

Technical note: Ffridd Rasmus Landfill Site - Air Emissions Screening Assessment

1. Introduction

Ffridd Rasmus Landfill ('the site') is located approximately 3 km north of Harlech at National Grid Reference (NGR) SH577338. The site is operated by Gwynedd Council and comprises Areas 1, 2 and 3. Area 1 has not been subject to waste disposal, Area 2 is an unlined landfill in its aftercare phase and Area 3 is an engineered landfill, which has been capped. Area 2 is regulated under the conditions of Environmental Permit (EP) ref: PP3294FJ/V008 (dated 21 May 2013) and Area 3 is regulated under the conditions of EP ref: GP3330BY.

The site ceased accepting waste in January 2014, capping was completed in April 2014 and the site entered definitive closure in April 2016. Landfill gas is currently managed by collection through an extraction system and combusted in a 500 m³/hour high temperature enclosed flare. Gwynedd Council now wish to utilise the landfill gas extracted and propose to install a 50kW gas micro turbine at the site. An application to vary the EP is required to include the micro turbine as a directly associated activity. The landfill gas flare will be retained as a backup management technique. In consultation with Natural Resources Wales (NRW), it is considered the application is a 'normal variation' and should be supported by an Air Quality Assessment.

This technical note has been produced in support of the variation application setting out a 'stage 1' air quality screening assessment for the proposed micro turbine and the flare to demonstrate emissions will be 'insignificant'.

2. Methodology

The assessment has been produced using the Environment Agency guidance 'Air emissions risk assessment for your environmental permit' (dated 2 August 2016 - <https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit>) and in accordance with the guidance provides calculations of the Process Contribution (PC) for Nitrogen Dioxide (NO₂), Carbon Monoxide (CO) and VOCs (100% benzene) for both the gas engine and the flare to determine if the emissions can be screened out as insignificant.

Air emissions are considered to be insignificant if:

- ▶ Maximum Process Contribution (short-term) ≤ 10% of the short-term Environmental Assessment Level (or Environmental Quality Standard); and
- ▶ Maximum Process Contribution (long-term) ≤ 1% of the long-term Environmental Assessment Level (or Environmental Quality Standard).

The environmental standards for both NO₂ and CO are provided in Table 2.1 and taken from the above EA guidance.

Table 2.1 Relevant Environmental Standards

Substance	Emission period	Limit (average)	Standard
Nitrogen dioxide	1 hour	200 micrograms per cubic metre	AAD Limit Value
Nitrogen dioxide	Annual	40 micrograms per cubic metre	AAD Limit Value
Carbon monoxide	8 hour running average across a 24 hour period	10 milligrams per cubic metre	AAD Limit Value
VOC (Benzene)	1 hour	195 micrograms per cubic metre	EAL
VOC (Benzene)	Annual	5 micrograms per cubic metre	AAD Limit Value

3. Process Contribution (PC)

The first step in the air emissions risk assessment is to calculate the environmental concentration of each substance released into the air, known as the process contribution (PC). This has been done for emissions from both the micro turbine and the landfill gas flare and these are considered separately as the flare will not be in operation when the micro turbine is.

Landfill Gas Micro Turbine

Both the short term and the long term PC to air are calculated for Nitrogen Dioxide and Benzene (VOC) and the short term PC for Carbon Monoxide.

The dispersion rates and the environmental standards for air emissions are taken from the EA guidance. As the height of the micro turbine including the stack is 2.65m, the effective height of release of 0m from the table has been used. The release rates for emissions of Nitrogen Oxides, Carbon Monoxide and VOCs have been determined from the Technical Specification reference document provided by equipment supplier. A copy is provided at Appendix A. The results are shown in Table 3.1 and the calculations are provided at Appendix B.

Table 3.1 Process Contribution from the landfill gas micro turbine

Determinant	Release rate (g/s)	Process Contribution (ug/m3)	Environmental Standard (ug/m3)	Process Contribution (%)
Short Term				
NO ₂ (short term)*	0.0038	0.05	200	0.03
VOC (short term)	0.0008	0.65	195	0.33
CO (short term)**	0.0328	18.1	10,000	0.18
Long Term				
NO ₂ (long term)	0.0038	0.094	40	0.24
VOC (long term)	0.0008	0.02	5	0.41

* EA guidance assumes 50% NO_x convert to NO₂ in the environment for short term. PC divided by 50 – see calculations in Appendix B

** Multiplied by 0.7 to give 8 hour average as specified in guidance

From the table it can be seen that the worst case NO₂, VOC and CO emissions from the micro turbine will be less than 10% of the respective short term standard and for NO₂ and VOC are less than 1% of the respective long term standard.

Landfill Gas Flare

The flare is existing at the site and will serve as a backup only. Based on site monitoring data for the flare for the period 2012 to 2016, the average down time has been 1% so we have assumed that the landfill gas turbine will be operating for 99% of the time and the landfill gas flare for 1% of the time.

Again, both the short term and the long term PC to air are calculated for Nitrogen Dioxide and Benzene (VOC) and the short term PC for Carbon Monoxide.

The dispersion rates and the environmental standards for air emissions are taken from the EA guidance. The height of the stack is 7.85m so the effective height of release of 8m from the table has been used. The release rates for emissions of Nitrogen Dioxide, VOC and Carbon Monoxide have been calculated from the latest flare monitoring report provided by Exova Catalyst (CAT-2599, 20th April 2016) and site data on flare flow rates for 2016. The results are shown in Table 3.2 and the calculations are provided at Appendix B.

Table 3.2 Process Contribution from landfill gas flare

Determinant	Release rate (g/s)	Process Contribution (ug/m3)	Process Contribution (ug/m3) for 1% operational time	Environmental Standard	Process Contribution (%)
Short Term					
NO ₂	0.004	0.57	0.006	200	0.0029
VOC	0.00002	0.0024	0.000024	195	0.000012
CO*	0.00001	0.001	0.00001	10,000	0.0000001
Long Term					
NO ₂	0.004	0.023	0.00023	40	0.00057
VOC	0.00002	0.0001	0.000001	5	0.00002

* Multiplied by 0.7 to give 8 hour average as specified in guidance

From the table it can be seen that NO₂, VOC and CO emissions from the landfill gas flare operating for 1% of the time will be less than 10% of the respective short term standard and less than 1% of the respective long term standard for NO₂ and VOC.

4. Conclusion

It has been determined that the PC of NO₂, VOC and CO emissions from both the micro turbine and the landfill gas flare (assumed to be operating for 1% of the time) have been screened out as insignificant and no further assessment is required.



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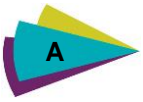
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Appendix A Capstone Technical Reference



Technical Reference

Capstone MicroTurbine™ Systems Emissions

Summary

Capstone MicroTurbine™ systems are inherently clean and can meet some of the strictest emissions standards in the world. This technical reference is to provide customers with information that may be requested by local air permitting organizations or to compare air quality impacts of different technologies for a specific project. The preferred units of measure are “output based”; meaning that the quantity of a particular exhaust emission is reported relative to the useable output of the microturbine – typically in pounds per megawatt hour for electrical generating equipment. This technical reference also provides volumetric measurements in parts per million and milligrams per normal cubic meter. A conversion between several common units is also provided.

Maximum Exhaust Emissions at ISO Conditions

Table 1 below summarizes the exhaust emissions at full power and ISO conditions for different Capstone microturbine models. Note that the fuel can have a significant impact on certain emissions. For example landfill and digester gas can be made up of a wide variety of fuel elements and impurities, and typically contains some percentage of carbon dioxide (CO₂). This CO₂ dilutes the fuel, makes complete combustion more difficult, and results in higher carbon monoxide emissions (CO) than for pipeline-quality natural gas.

Table 1. Emission for Different Capstone Microturbine Models in [lb/MWhe]

Model	Fuel	NOx	CO	VOC ⁽⁵⁾
C30 NG	Natural Gas ⁽¹⁾	0.64	1.8	0.23
CR30 MBTU	Landfill Gas ⁽²⁾	0.64	22.0	1.00
CR30 MBTU	Digester Gas ⁽³⁾	0.64	11.0	1.00
C30 Liquid	Diesel #2 ⁽⁴⁾	2.60	0.41	0.23
C65 NG Standard	Natural Gas ⁽¹⁾	0.46	1.25	0.10
C65 NG Low NOx	Natural Gas ⁽¹⁾	0.17	1.30	0.10
C65 NG CARB	Natural Gas ⁽¹⁾	0.17	0.24	0.05
CR65 Landfill	Landfill Gas ⁽²⁾	0.46	4.0	0.10
CR65 Digester	Digester Gas ⁽³⁾	0.46	4.0	0.10
C200 NG	Natural Gas ⁽¹⁾	0.40	1.10	0.10
C200 NG CARB	Natural Gas ⁽¹⁾	0.14	0.20	0.04
CR200 Digester	Digester Gas ⁽³⁾	0.40	3.6	0.10

Notes:

- (1) Emissions for standard natural gas at 1,000 BTU/scf (HHV) or 39.4 MJ/m³ (HHV)
- (2) Emissions for surrogate gas containing 42% natural gas, 39% CO₂, and 19% Nitrogen
- (3) Emissions for surrogate gas containing 63% natural gas and 37% CO₂
- (4) Emissions for Diesel #2 according to ASTM D975-07b
- (5) Expressed as Methane

Table 2 provides the same output-based information shown in Table 1, but expressed in grams per horsepower hour (g/hp-hr).

Table 2. Emission for Different Capstone Microturbine Models in [g/hp-hr]

Model	Fuel	NOx	CO	VOC ⁽⁵⁾
C30 NG	Natural Gas ⁽¹⁾	0.22	0.60	0.078
CR30 MBTU	Landfill Gas ⁽²⁾	0.22	7.4	0.340
CR30 MBTU	Digester Gas ⁽³⁾	0.22	3.7	0.340
C30 Liquid	Diesel #2 ⁽⁴⁾	0.90	0.14	0.078
C65 NG Standard	Natural Gas ⁽¹⁾	0.16	0.42	0.034
C65 NG Low NOx	Natural Gas ⁽¹⁾	0.06	0.44	0.034
C65 NG CARB	Natural Gas ⁽¹⁾	0.06	0.08	0.017
CR65 Landfill	Landfill Gas ⁽²⁾	0.16	1.4	0.034
CR65 Digester	Digester Gas ⁽³⁾	0.16	1.4	0.034
C200 NG	Natural Gas ⁽¹⁾	0.14	0.37	0.034
C200 NG CARB	Natural Gas ⁽¹⁾	0.05	0.07	0.014
CR200 Digester	Digester Gas ⁽³⁾	0.14	1.3	0.034

Notes: - same as for Table 1

Emissions may also be reported on a volumetric basis, with the most common unit of measurement being parts per million. This is typically a measurement that is corrected to specific oxygen content in the exhaust and without considering moisture content. The abbreviation for this unit of measurement is “ppmvd” (parts per million by volume, dry) and is corrected to 15% oxygen for electrical generating equipment such as microturbines. The relationship between an output based measurement like pounds per MWh and a volumetric measurement like ppmvd depends on the characteristics of the generating equipment and the molecular weight of the criteria pollutant being measured. Table 3 expresses the emissions in ppmvd at 15% oxygen for the Capstone microturbine models shown in Table 1. Note that raw measurements expressed in ppmv will typically be lower than the corrected values shown in Table 3 because the microturbine exhaust has greater than 15% oxygen.

Another volumetric unit of measurement expresses the mass of a specific criteria pollutant per standard unit of volume. Table 4 expresses the emissions in milligrams per normal cubic meter at 15% oxygen. Normal conditions for this purpose are expressed as one atmosphere of pressure and zero degrees Celsius. Note that both the ppmvd and mg/m³ measurements are for specific oxygen content. A conversion can be made to adjust either unit of measurement to other reference oxygen contents, if required. Use the equation below to convert from one reference oxygen content to another:

$$\text{Emissions at New O}_2 = \frac{(20.9 - \text{New O}_2 \text{ Percent})}{(20.9 - \text{Current O}_2 \text{ Percent})} \times \text{Emissions at Current O}_2$$

For example, to express 9 ppmvd of NOx at 15% oxygen to ppmvd at 3% oxygen:

$$\text{Emissions at 3\% O}_2 = \frac{(20.9 - 3.0)}{(20.9 - 15.0)} \times 9 = 27 \text{ ppmvd}$$

Table 3. Emission for Different Capstone Microturbine Models in [ppmvd] at 15% O₂

Model	Fuel	NOx	CO	VOC
C30 NG	Natural Gas ⁽¹⁾	9	40	9
CR30 MBTU	Landfill Gas ⁽²⁾	9	500	40
CR30 MBTU	Digester Gas ⁽³⁾	9	250	40
C30 Liquid	Diesel #2 ⁽⁴⁾	35	9	9
C65 NG Standard	Natural Gas ⁽¹⁾	9	40	7
C65 NG Low NOx	Natural Gas ⁽¹⁾	4	40	7
C65 NG CARB	Natural Gas ⁽¹⁾	4	8	3
CR65 Landfill	Landfill Gas ⁽²⁾	9	130	7
CR65 Digester	Digester Gas ⁽³⁾	9	130	7
C200 NG	Natural Gas ⁽¹⁾	9	40	7
C200 NG CARB	Natural Gas ⁽¹⁾	4	8	3
CR200 Digester	Digester Gas ⁽³⁾	9	130	7

Notes: same as Table 1

Table 4. Emission for Different Capstone Microturbine Models in [mg/m³] at 15% O₂

Model	Fuel	NOx	CO	VOC ⁽⁵⁾
C30 NG	Natural Gas ⁽¹⁾	18	50	6
CR30 MBTU	Landfill Gas ⁽²⁾	18	620	30
CR30 MBTU	Digester Gas ⁽³⁾	18	310	30
C30 Liquid	Diesel #2 ⁽⁴⁾	72	11	6
C65 NG Standard	Natural Gas ⁽¹⁾	19	50	5
C65 NG Low NOx	Natural Gas ⁽¹⁾	8	50	5
C65 NG CARB	Natural Gas ⁽¹⁾	8	9	2
CR65 Landfill	Landfill Gas ⁽²⁾	18	160	5
CR65 Digester	Digester Gas ⁽³⁾	18	160	5
C200 NG	Natural Gas ⁽¹⁾	18	50	5
C200 NG CARB	Natural Gas ⁽¹⁾	8	9	2
CR200 Digester	Digester Gas ⁽³⁾	18	160	5

Notes: same as Table 1

The emissions stated in Tables 1, 2, 3 and 4 are guaranteed by Capstone for new microturbines during the standard warranty period. They are also the expected emissions for a properly maintained microturbine according to manufacturer's published maintenance schedule for the useful life of the equipment.

Emissions at Full Power but Not at ISO Conditions

The maximum emissions in Tables 1, 2, 3 and 4 are at full power under ISO conditions. These levels are also the expected values at full power operation over the published allowable ambient temperature and elevation ranges.

Emissions at Part Power

Capstone microturbines are designed to maintain combustion stability and low emissions over a wide operating range. Capstone microturbines utilize multiple fuel injectors, which are switched on or off depending on the power output of the turbine. All injectors are typically on when maximum power is demanded, regardless of the ambient temperature or elevation. As the load requirements of the microturbine are decreased, injectors will be switched off to maintain stability and low emissions. However, the emissions relative to the lower power output may increase. This effect differs for each microturbine model.

Emissions Calculations for Permitting

Air Permitting agencies are normally concerned with the maximum amount of a given pollutant being emitted per unit of time (for example pounds per day of NO_x). The simplest way to make this calculation is to use the maximum microturbine full electrical power output (expressed in MW) multiplied by the emissions rate in pounds per MWh times the number of hours per day. For example, the C65 CARB microturbine operating on natural gas would have a NO_x emissions rate of:

$$\text{NO}_x = .17 \times (65/1000) \times 24 = .27 \text{ pounds per day}$$

This would be representative of operating the equipment full time, 24 hours per day, at full power output of 65 kWe.

As a general rule, if local permitting is required, use the published agency levels as the stated emissions for the permit and make sure that this permitted level is above the calculated values in this technical reference.

Consideration of Useful Thermal Output

Capstone microturbines are often deployed where their clean exhaust can be used to provide heating or cooling, either directly or using hot water or other heat transfer fluids. In this case, the local permitting or standards agencies will usually consider the emissions from traditional heating sources as being displaced by the useful thermal output of the microturbine exhaust energy. This increases the useful output of the microturbine, and decreases the relative emissions of the combined heat and power system. For example, the CARB version C65 ICHP system with integral heat recovery can achieve a total system efficiency of 70% or more, depending on inlet water temperatures and other installation-specific characteristics. The electric efficiency of the CARB version C65 microturbine is 28% at ISO conditions. This means that the total NO_x output based emissions, including the captured thermal value, is the electric-only emissions times the ratio of electric efficiency divided by total system efficiency:

$$\text{NO}_x = .17 \times 28/70 = .068 \text{ pounds per MWh (based on total system output)}$$

This is typically much less than the emissions that would result from providing electric power using traditional central power plants, plus the emissions from a local hot water heater or boiler. In fact microturbine emissions are so low compared with traditional hot water heaters that installing a Capstone microturbine with heat recovery can actually decrease the local emissions of NO_x and other criteria pollutants, without even considering the elimination of emissions from a remote power plant.

Greenhouse Gas Emissions

Many gasses are considered “greenhouse gasses”, and agencies have ranked them based on their global warming potential (GWP) in the atmosphere compared with carbon dioxide (CO₂), as well as their ability to maintain this effect over time. For example, methane is a greenhouse gas with a GWP of 21. Criteria pollutants like NO_x and organic compounds like methane are monitored by local air permitting authorities, and are subject to strong emissions controls. Even though some of these criteria pollutants can be more troublesome for global warming than CO₂, they are released in small quantities – especially from Capstone microturbines. So the major contributor of concern is carbon dioxide, or CO₂. Emission of CO₂ depends on two things:

1. Carbon content in the fuel
2. Efficiency of converting fuel to useful energy

It is for these reasons that many local authorities are focused on using clean fuels (for example natural gas compared with diesel fuel), achieving high efficiency using combined heat and power systems, and displacing emissions from traditional power plants using renewable fuels like waste landfill and digester gasses.

Table 5 shows the typical CO₂ emissions due to combustion for different Capstone microturbine models at full power and ISO conditions. The values do not include CO₂ that may already exist in the fuel itself, which is typical for renewable fuels like landfill and digester gas. These values are expressed on an output basis, as is done for criteria pollutants in Table 1. The table shows the pounds per megawatt hour based on electric power output only, as well as considering total useful output in a CHP system with total 70% efficiency (LHV). As for criteria pollutants, the relative quantity of CO₂ released is substantially less when useful thermal output is also considered in the measurement.

Table 5. CO₂ Emission for Capstone Microturbine Models in [lb/MWh]

Model	Fuel	CO ₂	
		Electric Only	70% Total CHP
C30 NG	Natural Gas ⁽¹⁾	1,690	625
CR30 MBTU	Landfill Gas ⁽¹⁾	1,690	625
CR30 MBTU	Digester Gas ⁽¹⁾	1,690	625
C30 Liquid	Diesel #2 ⁽²⁾	2,400	855
C65 NG Standard	Natural Gas ⁽¹⁾	1,520	625
C65 NG Low NO _x	Natural Gas ⁽¹⁾	1,570	625
C65 NG CARB	Natural Gas ⁽¹⁾	1,570	625
CR65 Landfill	Landfill Gas ⁽¹⁾	1,520	625
CR65 Digester	Digester Gas ⁽¹⁾	1,520	625
C200 NG	Natural Gas ⁽¹⁾	1,330	625
C200 NG CARB	Natural Gas ⁽¹⁾	1,330	625
CR200 Digester	Digester Gas ⁽¹⁾	1,330	625

Notes:

(1) Emissions due to combustion, assuming natural gas with CO₂ content of 117 lb/MMBTU (HHV)

(2) Emissions due to combustion, assuming diesel fuel with CO₂ content of 160 lb/MMBTU (HHV)

Useful Conversions

The conversions shown in Table 6 can be used to obtain other units of emissions outputs. These are approximate conversions.

Table 6. Useful Unit Conversions

From	Multiply By	To Get
lb/MWh	0.338	g/bhp-hr
g/bhp-hr	2.96	lb/MWh
lb	0.454	kg
kg	2.20	lb
kg	1,000	g
hp (electric)	.746	kW
kW	1.34	hp (electric)
MW	1,000	kW
kW	0.001	MW

Definitions

- ISO conditions are defined as: 15 °C (59 °F), 60% relative humidity, and sea level pressure of 101.3 kPa (14.696 psia).
- HHV: Higher Heating Value
- LHV: Lower Heating Value
- kW_{th}: Kilowatt (thermal)
- kW_e : Kilowatt (electric)
- MWh: Megawatt-hour
- hp-hr: horsepower-hour (sometimes referred to as “electric horsepower-hour”)
- Scf: Standard cubic foot (standard references ISO temperature and pressure)
- m³: Normal cubic meter (normal references 0 °C and one atmosphere pressure)

Capstone Contact Information

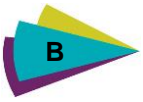
If questions arise regarding this technical reference, please contact Capstone Turbine Corporation for assistance and information:

Capstone Applications

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Appendix B Calculations

Determination of emission rates in grams/second

	Max microturbine		Emission rate				Emission rate (g/s)
	Emission Rate (lb/Mwhe)*	full electrical output (MW)	hours/day	Emission rate per day (lb)	Emission rate per day (kg/day)	Emission rate per day (g)	
NOx	0.46	0.065	24	0.7176	0.3257904	325.7904	0.0038
CO	4	0.065	24	6.24	2.83296	2832.96	0.0328
VOCs	0.1	0.065	24	0.156	0.070824	70.824	0.0008

GAS ENGINE

Short Term Calculations

	Emission rate (g/s)	Dispersion factor**	PC (µg/m3)	PC - NOx converted to NO2 (50%)	8hour average conversion	EAL (µg/m3)	%of EAL	<10%
NOx***	0.0038	790	2.978870556	0.05957741		200	0.03	✓
CO	0.0328	790	25.90322222		18.13225556	10000	0.18	✓
VOC****	0.0008	790	0.647580556			195	0.33	✓

Long Term Calculations

	Emission rate (g/s)	Dispersion factor**	PC (µg/m3)	EAL (µg/m3)	%of EAL	<1%
NOx	0.0038	25	0.094268056	40	0.24	✓
VOC	0.0008	25	0.020493056	5	0.41	✓

* Data from Table 1 of Capstone Technical reference document

** Taken from EA guidance for gas engines

*** EA guidances assumes 50% NOx converted to NO₂ for short term

**** EA guidance assume VOC 100% benzene

Determination of emission rates in grams/second

	Concentration (mg/m3)*	Average hourly flow rate (m3/hr)**	Flow rate (m3/s)	Release rate (g/s)
NO2	130	113	0.0316	0.00411
CO	0.46	113	0.0316	0.00001
VOC	0.55	113	0.0316	0.00002

FLARE

Short Term Calculations

	Emission rate (g/s) *****	Dispersion factor**	PC (µg/m3)	8hour average conversion	PC (ug/m3) 1% operational time	EAL (µg/m3)	%of EAL	<10%
NOx	0.00411	140	0.575848		0.00575848	200	0.0028792	✓
CO	0.00001	140	0.002037616	0.001426331	0.000014	10000	0.0000001	✓
VOC****	0.00002	140	0.00243628		0.000024	195	0.0000125	✓

Long Term Calculations

	Emission rate (g/s)	Dispersion factor**	PC (µg/m3)	PC (ug/m3) 1% operational time	EAL (µg/m3)	%of EAL	<1%
NOx	0.00411	5.5	0.0226226	0.000226226	40	0.00057	✓
VOC	0.00002	5.5	0.000095711	0.00000096	5	0.00002	✓

* Data from flare monitoring report provided by Exova Catalyst (CAT-2599, 20th April 2016)

** Data supplied by Gwynedd Council. Aaverage hourly flow based on site data for 2016