Combustion Technology	Cost Effectiveness ($/metric ton of CO_2e reduced)	Cost Effectiveness ($/metric ton of CO_2e reduced and through avoided electricity)
Flare	$6 - $25	NA
Engine	$12 - $16	$11 - $14
Turbine	$12 - $18	$12 - $16
Microturbine	$2 - $13	$1 - $12
Small Engine	$11	$11
CHP Engine[c]	$7 - $57	$6 - $52
CHP Turbine[c]	$4 - $51	$4 - $47
CHP Microturbine[c]	$9 - $64	$8 - $59

[a] Source: BAAQMD, 2008. Except for flares, values presented in BAAQMD, 2008 were based on CO_2e avoided through reduction in electricity generated. These values were adjusted to take into account the CO_2e reduced through combustion of CH_4. See Appendix A for detailed calculations.
[b] Except for flares, all cost effectiveness values shown do not include costs for the gas collection system. A gas collection system would increase the cost effectiveness by between $5 and $10 per metric ton of CO_2e reduced.
[c] CHP values do not include CO_2e reductions due to reduction of fuel use where the heat or steam is being used.

In general, it is more economical for larger landfills with high waste densities to install LFG control technologies since their LFG generation rates are higher. The cost of installing combustion technologies is lower for landfills with pre-existing gas collection systems. Flaring is the cheapest combustion technology for most landfills, but flares do not have the potential to generate revenue from LFGE projects.

The cost effectiveness for biocovers was estimated to be $745 per metric ton of CO_2e reduced, according to the report prepared by BAAQMD (2008). Since the cost estimates for biocovers were based on a few test sites, the actual cost effectiveness may vary widely.

VI. Bioreactor Landfill Systems

A bioreactor is typically defined as an MSW landfill where enhanced microbial processes are used to expedite waste decomposition and biological stabilization. To properly manage the stabilization process, certain system design and operational modifications are required (Townsend, 2008). A bioreactor landfill employs the addition of liquid and air into the landfill cell to enhance microbial processes. The most common liquid recirculated in bioreactor landfills is leachate (waste liquid that drains from the landfill), but other liquids may be added to account for lack of moisture in the waste mass (BAAQMD, 2008).

A hybrid (both aerobic and anaerobic enhancements) bioreactor landfill uses two primary processes:

- Air is injected in the top portion of the cell to increase aerobic activity; and
- Liquid is injected into the lower (older) portions of the cell to regulate moisture and promote anaerobic activity (BAAQMD, 2008).

While the term bioreactor is not specifically defined under Subtitle D of the Resource Conservation and Recovery Act (RCRA), there are provisions that allow for short term research, development, and demonstration (RDD) permits specific to bioreactor operations (Townsend, 2008). RCRA Subtitle D prohibits the disposal of bulk liquids unless an RDD permit is granted and allows leachate and LFG condensate recirculation for landfills meeting composite liner requirements. There are also provisions for the prevention of gas migration.

Enhanced degradation in bioreactor landfills also accelerates LFG generation. Compared to conventional landfills, decomposition reaches a higher peak at the year of closure and then declines more rapidly. For anaerobic bioreactors, CH_4 generation rates typically increase 200-250% (Pichtel, 2005). Since LFG is generated more rapidly and the CH_4 concentration in LFG is greater for bioreactor landfills, the gas can be collected and sold for energy recovery earlier than non-bioreactor landfills. To account for accelerated LFG generation and ultimately mitigate GHG emissions from bioreactors, the National Emission Standards for Hazardous Air Pollutants (NESHAP) for landfills requires installation of the collection system and controls prior to liquids addition (40 CFR 63, Subpart AAAA). It should also be noted that under the NESHAP bioreactors are defined as having a minimum average moisture content of 40% by weight. The NESHAP definition of bioreactors also excludes leachate and LFG condensate.

The feasibility of a bioreactor landfill depends on the landfill characteristics and climate. The potential disadvantages of bioreactor landfills include increased odors, physical instability of the waste mass, liner instability, surface seeps, and landfill fires from air addition. Benefits include increased disposal capacity (i.e., more waste can be placed within a fixed volume of landfill air space), shorter post-closure maintenance periods for LFG and leachate management, and better profiles for energy recovery from LFG.

Due to its high capital cost, the implementation of a bioreactor landfill design is suitable primarily for newer active landfill cells that are equipped with the appropriate lining. For existing landfills, converting conventional landfills to bioreactor landfills would require significant changes in landfill design.

VII. Management Practices

Organic materials account for about 55% of waste currently reaching landfills, primarily consisting of food scraps, yard trimmings, wood, and paper/paperboard (EPA, 2010e). Due to their role as the source of CH_4 in landfills, the diversion of these materials prior to landfilling may be used as a GHG reduction strategy. Diversion methods include composting, recycling, and anaerobic digestion.

Organic waste diversion from landfills prevents CH_4 generation. Methane generation at landfills is reduced proportionally to the amount of organic waste diverted. For example, CH_4 generation at landfills is halved with a 50% organic waste diversion rate. Combining organic waste diversion with a gas collection and control system can further reduce GHG emissions.

Recycling reduces the use of and emissions associated with virgin materials, thus reducing GHG emissions associated with producing the material. Additionally, paper recycling reduces harvesting of trees, thus stabilizing carbon sequestration from forests. According to EPA's Waste Reduction Model (WARM), paper recycling reduces GHG emissions using a lifecycle perspective (EPA, 2010f). There are, however, processing and manufacturing emissions associated with recycling (EPA, 2010e).

Well-managed composting operations facilitate aerobic decomposition. While CH_4 and nitrous oxide (N_2O) emissions result from anaerobic conditions in the compost pile, a large degree of uncertainty exists in quantifying these emissions. Production of CH_4 and N_2O from composting varies greatly and results from several factors including: moisture content, carbon-to-nitrogen ratio, stage of the composting process, and the technology used (e.g. windrows, aerated static piles, and in-vessel). While composting operations may reduce GHG emissions, there are emissions associated with pre-processing and on-site equipment (e.g. windrow turners, screens, and blowers); these emissions vary greatly based on the technology used (EPA, 2010e).

Anaerobic digestion is a process where microorganisms break down organic materials in the absence of oxygen. Organic materials are digested in closed containers, minimizing fugitive GHG emissions. Anaerobic digestion yields two products: biogas and a solid residue that can be used as a soil amendment, which can offset conventional fertilizer production and use. Biogas can be used for electricity generation, fuel, or cogeneration.

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References

Abichou, 2006. *Field Performance of Biocells, Biocovers, and Biofilters to Mitigate Greenhouse Gas Emissions from Landfills*. Abichou, T., et al. Florida Center for Solid and Hazardous Waste Management. March 2006. http://www.floridacenter.org/publications/Abichou%200432028-06.pdf

ATSDR, 2001a. *Landfill Gas Primer – An Overview for Environmental Health Professionals, Chapter 2: Landfill Gas Basics.* Agency for Toxic Substances and Disease Registry (ATSDR). November 2001. http://www.atsdr.cdc.gov/hac/landfill/html/ch2.html

ATSDR, 2001b. *Landfill Gas Primer – An Overview for Environmental Health Professionals, Chapter 5: Landfill Gas Control Measures*. Agency for Toxic Substances and Disease Registry (ATSDR). November 2001. http://www.atsdr.cdc.gov/hac/landfill/html/ch5.html

BAAQMD, 2008. *Greenhouse Gas Mitigation: Landfill Gas and Industrial, Institutional and Commercial Boilers, Steam Generators and Process Heaters*. Bay Area Air Quality Management District (BAAQMD), prepared by URS Corporation. April 2008. http://www.baaqmd.gov/~/media/Files/Planning%20and%20Research/Climate%20Protection%20Program/GHG_Mitigation_Phase2_001.ashx

CCAR, 2009. *General Reporting Protocol. Version 3.1*. California Climate Action Registry (CCAR). January 2009. http://www.climateregistry.org/resources/docs/protocols/grp/GRP_3.1_January2009.pdf

CCTP, 2005. *Technology Options for the Near and Long Term, Section 4.1.2: Conversion of Landfill Gas to Alternative Uses*. U.S. Climate Change Technology Program (CCTP). August 2005. http://www.climatetechnology.gov/library/2005/tech-options/tor2005-412.pdf

CEC, 2003. *California Distributed Energy Resource (DER) Guide, DER Equipment: Fuel Cells*. California Energy Commission (CEC). August 19, 2003. http://www.energy.ca.gov/distgen/equipment/fuel_cells/fuel_cells.html

EPA, 1998a. *Compilation of Air Pollutant Emission Factors (AP-42), 5th Ed., Volume I, Chapter 2.4: Municipal Solid Waste Landfills*. Office of Air Quality Planning and Standards, U.S. EPA. November 1998. http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf

EPA, 1998b. *Emerging Technologies for the Management and Utilization of Landfill Gas*. Office of Research and Development, U.S. EPA. January 1998. http://www.epa.gov/ttn/catc/dir1/etech_pd.pdf

EPA, 1998c. *Demonstration of Fuel Cells to Recover Energy from Landfill Gas: Phase III. Demonstration Tests, and Phase IV. Guidelines and Recommendations*. National Risk Management Research Laboratory, U.S. EPA. March 1998. http://www.epa.gov/nrmrl/pubs/600sr98002/600sr98002.pdf

EPA, 2008a. *Background Information Document for Updating AP42 Section 2.4 for Estimating Emissions from Municipal Solid Waste Landfills.* National Risk Management Research Laboratory, Air Pollution Prevention and Control Division, U.S. EPA. September 2008. http://www.epa.gov/ttn/chief/ap42/ch02/draft/db02s04.pdf

EPA, 2008b. *Clean Energy Strategies for Local Governments, Section 7.4: Landfill Methane Utilization, Draft*. Landfill Methane Outreach Program (LMOP), Climate Change Division, U.S. EPA. December 10, 2008. http://www.epa.gov/statelocalclimate/documents/pdf/7.4_landfill_methane_utilization.pdf

EPA, 2010a. *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009*. Solid Waste and Emergency Response, U.S. EPA. December 2010. http://www.epa.gov/epawaste/nonhaz/municipal/pubs/msw2009-fs.pdf

EPA, 2010b. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*. U.S. EPA. April 2010. http://epa.gov/climatechange/emissions/usinventoryreport.html

EPA, 2010c. *Landfill Gas Energy Project Development Handbook*. Landfill Methane Outreach Program (LMOP), Climate Change Division, U.S. EPA. January 2010. http://epa.gov/lmop/publications-tools/handbook.html

EPA, 2010d. *Landfill Gas Energy Cost Model (LFGcost), Version 2.2*. Landfill Methane Outreach Program (LMOP), Climate Change Division, U.S. EPA. July 2010.

EPA, 2010e. *Waste Diversion as a Greenhouse Gas Control Strategy for Landfills.* EPA Region 9 Air and Waste Divisions, U.S. EPA. September 2010.

EPA, 2010f. *Waste Reduction Model (WARM)*. U.S. EPA. August 2010. http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html

Morales, 2006. *Mitigation of Landfill Methane Emissions from Passive Vents by Use of Oxidizing Biofilters*. Morales, J.J., Florida State University, FAMU/FSU College of Engineering. Fall 2006. http://etd.lib.fsu.edu/theses/available/etd-11102006-114600/unrestricted/JoseMoralesThesis.pdf

NREL, 1998. *Landfill Gas Cleanup for Carbonate Fuel Cell Power Generation*. Steinfeld, G. and R. Sanderson, Energy Research Corporation. National Renewable Energy Laboratory (NREL), U.S. DOE. February 1998. http://www.nrel.gov/docs/legosti/fy98/26037.pdf

Pichtel, 2005. *Waste Management Practices: Municipal, Hazardous, and Industrial*. Pichtel, John. CRC Press. 2005.

Potas, 1993. *Gas Recovery and Utilization from Municipal Solid Waste Landfills*. Potas, T.A., RUST Environment & Infrastructure. American Chemical Society, Division of Fuel Chemistry, National Meeting & Exposition, Chicago. Fall 1993. http://www.anl.gov/PCS/acsfuel/preprint%20archive/Files/38_3_CHICAGO_08-93_0895.pdf

Spokas et al., 2005. *Methane Mass Balance at Three Landfill Sites: What is the Efficiency of Capture by Gas Collection Systems?* Spokas, K., et al. Waste Management. July 29, 2005. http://www.landfillsplus.com/pdf/article.pdf

SWICS, 2009. *Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills*. Solid Waste Industry for Climate Solutions (SWICS), prepared by SCS Engineers. Version 2.2, January 2009. http://www.scsengineers.com/Papers/Sullivan_SWICS_White_Paper_Version_2.2_Final.pdf

Townsend, 2008. *Bioreactor Landfill Operation: A Guide for Development, Implementation, and Monitoring: Version1.0.* Townsend, T., et al. Department of Environmental Engineering Sciences, University of Florida. July 1, 2008. http://www.bioreactor.org/BioreactorFinalReport/FinalReportVOLUME1_10/AttachmentforVOLUME8/Bioreactor_Landfill_OperationV10.pdf

Vargas, 2008. *Introduction to the Future's Energy: Fuel Cells*. Vargas, E., The Chemical Engineers' Resource Page. August 2008. http://www.cheresources.com/fuelcell.shtml

Appendix A

Calculations to Estimate Cost Effectiveness for CO_2e Reduced

Cost effectiveness values in Tables 1 and 4 of this paper were derived from cost effectiveness values in a report published by California's Bay Area Air Quality Management District (BAAQMD, 2008). However, the values contained in the BAAQMD report for energy recovery technologies are in units of dollars per metric ton of CO_2e emissions reduced due to avoided electricity generation at the power plant. The cost effectiveness values from the 2008 BAAQMD report were adjusted to produce cost effectiveness values in units of dollars per metric ton of CO_2e emissions reduced based on the conversion of CH_4 to CO_2, a less potent global warming pollutant. Cost effectiveness values were also generated based on the GHG emission reductions from both the conversion of CH_4 to CO_2 (referred to as direct CO_2e reductions) and the CO_2 emissions avoided from less electricity generated at the power plant (referred to as avoided CO_2e reductions). This appendix details the calculations for both cost effectiveness values. The cost effectiveness values for flares in the BAAQMD report are based on CH_4 destruction because no energy is recovered (i.e., no electricity avoided); therefore, flare cost effectiveness values were used directly from the report.

The BAAQMD report presents a range of cost effectiveness values for each technology to account for different sized landfills (10 acres, 20 acres & 40 acres). The BAAQMD cost effectiveness values for electricity generation technologies do not include costs for the gas collection system.

A.1 Cost Effectiveness Values Based on Direct CO_2e Reductions

The BAAQMD report referenced the California Climate Action Registry's *General Reporting Protocol* for estimating emission reductions from avoided electricity generation. Tables E.1 and E.3 of the *General Reporting Protocol* contain the 2007 California electricity emission factors listed below. It was assumed that these factors, in units of pounds (lb) per megawatt-hour (MWh), were used to estimate avoided emissions from the power plant (CCAR, 2009).

CO_2 electricity emission rate = 878.71 lb/MWh
CH_4 electricity emission rate = 0.0067 lb/MWh
N_2O electricity emission rate = 0.0037 lb/MWh

To determine the total amount of CO_2e reduced from avoided electricity generation, global warming potentials were applied to the CH_4 and N_2O emission rates. The consolidated CO_2e emission rate was calculated as follows:

Overall CO_2e electricity emission rate = (878.71) + (0.0067 x 21) + (0.0037 x 310)
= 880 lb CO_2e/MWh

The BAAQMD report utilized LMOP's LFGcost software (EPA, 2010c). To properly adjust the cost effectiveness values, fuel use rates and efficiencies for each electricity generation technology from LFGcost were used. These default values are provided in Table A-2.

Table A-2. LFGcost Fuel Use Rates and Efficiencies for LFG Electricity Generation Technologies

LFG Technology	Fuel Use Rate (Btu/kWh generated)	Efficiency (%)
Engine	11,250	93
Turbine	13,000	88
Microturbine	14,000	83
Small Engine	18,000	92
CHP Engine	11,250	93
CHP Turbine	13,000	88
CHP Microturbine	14,000	83

Source: EPA, 2010c

The example calculation outlined below is for the low value of the cost effectiveness range for engines ($122 per metric ton (MT) of CO_2e avoided). The first step is to use the overall CO_2e electricity emission rate to convert the cost effectiveness value from dollars per metric ton of CO_2e avoided to dollars per amount of electricity produced (in units of MWh), as follows:

($122/metric ton CO_2e) x (metric ton/2205 lb) x (880 lb CO_2e/MWh) = $48.7 per MWh

The second step is to use the appropriate fuel use rate and efficiency from Table 2 and the heat content and density of CH_4 to calculate the cost in terms of dollars per metric ton of CH_4 produced by the landfill, as follows:

($48.7/MWh) x (MWh/1000 kWh) x (kWh/11,250 Btu) x 0.93 x (1012 Btu/ft^3 CH_4) x
(ft^3 CH_4/0.0423 lb CH_4) x (2205 lb/metric ton) = $212 per metric ton CH_4

The next step is to calculate the amount of CO_2e reduced from the conversion of CH_4 to CO_2. The global warming potential of CH_4 is 21, which is used to express the amount of CH_4 destroyed in terms of CO_2e. The amount of CO_2 generated from the combustion of CH_4 must be subtracted from the amount of CH_4 destroyed using a mass balance method to result in an accurate measure of CO_2e reduced. The overall CO_2e reduced is calculated as:

CO_2e reduced = (CH_4 destroyed as CO_2e) - (CO_2 generated by CH_4 combustion)
CO_2e reduced = (21 metric tons CO_2e/metric ton CH_4) - (44 metric tons CO_2/16 metric tons CH_4)
CO_2e reduced = 18.25 metric tons CO_2e per metric ton CH_4

Lastly, the dollars per metric ton of CH_4 produced by the landfill are divided by the overall CO_2e reduced to estimate the cost effectiveness values in terms of dollars per metric ton of direct CO_2e reduced, as follows:

Adjusted cost effectiveness = ($212/metric ton CH_4) x (metric ton CH_4/18.25 metric tons CO_2e)
Adjusted cost effectiveness = $12 per metric ton direct CO_2e reduced

Tables 1 and 4 in the main section of this paper contain the adjusted cost effectiveness values for direct CO_2e reduced for all seven electricity generation technologies.

A.2 Cost Effectiveness Values Based on Direct and Avoided CO_2e Reductions

The original cost effectiveness values in the 2008 BAAQMD report represent avoided CO_2e reductions and the adjusted cost effectiveness values, as discussed in section A.1, represent direct CO_2e reductions. Therefore, the calculation of cost effectiveness values that represent both direct and avoided CO_2e reductions can be accomplished using the original and adjusted cost effectiveness values. The derivation of the equation used to determine cost effectiveness values in units of dollars per metric ton of direct and avoided CO_2e reductions is as follows:

$/D = $ per metric ton of direct CO_2e reduced
$/A = $ per metric ton of avoided CO_2e reduced
$/(D+A) = $ per metric ton of direct and avoided CO_2e reduced

$/(D+A) = ($/A) / ((D+A)/A) = ($/A) / ((D/A) + (A/A)) = ($/A) / ((D/A) + 1)
$/(D+A) = ($/A) / (($/A)/($/D) + 1)

Using the example calculation for the low cost effectiveness value for engines from section A.1, the cost effectiveness value for direct and avoided CO_2e reduced is calculated as:

$/D = $12/metric ton of direct CO_2e reduced
$/A = $122/metric ton of avoided CO_2e reduced

$/(D+A) = ($122/metric ton) / (($122/metric ton)/($12/metric ton) + 1) = $11/metric ton

Cost effectiveness for direct & avoided CO_2e reduced = $11 per metric ton of CO_2e reduced

Table 4 in the main section of this paper contains the cost effectiveness values for direct and avoided CO_2e reduced for all seven electricity generation technologies.