DEPARTMENT OF
ECOLOGY
State of Washington

Technical Support Document for Dairy Manure Anaerobic Digester Systems with Digester Gas Fueled Engine Generators

General Order of Approval
No. 12AQ-GO-01

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1. SUMMARY

The General Order of Approval supported by this Support Document provides for the simplified permitting of dairy manure anaerobic digester systems that meet the exemption from solid waste permitting contained in RCW 70.95.330. Under the terms of the Proposed General Order, a dairy manure anaerobic digester system could be installed to serve almost all dairy operations in counties under the jurisdiction of the Department of Ecology.

This General Order is limited to the engine generators and flares installed on dairy manure anaerobic digester systems that comply with the solid waste permit exemption and are designed to produce between 20,000 and 400,000 cu. ft./day of digester gas. Based on the current thresholds in WAC 173-400-110(45), dairy manure anaerobic digester systems that are designed to produce digester gas at or below 20,000 cu. ft./day are exempt from permitting. A dairy with approximately 140 or fewer animals would likely produce biogas below this limit. Based on the dairy herd size information available from the Washington Department of Agriculture, of the 443 dairies in Washington, there are 16 individual dairies that could produce digester gas at a rate above the upper digester size limitation of this General Order. Therefore, this General Order is capable of covering the majority of potential dairy manure anaerobic digesters across the state of Washington provided that the anaerobic digester facilities meet the other requirements (e.g. the digester meets the solid waste permit exemption, the biogas is combusted in a reciprocating internal combustion engine, etc.) and the General Order is adopted for use by all local authorities in Washington.

The General Order sets out emission point location and height requirements, engine-generator emission criteria, flare criteria, and requires the prevention of odors from non-manure waste usage. All emission limitations included in the General Order have been met in practice by one or more dairy manure anaerobic digester systems currently in operation in Washington or match performance guarantees provided to Washington system owners from engine–generator manufacturers.

Ecology intends to review the criteria for this General Order no later than five years after it is issued in order to make changes to the requirements reflecting changes in regulations, ambient air quality standards, system designs, and available and installed emission controls. If a revised General Order for dairy manure anaerobic digester systems is issued in the future, systems permitted under this initial General Order do not have to comply with the requirements of the revised Order, just the version in place when the system is permitted.

The five main elements of this Technical Support Document (TSD) are: (1) A description of the emission source, (2) Applicable emission control regulations, (3) Best Available Control Technology (BACT) review, (4) Emissions, (5) Ambient impacts analysis, (6) Proposed Emission limitation and siting criteria, and (8) Conclusion.

2. DESCRIPTION OF THE EMISSION SOURCE

The basic system involves an anaerobic digester producing biogas that is combusted in an engine-generator that produces electricity for sale or farm use, plus hot water for digester heating and other uses. The digester is supplied with manure from the dairy and other organic materials which may come from the farm or from offsite. The digester produces a biologically-generated "bio" gas containing methane (CH_4), carbon dioxide (CO_2), hydrogen sulfide (H_2S), water, and trace gases[1].

Anaerobic digesters are commonly used in the wastewater treatment industry to stabilize waste organic sludges (biosolids) and recover CH_4. Anaerobic digesters take many forms ranging from simple tanks in the ground that generate CH_4 for cooking and heating for a single household or small village, to sophisticated egg shaped mechanically mixed systems used at major wastewater treatment plants[2]. In spite of the various levels of sophistication, anaerobic digesters fall into one of two design types, either plug flow or complete mix.

In general, the simplest and most common designs for both the complete mix and plug flow digesters will result in the same hydraulic retention time (HRT) and overall volume. However, even within this common feature, some designs will result in lower HRTs due to more easily stabilized substrates or the ability to recycle digester solids to increase the solids retention time (SRT) of the digester system. At a given HRT, a longer SRT usually results in more complete stabilization of the digestate produced. At dairies, it is possible for a manure digester to be comprised of a single covered anaerobic lagoon, with no mixing. An anaerobic lagoon functions as neither a plug flow nor a complete mix system. Anaerobic lagoons are usually operated at ambient temperature and are relatively inefficient at stabilizing manure introduced to them.

In common design practice, the SRT and HRT are both adjusted to provide a final design which minimizes construction cost and digester volume while maximizing SRT to achieve the highest possible digester gas production and volatile solids (VS) destruction[3]. For a complete mix system, the minimum recommended HRT is 15 - 17 days. With solids recycling, the HRT can be reduced while still maintaining the appropriate SRT and VS destruction.

Digesters of either design can operate at psychrophilic (ambient), mesophilic (95 – 105°F), or thermophilic (125 – 135°F) temperatures. Ambient temperature digesters (commonly covered lagoons) can be used in warm climates (central California, southern Texas, or the Tropics); although more complete digestion and waste stabilization can occur through the use of mesophilic digesters in these areas. In locations with lower ambient temperatures, such as the middle and high latitudes, mesophilic or thermophilic designs are required for efficient gas production.

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[1] Known trace gases include ammonia, ethane, and other reduced sulfur compounds

[2] Dairy Waste Anaerobic Digestion Handbook by Dennis A. Burke, PE, Environmental Energy Company, June 2001,

[3] Dairy Waste Anaerobic Digestion Handbook by Dennis A. Burke, PE, Environmental Energy Company, June 2001, Pages 20 – 23,

Complete Mix Digesters
In a complete mix digester, new waste material is completely mixed with the materials already in the digester.

Examples of complete mix digesters are shown in Figure 1. The system may be made of a single tank, two tanks in series, or multiple tanks. In systems with two tanks in series, the first tank is commonly used to keep the solids in suspension and maximize the contact time between the incoming waste and the anaerobic microorganisms that do the work of producing biogas. This mixing, which may be continuous or intermittent, increases the effectiveness of the microbial digestion of available VS[4] to more efficiently and effectively produce biogas. It also stabilizes the digestate more than plug flow or lagoon systems. Feeding of the digester can be either continuous or intermittent. The solids content of the digester feed is normally in the range of 2 – 10% solids. The new feed to the digester displaces the same volume to the second stage, or in single stage systems, to dewatering and final disposal.

The second tank in a two tank system is unmixed. Its primary purpose is to allow the digester gas to rise to the liquid surface to be collected for use. The flow from the primary digester is sent to the secondary digester where an equal volume of material is displaced from the tank.

Complete mix systems are normally constructed above ground. They are constructed of reinforced concrete or steel, externally insulated, and heated by an engine-generator or boiler fired by digester gas. The digester gas may or may not be treated to remove water or H_2S prior to use in the boiler. If left untreated, the combustion device must be built of corrosion resistant metals. Digester heating in a complete mix system at municipal wastewater treatment plants often uses a spiral heat exchanger to avoid plugging and maximize heat transfer to the digester contents. Since the heat exchanger in this type of system is external to the digester, maintenance of the heat exchanger can be done without taking the digester completely out of service.

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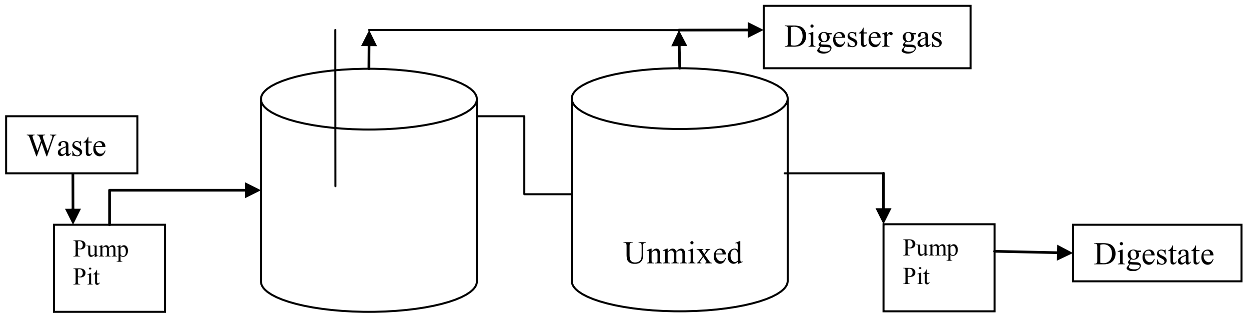
[4] Volatile solids are the primary food for the microorganisms that produce the methane in an anaerobic digester. Anaerobic digester designs focus on maximizing volatile solids reduction, which results in maximum digester gas (biogas) production.

Figure 1: Complete Mix system Schematic



Plug Flow Digesters

In the plug flow digester system design, the digester feed is introduced at one end of a long chamber. These are among the simplest digesters to install and operate.
An example of a plug flow digester is shown in Figure 2. The new feed is heated after it enters the digester and as needed along the length of the flow path. A plug flow digester can be fed continuously or intermittently. The feed to a plug flow digester should be mixed prior to its introduction to the digester. If pre-consumer food wastes are used in a plug flow digester system, they need to be mixed with manure prior to introducing to the digester to prevent adverse effects on the digester system. Ideally the solids content of the feed to a plug flow digester should be higher than in a complete mix system and may be in the 10 – 13% solids range. Thicker materials can be diluted with more liquid materials (like milk parlor wastes) to the acceptable range. Some plug flow digester designs, such as the partial mix plug flow design, include mechanical mixing of the digester contents to reduce solids settling on the floor of the digester.

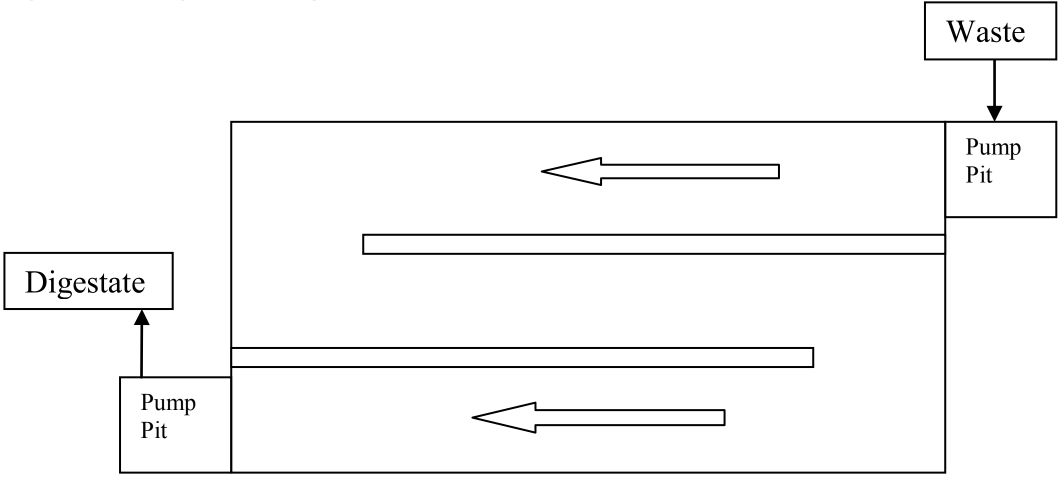
The fresh waste introduced to the digester displaces an equal volume of digestate from the other end of the system. As with the complete mix system this digestate needs to be properly treated and disposed in conformance with other environmental and health protection laws and regulations.

Plug flow systems are commonly built completely or partially underground of reinforced concrete. The concrete is insulated with foam on the outside of the tank and the tank is backfilled against the foam. Heat transfer piping is placed along the walls of the digester tank to heat the digester. The plug flow digester is covered with an impervious membrane to collect the biogas that is produced by microbial digestion of the waste.

In contrast to a complete mix system, little or no energy is used to mix the digester contents. Energy is used to pump the fresh waste into the digester and to collect the treated digestate.

Plug flow digester designs are usually based on HRT necessary to achieve the desired VS reduction and digester gas production. For dairy manure systems, normal HRTs of 20 – 25 day will achieve the desired VS destruction and waste stabilization.

Figure 2: Plug Flow Digester Schematic



Other design alternatives

There are a number of other variations, to the anaerobic digestion process that have been used or tried around the world. Some of these variations are useable for dairy wastes, while others such as the high solids digesters may not be suitable for dairy wastes.

As noted above, conventional complete mix digestion systems can be modified by the inclusion of solids separation and recycling. Solids separation and recycling can be utilized to reduce the overall HRT of the digester system (i.e. thereby allowing the use of smaller tanks) while maintaining the same solids retention time and VS destruction effectiveness. In addition to reducing tank size, solids recycling assists in retaining the microorganisms in the digester, which increases the speed of system start-up and helps the system maintain stability.

One relatively new anaerobic digester design is the high solids digester system. In this system, biodegradable wastes such as manure, pre- and post-consumer food wastes, and any other anaerobically degradable organic materials are placed into chambers with solid material handling equipment such as conveyor belts or front-end loaders. The waste is sealed in a chamber where it anaerobically degrades, producing a CH_4 rich biogas. The chamber is heated to the mesophilic range for the most efficient operation. Digester gas is collected and stored in a bladder above the digestion chambers. These systems are normally composed of several chambers to provide a nearly continuous process, though each digestion chamber is a batch process. The solids remaining after this process still must be stabilized via a process like aerobic composting before it can be beneficially used. At this time, we were unable to find a high solids digester operating on dairy manure in the United States.

Alternatives to the basic digestion process design are not covered by this General Order, but nothing in this Order limits the types of digesters that operators can install.

Basic operation of a diary manure anaerobic digester system

Manure from dairy barns and milk houses is delivered to a manure tank at the site of the digester. Additional manure from nearby dairies may also be piped or trucked to the digester. The mixed manure is then pumped into the digester. In the digester, the waste is anaerobically degraded and stabilized producing a digester gas containing 55 – 70% CH_4 and a stabilized digestate suitable for land application in conformance with water quality, solid waste, and dairy management regulations and law requirements. In many cases, the digested solids are separated from the liquid portion through conventional wire screens. The solids can be used for dairy cow bedding, applied to the farmer's fields, or be further processed to reduce pathogens and sold as soil amendment or a substitute for peat moss.

Many existing dairy digester operations also receive pre-consumer[5] food wastes. These wastes may already be partially decomposed when they arrive at the diary. This results in the need for the dairy manure digester operator to carefully control odors generated by the waste. This food waste is introduced to the manure tank and mixed with manure prior to pumping into the digester. The liquid digestate is high in nutrients and must be managed in accordance with the farm's dairy nutrient management plan. If too much non-dairy manure waste is used, it is possible that the liquid portion of the waste will need to be managed under terms of a wastewater discharge permit rather than the nutrient management plan. However, this is outside of the scope of an air quality General Order of Approval.

The digester gas is removed from the digester and used as fuel for heating equipment or electricity generation. As a minimum, the digester gas must be compressed to pressures required to run the engine or boiler. Usually, the engines require that at least the water be removed from the digester gas, and some also require that the H_2S content be reduced to prevent corrosion of the engine internal parts.

When engines are included, they are attached to electrical generators which produce electricity for sale to the local utility, another utility, or for internal use by the diary. Excess heat from the digester engine is used to heat the digester to mesophilic (or thermophilic) temperatures, and provide hot water for the milk house, or any other use for which hot water is appropriate.

Anaerobic digester gas in excess of what can be used in the engine-generator is sent to a flare for destruction. As an alternate to a flare, excess gas could be treated to removeH_2S, water, and CO_2 and used for residential heating and cooking, as motor vehicle fuel in cars, trucks, and farm equipment (as compressed or liquefied natural gas), in a boiler, or for sale to a natural gas utility.

Description of emissions

The gas produced by an anaerobic digester typically contains 55 - 70% CH_4, 30 - 45 % CO_2 and up to 1% other gases, predominantly H_2S (0.15 – 0.5%), water, and ammonia (NH_3) (normally a

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[5] Operating an Anaerobic Digester Exempted From Solid Waste Handling Permit, August 2009, Ecology Publication no. 09-07-029.

trace, amount ammonia produced is dependent on the pH of the digester). When digester gas is combusted, various product of combustion are formed, primarily sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs).

CH_4 is a greenhouse gas with a global warming potential of 21, which means it warms the atmosphere 21 times more than an equivalent mass of CO_2. It is flammable and not regulated as a VOC. CO_2 is a greenhouse gas with a global warming potential of one. It is non-toxic and is not regulated as a VOC.

H_2S is a toxic, corrosive air pollutant and is listed as a toxic air pollutant in Washington air quality regulations. It is not a greenhouse gas or a VOC. There are no ambient air quality standards for this pollutant. As a point of reference, the state regulation for kraft pulp mills limits the emission rate for H_2S to 17 ppb. H_2S can be oxidized to elemental sulfur and forms SO_2 when combusted.

SO_2 is listed as a toxic air pollutant in Washington air quality regulations and state and federal and ambient air quality standards apply. It is not a greenhouse gas. In the atmosphere, SO_2 forms particulates that cause visible haze and health impacts. It also contributes to acid rain.

NH_3 is listed as a toxic air pollutant in Washington air quality regulations. It is not a greenhouse gas or a VOC. There are no ambient air quality standards for this pollutant. NH_3 forms NO_x when combusted.

NO_x is formed in the combustion process through the combination of atmospheric nitrogen and oxygen. NO_x emitted by combustion equipment forms NO_2 in the atmosphere. NO_2 is a Washington toxic air pollutant with state and federal ambient air quality standards. NO_2 is not a greenhouse gas or a VOC. It also contributes to acid rain and ozone.

The combustion of CH_4 and any other organic compounds in the digester gas will produce a variety of trace chemicals as products of incomplete combustion. CO is commonly used as an indicator of incomplete combustion; low CO emissions coupled with low excess air indicate complete combustion. CH_4 combustion in engines also results in the formation of aldehydes and ketones at low levels.

3. APPLICABLE EMISSION CONTROL REGULATIONS
Air Quality Regulatory Framework - Federal State and Local Agency Requirements

There are a number of federal regulations applicable to combustion units that can be used to convert digester gas into more useful forms of energy. In the case of this General Order, the end product is electricity generated by combusting the digester gas in a spark ignition reciprocating engine. Digester facilities that use the gas in a boiler, combustion turbine, or clean it to natural gas pipeline quality, are outside of the scope of this General Order.

Washington state air quality regulations do not contain any emission standards applicable to reciprocating engines other than the applicable federal regulations that have been adopted in state rule and specific requirements for diesel engines producing emergency power. For anaerobic dairy manure digestion and electricity production systems, the emission requirements are those found in federal regulations for spark ignition engines and those determined through the Best Available Control Technology (BACT) analysis (discussed in the next section).

Ecology has adopted the federal New Source Performance Standard (NSPS) for spark ignition reciprocating engines (40 CFR Part 60, Subpart JJJJ). The regulation establishes emission standards applicable to the engines based on year of manufacturer, fuel-to-air ratio, and type of fuel used. Engines fueled with digester or landfill gas are specifically listed with emission standards. This regulation specifies a number of requirements applicable to the owner/operator of the engine. The emission standards for digester gas fueled engines are contained in Table 1. Since January 1, 2011, rich burn engines and lean burn engines fueled by digester or landfill gas are required by this regulation to meet the same emission standards.

Table 1: Federal NSPS emission standards for new spark ignition engines fueled with digester gas

Engine type and fuel	Maximum engine power	Engine Manufactured after date	Emission standards[a]					
			grams/HP-hr			ppmvd at 15% O_2		
			NO_X	CO	VOC[b]	NO_X	CO	VOC[b]
Landfill/Digester Gas (except lean burn 500≤HP<1,350)	HP<500	1/1/2011	2.0	5.0	1.0	150	610	80
	HP≥500	7/1/2010	2.0	5.0	1.0	150	610	80
Landfill/Digester Gas Lean Burn	500≤HP<1,350	7/1/2010	2.0	5.0	1.0	150	610	80

Notes to table:

[a] Owners and operators of stationary non-certified SI engines may choose to comply with the emission standards in units of either grams/HP-hr or ppmvd at 15 percent O_2.

[b] For purposes of this subpart, when calculating emissions of VOCs, emissions of formaldehyde should not be included.

Washington state law and regulation requires that all new and modified sources of air pollution install and use Best Available Control Technology (BACT) to reduce emissions. All combustion units, including stationary engines, must meet the particulate emission standard s contained in WAC 173-400-050 and 075. All non-exempt emission units or activities[6] that are not de minimis in size also have to comply with WAC 173-460, Controls for New Sources of Toxic Air Pollutants. In addition, to requiring BACT, the permitting authority is required to assure compliance with ambient air quality standards.

The Ecology regulations also regulate nuisance odors from all types of sources. This general nuisance odors provision is modified by the provisions in state law on addressing nuisance odors from agricultural operations contained in RCW 70.94.640.

The WAC 173-400 does specify de minimis emission units, combustion sources, and emission rates (WAC 173-400-110(4) and (5)). The sources and emission rates listed as de minimis have been found to not cause any ambient air quality impact issues. Since the de minimis emission requirements have been installed in state rule, permitting has been simplified for owners of those source types that do not cause significant degradation of ambient air quality in the state.

De minimis requirements in state regulation that could apply to engines fueled by digester gas are the emission rates in WAC 173-400-110(5), Table 110(5). There are no exempt units or activities in the rule that specifically exempt digester gas-fueled boilers, turbines, or engines from permitting.

Local air pollution control agency requirements

During development of this General Order, the three local agencies[7] directly involved in its development have not identified any agency specific regulations or requirements applicable to anaerobic dairy manure digester systems beyond the regulations and requirements already discussed.

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[6] Emission unit and activity exemptions are contained in WAC 173-400-110(4)

[7] Northwest Clean Air Agency, Puget Sound Clean Air Agency, and Yakima Regional Clean Air Agency

4. BACT

State law and rule[8] defines BACT as "an emission limitation based on the maximum degree of reduction for each air pollutant subject to regulation under the Washington Clean Air Act emitted from or which results from any new or modified stationary source, which the permitting authority, on a case-by-case basis, taking into account energy, environmental and economic impacts and other costs, determines is achievable for such source or modification through application of production processes and available methods, systems, and techniques, including fuel cleaning, clean fuels, or treatment or innovative fuel combustion techniques for control of each pollutant."

Ecology requires a permit applicant to use the "top-down" process to determine what BACT is for notice of construction reviews. In the "top-down" analysis process, the applicant lists and ranks all potential pollutant control options from highest level of control (lowest emission rate) to the lowest (highest emission rate). Next, those emission control options that are technically infeasible are removed from the list of available controls. If a particular emission control has been installed and is operating at an identical or similar facility, it is considered to be an available control. The highest level of control remaining is considered technically feasible to implement on the emission unit. An applicant may choose to demonstrate that the highest level of emissions control is not financially feasible (not cost-effective) to implement or has adverse environmental or energy impacts. In this case, the applicant evaluates the economic, environmental, and energy impacts of the next most stringent level of control until a level of control is demonstrated to be economically feasible.

In the case of this General Order of Approval, there is no identified applicant. Thus, Ecology is responsible for providing a BACT analysis that compares the economic feasibility of available emission control options.

A review of EPA's RACT/BACT/LAER Clearinghouse, the California Air Resources board, and discussions with local permitting authority permitting staff was used to identify emission control equipment and emission limitations that have been developed in other jurisdictions.

The pollutants of concern for engines fueled by anaerobic digester gas are sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate material (PM), VOCs, acetaldehyde, acrolein, and formaldehyde. Odor from the receiving and storage of non-food wastes is also a concern.

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[8] RCW 70.94.030(7) and WAC 173-400-030(12).

Table 2: Pollutants and potential emission control approaches:

Pollutant	Control	Pre combustion, combustion modification, or post combustion	Examples
NO_x			
	Lean burn techniques	Combustion modification	Basis for EPA engine standard
	Selective Catalytic Reduction	Post combustion	Used on lean burn natural gas engines
	Selective Noncatalytic Reduction	Post combustion	Used on lean burn natural gas engines
	NSCR/3-way catalyst	Post combustion	Used on rich burn engines to control NO_x, CO, VOC, and PM
	Exhaust gas recirculation	Combustion modification	Not used on digester/landfill gas engines, does not meet EPA emission standards
SO_2			
	Air injection to digester gas	Pre-combustion	Andgar/GHD digesters
	Biological H_2S removal	Pre-combustion	Biosorb, BioCube, proprietary systems
	Iron sponge	Pre-combustion	
	Wet scrubbing	Pre-combustion	Wet caustic scrubber to remove H_2S
	Activated Carbon	Pre-combustion	Municipal wastewater treatment plant digester gas polishing, landfill gas polishing
CO			
	NSCR/3-way catalyst	Post combustion	Used on rich burn engines to control NO_x, CO, VOC, and PM
	Oxidation catalyst	Post combustion	Useable on rich and lean burn engines to reduce CO and VOCs
	Lean burn techniques	Combustion modification	Basis for EPA lean-burn engine standards

4.1 BACT: NO_x & CO

When biogas is burned in an engine-generator to produce electricity the byproducts of combustion include NO_x and CO. CO and NO_2 (a portion of NO_x) are criteria air pollutants (with federal and state ambient air quality standards) as well as Washington State toxic air pollutants. NO_x also participates in the formation of ozone. For all of these reasons, NO_x and CO emissions must be limited.

In evaluating BACT, the two primary strategies are:
1) look at process changes that would minimize emissions *before* they are formed; and
2) look at control technologies that would reduce emissions *after* they are formed.

4.1.1 Identify Available Control Technologies

Previous top-down BACT analyses have been done for engines burning biogas to produce electricity at two Seattle area facilities: Bio Energy of Washington (Bio Energy) and the King County West Point Wastewater Treatment Plant (WPTP). The engines at Bio Energy burn biogas from Cedar Hills landfill while engines at WPTP burn biogas from the wastewater treatment plant's anaerobic digesters. There are also numerous published BACT analyses for engines burning anaerobic digester biogas in California. BACT decisions for spark ignition gas fueled engines in Washington and other states have included:
1) Use of lean-burn engines
2) Use of Selective Non-Catalytic Reduction (SNCR) post-combustion controls
3) Use of Non-Selective Catalytic Reduction (NSCR) post-combustion controls
4) Use of Selective Catalytic Reduction (SCR) post-combustion controls
5) Use of CO catalysts

Use of lean-burn engines is an example of a process change that a facility could implement to minimize emissions before they are formed. Further NO_x reduction can be achieved through the use of post-combustion (add-on) controls.

Lean-burn vs. rich-burn engines

Engines used for biogas combustion can be divided into "rich-burn" or "lean-burn" engines. The difference between these two engine types is that lean-burn engines are designed to operate with more dilute gas streams (a higher air-to-fuel ratio) whereas rich-burn engines are designed to operate with more concentrated gas streams (air-to-fuel ratio closer to stoichiometric). Because they operate on more dilute gas streams, lean-burn engines also operate at lower combustion temperatures. NO_x formation is temperature dependent, and more NO_x is formed at higher combustion temperatures. Since lean-burn engines operate at lower temperatures than rich-burn engines, they also produce less NO_x. Within certain operational limits, lean-burn engines can be set to operate at different degrees of „leanness', producing different NO_x emissions. More lean operation of the engines requires computer control rather than manual control to minimize adverse effects on the engine.

Use of lean-burn engines has been required in many applications in California and other states for engines larger than 250 kW (335 Hp). Rich-burn engines require post-combustion controls to meet the same low NO_x and CO emission levels required for lean-burn engines. The federal engine standards anticipate that post combustion controls will be used on rich-burn engines.

In a 2011 permit application for Rainier Biogas[9], a new anaerobic manure digester proposed for Enumclaw, WA, the following engine manufacturer guarantee was provided for a 1,475 bhp Guascor Power lean-burn engine, Model SFGM 560:

- NO_x: 1 g/bhp-hr.
- CO: < 2.2 g/bhp-hr.

Permit applications submitted to Northwest Clean Air Agency for Andgar/GHD design and constructed facilities have proposed and installed lean-burn engines from Guascor with the same emission guarantee from the manufacturer, even when different engine sizes have been installed.

A review of manufacturers' specifications for other brands of spark ignition engines[10] fueled by low Btu gases indicates guarantees of 1 g/bhp-hr are common for lean-burn engines.

The California Bay Area Air Quality Management District (AQMD) has examined emissions from landfill and anaerobic digester gas-fired lean-burn engines and published their findings. The Bay Area AQMD's review of digesters permitted and operating in their jurisdiction were used to base their evaluation of BACT. For landfill gas-fired engines, they concluded that BACT for engines that are 250 hp or greater are as follows:[11]

- NO_x: 0.5-0.6 g/bhp-hr.
- CO: 2.1-2.5 g/bhp-hr initial standard (after overhaul), with a Not to Exceed standard of 3.6-3.9 g/bhp-hr.

For digester gas-fired engines, the Bay Area AQMD concluded that BACT for engines that are 250 hp or greater are as follows:[12]

- NO_x: 1.0-1.25 g/bhp-hr.
- CO: 2.1-2.65 g/bhp-hr initial standard (after overhaul), with a Not to Exceed standard of 3.6-3.9 g/bhp-hr.

Prior to 2009, the California Bay Area AQMD BACT[13] for landfill gas-fired lean-burn engine (250 hp+) was:

- NO_x: 1.0 g/bhp-hr is technologically feasible and cost effective; 1.25 g/bhp-hr is achieved in practice using lean burn technology

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[9] November 14, 2011 letter from Farm Power Northwest to PSCAA, referencing NOC Application 10223.

[10] Specific manufacturers reviewed: Catepillar, Waukesha, and Jennbacher

[11] White Paper: "Revisiting BACT for Lean Burn Landfill Gas Fired Internal Combustion Engines" by Randy Frazier, and Carol Allen. (Feb. 26, 2009). http://hank.baaqmd.gov/pmt/bactworkbook/white_paper-lb_lfg_ice_bact_2-26-09_final.pdf.

[12] White Paper: "BACT for Lean Burn Digester Gas Fired Internal Combustion Engines" by Randy Frazier. (May 14, 2009). http://hank.baaqmd.gov/pmt/bactworkbook/white_paper_addendum-LB-DG-ICE-051409.pdf

[13] White Paper: "Revisiting BACT for Lean Burn Landfill Gas Fired Internal Combustion Engines" by Randy Frazier, and Carol Allen. (Feb. 26, 2009). http://hank.baaqmd.gov/pmt/bactworkbook/white_paper-lb_lfg_ice_bact_2-26-09_final.pdf.

- CO: 2.1 g/bhp-hr is technologically feasible and cost effective; 2.65 g/bhp-hr is achieved in practice using lean burn technology

In 2007, South Carolina established a minimum control requirement of 1.25 g NO_x /bhp-hr for digester gas-fired, lean-burn engines.

SNCR

NO_x emissions from both lean-burn and rich-burn engines can be controlled through the use of Selective Non-catalytic Reduction (SNCR) post-combustion control. SNCR is a post-combustion control technology based on the chemical reduction of NO_x into molecular nitrogen (N_2) and water vapor (H_2O). SNCR requires the injection of ammonia or urea into a duct. [14]

NSCR (3-way catalyst)

Non-selective catalytic reduction (NSCR) is also known as a "3-way catalyst". NSCR uses the residual hydrocarbons and CO in the rich-burn engine exhaust as a reducing agent for NO_x. In an NSCR, hydrocarbons and CO are oxidized by O_2 and NO_x, PM is reduced primarily through the reduction of hydrocarbons. The excess hydrocarbons, CO, and NO_x pass over a catalyst (usually a noble metal such as platinum, rhodium, or palladium) that oxidizes the excess hydrocarbons and CO to H_2O and CO_2, while reducing NO_x to N_2. EPA states that NSCR is limited to engines with normal exhaust oxygen levels of 4 percent or less. It is, therefore, not effective for lean-burn engines. [15] NSCR is required by rich burn engines to meet the EPA engine specifications.

SCR

Due to their lower temperature operations, lean-burn engines have inherently lower NO_x emissions than rich-burn engines. NO_x emissions can be further reduced through the use of Selective Catalytic Reduction (SCR). SCR is a post-combustion control technology based on the chemical reduction of NO_x into N_2 and H_2O. [16] SCR uses ammonia injection and a catalyst to increase NO_x removal efficiency. The use of a catalyst allows the process to occur at a lower temperature than it otherwise would without the catalyst. This in turn makes SCR suitable for use with lean-burn engines.

Exhaust gas recirculation

Exhaust gas recirculation is an older NO_x reduction technique applied to many types of combustion units. Exhaust gas recirculation reduces the available oxygen in the combustion chamber leading to lower peak combustion temperature and thus lower NO_x formation. Automobile engines have utilized exhaust gas recirculation for several decades to reduce NO_x emissions. On its own, exhaust gas recirculation does not meet the emission standards EPA has established for stationary spark ignition engines.

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[14] Section 4.2 of EPA's Air Pollution Control Cost Manual, Sixth Edition, http://www.epa.gov/ttn/catc/dir1/cs4-2ch1.pdf.

[15] EPA AP-42: http://www.epa.gov/ttnchie1/ap42/ch03/final/c03s02.pdf

[16] Section 4.2 of EPA's Air Pollution Control Cost Manual, Sixth Edition, http://www.epa.gov/ttn/catc/dir1/cs4-2ch2.pdf.

CO oxidation catalyst

CO oxidation catalysts can be used to control CO emissions. According to the EPA, "the CO catalyst promotes the oxidation of CO and hydrocarbon compounds to CO_2 and H_2O as the emission stream passes through the catalyst bed. The oxidation process takes place spontaneously, without the requirement for introducing reactants."[17] CO catalysts have the additional benefit of reducing VOC and organic toxic air pollutant emissions.

4.1.2 Eliminate technically infeasible options

As discussed in the Identify Control Technologies section, some post-combustion control technologies can only be used for lean-burn engines while others can only be used for rich-burn engines. If a facility selects a rich-burn engine for a particular application, the control options used for lean-burn engines are infeasible. The same can be said for the control options available for rich-burn engines if a lean-burn engine is selected.

- SCR and CO oxidation catalysts are infeasible for rich-burn engines.
- NSCR (3-way catalysts) are infeasible for lean-burn engines.
- SNCR can be used for both lean-burn and rich-burn engines.

In addition to the above considerations for post-combustion control technologies, there are also limitations on when lean-burn engines can be used. While lean-burn engines do produce less direct NO_x than rich-burn engines, lean-burn technology is not readily available for smaller applications (less than 470 bhp (350 kW)[18]). Facilities that have insufficient biogas to fuel an engine larger than 470 bhp must use rich-burn engines instead of lean-burn.

Table 3 Rank remaining control technologies by control effectiveness

Control Technology	Use for rich-burn or lean-burn engines?	Typical Control Efficiency Range	Demonstrated in Practice?
Lean-burn instead of rich-burn	Lean-burn	NO_x: 0.5 – 1.25 g/bhp-hr CO: 2.1 – 2.65 g/bhp-hr	Yes, for larger engines
SNCR	Both	Up to 70% NO_x [19]	Yes
NSCR (3-way catalyst)	Rich-burn	NO_x: 90%+ CO: 90% [20]	Yes
SCR	Lean-burn	Up to 94% NO_x [21]	Yes
CO oxidation catalyst	Lean-burn	90%+ in CO [22]	Yes

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[17] EPA AP-42: http://www.epa.gov/ttnchie1/ap42/ch03/final/c03s01.pdf

[18] "Biomethane from Dairy Waste – A sourcebook for the production and use of renewable natural gas in California" by Ken Krich, Don Augenstein, JP Batmale, John Benemann, Brad Rutledge, and Dara Salour. (July 2005). http://www.suscon.org/news/biomethane_report/Full_Report.pdf.

[19] November 1999 EPA Technical Bulletin: Nitrogen Oxides, Why and How They are Controlled (EPA 456/F-99-006R), http://www.epa.gov/ttn/catc/dir1/fnoxdoc.pdf

[20] EPA AP-42: http://www.epa.gov/ttnchie1/ap42/ch03/final/c03s02.pdf

[21] November 1999 EPA Technical Bulletin: Nitrogen Oxides, Why and How They are Controlled (EPA 456/F-99-006R), http://www.epa.gov/ttn/catc/dir1/fnoxdoc.pdf.

[22] EPA AP-42: http://www.epa.gov/ttnchie1/ap42/ch03/bgdocs/b03s02.pdf

4.1.4 Evaluate most effective controls and document results

As shown above, SNCR is not the most effective control technology. Therefore, it is not discussed further in this section.

Lean-burn vs. rich-burn engines

We were unable to find a side-by-side comparison of the cost a lean-burn engine vs. a rich-burn engine. However, lean-burn engines are widely implemented and have clearly been found cost effective in a number of projects. As discussed earlier, the only caveat is that lean-burn technology may not be available for small engines, requiring the use of rich burn engines with post-combustion controls installed.

NSCR (3-way catalyst)

A 2011 permit application for biogas combusting engines at WPTP provides a cost analysis for NSCR for a project involving three rich-burn engines and a combined power rating of 1,320 hp (985 kW). These engines already exist at the facility and burn either propane or biogas. The BACT analysis examines the feasibility of replacing these engines with lean-burn engines and concludes that it was not technically feasible due to site specific conditions.

The WPTP BACT analysis relies on a vendor guarantee of 90% NO_x reduction for NSCR. The BACT analysis includes a significant cost for biogas pre-treatment to remove siloxane, which can damage the catalyst. Siloxane is present in biogas at WPTP due to consumer products like shampoo in the wastewater. Siloxane is not normally present in the gas from a dairy anaerobic digester. The WPTP analysis also includes retrofit costs as well as piping modification costs which would not be part of the cost for a new system at a diary anaerobic digester. Even including all of these additional costs, WPTP estimates a cost of $1,670 per ton of NO_x removed when operating at maximum biogas flow rates. The Puget Sound Clean Air Agency (PSCAA) has not concluded their review of the WPTP permit application. However, a cost of $1,670 per ton of NO_x removed is in line with what has been accepted as cost-effective (meeting BACT) for other projects.

A dairy anaerobic digester would not be required to include siloxane removal unless large quantities of commercial fats and greases are used in addition to dairy cow manure, as fats and greases sometimes contain siloxane additives to inhibit foaming. The WPTP retrofit and piping costs are also not applicable to a new dairy manure anaerobic digester. If these costs are removed from the analysis for the WPTP, the cost of NSCR treatment would drop by over 90% to $167 per ton of NO_x removed, or less. This NSCR cost is applicable to a large project such as the WPTP project with a combined power rating of 985 kW and a NO_x reduction of 288 tons per year (when operating on propane) and 75 tons per year when operating on digester gas. Cost for NSCR control for a different size project can be estimated using the rule of six-tenths.[23]

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[23] The rule of six-tenths is a common method used for approximating costs for different sizes of equipment. The rule appears to date back to a December 1947 article by Roger Williams, Jr. in *Chemical Engineering* magazine. The rule is expressed by the following formula: Cb = Ca (Sb/Sa)^0.6, where Cb = approx. cost of equipment having size Sb & Ca = is the known cost of equipment having corresponding size Sa.

The WPTP project costs were for three engines with a total of 1,320 hp. For a single 470 hp engine (common basis used throughout this BACT evaluation) the NO_x reduction would be 35.5% of the reduction estimated in the WPTP permit, or 26.6 tons per year when operating on digester gas[24]. The WPTP project estimated a capital cost of $41,700[25] for NSCR and total annualized costs of $93,500[26]. Based on seven percent interest rate and ten year life, the total annual cost is $98,900 for WPTP. For a 470 hp engine, using the rule of six-tenths, the annual cost is $53,200. If 26.6 tons of NO_x are removed, the cost per ton is $2,000. Using the same analysis, for a 470 bhp (350 kW) engine, the NOx reduction to get from the NSPS limit of 2 gram/bhp-hr to 1 g/bhp-hr, a 4.5 ton per year reduction results in a cost effectiveness of $3753/ton.

Even though NSCR controls both NO_x and CO, the WPTP BACT analysis did not quantify CO reductions. WPTP stated that this is because the existing engines will need to be operated in a slightly different mode to be compatible with the NSCR. This new operating mode will raise the pre-NSCR CO emissions. The resulting reduction due to the NSCR control will bring CO emissions back down to pre-project levels.

SCR

In 2009 Bio Energy gained approval from the PSCAA to operate twelve lean-burn engines, with each engine powering a 470 hp (350 kW) engine-generator. The engines combust biogas from a landfill. The approval requires operation of two SCRs to control NO_x emissions from the twelve engines. The application estimated 75% NO_x reduction through the use of SCR, a total reduction of 46.1 tons of NO_x, and a total annual cost of $252,612. The cost per ton of NO_x controlled is $5,480. SCR was found to be BACT for Bio Energy.

The cost for SCR control for a different size project can be estimated using the rule of six-tenths as discussed above. Using the rule of six-tenths, the annual cost of SCR for a 470 bhp project (1/12th of size of Bio Energy project) is $56,900. The NOx emission reduction for a project that is 1/12th of the size of Bio Energy is 1/12th of 46.1 tons per year, or3.84 tons of NOx per year. The resulting cost of NO_x removal is $14,800 per ton.

One additional aspect of the Bio Energy project is worthy of mention. The Bio Energy project assumes that the oxidation catalyst would need to be replaced annually due to siloxane poisoning. Catalyst replacement was identified as costing $27,600. Siloxane is present in biogas at Bio Energy due to the presence of consumer products at the landfill. Siloxane would not be expected to be present in the gas from an anaerobic digester at a dairy unless one or more

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[24] A 470 hp engine has 35.5% of the hp of the WPTP engines and 35.5% of the emissions. The control device will have the same removal efficiency for the NO_x coming from the 470 hp engine as for the WPTP engines. Hence, the NO_x reduction for the 470 hp engine will be 35.5% of the reduction for WPTP

[25] Capital cost based on Table 5.2 of letter submitted by WPTP to PSCAA on January 27, 2011. Table 5.2 identified a capital cost of $38,029 for NSCR, plus 9.5% sales tax, for a total of $41,642. Gas treatment costs, air-to-fuel ratio controller costs, retrofit costs, and King County Allied Costs in Table 5.2 are not included as they are not applicable to the General Order analysis.

[26] Annual operating and maintenance cost based on section 5.2 of letter submitted by WPTP to PSCAA on January 27, 2011. Annual gas treatment media and sampling costs are included as sampling is a valid cost for the NSCR evaluated under the General Order

feedstocks contain it. According to EPA, a SCR catalyst is typically guaranteed for 16,000 to 24,000 operating hours.[27] If SCR was used at a dairy anaerobic digester, catalyst replacement would likely occur less frequently than at Bio Energy, which would further reduce the cost of NO_x control.

CO oxidation catalyst

In 2009 Bio Energy gained approval from the PSCAA to operate twelve lean-burn engines, with each engine powering a 350 kWe generator. The engines combust biogas from a landfill. The approval requires operation of two CO catalysts to control CO emissions from the twelve engines. The application estimated 97% CO reduction for a total reduction of 63 tons of CO, and a total annual cost of $313,500. The cost per ton of CO controlled is $4,980. In addition, Bio Energy states that the catalyst also controls 35% of particulate emissions and 97% of formaldehyde emissions. However, this additional level of control is not taken into account in the cost analysis. Use of CO catalysts was found to be BACT for Bio Energy.

The cost for a CO catalyst for a different size project can be estimated using the rule of six-tenths as discussed above. Using the rule of six-tenths, the annual cost of a CO catalyst for a 470 hp project (1/12th of size of Bio Energy project) is $70,589. The CO emission reduction for a project that is 1/12th the size of Bio Energy is 1/12th of 63 tons per year, or 5.25 tons of CO per year. The resulting estimated cost of CO removal is $13,400 per ton.

One additional aspect of the Bio Energy project is worthy of mention. Bio Energy assumed that the oxidation catalyst would need to be replaced annually due to siloxane poisoning. Catalyst replacement was identified as costing $62,300. Siloxane is present in biogas at Bio Energy due to consumer products in the landfill. Siloxane is not normally present in the gas from a dairy anaerobic digester. According to EPA, a catalyst is typically guaranteed for 16,000 to 24,000 operating hours.[28] If a CO catalyst was used at a dairy anaerobic digester, catalyst replacement would likely occur less frequently than at Bio Energy, which would reduce the cost of CO control.

4.1.5 Selected BACT

Use of lean-burn engines meeting 1 g/bhp-hr NO_x and 2.2 g/bhp-hr CO with no post-combustion controls is found to be BACT for spark ignition engines installed at Digesters covered by this General Order. This limit is based on the emission guarantee provided by more than one engine manufacturer for these engines. Post-combustion control technologies for lean-burn engines have been found to be too expensive.

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[27] Section 4.2 of EPA's Air Pollution Control Cost Manual, Sixth Edition, http://www.epa.gov/ttn/catc/dir1/cs4-2ch2.pdf.

[28] Section 4.2 of EPA's Air Pollution Control Cost Manual, Sixth Edition, http://www.epa.gov/ttn/catc/dir1/cs4-2ch2.pdf.

4.2 BACT for Sulfur Dioxide

This BACT analysis addresses SO_2 emissions from an engine generator and a flare that combust biogas produced in a dairy manure anaerobic digester. H_2S is produced by anaerobic microbial metabolism within the digester; when the biogas is combusted, SO_2 emissions are generated.

4.2.1 Identify Available Control Technologies

H_2S may be removed from biogas using a variety of available processes, each of which is described below:

- Air recirculation / biological fixation
- Air recirculation / biological fixation + activated/impregnated carbon filter system
- Caustic (sodium hydroxide) scrubbing
- Ferric (iron) chloride added to the digester influent
- Reaction with iron oxide or iron hydroxide (iron sponge)

Air Recirculation / Biological Fixation

Biological fixation of H_2S by sulfur-oxidizing bacteria can be promoted in digester tanks or in separate biological scrubbing towers by injecting a small amount of air or oxygen into the biogas. In this process, bacteria that convert H_2S to elemental sulfur grow on digester walls and surfaces above the liquid surface, on the liquid surface, or on a biological filter medium. At best, this approach is able to reduce H_2S concentration to less than 50 ppm. This process also reduces ammonia content in the biogas.

When done inside the digester, the sulfur precipitates as elementary sulfur into the digestate. When done external to the digester, the elementary sulfur is washed to the bottom of the treatment unit by the water used to keep the microorganisms alive. The efficiency of biological desulfurization depends on the time allowed for oxygen to react and on the availability of media for bacteria to grow on. Typically, the oxygen content in the biogas after desulfurization will be about 0.5 – 1.8 % by volume and the H_2S content will be 60 – 200 ppm[29].

Based on manufacturers' literature, animal waste digesters in Europe commonly incorporate this biological fixation step as part of the digester gas treatment system prior to combustion of the digester gas.

Examples of this technology include the air injection system common to Andgar/GHD digesters in western Washington, the Applied Filter Technologies' BioStrip tower, and the EnergyCube "Bug-in-a-box" system. The latter two systems are add-on controls whereas the Andgar/GHD system works within the digester itself.

Air recirculation / Biological Fixation + Activated/Impregnated Carbon Filter System

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[29] Electrigaz Technologies Inc, 2008

Activated carbon is a form of carbon that has been processed to make it extremely porous and thus have a very large surface area available for adsorption or other chemical reactions. Activated carbon can be impregnated with alkaline or oxide solids to improve adsorption of H_2S. Common coatings include sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), potassium hydroxide (KOH), potassium iodide (KI), and metal oxides. Activated carbon beds need regeneration or replacement when saturated. Activated carbon is usually used in combination with and subsequent to ventilation of air into the biogas[30]. One digester system in Washington uses this combination of H_2S control techniques.

Caustic Scrubber

A caustic scrubber is an add-on control device in which biogas flows countercurrent to a solution of sodium hydroxide (NaOH) and water. Compared to a water scrubber, a caustic scrubber has enhanced scrubbing capabilities for both H_2S and CO_2 removal because the physical absorption capacity of the water is increased by the chemical reaction of the NaOH with H_2S and CO_2. This reaction results in the formation of sodium sulfide (Na_2S) and sodium hydrosulfide (NaHS), which are insoluble and non-regenerative. This leads to a high operational cost as contamination of the scrubbing solution necessitates more frequent changes of the solution[31]. Caustic scrubbers are being used to reduce H_2S on the very large[32] dairy manure anaerobic digester systems being installed in Idaho.

Ferric Chloride Addition to the Digester Influent

Aqueous solutions of ferric (iron) chloride ($FeCl_3$) can be added to anaerobic digester feedstock to diminish H_2S production. The solution is injected directly into the digester or with the digester feedstock by using an automatic dosing unit. This method is particularly effective at reducing very high levels of H_2S to more moderate (40-100 ppm) levels. This control system is relatively simple, but operational costs are an important consideration since ferric chloride ($FeCl_3$) solution is expensive to purchase and transport. Seldom used by itself, this method can reliably reduce the H_2S load on other removal components downstream. The sulfur ends up in the digestate solution. Digesters running on protein-rich feedstock, like slaughterhouse waste, often use this technique. In Sweden, plants use an average of four grams of $FeCl_3$ per liter of feedstock to achieve H_2S levels below 100 ppm[33].

Reaction with Iron Oxide or Iron Hydroxide (Iron Sponge)

H_2S reacts endothermicaly with iron hydroxides or iron oxides to form iron sulfide. A process often referred to as “iron sponge” makes use of this reaction to remove H_2S from gas. The name comes from the fact that rust-covered steel wool may be used to form the reaction bed. Steel wool, however, has a relatively small surface area, which results in low binding capacity for the sulfide. Because of this, wood chips impregnated with iron oxide have been used as reaction bed material. The iron-oxide impregnated chips have a larger surface area-to-volume ratio than steel

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[30] BC Ministry of Environment, 2010
[31] Electrigaz Technologies Inc, 2008
[32] Each larger than 10,000 milking head
[33] Electrigaz Technologies Inc, 2008

wool and a lower surface-to-weight ratio due to the low density of wood. Roughly 20 grams of H_2S can be bound per 100 grams of iron oxide-impregnated chips.

Iron oxide or iron hydroxide can also be bound to the surface of pellets made from red mud (a waste product from aluminum production). These pellets have a higher surface area-to-volume ratio than steel wool or impregnated wood chips, though their density is much higher than that of wood chips. At high H_2S concentrations (1,000 to 4,000 ppm), 100 grams of pellets can bind 50 grams of sulfide. However, the pellets are likely to be somewhat more expensive than wood chips.

The iron oxide can be regenerated by flowing oxygen (air) over the bed material. Typically, two reaction beds are installed, with one bed undergoing regeneration while the other is operating to remove H_2S from the biogas. One problem with this technology is that the regenerative reaction is highly exothermic and can, if air flow and temperature are not carefully controlled, result in self-ignition of the wood chips. Thus some operations, in particular those performed on a small scale or that have low levels of H_2S, elect not to regenerate the iron sponge on-site[34].

During regeneration, elemental sulfur is formed, some of which remains on the media while the remaining portion forms SO_2. For on-farm regeneration, this does not ultimately solve the SO_2 emissions problem, but rather moves the emissions from the engine exhaust to the media regeneration area. For off-farm media regeneration, which is likely more typical, one can presume that there are SO_2 emissions controls in place.

Potential Technologies not Being Considered

Water Scrubbing

Water scrubbing is a well-established and simple technology that can be used to remove both H_2S and CO_2 from biogas, because both of these gases are more soluble in water than CH_4. Likewise, H_2S can be selectively removed by this process because it is more soluble in water than CO_2.

While water scrubbing can reduce H_2S in the biogas, further process information would be necessary to determine if a water scrubber is acting as an air pollution control device or merely shifting some portion of the emissions to the exhaust from an associated air stripper. Pre-removal of H_2S (e.g., using iron sponge technology) prior to CO_2 removal with a water scrubber has been found by industry to be a more practical approach to biogas upgrading[35]. This technology seems to lack proponents and may have emissions associated with onsite regeneration. Water scrubbers will not be considered further in this evaluation.

EnergyCube BioScrub

EnergyCube is the sister company to Martin Machinery, which is listed by the Spanish engine manufacturer Guascor as their only US distributor/dealer at the time of this BACT analysis.

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[34] Krich, Augenstein, Batmale, Benemann, Rutledge, & Salour, 2005
[35] Krich, Augenstein, Batmale, Benemann, Rutledge, & Salour, 2005

Guascor engines appear to be a common choice for dairy manure anaerobic digesters in western Washington, with five of the six built systems selecting Guascor engines. EnergyCube manufactures two types of add-on H_2S controls for biogas: a biological scrubber (essentially equivalent to "biological fixation" discussed above) and a liquid biogas scrubbing technology referred to as BioScrub. BioScrub is an add-on control device that uses oxygenated effluent to remove H_2S. The system is composed of two chambers. In the first chamber, ambient air is mixed with and dissolved into liquid effluent from the digester. The oxygenated effluent is then transferred to a second chamber. When biogas is pumped through the oxygenated effluent, the H_2S in the gas reacts with the dissolved oxygen in the effluent and oxidizes to elemental sulfur. The sulfur-laden effluent is then drained to the lagoon. Through phone conversations with EnergyCube, it appears that there are fewer than ten of these systems currently operational at dairy manure anaerobic digester facilities, and a significant portion of those installations are demonstration projects. A control technology must be "available" to be considered in a BACT determination. This means that the technology has progressed beyond the conceptual stage and pilot testing phase and must have been demonstrated successfully on full-scale operations for a sufficient period. Theoretical, experimental, or developing technologies are not "available" under BACT. While the BioScrub process appears to have promise as a viable control in the future, it does not meet the requirement of being "available" and will not be considered further in this BACT analysis. It should be considered again in the future.

4.2.2 Eliminate Technically Unfeasible Control Technologies

Activated/impregnated carbon filter system

Activated carbon is an effective control technique for H_2S, but discussions with vendors revealed a reluctance to offer it as the only control technology for an uncontrolled biogas stream of 3,500 ppm H_2S or more. The concern was one of practicality (unit size) and media cost/changeout frequency. The technology was offered only as a "polishing" step after another control system such as biological control. It is only in that combination that it will be considered further in this review.

Technically Feasible Control Technologies

The following are all considered to be technically feasible processes to reduce H_2S in a biogas stream.

- Air recirculation / biological fixation
- Air recirculation / biological fixation + activated/impregnated carbon filter system
- Caustic (sodium hydroxide) scrubbing
- Ferric (iron) chloride added to the digester influent
- Reaction with iron oxide or iron hydroxide (iron sponge)

Table 4 Rank Remaining Control Technologies by Control Effectiveness

Control Technology	Typical Control Efficiency Range	Demonstrated in Practice?	Technically Feasible
Air recirculation / Biological fixation + Activated/impregnated carbon filter system	Up to 99%+[2]	Yes	Yes
Caustic () scrubbing	Up to 99%+[1]	Yes	Yes
Ferric (iron) chloride added to the digester influent	Up to 95%[2]	Yes	Yes
Reaction with iron oxide or iron hydroxide (iron sponge)	Up to 99%+[1]	Yes	Yes
Air recirculation / Biological fixation	Up to 95%[1]	Yes	Yes

1 Biomethane from Dairy Waste A Sourcebook for the Production and Use of Renewable Natural Gas in California Prepared for Western United Dairymen Michael Marsh, Chief Executive Officer Research Manager Ken Krich Authors: Ken Krich Don Augenstein JP Batmale John Benemann Brad Rutledge Dara Salour July 2005
2 Feasibility Study – Biogas upgrading and grid injection in the Fraser Valley, British Columbia
Electrigaz Technologies Inc Final Report June 2008

4.2.4 Evaluate most effective controls and document results

To establish cost effectiveness, the amount of H_2S in the biogas from an uncontrolled digester must first be established. There seems to be general consensus that the H_2S concentration from an uncontrolled digester would be in the multi-thousand ppm range. Literature suggests that manure digesters on dairy farms produce biogas with H_2S levels of 1,500 to 3,500 ppm, and those digesters that also utilize food processing wastes will see uncontrolled H_2S levels of 300-700 ppm[36]. Other literature and direct evidence from a dairy manure digester in western Washington suggest that the H_2S can be 5,000 ppm or higher upon initial startup. To be conservative from a cost standpoint, 3,500 ppm was selected as the uncontrolled H_2S concentration for this evaluation. For vendor quotes, a gas flow rate of 300,000 scf/day was used. Smaller units such as those designed to produce 100,000 scf/day were uniformly found to have higher control costs at similar inlet H_2S loadings.

Several of the controls can achieve 99%+ control of H_2S and are evaluated in no particular order.

Air Recirculation / Biological Fixation + Activated/Impregnated Carbon Filter System

Air recirculation with biological fixation is an increasingly common control technique. For the GHD digesters common thus far in Washington, the feature is built in and not considered to be an option, although it requires ongoing maintenance of system components and digester reactor temperature and can be deactivated by the operator. Maximum level of control can be reached by coupling this control with a polishing step such as activated carbon.

This control option was found to have a cost of $24,206 per ton of SO_2 controlled at a digester gas production rate of 300,000 cu. ft./day. This is determined to be not economically feasible

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[36] Greer, 2010

and this option is discarded. Note that it may be feasible for a digester with a biological system that is not achieving typical low H_2S concentrations.

Caustic (NaOH) Scrubbing

Although caustic scrubbing is technically feasible, there was a general reluctance among control technology vendors to quote a price for a caustic scrubber on relatively small digesters such as the ones considered here. Caustic scrubbers were considered to be not cost effective. Replacing the non-regenerable scrubbing solution leads to a high annual operating cost that makes this option unattractive compared to other control options. Though no cost information was supplied, the reluctance among control technology vendors to pursue this option because of high operating costs leads to the conclusion that they probably have an operating cost higher than activated carbon, which was found to be not economically feasible. This option is therefore discarded as not economically feasible at the scale being investigated for this General Order, though this may be revisited if a control technology vendor supplies information to the contrary.

Reaction with Iron Oxide or Iron Hydroxide (Iron Sponge)

Two different vendor quotes were obtained for equipment based on or similar to the iron sponge technology. Both were reviewed as a polishing step after biological treatment.

The first, Applied Filter Technologies' SulfrPack CIS, is an anaerobic or aerobic iron sponge-based treatment system that eliminates sulfur from biogas streams at ranges of 0-2,500 ppm. The SulfrPack CIS process uses the chemical reaction of ferric oxide with H_2S to sweeten gas streams. The reaction requires the presence of slightly alkaline water and a temperature below 110°F. If the gas does not contain sufficient water vapor, water may need to be injected into the inlet gas stream. A pH level of 8-10 should be maintained through the injection of caustic soda with the water. According to the manufacturer, the maximum amount of sulfur that can be economically treated is 2,500 ppm. The control cost was found to be approximately \$35,000 per ton (approximate because it is based on a quote for a larger system). This is found to be economically infeasible and will not be considered further.

The second technology, SulfaTreat, was found to cost approximately \$20,000 per ton of SO_2 controlled. SulfaTreat works best on gas streams that are water saturated and between 34 and 210 ^{o}F, which makes SulfaTreat an excellent fit for dairy manure anaerobic digester biogas. At the time of this BACT analysis, SulfaTreat was in use at the Klickitat Public Utility District H. W. Hill Landfill Gas Power Plant as an effective H_2S control for landfill gas prior to siloxane removal. SulfaTreat has the advantage of remaining non-hazardous in both new and spent forms, unlike standard spent iron sponge material that may become pyrophoric. Iron pyrite (FeS_2) is formed as H_2S reacts irreversibly with the SulfaTreat medium, and the spent medium can generally be disposed as non-hazardous waste. The reaction is dependent only on, and is proportionate to, the presence of H_2S. At \$20,000 per ton, this option is found to be economically infeasible and will not be considered further.

Ferric Chloride Added to the Digester Influent

$FeCl_3$ has been found to be an effective, relatively simple way to reduce H_2S concentrations in anaerobic digester biogas to approximately the same level as a biological system, though at a higher cost. The limited cost data suggest that, as a stand-alone control option, the costs are in the range of $7,000 per month[37]. There is also the potential that the $FeCl_3$ can impact the pH of the digester and reduce CH_4 production. This option is not considered further as a stand-alone option but may be an effective technique to reduce H_2S concentrations during periods of digester upset.

Air recirculation / Biological Fixation

This option, integral to GHD-brand digesters of the type common to western Washington, is included in the initial cost of the digester and has an insignificant annual operating cost. Based on experience with digesters in Washington, this technology – when operated and maintained adequately – is capable of consistently meeting the permitted emission limits of 350 ppmv H_2S rolling 30-day average with a maximum reading of 550 ppmv. However, one operator with two facilities has consistently had difficulty meeting the limits. The manufacturer stands behind these installations as being capable of meeting the emission limits with adequate operation and maintenance and has proposed a new facility in western Washington as being compliant with the same limit. There are three other facilities in Washington using equipment from this manufacturer that do meet, or appear capable of meeting, this emission limit.

4.2.5 Select BACT

BACT for SO_2 is determined to be air recirculation/biological treatment meeting the following emission limits:

The concentration of H_2S in the biogas immediately upstream of the flare and engine generator shall not exceed 350 ppmv on a rolling 30-day average nor shall the biogas immediately upstream of the flare and engine generator exceed 550 ppmv at any time.

Selected BACT emission controls

Based on the evaluation above, the BACT limit for NO_x from lean-burn spark ignition engines is 1 gram/brake horsepower-hour. The BACT limit is based on both the manufacturers' guaranteed NO_x emission performance and the capabilities of installed digester and landfill gas-fueled engines. Rich-burn spark ignition engines are capable of meeting the selected BACT emission limit with the use of add-on emission controls.

The CO BACT limit is met by lean-burn engines that achieve a limit of not to exceed 2.2 gram/brake horsepower hour. Rich-burn engines with add-on emission control can meet this limitation.

The VOC BACT limit is the emission limitation in 40 CFR Part 60, Subpart JJJJ for engines manufactured after January 1, 2011, which is 1 gram/brake horsepower-hour.

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[37] Soroushian, Shang, Whitman, Garza, & Zhang, 2006

SO_2 BACT is meeting a 30-day average digester gas H_2S content limit of 350 ppmv and a maximum digester gas H_2S content limit of 550 ppmv. Both concentrations are as measured at digester gas conditions of temperature, pressure, and water content at the inlet to the engine or flare. There are emission controls available and potentially cost effective to control H_2S: these controls would result in lower H_2S concentrations in the digester gas that have been determined to be BACT for this General Order. Many of these systems have not been demonstrated in long-term operation on anaerobic dairy digester gas and we consider them to be „experimental' systems at this time. As a result, the SO_2 BACT is based on air/oxygen injection to the digester gas to remove H_2S from the biogas.

The selected BACT emission limitations have all been met in practice and, in the case of NO_x, reflects the engine manufacturer guarantee[38] for NO_x emissions from its engines.

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[38] Documented in product specification sheets available from engine manufacturers.

5. EMISSIONS

In order to establish the maximum size anaerobic digester-engine generator system that qualifies for this General Order we evaluated air pollutant emission rates after application of BACT to the engine generator's emissions. We identified the largest digester systems that could qualify for coverage under the BACT emission limitations developed in Section 4. The resulting emissions were modeled with AERSCREEN, the currently accepted screening model, to determine ambient air impacts. The next section will further discuss the modeling process.

For the de minimis facility we considered that there would be no control of the H_2S produced in the digester. Based on available information, this uncontrolled H_2S from anaerobic digesters using dairy manure, with and without additional materials, could range from as low as 1,500 ppmv to as high as 5,000 ppmv. The most commonly reported values range from 2,000 to 3,500 ppmv.

We utilized the available data from Washington's operating digester systems to arrive at the assumption that the H_2S concentration in an uncontrolled system is 3,500 ppmv.

We assumed that the de minimis facility would use a spark ignition engine meeting the EPA NSPS and NESHAP engine emission requirements for NO_x, CO, formaldehyde, and VOCs.

We established an upper range for anaerobic digesters that can utilize the General Order. The upper size is based on several considerations. First, the systems utilize BACT as determined in Section 4 for digester engines to control all air pollutants. Second, the size is based on AERSCREEN modeling of an example facility utilizing building dimensions and engine exhaust locations derived from existing facilities in Washington (see Section 6 for further information). We have also established a target that any one digester facility may utilize no more than one third to one half of the NAAQS at the property line. The target ambient concentration at the property line accounts for the lack of background concentrations in the analysis and impacts from other existing and future emission sources to affect the same location.

Using the above criteria, the largest facility that would be allowed to utilize the General Order is designed to produce 400,000 cu. ft./day of digester gas. The range between the de minimis and upper digester size enables an anaerobic digester and engine generator facility to be permitted under the General Order at all but 16 of the 443 diaries registered with the Washington State Department of Agriculture.

Table 5 displays the emissions data used for modeling. The maximum facility size is based on 400,000 cu ft of digester gas with a heat content of approximately 565 Btu/cu. ft, containing an average of 350 ppmv H_2S and a maximum test content of 550 ppmv, and NO_x emissions from the engine of 1.0 gram/brake horsepower-hour.

Table 5: Criteria Pollutant Emissions Used for Modeling

De Minimis Scale Digester System: 20,000 cu.ft./day (approximately 140 head)		**Engine Generator and Flare**			
		SO_2	**NO_x**	**H_2S**	**$PM_{2.5}$**
	ton/yr	2	0.3	0.023	0.023
	lb/hr	0.476	0.063	0.00525	0.00525
	gram/second	0.060	0.008	0.00066	0.00066

Maximum Scale Digester System: 400,000 cu.ft./day (approximately 2,840 head)		**Engine Generator and Flare**			
		SO_2	**NO_x**	**H_2S**	**$PM_{2.5}$**
	ton/yr	6.70	13.47	0.072	0.376
	lb/hr	1.53	3.08	0.0164	0.086
	gram/second	0.192	0.388	0.002071	0.0108

Toxic Air Pollutants

A number of toxic air pollutants are emitted by dairy manure anaerobic digester systems. For the digester itself, the principle toxic air pollutant is H_2S.

Combustion of digester gas in a spark ignition engine produces products of combustion, which are principally NO_x, SO_2, CO, formaldehyde, acrolein and acetaldehyde. A review of permits for digester gas combustion from other states indicates these are the principle toxic air pollutants emitted. Emissions of these air pollutants have been evaluated against the criteria in WAC 173-460 to determine if they are emitted at acceptable rates. Table 6 lists the emissions of toxic air pollutants from the maximum sized digester system evaluated for inclusion in this General Order. The toxic air pollutant emissions from the de minimis sized system were not evaluated. However, those emissions would be about one-twentieth of the maximum sized system emissions and off-site impacts.

Table 6: Toxic Air Pollutants Emitted from Maximum Size Digester System

Pollutant		**H_2S [††]**	**Acrolein***	**Acetaldehyde***	**Formaldehyde****	**NO_2[†]**	**SO_2[††]**	**CO[†]**
Averaging Period		24 hour	24 hour	annual	Annual	1 hour	1 hour	1 hour
Engine Generator and Flare Emissions	lb/yr			4.37	15.67	26,940	13,052	59,269
	lb/day	0.394521	0.00588					
	lb/hr	0.016438	0.00024	0.00050	0.00179	3.08	1.49	6.77
De Minimis	Pounds per averaging period	0.0131 lb/24 hours	0.000394 lb/ 24 hours	3.55 lb/yr	1.6 lb/yr	0.457 lb/hr	0.457 lb/hour	1.14 lb/hour
SQER	Pounds per averaging period	0.263 lb/ 24 hours	0.00789 lb/24 hours	71 lb/yr	32 lb/yr	1.03 lb/hour	1.45 lb/hour	50.4 lb/ hour
ASIL	µg/m3 over averaging period	2	0.06	0.37	0.167	470	660	23,000
Below De Minimis	(Yes or No)	No	Yes	No	No	No	No	No
Below SQER	(Yes or No)	No	Yes	Yes	Yes	No	No	Yes
Below ASIL	(Yes or No)	Yes	N/A	N/A	N/A	Yes	Yes	N/A
		Note: N/A is not applicable because the pollutant is below the de minimis level or SQER.						

Notes for the table

* Based on AP-42 emission factor for lean burn engines on natural gas

** Based on the 40 CFR Part 63 Subpart ZZZZ formaldehyde emission standard of 14 ppmdv for four stroke lean burn spark ignition engines.

[†] Based on engine emission standards in 40 CFR Part 60, Subpart JJJJ

[††] Based on BACT established maximum digester gas H_2S limitation

6. AMBIENT IMPACT ANALYSIS

A screening air dispersion model (AERSCREEN 11126) was used to evaluate the impacts against the National and State Ambient Air Quality Standards (AAQS). Fugitive emissions were not included in the modeling analysis. The modeling assumed all digester gas was combusted in either the engine generator or the flare, and that emission rates of the toxic air pollutants would be the same through either device. With the exception of H_2S, NO_x and SO_2, all toxic air pollutants were either below their de minimis rate or the Small Quantity Emission Rate (SQER) and as a result were not modeled.

Modeling used generic site characteristics and building parameters based on the Farm Power Lynden and Rainier Biogas permit applications, both of which were readily available, and it was assumed, would typify the minimum sized parcel for siting a digester system. The area around these sites is typical for many locations where diaries are located: these sites can be characterized as flat sites located in flat to slightly rolling open agricultural land. Downwash effects from nearby buildings were included in the dispersion modeling. The modeling results demonstrate the highest ambient concentrations occur within the downwash cavity of the buildings. Appendix C contains the model input and output tables along with an evaluation of the effects of various H_2S and gas production rates against the 1 hr NO_2 and SO_2 ambient air quality standards.

General Orders are intended to be conservative with respect to ambient air quality impacts. This is because the facility permitted under the General Order may be in any location, and the site may have existing air quality impacts from existing and future emission sources in the area. As a result location specific characteristics are not analyzed. In addition, since this is a generic air quality impact analysis, we assume that more than one digester system or other stationary source of NO_2, SO_2, and $PM_{2.5}$ will impact the same ambient air location. Even in a currently rural area, the assumption of more than one emission source affecting a specific location is reasonable. Dairies are often clustered together or interspersed with nonagricultural activities such as schools, residences, and industrial operations (such as a food processor). They may be located downwind of large stationary sources of NO_2 or SO_2 such as natural gas compressor stations, oil refineries, or commercial boilers in the area where the plumes from those facilities impact ground level ambient air quality.

In order to anticipate more than one source of SO_2 or NO_2 impacting a location, Ecology is adopting the approach of using the maximum day impacts predicted by AERSCREEN and assuming that at least one more air pollution source with the same scale or larger emissions will be located to impact the ambient air at the same location. Thus we are allowing a single source to consume between one third and one half of the ambient air quality standard at the point of maximum offsite concentration. We are also establishing stack siting criteria that would assure the maximum impact predicted is located within the property line of the parcel containing the digester system.

Using the results of the modeling, we are limiting the maximum amount of the AAQs that can be consumed by any one dairy manure anaerobic digester system to between one third and one half of the most restrictive NAAQS at the closest property line to the emission point. This approach assures that the ambient air quality standards for SO_2 and NO_2 will be complied with even if multiple sources affect the same location.

Based on these assumptions and principles, a de minimis-sized dairy manure anaerobic digester system would be in compliance with the NAAQS regardless of where the stacks are located on the property.

For the maximum-sized digester system, the modeling indicates that there must be stack height restrictions and setbacks from the property line for both the engine and flare stacks. In order to minimize the required distance from the stacks to the property line, they must be at least 6 feet higher than the heights of nearby buildings to minimize building downwash effects.

Table 7 lists the state and federal AAQS.

Table 7: National Ambient Air Quality Standards (NAAQS)

Pollutant	Averaging Period	NAAQS Micrograms Per Cubic Meter (µg/m^3)	Washington State AAQS (µg/m^3)
		Primary	
SO_2	Annual	N/A	53
	24-hr	N/A	266
	1-hour[a]	199	500
NO_2	Annual	101.4	95.6
	1-hour[b]	191	--
$PM_{2.5}$	Annual	15	--
	24-hr	35	--

Notes to this table

[a] The standard is the average of the 8th highest one hour values over three consecutive years

[b] The standard is average of the 4th highest one hour values over three consecutive years

Table 8 compares the maximum ambient concentrations to the AAQS.

Table 8: Ambient Impact Levels from De Minimis-Sized Digester System

Pollutant	Averaging Period	Modeled Maximum off-site Concentration, µg/m3	Most restrictive AAQS, µg/m3	Above or below AAQS
SO_2	Annual	5.6	53	Below
	24-hr	22.5	266	Below
	1-hour[a]	56.3	199	Below

Pollutant	Averaging Period	Modeled Maximum off-site Concentration, µg/m3	Most restrictive AAQS, µg/m3	Above or below AAQS
NO_2	Annual	0.75	95.6	Below
	1-hour[b]	7.5	191	Below
$PM_{2.5}$	Annual	0.34	15	Below
	24-hr	1.36	35	Below

Table 9: Ambient Air Pollutant Levels from Maximum-Sized Digester System

Pollutant	Averaging Period	Modeled Concentration at property line more than 85 ft (26 meters) from stack, µg/m3	Most restrictive AAQS, µg/m3	Above or below AAQS
SO_2	Annual	8.8	53	Below
	24-hr	35.2	266	Below
	1-hour[a]	88	199	Below
NO_2	Annual	3.76	95.6	Below
	1-hour[b]	37.6	191	Below
$PM_{2.5}$	Annual	0.49	15	Below
	24-hr	1.96	35	Below

7. PROPOSED EMISSION LIMITATION AND SITING CRITERIA

Development of permit conditions
Based on the analyses performed and discussed above, we propose that the General Order contain the siting and operational restrictions contained in Table 10 below.

Digester gas sampling methods
Routine sampling of the digester gas for H_2S can be performed in a number of ways. Disposable gas detection tubes such as Draeger® tubes are a common method for anaerobic digester gas sampling. An example of a gas sampling protocol for reduced sulfides using gas detection tubes can be found in South Coast Air Quality Management District (SCAQMD) Method 307-91. As an alternate to gas detection tubes, portable gas analyzers are available (such as the Sewerin Multitec 540 H_2S gas analyzer) and may also be used. In petroleum refineries continuous reduced sulfur/H_2S monitors are commonly used, but due to cost and the high H_2S concentrations at dairy digesters, continuous monitors are not required for the systems covered in the General Order.

Table 10: Anaerobic Dairy Manure Digester System Applicability Criteria

Criterion	Limitation
Location in Washington	Any jurisdiction within which New Source Review requirements are regulated by Ecology's Air Quality Program. At the time of issuance of this General Order, this includes Adams, Asotin, Chelan, Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Kittitas, Klickitat, Lincoln, Okanogan, Pend Oreille, San Juan, Stevens, Walla Walla, and Whitman Counties,. This Order will also be adopted by Northwest Clean Air Agency, Puget Sound Clean Air Agency and Yakima Regional Clean Air Agencies for use in their jurisdictions. In the future it may be adopted by the other four air pollution control agencies in Washington.
Facility description	Anaerobic digester with engine generator, flare and associated manure and other waste handling and storage.
	Facility processes at least 50% by volume of dairy manure, at least 70% by volume dairy farm waste, and no more than 30% by volume solid waste exempt offsite materials. The anaerobic digester system is not part of a new major stationary source or major modification to a major stationary source, which is subject to review under the Prevention of Significant Deterioration (PSD) program, and the addition of an anaerobic digester to an existing source does not make the source subject to the Air Operating Permit (AOP) program or require a modification in an existing AOP permit.

Criterion	Limitation
Size	Digester facilities with maximum design gas production rate below 20,000 cu ft /day are de minimis emission sources and not required to undergo New Source Review.
	Digesters with a maximum design gas production rate between the de minimis size and less than 400,000 cu ft/day using reciprocating engines and flares to combust the digester gas may qualify for this General Order.
Design	Digester may be any design suitable for use on dairy manure
	Combustion device may be one or more reciprocating engines.
Equipment	Reciprocating engine must meet BACT as defined for this General Order.
	Flare must be designed to operate on digester gas and be sized to combust at least 100% of the maximum design digester gas production rate.
Siting restrictions	Stack must be at least 85 ft from location of public access or property line. Stack must be at least 6 ft taller than any structures within 20 ft of the stack

We have determined that a dairy manure anaerobic digester/combustion system without any H_2S control system and using an engine meeting the EPA stationary engine standards could produce 7,300,000 cu ft per year (20,000 cu ft/day) and still meet the de minimis emission rates in WAC 173-400-110(5). The emission rate for SO_2 is the controlling factor in establishing this lower threshold for the General Order.

Our BACT analysis has indicated that air recirculation or biological treatment for H_2S control on anaerobic digester gas is a cost effective control technology that can be installed on dairy manure anaerobic digester systems. The BACT limit for H_2S was determined to be 350 ppmv, 30-day rolling average and a 550 ppmv maximum concentration, representing a 90% reduction from a potential uncontrolled average H_2S concentration of 3,500 ppmv.

The largest size digester covered by this General Order is based on BACT for NO_2 and SO_2 and not exceeding 50% of the 1 hour SO_2 and NO_2 ambient air quality standards at the property line of the digester facility installation. The maximum-sized facility design gas production rate equates to a milking herd size of approximately 2,840 head.

BACT for NO_x is based on lean burn engines tuned to produce an emission rate of 1 gram/brake-horsepower or less. This rate is based on manufacturer’s guarantee of performance and documented compliance with this standard in other states.

BACT for CO is based on lean burn engines tuned to produce an emission rate of less than 2.2 gram/brake-horsepower. This rate is based on manufacturer’s guarantee of performance and documented compliance with this standard in other states and can be complied with while meeting the NO_x limitation.

BACT for VOCs is based on meeting the emission limitation in 40 CFR Part 60, Subpart JJJJ for digester gas-fired engines.

Experience with Washington digesters has indicated that digester gas production is usually greater than anticipated during design. As a result, there is often more digester gas produced than can be utilized by the installed engine-generator(s). We consider it prudent to require that the excess gas be combusted in a flare to prevent air quality and employee health issues from H_2S in the raw digester gas and to prevent potential explosive gas problems if the digester gas were allowed to build up in the digester. We are requiring that the flare be sized to combust at least 100% of the design digester gas production.

During anaerobic digester start-up, it is important that the H_2S content of the gas delivered to the engine and flare be monitored. Along with digester gas production rate, H_2S content of the digester gas has been shown in the Washington facilities to be an important operational parameter. In the systems using the GHD air recirculation to control H_2S, routine H_2S testing is an indicator of proper operation of both the digester and the control process. As stable operation is attained, we propose to reduce the frequency of H_2S monitoring from once per day to once per week. Given a standard hydraulic retention time of 14 to 22 days, this means that a given volume of manure entering a plug flow or complete mix digester would be in the reactor generating gas for two or three monitoring events.

However, if a weekly sample indicates that the digester gas exceeds the single test H_2S limit (550 ppmv), then our experience indicates that more frequent sampling must occur until the system is back into stable operation. For digester systems, we believe this more frequent sampling should occur for at least 90 days and continue until 90 consecutive samples are below both the single test and 30 day average limitations. This variable monitoring approach is used in permits for many different industries and emission units. It has proved successful in minimizing monitoring costs for the sources while still providing the regulators adequate information to determine compliance.

CONCLUSION

Ecology's Air Quality Program finds that this evaluation meets all the requirements of New Source Review.

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8. ACRONYMS AND ABBREVIATIONS

AAQS	Ambient Air Quality Standard
aka	Also known as
ASIL	Acceptable Source Impact Level
BACT	Best Available Control Technology
bhp	Brake Horsepower
CFR	Code of Federal Regulations
CO	Carbon Monoxide
Ecology	Washington State Department of Ecology
H_2S	Hydrogen Sulfide
kW	kilowatt of engine output
kWe	kilowatt of electrical output
lb/hr	Pound(s) per hour
NAAQS	National Ambient Air Quality Standard
NO_2	Nitrogen Dioxide
ppm	parts per million
ppmv	parts per million by volume
ppmdv	parts per million dry volume
NO_x	Nitrogen Oxides
PM	Particulate matter also known as total suspended particulate
PM_{10}	PM smaller than 10 microns in diameter
$PM_{2.5}$	PM smaller than 2.5 microns in diameter
RCW	Revised Code of Washington
SO_2	Sulfur Dioxide
SQER	Small Quantity Emission Rate
tpy	Tons per year
TSD	Technical Support Document
TSP	Total Suspended Particulate aka PM
WAAQS	Washington Ambient Air Quality Standard
WAC	Washington Administrative Code

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APPENDIX A. EMISSION RATES

Insert table from spread sheet calculating emission from engine and flare.
Emission calculation for NO_x, CO, and SO_2 are based on BACT determination. Emissions for pollutants other than NO_2 CO, and SO_2 will use either AP-42 or FIRE emission factors

Assumptions used in calculation of emissions from the mazimum size digester allowed under the General Order

Maximum Dairy Manure Digester Size Emissions Estimate

Digester gas production rate	400000	cf/day
Assumed Btu content	565	Btu/cf
Btu	9.416667	MMBtu/hr
Emission source spark ignition IC engine	1395	Horsepower
Heat rate (Assume Guascor engine)	6157	Btu/HP-hr
Fuel usage	8.589015	MMBtu/hr

.

							BACT Emissions based on engine capacity			
Pollutants		Emission factor, lbMMBtu	NSPS or NESHAP Emit factor, gram/Bhp-hr	BACT Emit factor, gram/Bhp-hr	Source		lb/hr	lb/day	Pound/yr	gram/sec
PM10		9.98E-03			AP-42 Emission Factors		0.09	2.06	750.97	0.010802
PM2.5		9.98E-03			AP-42 Emission Factors		0.09	2.06	751	0.010802
SO2					Assumed 550 ppmv H2S in digester gas		1.49	35.76	13,052	0.187740
NOx			2	1			3.08	73.81	26,940	0.387500
CO			5	2.2			6.77	162.38	59,269	0.852500
VOC			1	1			3.08	73.81	26,940	0.387500
Acetaldehyde		5.30E-05			AP-42 Emission Factors		0.000455	0.010925	3.99	0.000057
Acrolein		2.60E-05			FIRE Database		0.000223	0.005360	1.96	0.000028
Benzene		6.90E-04			FIRE Database		0.005926	0.142234	51.92	0.000747
Dichloromethane		1.01E-04			FIRE Database		0.000867	0.020820	7.60	0.000109
Formaldehyde		1.90E-04	14 ppm		AP-42 Emission Factors NESHAP		0.001632	0.039166	14.30	0.000206
Xylene isomers		1.37E-04			FIRE Database		0.001177	0.028241	10.31	0.000148
Hydrogen sulfide					Calculated value		0.016438	0.394521	144.00	0.002071
Selenium		1.10E-05			AP-42 Emission Factors		0.000094	0.002267	0.83	0.000012

							BACT Emissions based on engine capacity			
Pollutants		Emission factor, lbMMBtu	NSPS or NESHAP Emit factor, gram/Bhp-hr	BACT Emit factor, gram/Bhp-hr	Source		lb/hr	lb/day	Pound/yr	gram/sec
Styrene		5.26E-05			FIRE Database		0.000452	0.010843	3.96	0.000057
Toluene		2.62E-04			FIRE Database		0.002250	0.054008	19.71	0.000284
Trichloroethylene		2.00E-05			FIRE Database		0.000172	0.004123	1.50	0.000022
Vinyl chloride		5.60E-05			FIRE Database		0.000481	0.011544	4.21	0.000061

APPENDIX B HYDROGEN SULFIDE CONTROL COST DETAILS

Hydrogen Sulfide Control Cost Details

Air Recirculation / Biological Fixation + Activated/Impregnated Carbon Filter System

Cost Item	**EPA Control Cost Manual (500 ppm to < 50 ppm)**	
Direct Costs		
a. Primary Equipment	PUREAIR Filtration Quote 12/5/2011 (see 12/5/email)	$ 125,300
	= A	$ 125,300
Instrumentation	= 0.1 A	$ 12,530
Sales Tax	= 0.088 A	$ 11,026
Freight	= 0.05 A	$ 6,265
Purchased equipment cost, PEC	= B	$ 155,121
Direct installation costs		
Foundations & Supports	= 0.08 B	$ 12,410
Handling & erection	= 0.14 B	$ 21,717
Electrical	= 0.04 B	$ 6,205
Piping	= 0.02 B	$ 3,102
Insulation for ductwork	= 0.01 B	$ 1,551
Painting	= 0.01 B	$ 1,551
Direct installation costs, DIC	= 0.30 B	$ 46,536
Total Direct Cost, DC	= PEC+DIC	**$ 201,658**
Indirect costs (installation)		
Engineering	= 0.10 B	$ 15,512
Construction and field expenses	= 0.05 B	$ 7,756
Contractor fees	= 0.10 B	$ 15,512
Startup	= 0.02 B	$ 3,102
Performance test	= 0.01 B	$ 1,551
Contingencies	= 0.03 B	$ 4,654
Total Indirect Costs, IC	= 0.31 **B**	**$ 48,088**
Total Capital Investment (TCI)		**$ 249,700**
Total Annualized Capital Costs [TACC] (Estimate based on 10 years @ 7% interest)		**$ 35,552**
DIRECT AND INDIRECT ANNUALIZED COSTS		
DIRECT OPERATING COSTS (DOC)		

I. Labor for operations (From Rainier Biogas)			$ 8,213
II. Supervisory Labor (0.15* operations labor)			$ 1,232
III. Maintenance Labor (same as Farm Power)			$ -
IV. Replacement Parts			
V. Utility costs (From Rainier Biogas)			$ 720
VI. Replacement Media (PUREAIR Filtration)			$ 45,914
		= C	$ 56,078
INDIRECT OPERATING COSTS (IOC)			
VIII. Overhead (0.6*O&M costs(I-III of DOC)			$ 567
IX. Administration (0.02*TCC)			$ 4,995
X. Insurance (0.01*TCC)			$ 2,497
Total Direct and Indirect Annualized Costs [TDIAC] (DOC+IOC)			**$ 64,137**
TOTAL ANNUALIZED COSTS			**$ 99,689**
Pre-carbon emissions (500 ppm)	tons/year	*based on 100% production:*	4.16
Emissions w/Carbon	tons/year		0.04
% Reduction from Baseline	Percent	*(% per Applied Filter)*	*99%*
Total Emissions Reduction	tons/year		4.12
Cost per ton SO_2 Controlled	***$/ton***		**$ 24,206**

Reaction with Iron Oxide or Iron Hydroxide (Iron Sponge) - Applied Filter SulfrPack CIS

Cost Item			**EPA Control Cost Manual (500 ppm to 50 ppm)**	
Direct Costs				
a. Primary Equipment			Applied Filter Tech quote - Rainier Biogas	$ 125,731
			= A	$ 125,731
Instrumentation			= 0.1 A	$ 12,573
Sales Tax			= 0.088 A	$ 11,064
Freight			= 0.05 A	$ 6,287
Purchased equipment cost, PEC			= B	$ 155,655

Direct installation costs			
Foundations & Supports		= 0.08 B	$ 12,452
Handling & erection		= 0.14 B	$ 21,792
Electrical		= 0.04 B	$ 6,226
Piping		= 0.02 B	$ 3,113
Insulation for ductwork		= 0.01 B	$ 1,557
Painting		= 0.01 B	$ 1,557
Direct installation costs, DIC		= 0.30 B	$ 46,696
Total Direct Cost, DC		= PEC+DIC	**$ 202,351**
Indirect costs (installation)			
Engineering		= 0.10 B	$ 15,565
Construction and field expenses		= 0.05 B	$ 7,783
Contractor fees		= 0.10 B	$ 15,565
Startup		= 0.02 B	$ 3,113
Performance test		= 0.01 B	$ 1,557
Contingencies		= 0.03 B	$ 4,670
Total Indirect Costs, IC		= 0.31 **B**	**$ 48,253**
Total Capital Investment (TCI)			**$ 250,600**
Total Annualized Capital Costs [TACC]			
(Estimate based on 10 years @ 7% interest)			**$ 35,680**
DIRECT AND INDIRECT ANNUALIZED COSTS			
DIRECT OPERATING COSTS (DOC)			
I. Labor for operations (From Rainier Biogas)			$

			12,319
II. Supervisory Labor (0.15* operations labor)			$ 1,848
III. Maintenance Labor (same as Farm Power)			$ -
IV. Replacement Parts			
V. Utility costs (From Rainier Biogas)			$ 1,170
VI. Replacement Media (Rainier Biogas)			$ 85,337
		= C	$ 100,674
INDIRECT OPERATING COSTS (IOC)			
VIII. Overhead (0.6*O&M costs(I-III of DOC)			$ 850
IX. Administration (0.02*TCC)			$ 5,012
X. Insurance (0.01*TCC)			$ 2,506
Total Direct and Indirect Annualized Costs [TDIAC] (DOC+IOC)			**$ 109,042**
TOTAL ANNUALIZED COSTS			**$ 144,722**
Pre-carbon emissions (500 ppm: 1.41 lb/hr)	tons/year	*based on 100% production:*	4.16
Emissions w/Carbon	tons/year		0.04
% Reduction from Baseline	Percent	*(% per Applied Filter)*	*99%*
Total Emissions Reduction	tons/year		4.12
Cost per ton SO_2 Controlled	***$/ton***		**$ 35,140**

Reaction with Iron Oxide or Iron Hydroxide (Iron Sponge) - Mi SWACOSulfaTreat

Cost Item	**EPA Control Cost Manual (500 ppm to 50 ppm)**	
Direct Costs		
a. Primary Equipment	Mi SWACO Quote 12/20/2011 (see 12/20 email)	$ 93,302
	= A	$ 93,302
Instrumentation	= 0.1 A	$ 9,330
Sales Tax	= 0.088 A	$ 8,211
Freight	Included in quote	$ -
Purchased equipment cost, PEC	= B	$ 110,843
Direct installation costs		
Foundations & Supports	= 0.08 B	$ 8,867
Handling & erection	= 0.14 B	$ 15,518
Electrical	= 0.04 B	$ 4,434
Piping	= 0.02 B	$ 2,217
Insulation for ductwork	= 0.01 B	$ 1,108
Painting	= 0.01 B	$ 1,108
Direct installation costs, DIC	= 0.30 B	$ 33,253
Total Direct Cost, DC	= PEC+DIC	**$ 144,096**
Indirect costs (installation)		
Engineering	= 0.10 B	$ 11,084
Construction and field expenses	= 0.05 B	$ 5,542

Contractor fees		= 0.10 B	$ 11,084
Startup		= 0.02 B	$ 2,217
Performance test		= 0.01 B	$ 1,108
Contingencies		= 0.03 B	$ 3,325
Total Indirect Costs, IC		= 0.31 **B**	**$ 34,361**
Total Capital Investment (TCI)			**$ 178,500**
Total Annualized Capital Costs [TACC]			
(Estimate based on 10 years @ 7% interest)			**$ 25,414**
DIRECT AND INDIRECT ANNUALIZED COSTS			
DIRECT OPERATING COSTS (DOC)			
I. Labor for operations (From Rainier Biogas)			$ 12,319
II. Supervisory Labor (0.15* operations labor)			$ 1,848
III. Maintenance Labor (same as Farm Power)			$ -
IV. Replacement Parts			
V. Utility costs (From Rainier Biogas)			$ 1,170
VI. Replacement Media (Mi SWACO)			$ 35,853
VII. Media Disposal (Included in replacement media cost)			$ -
		= C	$ 51,190
INDIRECT OPERATING COSTS (IOC)			
VIII. Overhead (0.6*O&M costs(I-III of DOC)			$ 850
IX. Administration (0.02*TCC)			$ 3,569
X. Insurance (0.01*TCC)			$ 1,785
Total Direct and Indirect Annualized Costs [TDIAC] (DOC+IOC)			**$ 57,394**
TOTAL ANNUALIZED COSTS			**$ 82,808**
Pre-carbon emissions (500ppm)	tons/year	*based on 100% production:*	4.16
Emissions w/Carbon	tons/year		0.04
% Reduction from Baseline	Percent		*99%*
Total Emissions Reduction	tons/year		4.12
Cost per ton SO2 Controlled	***$/ton***		**$ 20,107**

APPENDIX C. AERSCREEN ANALYSIS INPUT FILE

```
STACK DATA
                    Rate          Height    Temp.      Velocity   Diam.    Flow
                    0.1200E+01    7.3200    628.0000   27.7705    0.3048   4294.

BUILDING DATA
                        BPIP   Height  Max dim.  Min dim.  Orient.  Direct.   Offset
                          Y    4.8800  18.2900   13.7200   0.0000   72.0000   9.0000

MAKEMET DATA
MinT    MaxT    Speed  AnemHt  Surf  Clim  Albedo  Bowen   Length  SC FILE
255.37  310.00  0.5    10.000  5     1     0.2000  0.5000  0.2000  "NA"

TERRAIN DATA
Terrain  UTM East  UTM North  Zone  Nada  Probe   PROFBASE  Use AERMAP elev
 N        0.0       0.0         0     4    2000.0   0.00       N

DISCRETE RECEPTORS
Discflag   Receptor file
       N      "NA"

UNITS/POPULATION
 Units  R/U  Population  Amb. dist.  Flagpole  Flagpole height
        M     R       0.       15.000       Y        1.40

OUTPUT FILE "Z:\ANAEROBIC-DIGESTER\ANAEROBIC-DIGESTER.OUT"


** Temporal sector: Summer, flow vector: 200 degrees, spatial sector:  1


CO STARTING

  TITLEONE ANAEROBIC-DIGESTER_STACK

**          REFINE STAGE 3

  MODELOPT CONC SCREEN  FLAT
  AVERTIME 1
  POLLUTID OTHER
  FLAGPOLE     1.40
  RUNORNOT RUN
```

```
CO FINISHED
SO STARTING
   LOCATION SOURCE POINT       0.0     0.0
   SRCPARAM SOURCE   0.1200E+01    7.320  628.000   27.771    0.305

   BUILDHGT SOURCE  36*4.88
   BUILDWID SOURCE  36*19.15
   BUILDLEN SOURCE  36*21.88
   XBADJ    SOURCE  36*-5.40
   YBADJ    SOURCE  36*-7.09
   SRCGROUP  ALL

SO FINISHED


RE STARTING

** Fence line receptor

   DISCCART        15.00        0.00

** Refined receptors

   DISCCART        16.00        0.00
   DISCCART        17.00        0.00
   DISCCART        18.00        0.00
   DISCCART        19.00        0.00
   DISCCART        20.00        0.00
   DISCCART        21.00        0.00
   DISCCART        22.00        0.00
   DISCCART        23.00        0.00
   DISCCART        24.00        0.00
   DISCCART        25.00        0.00
   DISCCART        26.00        0.00
   DISCCART        27.00        0.00
   DISCCART        28.00        0.00
   DISCCART        29.00        0.00
   DISCCART        30.00        0.00
   DISCCART        31.00        0.00
   DISCCART        32.00        0.00
   DISCCART        33.00        0.00
   DISCCART        34.00        0.00
   DISCCART        35.00        0.00
   DISCCART        36.00        0.00
   DISCCART        37.00        0.00
```

```
   DISCCART      38.00      0.00
   DISCCART      39.00      0.00
   DISCCART      40.00      0.00
   DISCCART      41.00      0.00
   DISCCART      42.00      0.00
   DISCCART      43.00      0.00
   DISCCART      44.00      0.00
   DISCCART      45.00      0.00
   DISCCART      46.00      0.00
   DISCCART      47.00      0.00
   DISCCART      48.00      0.00
   DISCCART      49.00      0.00
   DISCCART      50.00      0.00
   DISCCART      51.00      0.00
   DISCCART      52.00      0.00
   DISCCART      53.00      0.00
   DISCCART      54.00      0.00
   DISCCART      55.00      0.00
   DISCCART      56.00      0.00
   DISCCART      57.00      0.00
   DISCCART      58.00      0.00
   DISCCART      59.00      0.00
   DISCCART      60.00      0.00
   DISCCART      61.00      0.00
   DISCCART      62.00      0.00
   DISCCART      63.00      0.00
   DISCCART      64.00      0.00
   DISCCART      65.00      0.00
   DISCCART      66.00      0.00
   DISCCART      67.00      0.00
   DISCCART      68.00      0.00
   DISCCART      69.00      0.00
   DISCCART      70.00      0.00
   DISCCART      71.00      0.00
   DISCCART      72.00      0.00
   DISCCART      73.00      0.00
   DISCCART      74.00      0.00
   DISCCART      75.00      0.00


RE FINISHED
```

```
ME STARTING
   SURFFILE  AERSCREEN.SFC  FREE
   PROFFILE  AERSCREEN.PFL  FREE
   SURFDATA  11111   2010  SCREEN
   UAIRDATA  22222   2010  SCREEN
   PROFBASE    0.0 METERS
ME FINISHED


OU STARTING
   RECTABLE 1  FIRST
   MAXTABLE  ALLAVE  50
   FILEFORM  EXP
   RANKFILE  1 10 AERSCREEN.FIL
   PLOTFILE  1 ALL  FIRST  AERSCREEN.PLT
OU FINISHED
```