Oregon Department of **ENERGY**

Biogas and Renewable Natural Gas Inventory SB 334 (2017)

2018 Report to the Oregon Legislature

September 2018

OREGON DEPARTMENT OF ENERGY

EXECUTIVE SUMMARY

In 2017 the Oregon Legislature passed SB 334, directing the Oregon Department of Energy, in coordination with an ODOE-appointed advisory committee, to conduct a detailed inventory of all potential sources of biogas and renewable natural gas (RNG) available in Oregon. The bill also required that ODOE maintain and periodically update the inventory.

ODOE was authorized to estimate the potential production quantities of biogas and RNG within the state; as well as the energy content of biogas available at each site; document the location of existing biogas production facilities; and asses the supply chain infrastructure associated with each type of biogas. The bill required analysis of current technology for converting biomass to biogas and for processing biogas to RNG.

The report identifies financial, technical, market, policy and regulatory barriers to developing and using biogas and RNG as an energy source that can help Oregon reduce greenhouse gas emissions and improve air quality.

Advisory Committee Membership and Key Report Components

The ODOE-appointed RNG Advisory Committee included more than 40 individuals representing a broad range of stakeholder interests. Active members included representatives from three natural gas companies, interstate natural gas pipeline companies, private developers, agriculture and forestry interests, academia, state, regional and local government, wastewater treatment plants, landfills, waste food management, and transportation. Beyond fulfilling their statutory requirements to assist in the development of the inventory and identification of barriers and recommendations, members attended monthly meetings, hosted facility tours, and lent their technical expertise in determining the potential production quantities of biogas and RNG.

To prepare a detailed inventory of all potential sources of biogas and RNG available in Oregon, ODOE investigated anaerobic digestion and thermal gasification technologies, compiled a list of existing sites and producers, assessed the complex supply chain infrastructure, estimated the current and potential RNG production quantities, and determined their greenhouse gas emissions and air quality effects from using RNG as a fuel.

The inventory quantifies opportunities to convert persistent, long-term waste streams into useful energy. As they break down in the environment, municipal waste streams like garbage, wastewater, and waste food, as well as agricultural waste streams like manure, all generate methane, a powerful greenhouse gas. Redirecting these waste streams into controlled processes for optimization, capture, and utilization of the methane (CH_4) can be economically, socially, and environmentally beneficial to Oregon. Greenhouse gas emissions and air pollutants can be significantly reduced when RNG is substituted for fossil fuels in our transportation and stationary fuels sectors. If Oregon's potential volume of RNG could be captured and used to displace fossil-based natural gas for stationary combustion, we would prevent the release of approximately two million metric tons of greenhouse gases into the atmosphere. Redirecting this fuel source into these sectors can also potentially result in increased economic opportunity, and provide energy security and resilience for Oregon communities.

The Inventory

The inventory indicates that there is potential for a substantial amount of RNG to be produced in Oregon from a variety of biogas production pathways.

The gross potential for RNG production when using anaerobic digestion technology is around 10 billion cubic feet of methane per year, which is about 4.6 percent of Oregon's total yearly use of natural gas. The gross potential for RNG production when using thermal gasification technology is nearly 40 billion cubic feet of methane per year, which is about 17.5 percent of Oregon's total yearly use of natural gas.

Potential Barriers to RNG Development, Production, and Use

The report identifies barriers to developing, producing, and using biogas and RNG as a means to reduce greenhouse gas emissions and improve air quality. Barriers were identified by conducting a literature review of known RNG development barriers, and through discussions with the Advisory Committee. The identified barriers fell into the following categories: financial, informational, markets, policy and regulatory, and a general category of "other."

Recommendations

The Department of Energy worked with the Advisory Committee to propose policy solutions for future consideration by policymakers. ODOE synthesized their input and makes the following six recommendations, which if implemented, could enable the development of more RNG in Oregon:

1. Allow the natural gas companies to buy and sell RNG to and for their customers.
2. Allow local gas distribution companies to recover pipeline interconnection costs through their rates.
3. Study how best to expand natural gas transportation fueling infrastructure.
4. Explore development of voluntary gas quality standards for injection of RNG into the natural gas pipeline.
5. Explore financial incentives to help drive the nascent industry forward.
6. Coordinate with RNG stakeholders and state agencies to develop a tracking and accounting protocol for production and use of RNG.

The Department of Energy's full Biogas/RNG Inventory report, including detailed data, is available at https://www.oregon.gov/energy/Data-and-Reports/Pages/Reports-to-the-Legislature.aspx.

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COMMON TERMINOLOGY AND CONVERSIONS

Understanding the terminology of natural gas, biogas, and renewable natural gas can be helpful in understanding the potential production quantities of RNG.

Natural gas is measured in two ways: by energy content in British Thermal Units (Btu) and by volume in cubic feet (scf).

Volume Units		Energy Units
1 cubic foot (cf)	=	1,027 Btu
100 cubic feet (1 hcf)	=	1 therm (approximate)
1,000 cubic feet (1 Mcf)	**=**	**1,027,000 Btu (1 MMBtu)**
1,000 cubic feet (1 Mcf)	=	1 dekatherm (10 therms)
1 million (1,000,000) cubic feet (1 Mmcf)	=	1,027,000,000 Btu
1 billion (1,000,000,000 cubic feet (1 bcf)	=	1.027 trillion Btu
1 trillion (1,000,000,000,000) cubic feet (1Tcf)	=	1.027 quadrillion Btu

The average PNW home uses about 120 therms of natural gas per month in the winter, and 25 therms per month in the summer.

Key Words & Definitions

Anaerobic – in the absence of oxygen.

Anaerobic Digestion – the breakdown of organic materials by micro-organisms under controlled conditions in the absence of oxygen.

Biofuel – any biomass derived substance used for energy (heat, power, or motive) which is converted into a liquid state for use. Typically used to describe liquid transportation fuels derived from biomass.

Biogas – a naturally-forming gas that is generated from the decomposition of organic wastes or other organic materials in anaerobic environments or processes, such as gasification, pyrolysis or other technologies which convert organic waste to gas in the absence of oxygen. Has a lower methane content and heating value than natural gas and contains many impurities. It is the intermediate product in the process of creating renewable natural gas (RNG).

Biogas Production Pathways – the different ways by which biogas is produced. These include wastewater treatment plants, landfills, anaerobic digesters, thermal gasifiers and other methods which are defined by their primary input. For example, dairy biogas is a production pathway while dairy manure is a feedstock.

Biological Pathway – refers to the use of anaerobic digesters to provide suitable conditions for bacteria to break down organic material having low lignocellulosic content.

Biomass – any organic matter that is available on a renewable or recurring basis, such as agricultural and forestry residuals, animal wastes, food waste, and the organic fraction of municipal solid waste.

British Thermal Unit (Btu) – a unit used to measure the heat content of a substance.

Carbon Intensity – the amount of carbon dioxide released during the total lifecycle, being production, transportation, distribution, consumption and disposal, of a product or service per unit of fuel (i.e., kilograms of CO2 per Btu, or grams of CO2 per megajoule).

Clean-Up (of raw biogas) - the process of removing contaminants from raw biogas.

Compost – a nutrient-rich fertilizer and/or soil conditioner produced from composting.

Composting – aerobic decomposition of organic matter in a controlled environment by micro- and macro-organisms (such as bacteria, fungi, beetles, and worms).

Compressed Natural Gas (CNG) – natural gas stored at high pressure as a vehicle fuel.

Contaminates – elements or compounds which may harm machinery, infrastructure or air quality upon combustion of biogas and are removed during cleaning. Includes sulfur compounds, moisture, halogen compounds, silicon compounds, volatile organic compounds and particulate matter.

Digestate – a by-product of anaerobic digestion consisting of suspended solids and a liquid fraction containing soluble nutrients.

Diluent – elements or compounds which dilute/lower the energy content of biogas, such as carbon dioxide and nitrogen, and must be removed during biogas upgrading prior to pipeline injection as RNG.

Dissolved Solids – the part of total solids passing through the filter in a filtration procedure.

Energy Content - the number of Btu's produced when gas is combusted (e.g., Btu/cubic foot).

Feedstock – the basic, raw organic materials used to produce biogas or syngas.

Fixed Solids – the part of total solids, such as ash, which remain after volatile gases are driven off at 1,112 degrees Fahrenheit.

Forest Biomass – the waste material generated from logging or thinning activities in forests. Common aspects of this waste include branches, tops, and smaller, non-merchantable diameter lumber (less than 5 to 7 inches in diameter) which cannot be used for traditional lumber products.

Landfill Gas – biogas captured as a product of anaerobic decomposition of the organic portion of a landfill's buried waste.

Methane – a colorless, odorless, flammable hydrocarbon gas which is the main component of natural gas.

Methanogenic – meaning methane forming, it is the type of bacteria which produce methane and carbon dioxide in anaerobic environments and processes.

Million Standard Cubic Feet (MMSCF) – a unit used to measure the volume of natural gas.

Natural Gas – a naturally occurring hydrocarbon gas mixture consisting primarily of methane and used in chemical processes, building heating, electricity generation or vehicle fuel.

Pyrolysis – the direct thermal decomposition of the organic components in biomass in the absence of oxygen.

Renewable Natural Gas (RNG) – biogas that has been processed to be interchangeable with conventional natural gas for the purpose of meeting pipeline quality standards or transportation fuel-grade requirements. It is a resource which can be used and created in perpetuity from renewable sources.

Service Fee / Tip Fee – the per-ton fee charged by the processer to the producer or transporter for processing waste residuals.

Stationary Fuels Sector – where biogas or RNG are used to produce electricity, process steam or useful heat for industrial, commercial, institutional, and residential use, typically in manufacturing, cooking or heating.

Supply Chain – the sequence of processes involved in the production and distribution of a commodity.

Suspended Solids – the part of total solids removed by a filtration procedure.

Syngas – also known as synthesis gas, it is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and often some carbon dioxide. It is the intermediate product in the process of creating synthetic natural gas (SNG). Syngas is usually a product of gasification.

Thermal Gasification (Gasification) – the conversion of solid or liquid carbon-based materials by direct internal heating provided by partial oxidation.

Thermochemical Pathway – refers to the thermal gasification of high-lignocellulosic biomass into syngas.

Total Solids (TS) – used to characterize digester systems input feedstocks, it is the dry matter content of the prepared feedstock and is usually expressed as a percentage of the total weight of the sample. TS = 100% moisture content % of a sample. TS = VS plus ash content.

Upgrading (of cleaned biogas) – the process of removing diluents to improve the methane percentage of gas and thus the heat content and quality of the gas.

Urban Wood Waste – includes discarded wood and yard debris. This waste stream often ends up in landfills.

Virgin Biomass – the primary outcome of intentional biomass cultivation.

Volatile Solids (VS) – used to characterize digester system input feedstocks, they are the organic (carbon containing) portion of the prepared reactor feedstock and are usually expressed as a percentage of total solids but also as a fraction of total sample (wet) weight. In biogas production, volatile solids drive gas production.

Volume – space occupied in cubic units.

Waste Biomass – comprises the residual fraction from primary harvest of materials, livestock, municipal or other wastes.

Weight – quantity of mass.

Wheeling – the process whereby owners of electricity or natural gas pay to transport and distribute their commodity through another entity's distribution system (wire or pipeline).

Wood Products Residue – the wood waste generated at sawmills and other wood products plants, such as trim, shavings, woodchips, sawdust, bark, and other residues.

Yield – the amount of RNG that can be produced from each dry ton of biomass feedstock input. This unit is expressed in British Thermal Units (Btus) and Million Standard Cubic Feet (MMSCF) of natural gas equivalent.

INTRODUCTION

In 2017, the Oregon Legislature passed Senate Bill 334, which directed the Oregon Department of Energy to conduct an inventory of all resources within the state that can be used to produce biogas and renewable natural gas (RNG), also known as biomethane. ODOE is committed to developing and supporting policies that lead the state to a safe, clean, and sustainable energy future – one that balances economic, social, and environmental benefits. Senate Bill 334 is similarly motivated; it called for investigating and quantifying available resources as well as identifying options to promote, and remove barriers to producing, low-carbon, low-emission RNG and biogas in rural and metropolitan locations around Oregon. Energy from RNG can directly displace imported fuel, help support local economies and local jobs, and bolster energy security and community resiliency.

SB 334 specifically directed ODOE to produce a list of the potential sources of biogas within the state and to estimate the potential production quantities available from each source, along with estimates of energy content and information about technologies available to produce biogas and RNG. The legislation also directed ODOE to evaluate the potential for RNG to reduce greenhouse gases (GHG) and improve air quality. Finally, SB 334 directed ODOE to form an advisory committee to identify barriers to the production and use of RNG, and to propose potential solutions and policies to address those barriers.

This inventory indicates that there is potential for a substantial amount of RNG to be produced in Oregon from a variety of biogas production pathways. The gross potential for RNG production when using anaerobic digestion technology is around 10 billion cubic feet of methane per year. This is about 4.5 percent of Oregon's total yearly natural gas use. Once technical obstacles are overcome, thermal gasification technology could produce up to another 40 billion cubic feet per year, or about 17.5 percent of annual natural gas use. Currently, if this RNG is traded as a transportation fuel in the Oregon and California clean fuel markets, it has a high value because of its associated environmental attribute credits and the federal Renewable Fuels Standards credits. Obstacles to reaching these markets include the high cost of infrastructure necessary to clean and inject the resulting RNG into a common carrier pipeline so it can be incorporated into the clean transportation fuels markets, a lack of fueling infrastructure to encourage fleet conversions to RNG, the lack of a pathway that allows gas utilities to purchase RNG, and the difficulty in quantifying and realizing the benefits of RNG for stationary fuels customers.

The Biogas/RNG Landscape

To prepare this report, ODOE investigated anaerobic digestion (AD) and thermal gasification technologies, a list of existing sites, the complex supply chain infrastructure supporting them, and estimates of current and potential RNG production quantities as well as the impacts of using RNG as a fuel on air quality and emissions. This inventory quantifies opportunities to convert persistent, long-term waste streams into useful energy. As they break down in the environment, municipal waste streams like garbage, wastewater, and waste food, as well as agricultural waste streams like manure, all generate methane - a powerful greenhouse gas. Redirecting these waste streams into controlled processes for optimization, capture, and utilization of the methane can be economically, socially, and environmentally beneficial to Oregon. Further, redirecting this fuel source into the transportation fuels sector, and eventually into the stationary fuels sector, can result in increased economic opportunity and provide energy security and resilience for urban and rural communities. Reduced vehicle exhaust emissions will benefit the overall environment and directly improve air quality in some urban environments. Finally, capturing and burning the methane will reduce GHG emissions.

Biogas has been captured and used for heating and lighting since the late 1800s (Abbasi et al. 2012; Chawla 1986). Biogas is the result of organic material being broken down by bacteria and other microorganisms in an environment where there is no oxygen, known as an anaerobic environment. Biogas is composed of methane, carbon dioxide, nitrogen, oxygen, water, hydrogen sulfide, ammonia, and hydrogen.

Typical Biogas Composition	
Methane	40-75 %
Carbon Dioxide	20-55 %
Nitrogen	0-5%
Oxygen	0-2%
Water	0-10%
Hydrogen Sulfide	50-5000 ppm
Ammonia	0-1%
Hydrogen	0-1%

(Williams, Kaffka, and Oglesby 2014, 19)

Other elements, such as siloxanes or halides, can be present depending on feedstock or pathway. For example, if the gas originates from a municipal solid waste landfill, it may contain siloxanes due to the breakdown of products that contain silica, or produce halides due to reactions with plastics. These impurities in particular can be harmful to end-use technologies and must be removed.

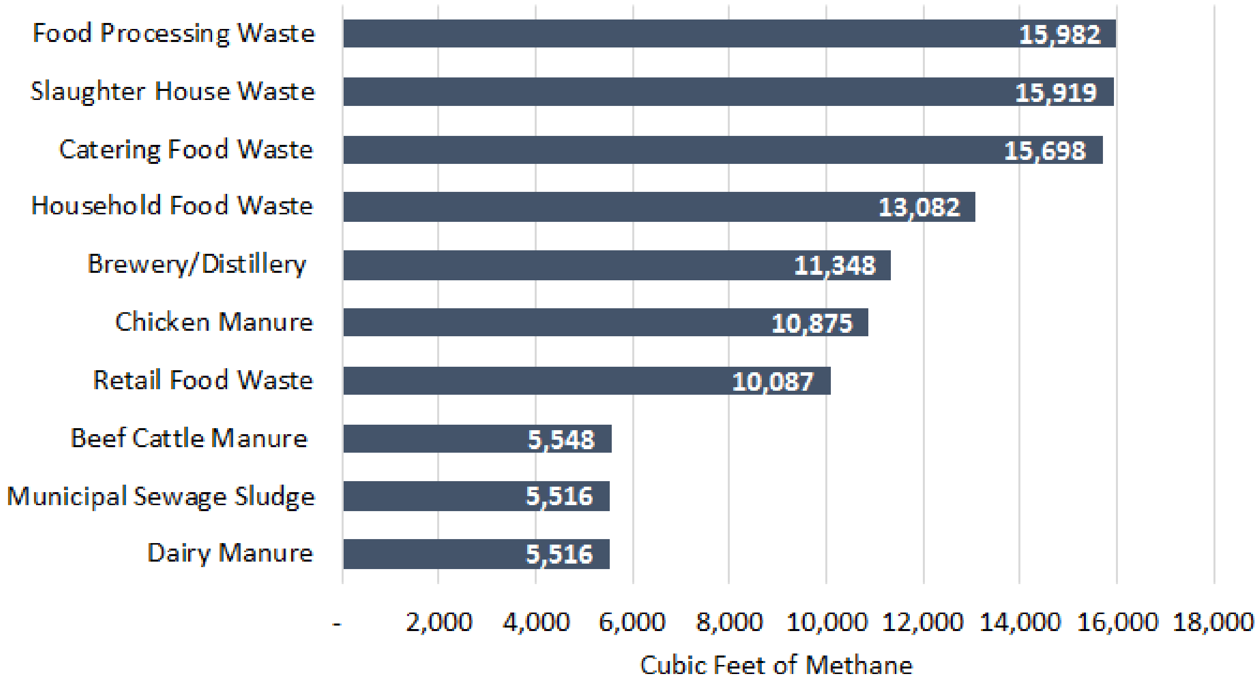
Common sources of biogas include wastewater treatment plants, landfills, and manure lagoons. Biogas can receive some minimal processing – such as removal of water, hydrogen sulfide, and siloxanes if present – and then be burned in special internal combustion engines (ICE) that are connected to generators to produce electricity.

Renewable natural gas (RNG), also known as biomethane, is biogas that has had both the contaminants and diluents removed, so that the remaining gas is around 98 percent methane and can be used interchangeably with conventional fossil fuel natural gas. RNG can be compressed and injected into common carrier natural gas pipelines for distribution anywhere in the United States, or it can be liquefied or compressed and transported by truck. RNG can be used as a transportation fuel in vehicles or as a stationary fuel for heating, cooking, process heat, electricity generation, or as a feedstock for some chemical manufacturing.

Oregon's Potential Resources for Biogas/RNG

This inventory examines the following anaerobic digestion biogas production pathways: waste food, agricultural manure, landfills, and wastewater treatment plants. This inventory also examined the potential RNG production from thermal gasification of forest and agricultural harvest residuals. Figure 1 shows the relative energy potential of various biogas feedstocks, comparing methane per ton of volatile solids (VS) in each feedstock after drying. Along with energy density, the ease of collection and preparation, transportation, and value of byproducts are important considerations in assessing the RNG production potential.

Figure 1. Methane Potential of Digestible Feedstocks.



Luna-delRisco, M, Noormak, and K. Orupold, 2011, Biochemical methane potential of different organic wastes and energy crops From Estonia, Agronomy Research 9 (1-2), (332-342).

Food waste waiting to be digested at JC Biomethane in Junction City, Oregon.

Waste food is a potential energy resource in the United States and Oregon. Between 25 and 40 percent of food produced or imported for consumption is discarded as waste (ODEQ 2017, 2). In Oregon, most waste food ends up in landfills, where it breaks down in an anaerobic environment and produces biogas (also referred to as landfill gas). Some municipalities have implemented rules that require source separation of organic material, diverting it from the landfill. In 2016, California prohibited food waste from the commercial sector to be landfilled.

Once separated, food waste is either sent to an anaerobic digester or a composting facility. Food waste is a high energy feedstock when cleaned of contaminants such as paper, packaging materials, and labels (EPA 2008). Only after the majority of these contaminants are removed can it be pulped and processed in an anaerobic digester.

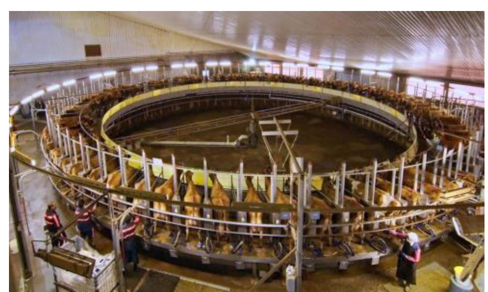
Two byproducts created from anaerobically digested material can become a value stream. These products are the liquid and solid fractions left over after the digestion process and are referred to as digestate. The liquid fraction is a high quality fertilizer, and the solid fraction can be used as a soil amendment. If the fiber is separated, dried, and sterilized, it can be used as animal bedding.

Landfills are another potential source for producing biogas. Organic material trapped in landfills undergoes several break-down phases; the environment quickly becomes anaerobic, and the methanogenic microorganisms begin producing biogas (or landfill gas). There are many strategies and regulatory requirements for capturing biogas at landfills. The most common is to drill or build in gas collection pipes at different layers in the materials pile, and then apply a slight vacuum to the collection system to pull the gas out. In this process, there is limited control over the biogas production, which is mostly driven by the types of wastes buried in the landfill. Fewer and less easily-degraded organic materials means less gas production. The volume of gas that landfills produce over time starts low, peaks, and then declines over a number of years.

A landfill gas well at Dry Creek Landfill in Eagle Point, Oregon.

Currently, when a landfill collects gas as part of its obligation under Title V of the Clean Air Act and Subtitle D of the Resource Conservation and Recovery Act, the landfill operators have two options: burn the gas in a flare, or clean the gas to a certain minimum level and then combust it in a specialized internal combustion engine to generate electricity with a generator. The generator can be connected to the electricity grid through appropriate infrastructure, and the landfill can sell electricity on to the grid via a power purchase agreement. This option is limited by the available capacity on the transmission lines at the landfill location. Some landfills also collect the heat generated during combustion and sell it as process heat. The next step is to further clean the biogas to pipeline quality and then inject the resulting RNG into a pipeline. Currently this path opens up other, more lucrative markets to this waste-derived biogas.

Agricultural manure is a biogas production pathway with a lot of potential in Oregon due to the large number of milk cows and beef cattle raised here. Currently, there are nine anaerobic digesters located on farms in Oregon (four are not operating at this time). Oregon dairy cows produce over 6.7 billion pounds of manure annually.



A milking carousel at Threemile Canyon Farms in Boardman, OR.

This inventory looked at dairy cows, beef cattle, broiler chickens, and laying chickens as the most likely sources of agricultural manure for production of biogas and then RNG. Dairy cow manure and chicken manure are feasible feedstocks for wet anaerobic digestion, which is a familiar form of AD (commonly found at a wastewater treatment plant). Beef cattle manure cannot be digested in a wet digester because it is collected from the ground, and significant amounts of sand and dirt end up in the waste stream, where these contaminants plug up the wet AD units. When an AD facility has to shut down for cleaning, it can take months before the microorganisms rebuild their populations to maximize gas production. There is a version of “dry” digestion that can use cattle manure as its feedstock, but there are currently no “dry” digester facilities in Oregon. Chicken manure, while higher in energy content than dairy cow manure, has a different chemical composition than other feedstocks and therefore traditionally needs a separate digester.

The collection and preprocessing of agricultural manure is complex, as is the management of the digestate after it has passed through the AD facility. Dairy waste is high in water content and is relatively expensive to transport. Once the animal manure has been transported to a digester, the liquid fraction of the digestate must be transported back to the farm for land application.

Wastewater treatment plants are ideal locations for AD. In Oregon, 26 of the state’s 49 largest WWTPs –plants with more than one million gallons a day of inflow – already have AD facilities in place. AD is considered a standard wastewater treatment protocol and is a well-developed technology. Some wastewater treatment plants accept additional high energy potential material such as fats, oils, and greases (FOG) or food waste to increase their production of biogas and collect additional tipping fees for disposing of regulated organic waste products. Many WWTPs with AD burn the biogas they produce in special internal combustion engines and produce electricity and heat for their own use and to sell onto the electricity grid or to neighboring facilities.

Anaerobic digesters at Oregon’s first RNG project: Columbia Boulevard Wastewater Treatment Plant in Portland, OR.

Forest and agricultural harvest residuals also represent two different biogas production pathways. These sectors produce lignocellulosic waste material as a result of their primary activity. Lignocellulosic refers to the woody stems, branches, and leaves of trees and shrubs. This material can eventually be broken down via anaerobic digestion, but the tough woody fibers (composed of lignocellulose) are better processed with thermal gasification or other technologies that are capable of breaking down the fibers more quickly.

A slash pile left behind after commercial timber harvest activities.

For this inventory, forest harvest residuals represent only the leftover material from a commercial forest harvest activity. These materials include tree tops and branches, and broken, twisted, or un-merchantable timber left over at a harvest site. This material is typically piled up at the harvest site and allowed to decompose or is burned on site. The Oregon Department of Forestry (ODF) suggests that for every 1,000 board feet of timber harvested, about 1.6 tons of green material is left behind in the forest. For this version of the RNG Inventory, the reported estimates do not include material harvested as part of forest health or fire fuels reduction activities. The U.S. Forest Service anticipates producing forest-specific residuals estimates sometime during the winter of 2018-19, and ODOE will include this information in a future iteration of this report.

Agricultural harvest residuals examined for this inventory are confined to wheat straw, grass straw, and corn stover (stover is the leftover parts of the corn plant, such as stalks, leaves, and cobs when it is harvested for grain). These three crops represent the largest sources of biomass in the agricultural community. Both forest and agricultural feedstock categories have significant economic challenges in their supply chains, primarily in collecting and transporting the raw feedstock material.

Straw agricultural residuals left behind in the field after harvest activities.

CHAPTER 1: CONVERSION TECHNOLOGIES AND PROCESS REVIEW

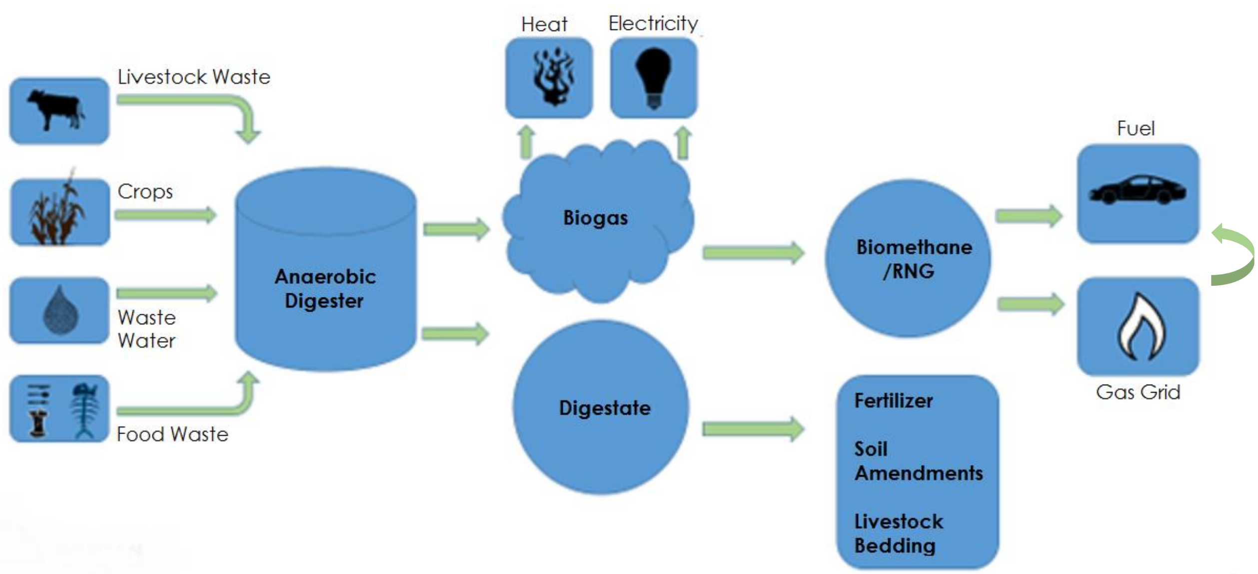
Biogas and RNG can be produced through numerous pathways. Two of the most common technologies for producing biogas are anaerobic digestion (AD) and thermal gasification. These processes produce gases that typically require additional steps before they can be marketed to various end users as RNG. This chapter will discuss these technologies and several near-commercial technologies, including power-to-gas (for producing hydrogen and methane) and hydro thermal processing, which increases the production of methane. In addition, commercially viable clean-up (the removal of destructive contaminants) and upgrading (removal of diluents) technologies will be briefly discussed.

Biogas Production Pathway Technologies

Anaerobic Digestion

The technique of anaerobically digesting waste is not new, and dates back to the tenth century when the Assyrians used it to heat bath water (Ostrem 2004, 2). It is a biological process employing methanogenic microorganisms to metabolically break down complex organic molecules in the absence of oxygen to produce biogas – a gas mixture made up primarily of methane and carbon dioxide, along with small amounts of hydrogen sulfide, nitrogen, oxygen, siloxanes, ammonia, and particulates (Ostrem 2004, 3). A second product of anaerobic digestion is digestate, which is a combination of solid material and liquid materials. Digestate can be used as a high-quality liquid fertilizer and in some cases, the solids can be separated, dried, and used as soil amendments or as livestock bedding (USDA, EPA, and USDOE 2014, 13). The makeup of these materials depends heavily on the organic materials used in the biogas fuel production pathway.

Figure 2. Anaerobic Digestion Production Pathway.



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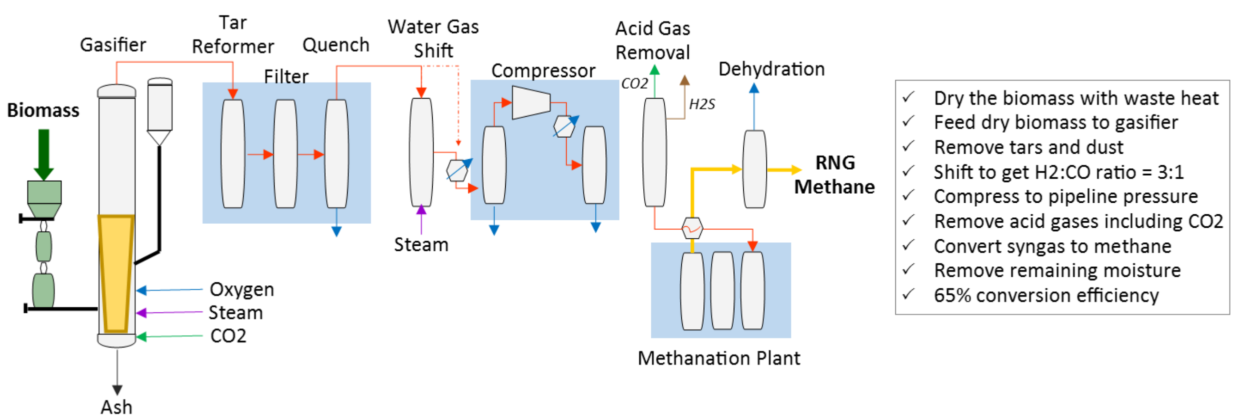
Thermal Gasification

Thermal gasification was first used in the 1800s for industrial and residential heating, and its primary product, synthesis gas, known as syngas, is made up primarily of highly-flammable carbon monoxide and hydrogen. Syngas can be converted to methane with additional processing. Historical feedstocks for thermal gasification include wood biomass and coal, but recently the use of municipal solid waste in gasification has been proposed. There are several thermal gasification technologies available with variations using different temperatures and heating approaches. High temperature approaches produce syngas while medium temperature approaches make "producer" gas, which has a slightly different chemical make-up but can also be converted to methane with additional processing (Sadaka 2010, 2). There are currently no commercial-scale thermal gasification plants in the United States that convert biomass into methane. The existing plants produce syngas, which is burned and used to generate heat and electricity. There are significant research efforts underway to bring down the cost of the conversion of syngas to methane.

Figure 3. Thermal Gasification Production Pathway.



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Other Near-Commercial Technologies

Power-to-gas (PtG)

PtG technology uses electrolysis to convert water to hydrogen. Excess renewable electricity generated by wind, PV, hydropower, or other renewable sources as the primary "feedstock" is used to "crack" water molecules to produce hydrogen and oxygen. When produced from renewable resources, hydrogen is a nearly carbon-free fuel that can be used in various industrial processes, as a standalone fuel, or converted to methane using catalytic or biological conversion methods (Persson et al. 2015, 6). If the existing national scale natural gas grid is used as a storage site for hydrogen, PtG can be a significant long-term storage strategy for low or carbon neutral energy that is currently being wasted. This is a developing technology that is being piloted at several locations around the United States but not yet in Oregon.

PyroCatalytic Hydrogenation (PCH)

This quickly developing technology uses low temperatures and hydrogen gas to vaporize feedstocks directly into methane and water vapor, as opposed to most gasifier technologies, which must gasify feedstock and convert the hydrogen into methane in a separate step (G4 Insights 2018). One model is a small modular design that can achieve around 70 percent thermal efficiency and methane purity levels of 98 percent using a proprietary pressure swing absorption process. The renewable synthetic natural gas produced from the technology meets all pipeline specifications, is considered a Super-Ultra-Low-Carbon transportation fuel in California, and produces very few waste byproducts. Any resulting hydrogen or bio-char can be reused in the process and is tar and oil-free. This technology is nearing commercial viability.

Hydrothermal Liquefaction

This is a process that relies on converting biomass into liquid fuels using hot, pressurized water to reduce the feedstock to primarily liquid components. In essence, hydrothermal liquefaction is the breakdown of organic material into simpler feedstocks and other by-products in hot liquid water (Snowden-Swan 2016, 1). Products of this technology include biocrude, which can be upgraded to liquid fuel specifications, as well as some off-gas, which can be used to heat the reactor vessel. Some designs can eliminate the wet waste entirely and produce significant quantities of renewable natural gas. A wide variety of wet and dry organic feedstocks can be used in hydrothermal liquefaction processes.

Biogas Cleaning & Upgrading Technologies

For biogas to become RNG, it must have contaminants and diluents removed. Biogas clean-up technologies remove contaminants, while biogas upgrading technologies remove the diluents.

Contaminants and Diluents

Contaminants are the trace components of biogas, and their prevalence varies based upon the biogas production pathway. They include sulfur compounds, silicon compounds, oxygen, Volatile Organic Compounds (VOCs), halogen compounds, and particulate matter such as dust, oil, or other inorganic particulates (Williams, Kaffka, and Oglesby 2014, 17).

Diluents are components of biogas that lower its methane content and require some level of removal when upgrading biogas for use as a fuel. Diluents include: carbon dioxide, nitrogen, and water vapor or moisture (Williams, Kaffka, and Oglesby 2014, 17).

Clean-Up Technologies

Raw biogas must be cleaned of contaminants to be economically and technologically viable for use in most combustion technologies and to meet pipeline standards. The cleanup process depends on the variety of contaminants produced by the various biogas fuel production pathways, as well as the requirements of end-use technology and regulations for the biogas. Some of the commercially available clean-up technologies include absorption, water scrubbing, biofiltration, and refrigeration/chilling. However, some of these technologies, such as refrigeration/chilling, are only capable of removing certain contaminants and must be paired with ancillary clean-up technologies.

Once biogas has been cleaned of impurities, its energy content can be increased by removing diluents and simultaneously increasing the methane content. The most common commercialized upgrading technologies include pressure swing absorption, chemical solvent scrubbing, pressurized water scrubbing and membrane separation technology.

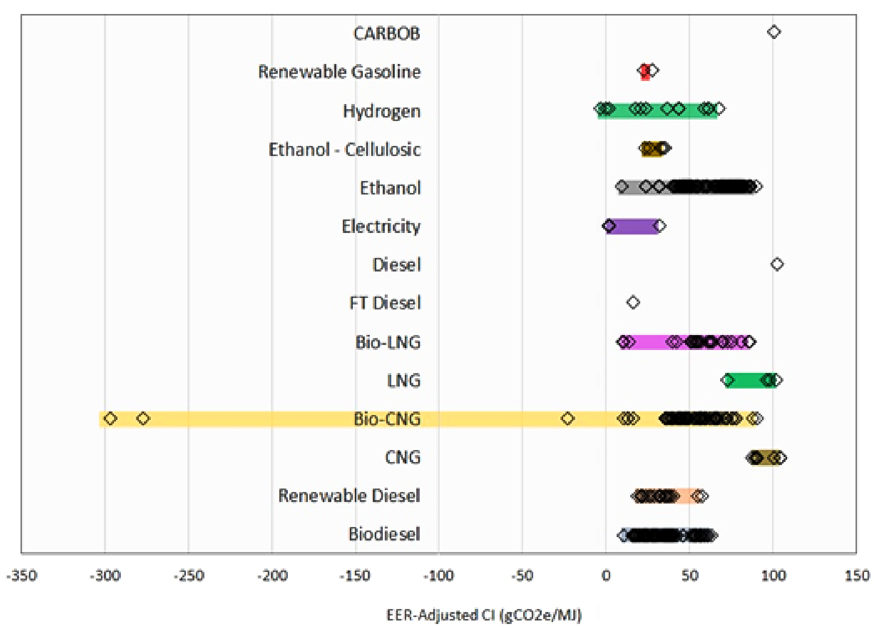
Biogas / Renewable Natural Gas Use

Biogas can be minimally cleaned and then burned in a specialized internal combustion engine that is attached to a generator to generate electricity for use onsite or commercial export to the electricity grid. The heat from the biogas combustion is frequently captured and used as process heat in an arrangement known as Combined Heat and Power (CHP) (Ostrem 2004, 3). This use of biogas is one of the most common approaches at locations that currently produce biogas via anaerobic digestion, or syngas via thermal gasification. Because biogas has a lower methane content, lower heat value, and contains contaminants and diluents, it cannot be injected into a common carrier natural gas pipeline.

By comparison, RNG is interchangeable with traditional fossil fuel natural gas and has significant value as a stationary or transportation fuel, and in chemical feedstock production applications.

When RNG is used as a vehicle fuel, there are significant reductions in GHG emissions and air pollutants. In 2003, a National Renewable Energy Lab research project showed that when diesel fuel was replaced with natural gas in heavy duty truck engines, CO emissions were reduced 87 to 93 percent, NOx emissions were reduced 24 to 45 percent, and total particulate matter was reduced 90 percent (NREL 2003). Figure 4 shows a comparison of carbon intensity for various alternative fuel pathways from the California Air Resources Board (CARB 2018).

Figure 4. CARB Carbon Intensity Values of Current Certified Pathways (2017).



California Air Resources Board Low Carbon Fuel Standard. 2017.

In Figure 4, the fuel type "Bio-CNG" is compressed RNG. Each of the diamonds on the individual rows shows the carbon intensity of the fuel as calculated for a specific fuel production pathway and location. The negative values shown for Bio-CNG represent RNG that is being produced from anaerobic digesters that are processing dairy manure. Dairy manure-derived RNG can have negative carbon intensity values because this form of RNG is capturing methane that would have been released to the atmosphere. It is the avoided methane emissions that make it negative.

Biogas that is not used to generate electricity or power vehicles is often flared. Flaring is the process of burning raw gas in a large external structure open to the atmosphere. This is the least productive means of using biogas, but emits lower greenhouse gas emissions than releasing methane directly into the atmosphere.

CHAPTER 2: PRODUCTION PATHWAYS AND METHANE PRODUCTION POTENTIAL

This chapter explains how the data for each of the biogas production pathways were compiled and the theoretical optimal amounts of biogas and methane production that can be achieved with current technology for each pathway. These values should be considered a starting place when evaluating potential gas production opportunities, with the caveats discussed below. The information is not at a site-specific scale where it could be used to make significant economic decisions about specific projects.

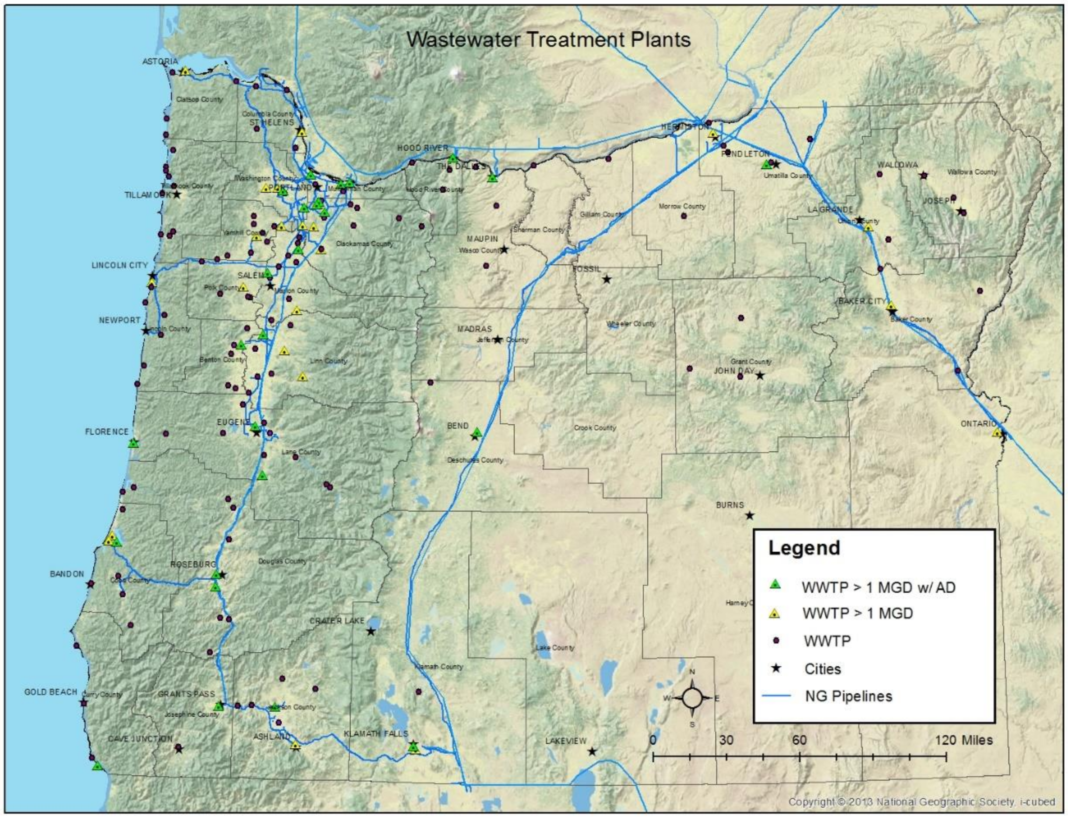
Anaerobic digestion is a variable biological process with several variables that affect the final volume and quality of gas production. The supply chains and the steps that each raw feedstock goes through, from origin to consumption of the final energy product, are in some cases long and complex. In all cases, the numbers represent a range of gas production potentials. When possible, ODOE used two different approaches to estimate the potential for each feedstock to give a realistic spread of expected outcomes. Approaches for each feedstock are described below.

For feedstocks that are being converted from raw material to methane via thermal gasification, there are currently no commercial operations in the United States that are processing wood or agricultural harvest residuals into methane. Research undertaken for this report found that the commercial-scale thermal gasification plants in the U.S. currently stop at an intermediate gas known as syngas, and then burn that gas for process heat and electricity generation. Considerable research underway at the near-commercial scale is looking at how to bring down the cost of creating, and increase the volume of, methane from lignocellulosic biomass (the tough woody parts of plants), to be more competitive with currently inexpensive fossil-based natural gas and RNG produced via anaerobic digestion. There is significant feedstock opportunity in Oregon's forest and agricultural harvest residuals, but the supply chain for these feedstocks can be long, complex, and expensive. Finally, a number of processes are nearing commercial scale application; because of this, and the level of interest in converting forest and agricultural harvest residuals into RNG, this report includes these biogas production pathways in the inventory.

Wastewater Treatment Plants – Anaerobic Digestion

Oregon has approximately 199 community-scale wastewater treatment systems. For the purposes of this study, ODOE evaluated community treatment plants that had at least one million gallons per day (1 MGD) of inflow. The 1 MGD parameter narrows down the number of viable locations to 48 plants. These results also represent a plant size that would serve a metropolitan area traditionally considered large enough to justify the expense of installing an anaerobic digestion facility. Twenty-six of these sized plants in Oregon already have anaerobic digesters (AD) in place and are producing biogas. New technologies are beginning to make the capture of biogas from other treatment technologies a viable option. In this initial inventory ODOE only reviewed traditional AD treatment locations.

Figure 5. Map of Oregon Wastewater Treatment Plants (2017).



Oregon Department of Energy. 2018.

Data for WWTP were developed using two slightly different approaches: modeled gas flow data and metered gas flow data. In both cases, the base technical information was provided by the plant operators. ODOE worked with the Oregon Association of Clean Water Agencies (OR ACWA) and various wastewater treatment plant engineers and operators to develop a modeled approach that took into account the challenge of groundwater inflow into the wastewater collection system infrastructure, which has the impact of diluting the potential material to create biogas. The joint modeling effort is based on estimated volatile solids content in the waste stream rather than reported inflow. Volatile solids are the source material that produces the biogas.

The 27 largest plants participated in a survey to provide base data used to generate the per capita volatile solids contribution value. Both data sets (metered gas flow and calculated gas production) are reported as normalized data (based on population) to help address the variability in the reported data. Averages for volatile solids production were calculated for plants that reported, then a general per capita value was derived and applied to all 48 plants. The data is presented by city and by county. Because biogas displays a range of methane concentrations, ODOE made estimates at three different methane concentrations.

Table 1. Gross Annual Methane Potential from WWTPs (2017).

Source	Cubic Feet of CH4 Per Year
Agricultural Manure	4,639,626,825
Wastewater	1,225,228,606
Food Waste	138,571,656
Landfill	4,351,052,420
Total	10,354,479,507

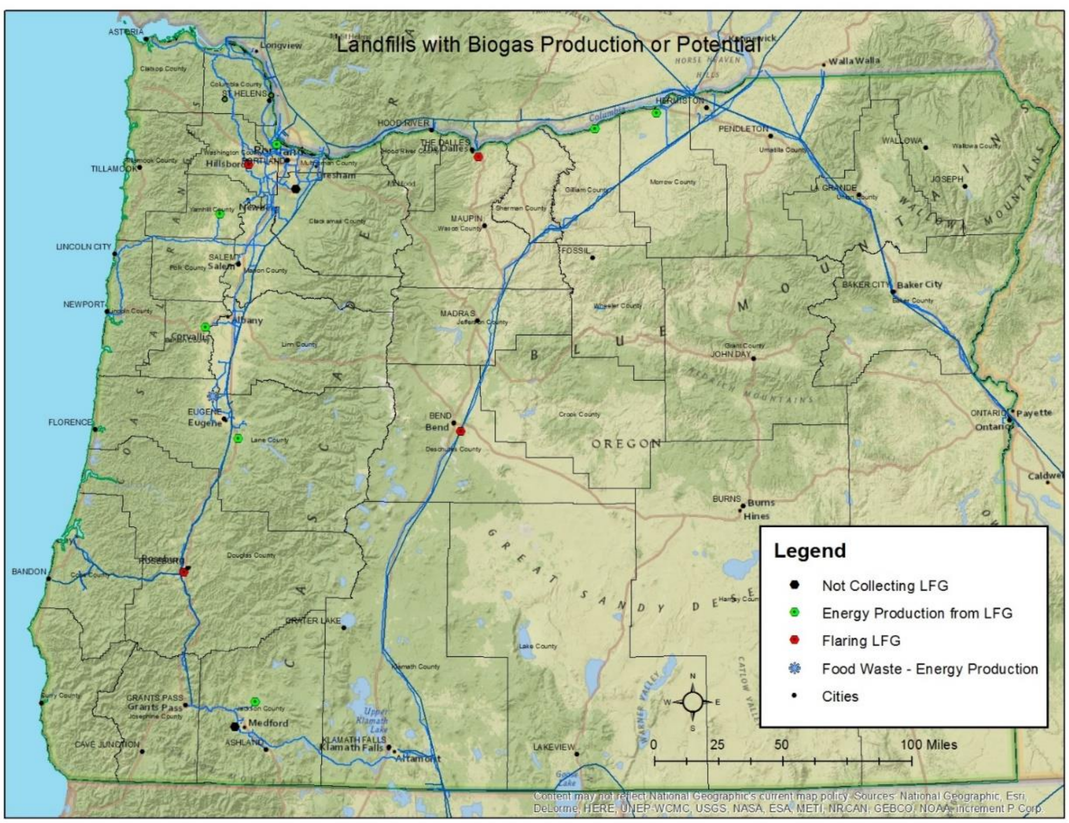
Oregon Department of Energy. 2018.

See Appendix B for individual wastewater treatment plant potentials.

Landfills – Anaerobic Digestion

ODOE collected data for landfills using two different approaches. One is modeled data used in an existing regulatory process managed by the Oregon Department of Environmental Quality (ODEQ); the other is based on operator reported data received via a formal survey ODOE conducted for this project.

Figure 6. Map of Oregon Landfill Sites (2017).



Oregon Department of Energy. 2018.

Thirteen landfills in Oregon receive or used to receive municipal solid waste. While other landfills exist in Oregon, these were not included because they were below the size threshold set for this inventory (one million tons of waste in place) or are categorized as construction and demolition landfills with large percentages of inorganic materials, and therefore have very low methane potentials.

The ODEQ Solid Waste Management Program data includes modeled values for carbon-dioxide-equivalent gas generation, oxidation, and emissions. The ODEQ data was reported as carbon dioxide-equivalents, and these values were converted to methane using the U.S. Environmental Protection Agency's definition of methane's greenhouse gas potential being 25 times that of carbon dioxide's, pound for pound, on a 100-year basis. The EPA value was then converted from metric tons to British Thermal Units and then to cubic feet of methane. ODEQ provided data for:

- Generation – the total amount of gas generated from the anaerobic decomposition of waste in place within the landfill
- Oxidation – a portion of the total generated methane that, upon migrating to the upper biologic layer of the landfill, reacts to form other gases
- Emissions – a portion of the total generated methane that migrates out of the landfill and escapes to the atmosphere
- Collection – a figure produced by subtracting the total generated methane from the sum of the oxidized and emitted methane. It is assumed that the product of this formula was collected through the landfill's gas collection system. [Collection = Generation – (Oxidization + Emission)]

The second data set is composed of information collected by ODOE staff via written and oral interviews with all 13 landfill operators. This data provides an additional on-the-ground perspective of biogas and methane potentials in comparison to the modeled data developed by ODEQ. It is important to remember that the *survey generated* dataset does not take into account all variables in methane potential of these landfills, such as generation, oxidation, and emission, all of which were accounted for in the ODEQ model. Additionally, this data hinges on the efficiency of landfill gas collection systems and accuracy of gas metering systems. While both data sets are reported in the appendices, the ODOE survey data is reported in the tables here.

Table 2. Gross Annual Methane Potential from Landfills (2017).

Source	Cubic feet of CH4 per year
Agricultural Manure	4,639,626,825
Wastewater	1,225,228,606
Food Waste	138,571,656
Landfill	4,351,052,420
Total	10,354,479,507

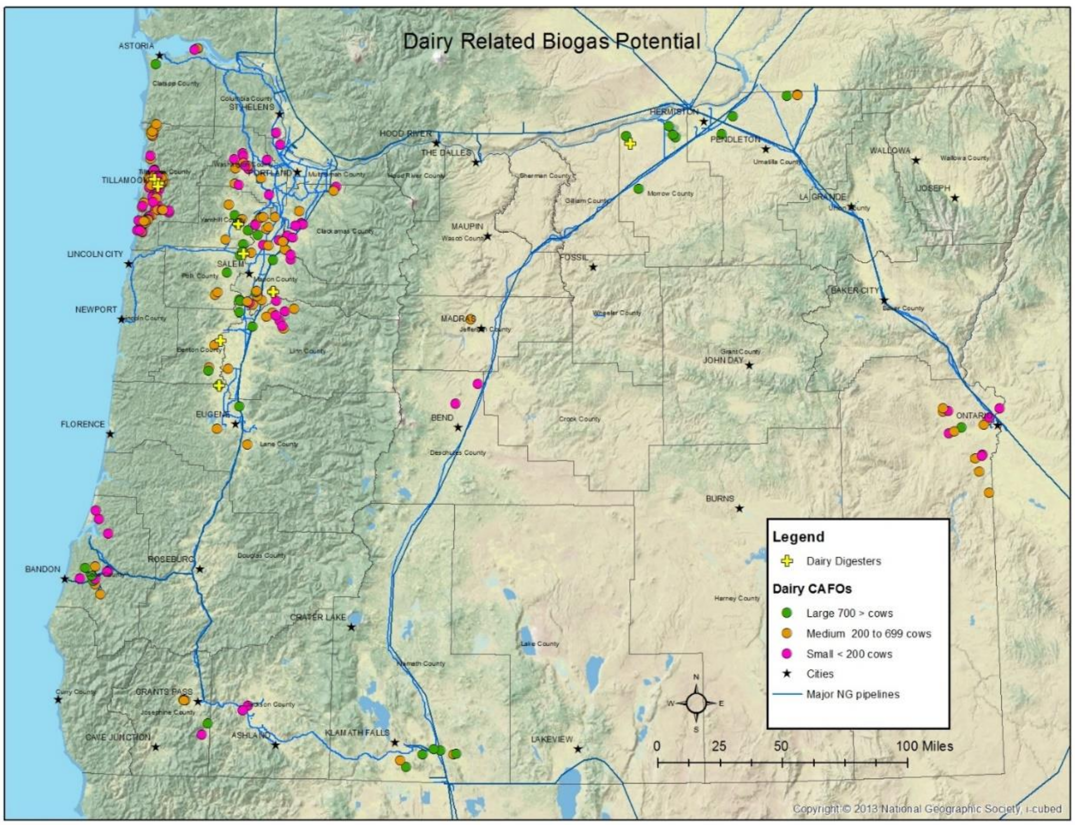
Oregon Department of Energy. 2018.

See Appendix B for individual landfill production potentials and both data sets.

Agricultural Manure – Anaerobic Digestion

ODOE worked with the Oregon Department of Agriculture (ODA) to produce a model and data set estimating the methane potential of several agricultural manure feedstocks within the state of Oregon. Biogas production pathways include dairies, beef cattle feed lots, laying chickens, and broiler chickens. Calculating methane production of agricultural manure relies on many protocols. Numerous variables differ from farm to farm and region to region, including rainfall, confined feeding strategies, pasture strategies, manure management strategies, and cattle breeds.

Figure 7. Map of Dairy CAFOs Sites (2017).



Oregon Department of Energy. 2018.

For the dairy manure biogas production pathway, ODOE and ODA initially reviewed all dairy Confined Animal Feeding Operations (CAFOs) and categorized them by region: coast, valley, and east. All CAFOs were divided by population into categories of large (700+ head of livestock), medium (200-699 head of livestock), and small (<200-head of livestock) sizes. Due to the number of dairy CAFOs throughout the state and their manure capture feasibility, a manure capture rate was developed to estimate the amount of manure that could realistically be captured from dairy cows at each of the 244 dairy CAFOs. This rate took into account the number of days the CAFO reported it grazed its cows, which was then subtracted from 365, the total days in a year, and then divided by 365 to leave an annual percentage rate that calculates the number of days dairy cows were housed on an impermeable surface that could support manure recovery (not pasture or open pens with dirt or sand floors), as well as dairy cows' life stages (i.e. cows being milked, dry cows, and heifers; ODOE and ODA did not include calves).

To calculate manure production rates in a uniform fashion, ODOE used rates for manure production in pounds per animal per day and volatile solids in pounds per animal per day. Calculations were derived from the *USDA Agriculture Waste Management Field Handbook*, in Chapter 4: Agricultural Waste Characteristics. The methane potential rate is sourced from the *U.S. EPA State's Workbook, Workbook 7: Methane Emissions from Animal Manure*, in Table 7-3 titled Maximum Methane Producing Capacity for U.S. Estimates.

As the investigation progressed, ODOE and ODA decided to use Animal Unit (AU) numbers, volatile solids per AU, methane production per pound of volatile solids, and manure capture rates, as not all manure produced can be collected for AD because of contamination from soil or sand. Understanding the quantity of material that has to be delivered to the supply chain is important, and therefore, manure quantity is included in Table 3. The research also included reported manure production and quantities as well, but these data were not used in the final methane estimations. A detailed explanation of the protocol can be found in Appendix C.

Other CAFOs

ODOE and ODA assembled data on other types of CAFOs, including beef cattle and broiler and laying chickens. Each type of operation brings additional challenges into the biogas/RNG production process. Beef cattle are raised in open feedlots, and the manure is scraped off the ground and placed in open piles. This introduces sand and dirt into the feedstock material stream, which plug up digesters, and result in multi-month-long shut-downs. This manure can be placed in a "dry" digester, and methane can be recovered from the anaerobic decomposition, but Oregon currently has no "dry digester" systems operating.

Chicken manure and the bedding that is typically mixed into it are a high-energy feedstock. Chicken production is limited to 32 CAFOs in Oregon, and there are no chicken waste anaerobic digesters operating in Oregon. Chicken manure is currently processed and sold as fertilizer.

For all other CAFOs, similar resources and methods were used to capture data, but did not incorporate variable manure capture rates (100 percent capture was assumed). Values for each animal type were sourced from the *USDA Agriculture Waste Management Field Handbook*, in Chapter 4: Agricultural Waste Characteristics. Methane potential rates corresponding to each animal type were sourced from the *U.S. EPA State's Workbook, Workbook 7: Methane Emissions from Animal Manure*, in Table 7-3 titled Maximum Methane Producing Capacity for U.S. Estimates.

Table 3. Gross Annual Methane Potential from Agricultural Manure (2017).

Source	Cubic feet of CH4 per year
Agricultural Manure	4,639,627,000
Wastewater	1,225,229,000
Food Waste	138,572,000
Landfill	4,351,052,000
Total	10,354,480,000

Oregon Department of Energy. 2018.

See Appendix B for separate CAFO type production potentials by county.

Food Waste – Anaerobic Digestion

Food waste is a growing source of energy and nutrient capture in the U.S. Of the feedstocks examined, food is one of the highest energy sources that can be processed in an anaerobic digester (see Figure 1).

Traditionally, food waste was sent to landfills, where it breaks down in an oxygen-free environment and releases methane and other gases. As previously described, some landfills capture those gases and convert them to usable energy. Recently, some communities have begun to separate food waste from their landfill waste streams and redirect it into other management pathways. One of those pathways leads to controlled anaerobic digestion of the food at an AD facility and the generation of biogas and renewable natural gas, as well as recapture of the nutrients and fiber found in the waste food stream. Much of this activity is driven by local ordinance on how waste food is collected and diverted. Oregon does not have a statewide waste food diversion plan, but Metro, the regional government in the metropolitan Portland area, does.

Figure 8. Food Waste Sites (2017).

Oregon Department of Energy. 2018.

The data used to estimate the amount of waste food comes from two studies. One is a study that ODEQ conducted on a statewide basis to determine the amount of waste food and green waste/yard debris available in the curbside garbage stream (ODEQ 2017). The second is a study on converting food into biogas via anaerobic digestion (EPA 2008). This second study gives the average conversion rate of wet food to cubic feet of methane from processing in an anaerobic digester.

The data collected was divided into three categories. Generated means the amount of food waste and urban green waste generated for each waste-shed. Disposed means how much of the generated food waste and urban green waste goes to a landfill. Recovered food waste and urban green waste is the waste that is diverted from landfills. This waste may be composted, or some of the food waste may be diverted into an anaerobic digester (yard debris composed of woody materials does not function well as a feedstock in a traditional municipal anaerobic digester). For this study it is assumed that all “recovered” food waste went to AD.

Table 4. Gross Annual Methane Potential from Food Waste (2017).

Source	Cubic feet of CH4 per year
Agricultural Manure	4,639,627,000
Wastewater	1,225,229,000
Food Waste	138,572,000
Landfill	4,351,052,000
Total	10,354,480,000

Oregon Department of Energy. 2018.

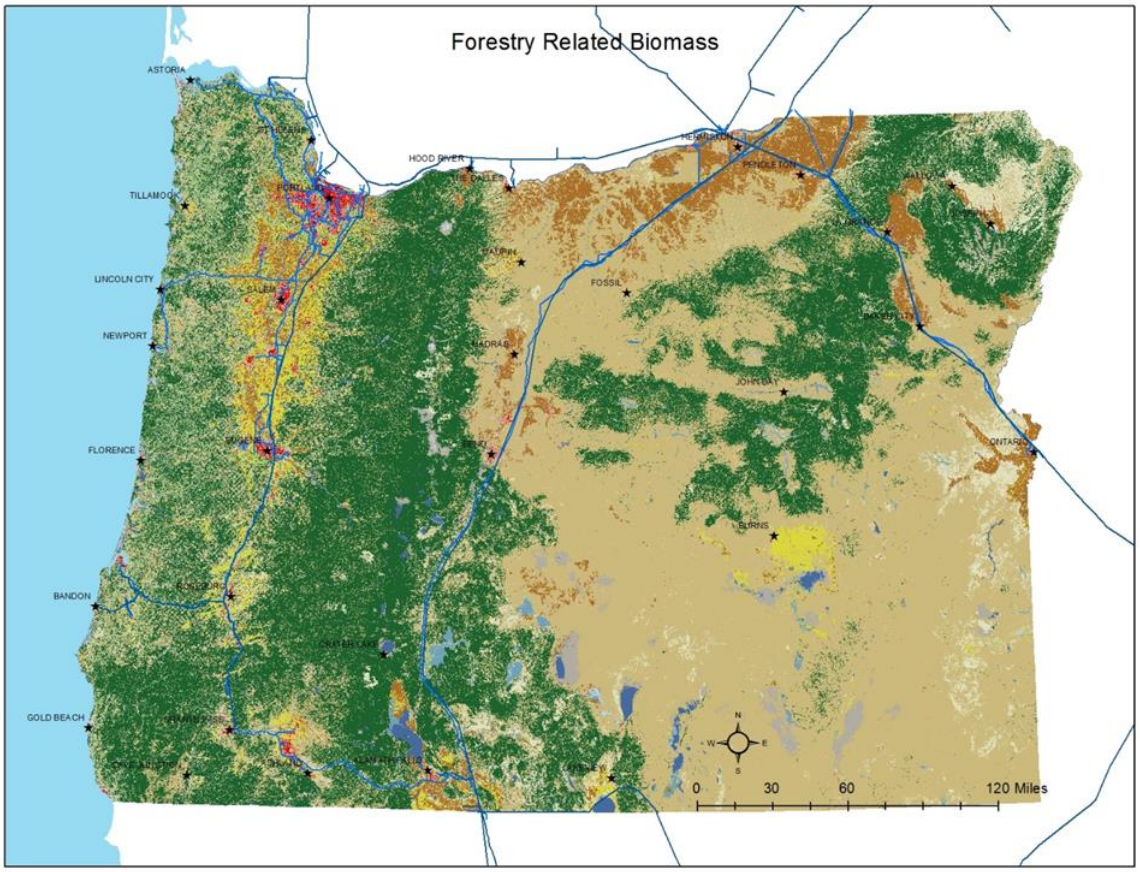
See Appendix B for individual wasteshed production potentials.

Forest Residuals – Thermal Gasification

Residuals from commercial forest harvest represent a potentially large supply of feedstock for conversion to RNG. However, because forest residuals require thermal gasification to create RNG there are economic and technological challenges to converting this material to RNG.

Forest harvest residuals were analyzed at the county level using commercial timber harvest data collected by the Oregon Department of Forestry (ODF). Harvest data was broken out by county and separated by geographic region due to differences in tree species west of the Cascade Mountains and east of the Cascade Mountains. The predominant tree type west of the Cascades is the Douglas Fir, while the Ponderosa Pine populates the landscape east of the Cascades. Each species has a different energy content, expressed in British Thermal Units (Btu), and it was assumed for this analysis that all trees harvested in counties west of the Cascades were Douglas Fir and all trees harvested in counties east of the Cascades were Ponderosa Pine.

Figure 9. Map of Forestry Residuals Resources (2017).



Oregon Department of Energy. 2018.

Average Btu values were determined for the potential residual parts of the trees (tops and branches) that would be the primary source for feedstock material. Additional information from ODF and a review of literature were used to determine the potential amount of feedstock that could be generated (Howard 1988, 4; Simmons et al. 2016). The resulting calculation is between 1.6 and 2 tons of wet timber residual generated for every 1,000 board feet harvested. Applying a 50 percent recovery rate of that material, the base amount of feedstock was calculated and converted from wet wood to bone dry tons based on Glass et al 2010. These dry tons of fuel were then applied to the average yearly harvest value for each county from 2010 to 2016 to produce the potential methane production.

Table 5. Gross Annual Methane Potential from Thermal Gasification (2017).

Source	Cubic Feet of CH4 Per Year
Forest Industry Residuals	16,998,109,000
Agricultural Industry Residuals	22,686,775,000
Total	39,684,884,000

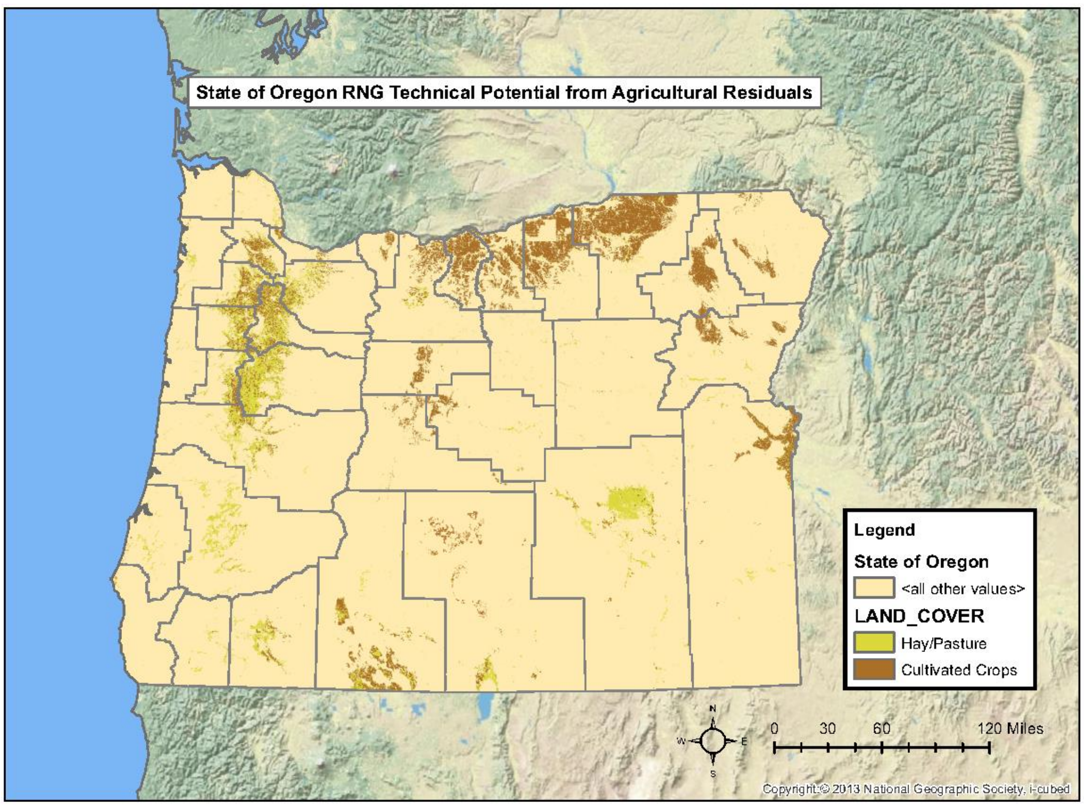
Oregon Department of Energy. 2018.

See Appendix B for individual county production potentials.

Agricultural Residuals – Thermal Gasification

Agricultural residuals were analyzed at the county level using county crop harvest data for wheat, grass seed, and grain corn. Wheat was analyzed for its wheat straw byproduct, grass seed for its grass seed straw byproduct, and grain corn for its corn stover by-product. Wheat straw and grass seed straw were both analyzed because of the large acreage produced. Grain corn was analyzed due to its high residual production rate per acre planted, rather than total acres planted. Data for the number of acres harvested was collected from the USDA Census of Agriculture (2012) for the most recent year data was available, 2012, for each crop type at the county level, in order to determine the amount of residuals produced for each crop type in each Oregon county.

Figure 10. Map of Agricultural Residuals Resources (2017).



Oregon Department of Energy. 2018.

Feedstock production estimates were calculated by determining the number of acres harvested per crop type, and multiplying that value by the respective rate of crop residue production per acre. The resulting figure was the total tons of bone dry residuals for each crop type, per acre, and at the county scale. A 50 percent recovery rate reduced the total volume. These three numbers were then multiplied by the number of Btus per ton of bone dry residual for their respective crop type. The final figures for each crop type were divided by 1,027 Btus to reach a theoretical cubic feet of methane value for each crop type (Hofstrand 2014, 1). A detailed analysis and example can be found in Appendix D.

Table 6. Gross Annual Methane Potential from Forestry Residuals (2017).

Source	Cubic Feet of CH4 Per Year
Forest Industry Residuals	16,998,109,000
Agricultural Industry Residuals	22,686,775,000
Total	39,684,884,000

Oregon Department of Energy. 2018.

See Appendix B for individual county production potentials.

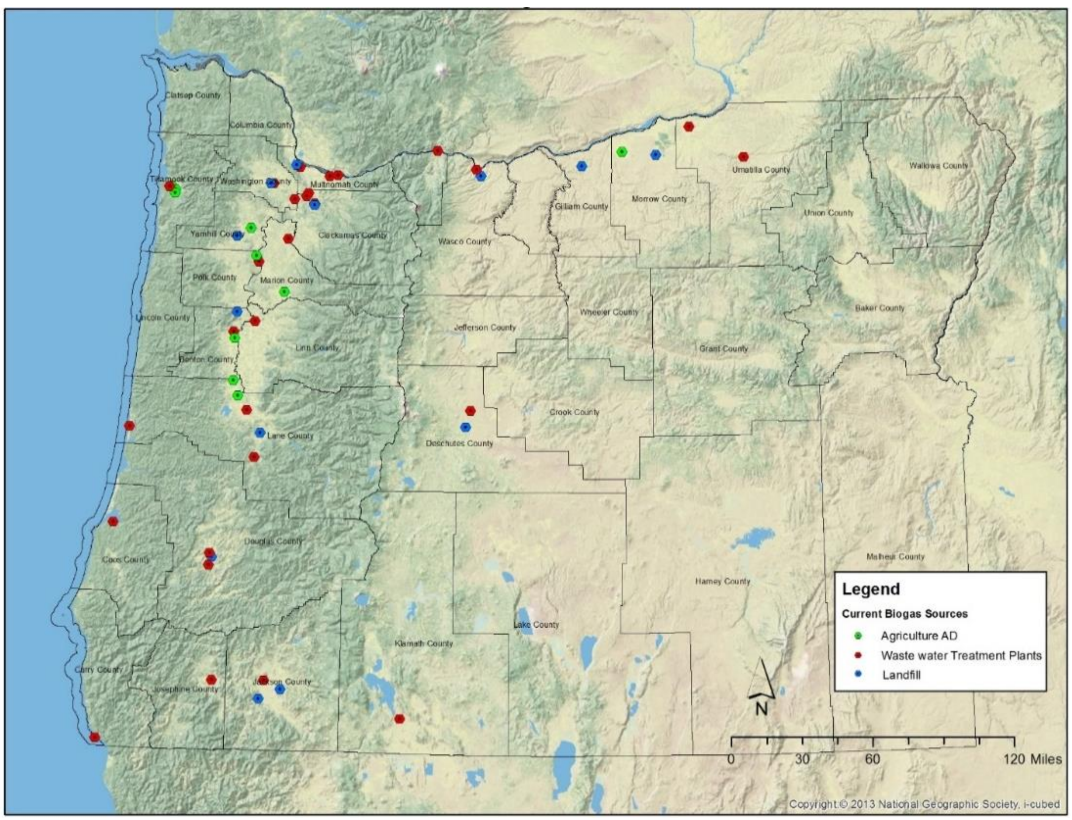
CHAPTER 3: CURRENT BIOGAS PRODUCERS AND SUPPLY CHAINS

The following chapter details biogas producing operations within the state, as well as general overviews of biogas production pathway supply chains. These topics were investigated using the most up-to-date data available.

Current Biogas Production Facilities

There are 49 biogas production facilities in Oregon currently producing or have produced biogas and electricity. Specifically, these facilities include nine Confined Animal Feeding Operations (CAFOs), one dedicated food waste processing facility, 26 WWTPs, and 13 landfills.

Figure 11. Current Biogas Production Facilities in the State of Oregon (2017).



Oregon Department of Energy. 2018.

All of these locations utilize anaerobic digestion; there are no commercial thermal gasification plants operating in Oregon. Some of the AD facilities are currently closed and there are several additional plants being considered for construction by private entities around the state. All of these plants produce biogas or landfill gas, conduct some level of gas clean up, and combust that gas in a flare or an internal combustion engine (ICE), which is connected to an electricity generator. In some cases, a portion of that electricity is consumed on site for station power, while some plants sell a portion of the resulting electricity onto the electric grid through a

Power Purchase Agreement (PPA). Several biogas plants also capture the heat from the engine jacket coolant water and the exhaust gas stream and use that heat for industrial processes, such as building heat, material drying heat, or to help heat the anaerobic digesters. All digesters require heat to operate efficiently. In Oregon, the digesters contain mesophilic microorganisms that need temperatures between 95 and 100.4°F in order to break down waste at an acceptable rate.

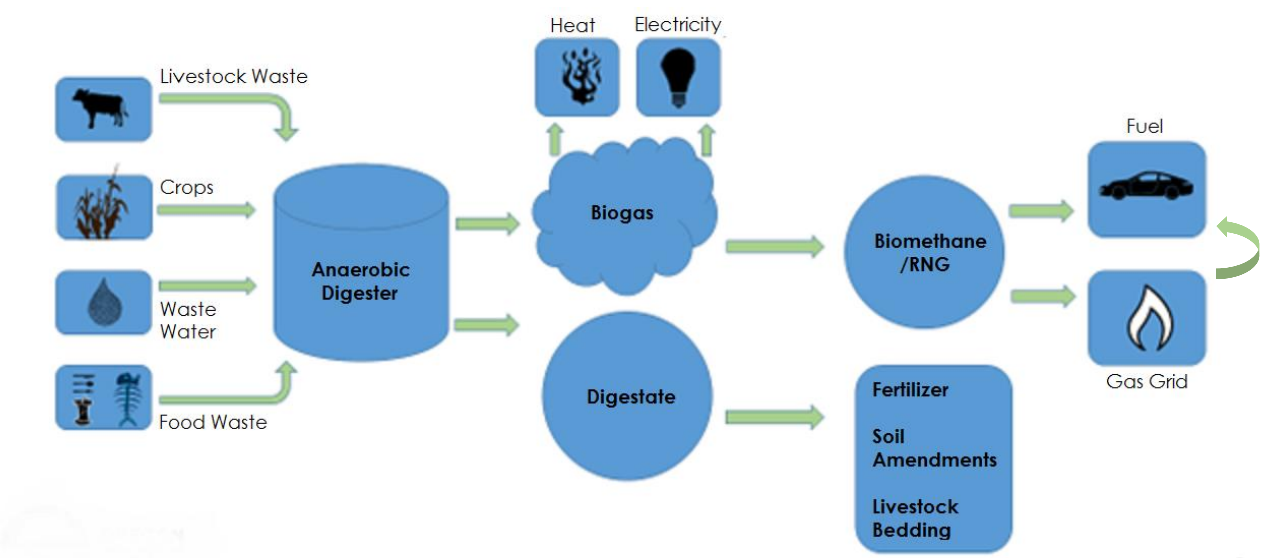
No biogas plants in Oregon currently produce RNG and inject it into a common carrier pipeline. The City of Portland's Columbia Boulevard Wastewater Treatment Plant, the largest WWTP in the state, will soon begin to clean biogas to RNG quality and inject it into a Northwest Natural gas pipeline, and the Metropolitan Wastewater Management Commission (MWMC) WWTP in Eugene will also soon be doing the same. Several other biogas production facilities are investigating the possibility of cleaning their biogas to pipeline quality RNG and injecting it into the pipeline.

Supply Chains

A supply chain is the individual steps that feedstocks go through, starting as a raw product and ending as a finished product or byproduct, such as animal bedding or RNG.

A simplified supply chain looks like the process described in Figure 12. The initial collection and transportation process may be fairly complex, as is the secondary processing of raw gas and injection into a common carrier natural gas pipeline.

Figure 12. Anaerobic Digestion Production Pathway.



ODOE. 2018.

It is important to have a clear understanding of the complexity and costs at each step to inform early pre-project planning. While supply chains can be complex and have many steps, this analysis focuses on material handling: raw material collection, transporting, pre-processing,

processing, production, and distribution of the final product. Each step has relevant management decisions and costs.

ODOE developed draft supply chains for each of the biogas production pathways. The long-term strategy for future iterations of this inventory is to pair economic and environmental costs with each step of each supply chain, such as capital expenses, operation and maintenance, replacement costs, and carbon intensity values. Additional expertise is needed to provide the economic analysis and carbon intensity analysis, and are therefore not included in this version of the supply chains.

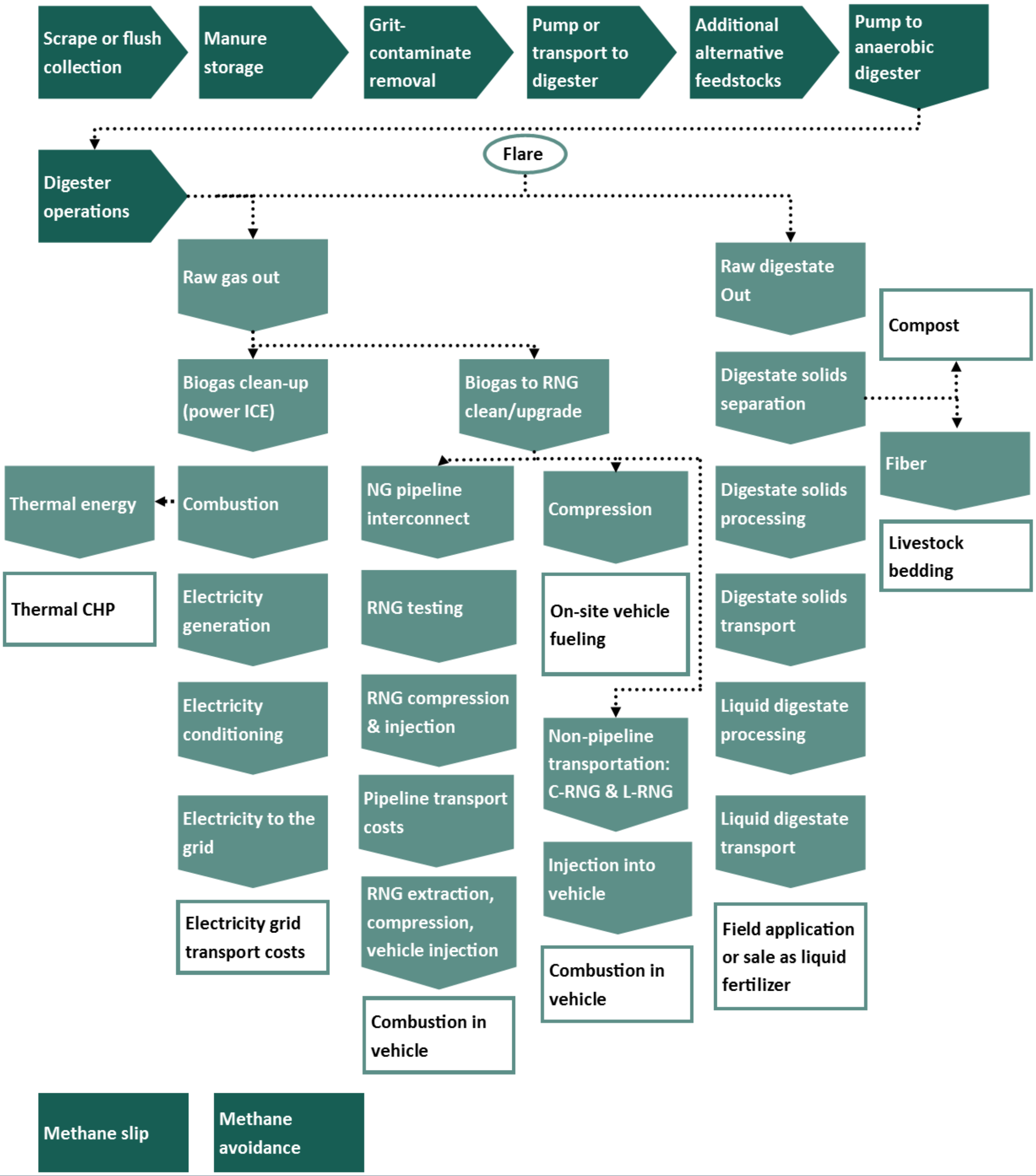
Several caveats exist in this iteration of the supply chain analysis:

- **Agricultural Manure:** the supply chain starts with manure deposition.
- **Wastewater Treatment Plants and Landfills:** the supply chain starts at the wastewater plant or landfill site.
- **Food Waste, Forest and Agricultural Residuals:** the supply chain starts at the regional collection facility, and for forest and agricultural harvest residuals the supply chain starts on the site where the original harvest occurred.

Methane Avoidance is the prevention of methane escaping into the atmosphere through combustion in an end-use, while Methane Slip increases the carbon intensity of the pathway and is the leakage of methane at different points in the process. This is usually a minor amount (approximately 2 percent) but can significantly affect the carbon intensity of the pathway and subsequently lower the value of the RNG in some markets. Both methane slip and methane avoidance are critical to understanding the economics of RNG production and will become increasingly integral components as ODOE moves forward in these analyses.

Figure 13. RNG Supply Chain: Agricultural Manure.

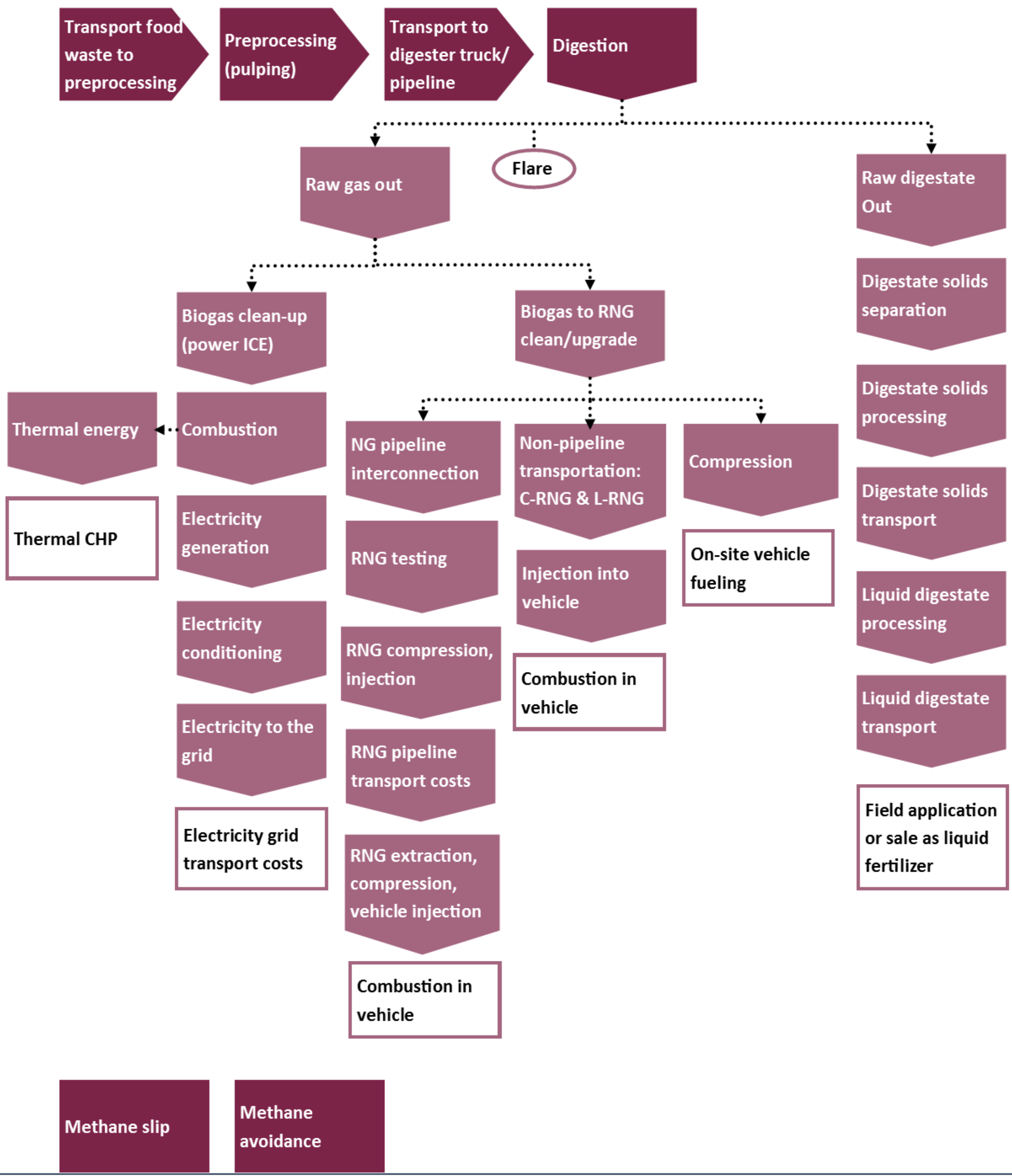
Carbon Intensity: The average Carbon Intensity (in gCO2e/MJ) for this pathway is –264.



Agricultural Manure – agricultural manures are sourced from confined animal feed operations and are either piped or trucked to an anaerobic digester to produce biogas and nutrient and fiber-rich byproducts. The biogas is cleaned of some impurities prior to use in one of three manners: combustion in a flare to destroy the methane, combustion in an ICE to capture heat and/or generate electricity, or cleaning and upgrading to pipeline-quality RNG for use in vehicle or stationary applications. If used for the latter, the RNG can be piped to an on-site facility or it can be trucked or injected into the natural gas grid for transport to an offsite location.

Figure 14. RNG Supply Chain: Waste Food.

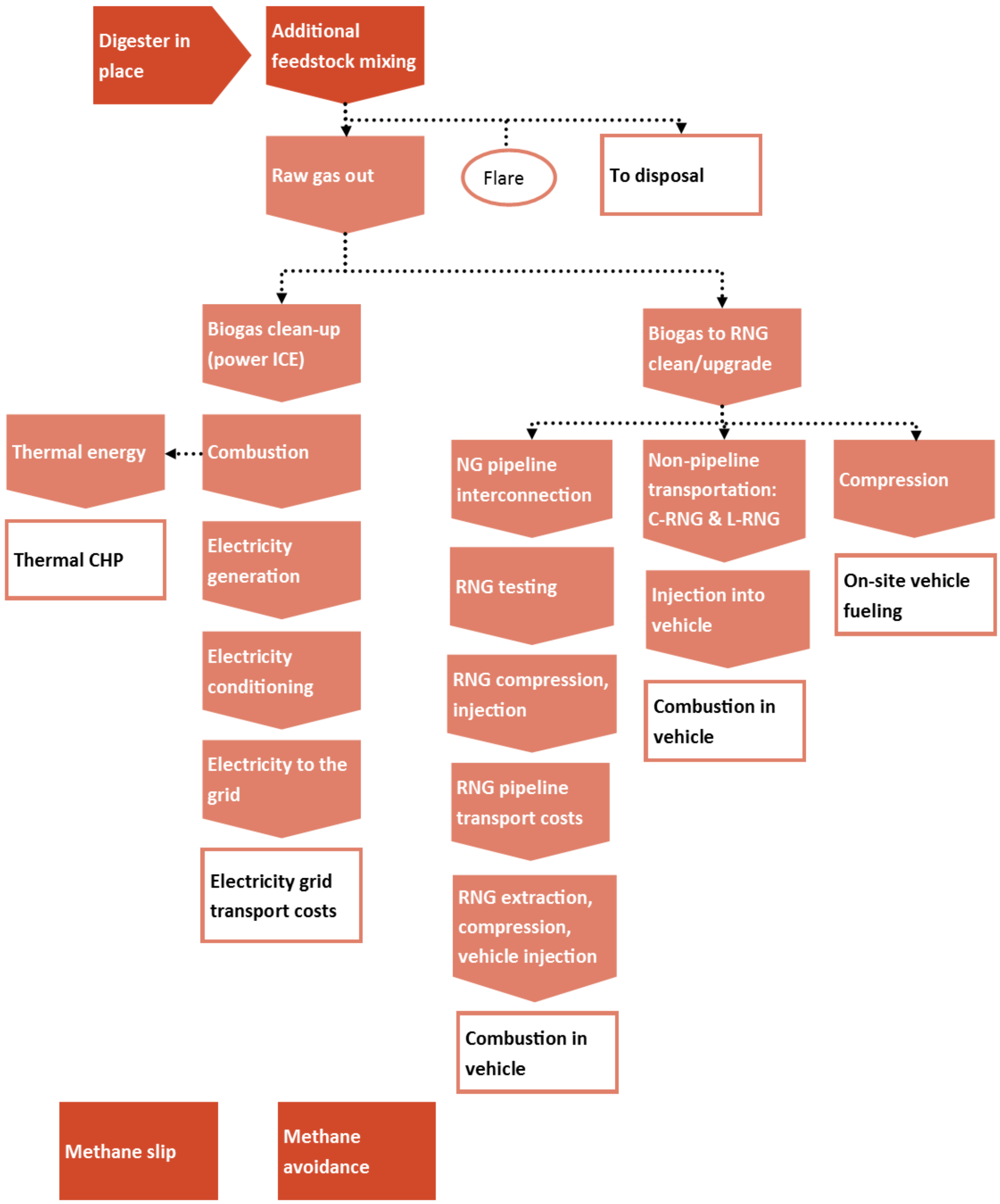
Carbon Intensity: The average Carbon Intensity (in gCO2e/MJ) for this pathway is –23.



Waste Food – waste food is diverted from the municipal solid waste stream, collected at a transfer station, and trucked to a processing facility to be pulped. It is then trucked or directly fed into a digester to produce biogas, which is cleaned of some impurities prior to end-uses. The biogas can be used in three manners: combustion in a flare to destroy the methane, combustion in an ICE to capture heat and/or generate electricity, or cleaning and upgrading to pipeline-quality RNG for use in vehicle or stationary applications. If used for the latter, the RNG can be piped to an on-site facility or it can be trucked or injected into the natural gas grid for transport to an offsite location.

Figure 15. RNG Supply Chain: Wastewater Treatment Plants.

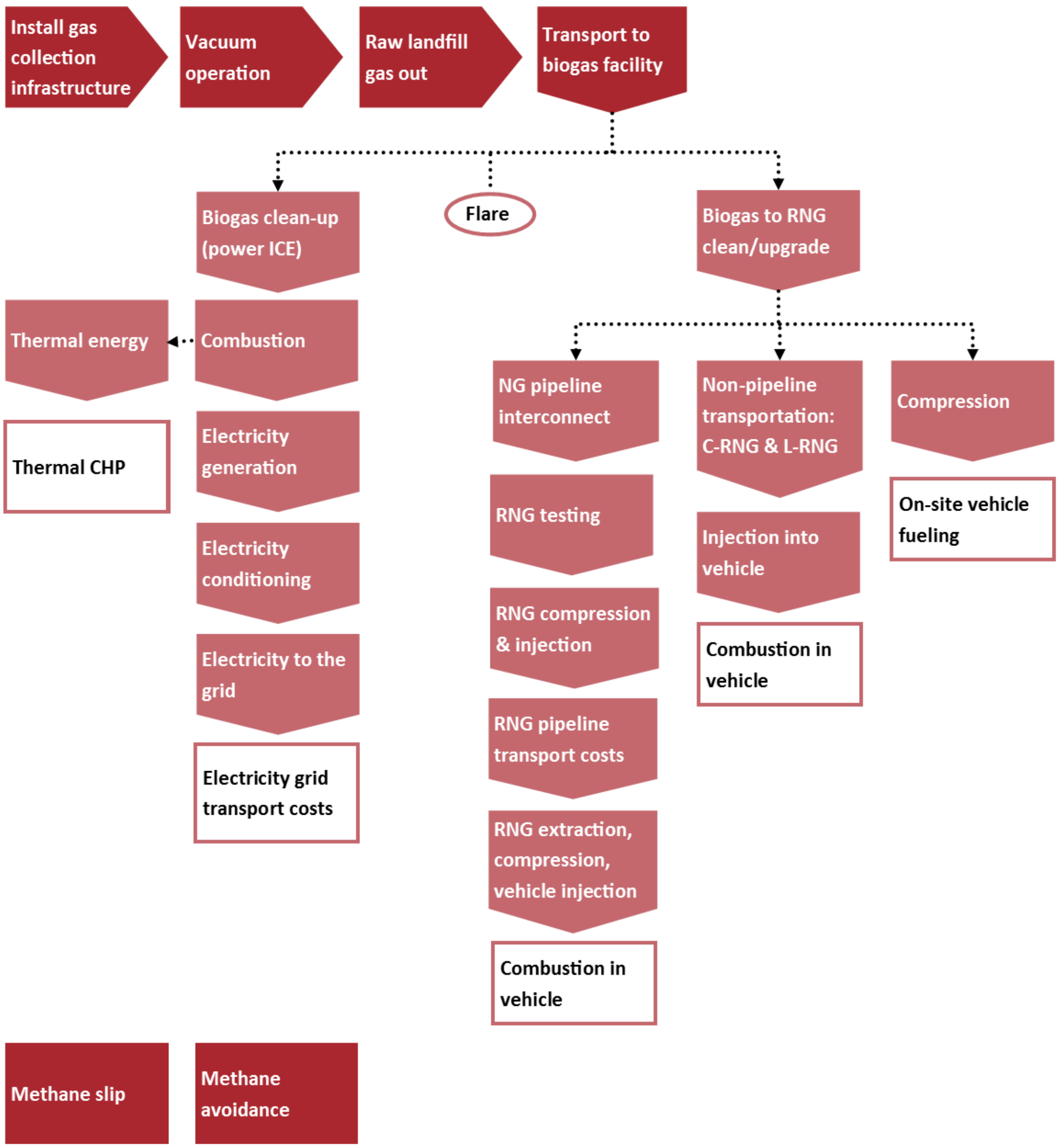
Carbon Intensity: The average Carbon Intensity (in gCO2e/MJ) for this pathway is 19.



Wastewater Treatment Plants – sewage at wastewater treatment plants is processed on-site in an anaerobic digester to produce biogas, which is cleaned of some impurities prior to end-uses. The biogas can be used in three manners: combustion in a flare to destroy the methane, combustion in an ICE to capture heat and/or generate electricity, or cleaning and upgrading to pipeline-quality RNG for use in vehicle or stationary applications. If used for the latter, the RNG can be piped to an on-site facility or it can be trucked or injected into the natural gas grid for transport to an offsite location.

Figure 16. RNG Supply Chain: Landfill.

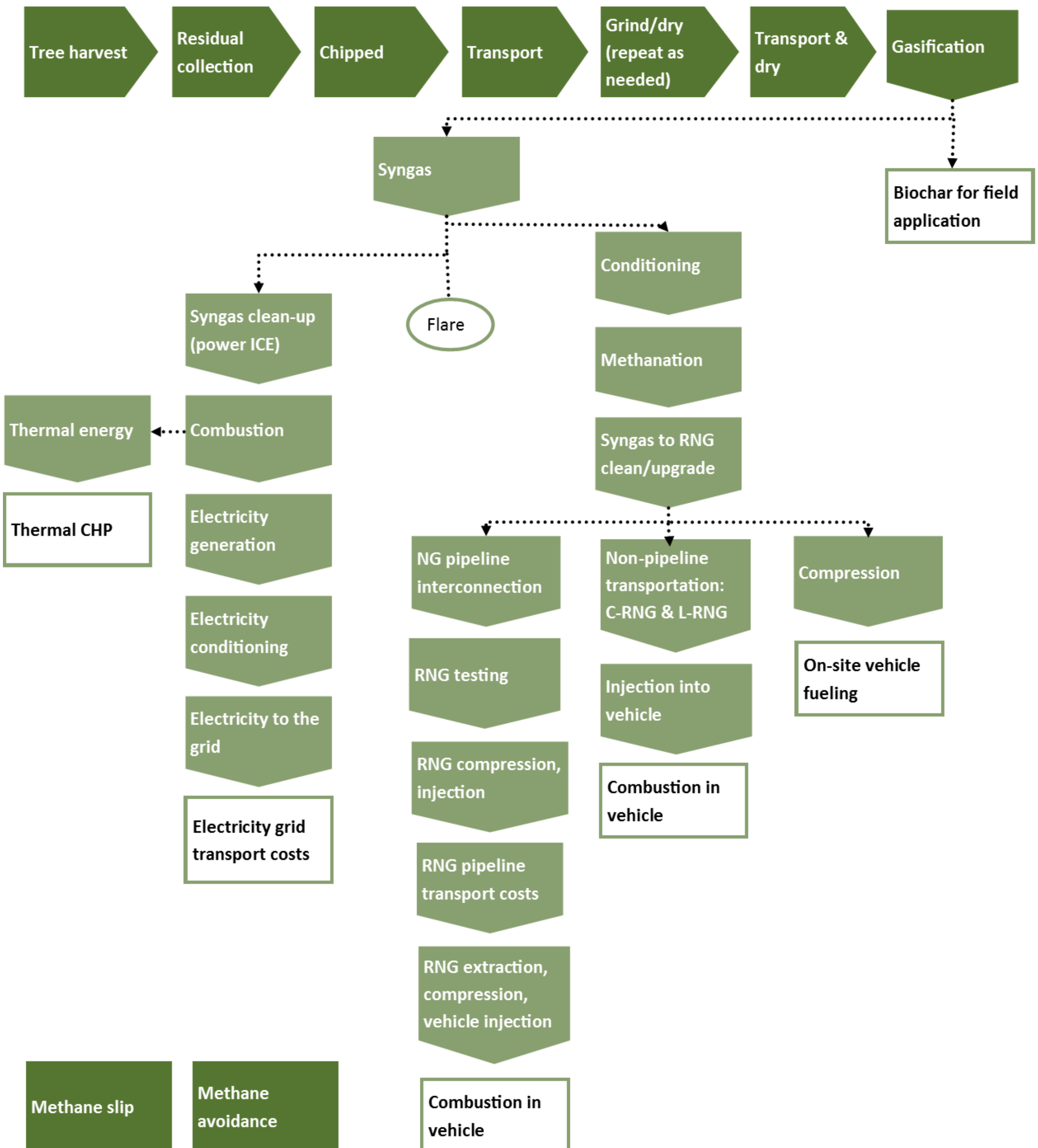
Carbon Intensity: The average Carbon Intensity (in gCO2e/MJ) for this pathway is 47.



Landfill – waste decomposes in an anaerobic environment within the landfill to produce biogas, which is collected via a pre-installed gas collection system for piping to a biogas facility where it is cleaned of some impurities. The biogas can be used in three manners: combustion in a flare to destroy the methane, combustion in an ICE to capture heat and/or generate electricity, or cleaning and upgrading to pipeline-quality RNG for use in vehicle or stationary applications. If used for the latter, the RNG can be piped to an on-site facility or it can be trucked or injected into the natural gas grid for transport to an offsite location.

Figure 17. RNG Supply Chain: Forestry Residuals.

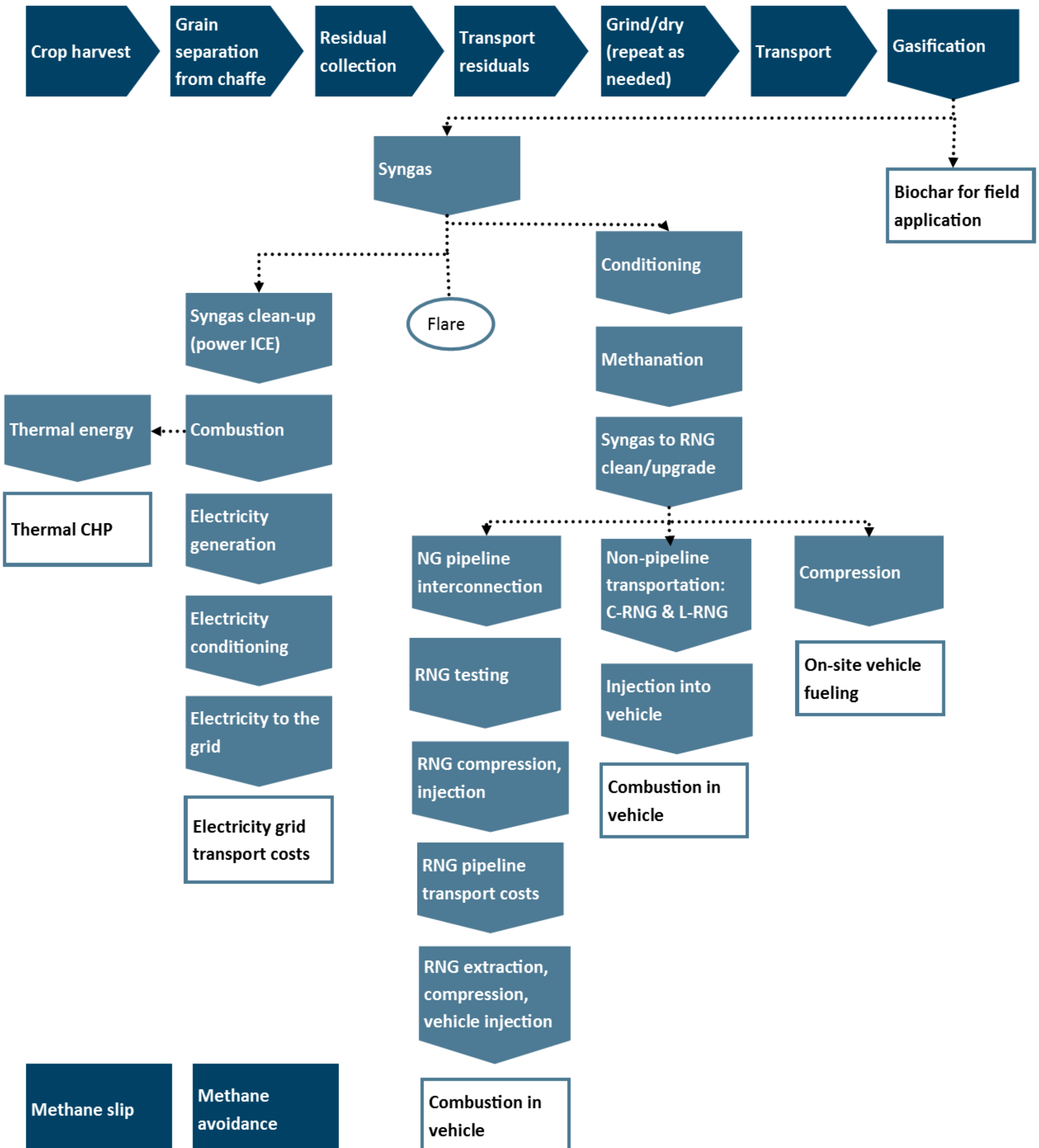
Carbon Intensity: The average Carbon Intensity (in gCO2e/MJ) for this pathway is undetermined.



Forestry Residuals – commercial timber harvest activities produce residuals, which can be collected from the forest and transported to a facility for processing. The processed materials are then either trucked or directly conveyed to a gasification facility to produce syngas. The syngas is cleaned of some impurities before it is combusted to generate heat and/or electricity, or converted to methane. If converted to methane, the syngas undergoes methanation and is subsequently cleaned of any impurities and upgraded to pipeline-quality RNG. The RNG can be trucked or injected into the natural gas grid.

Figure 18. RNG Supply Chain: Agricultural Residuals.

Carbon Intensity: The average Carbon Intensity (in gCO2e/MJ) for this pathway is undetermined



Agricultural Residuals – crops are harvested and the residuals deposited in the field. Residuals are then collected and transported to a processing facility for grinding and drying as needed before being trucked or directly conveyed to a gasification plant. The syngas cleaned of some impurities and is combusted to generate heat and/or electricity, or converted to methane. If converted to methane, the syngas undergoes methanation and is subsequently cleaned of any impurities and upgraded to pipeline-quality RNG. The RNG can be trucked or injected into the natural gas grid.

CHAPTER 4: GREENHOUSE GAS AND AIR POLLUTION IMPACTS

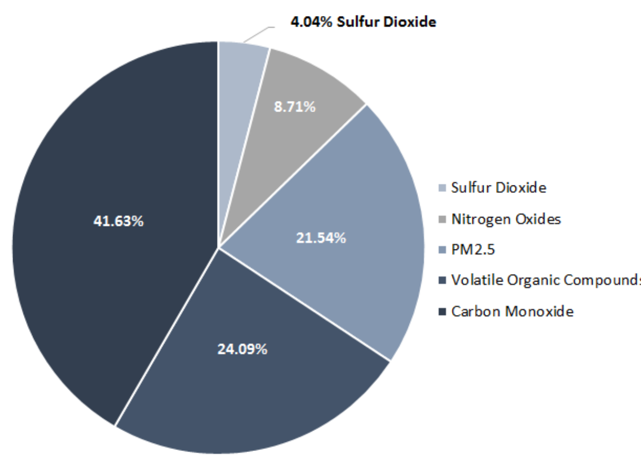
SB 334 stated that the Advisory Committee will make recommendations to the department regarding the identification and removal of barriers to producing and utilizing biogas and renewable natural gas in this state as a means toward providing the greatest feasible reductions in greenhouse gas emissions and improvements in air quality.

Greenhouse gas (GHG) emissions and air pollutants can be significantly reduced when RNG is substituted for fossil fuels in vehicular transportation operations and in displacing traditional natural gas used in the stationary fuels sector, such as heating, cooking, electricity generation or industrial process heat. Typically, to understand the overall production of GHG emissions, a life cycle assessment (LCA) is conducted. The stages included in a LCA are raw material acquisition, transportation, processing, product manufacturing, distribution, use, and disposal or recycling.

Stationary Fuels in the State of Oregon

Air Quality: The stationary fuel sector produces 28 percent of the state's criteria air pollutants, including sulfur dioxide (SO2), nitrogen oxides (NOx), fine particulate matter 2.5 (PM 2.5), VOCs, and carbon monoxide (CO) (EPA 2014). Air pollution from stationary sources in Oregon is made up of nearly 42 percent carbon monoxide emissions, 24 percent of volatile organic compounds (VOCs), over 21 percent of particulate matter (2.5), 8.7 percent of nitrogen oxides, and 4 percent of sulfur dioxide emissions (EPA 2014).

Figure 19. Stationary Fuel Sector Air Pollutant Emissions (2014).



United States Environmental Protection Agency, National Emissions Inventory Report. 2014.

Most stationary sources of air pollution are related to electricity generation. Other sources include residential heating fuels such as natural gas, wood stoves, and fuel oil, and industrial process fuels such as natural gas and coal.

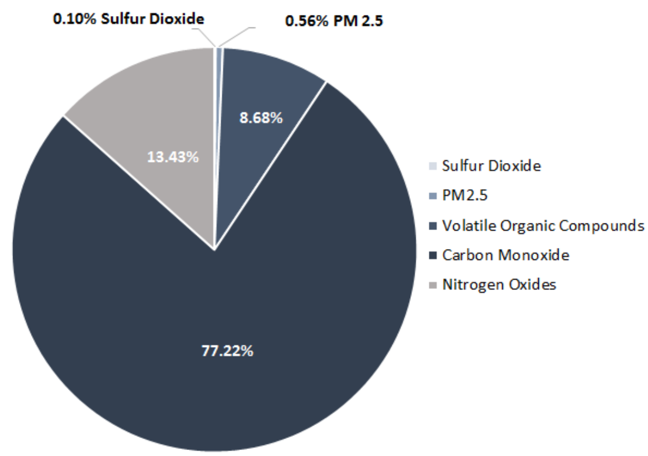
Greenhouse Gases: GHG emissions from stationary fuels use in Oregon produced 37 million metric tons of carbon dioxide-equivalent (MTCO2e) emissions in 2016, or about 60 percent of the state's emissions total (EPA 2014). Electricity use produced 16.2 MTCO2e emissions, while natural gas use produced 7.3 MTCO2e emissions (EPA 2014).

RNG as an Alternative: RNG production prevents methane from sources like landfills and animal waste from being directly emitted to the atmosphere. The combustion of captured gas results primarily in carbon dioxide, a GHG that is at least 25 times less potent in the atmosphere than methane. If the volume of RNG that could be potentially captured and utilized in Oregon displaced fossil fuel natural gas for stationary combustion, approximately 2 million metric tons of fossil fuel-based carbon dioxide would be prevented from entering the atmosphere.

Transportation Fuels in the State of Oregon

Air Quality: Transportation fuel use in the state is responsible for 72 percent of all criteria air pollutants emitted. The largest shares of pollutants produced by transportation fuel combustion include carbon monoxide at 89 percent, nitrogen oxides at just over 13 percent, and VOCs at 8.6 percent. A smaller percentage of the criteria pollutants stem from PM 2.5, which is an ultrafine particulate (EPA 2014). The Oregon DEQ states that health studies show harmful effects from breathing these particles.

Figure 20. Transportation Sector Air Pollution Emissions (2014).



United States Environmental Protection Agency, National Emissions Inventory Report. 2014.

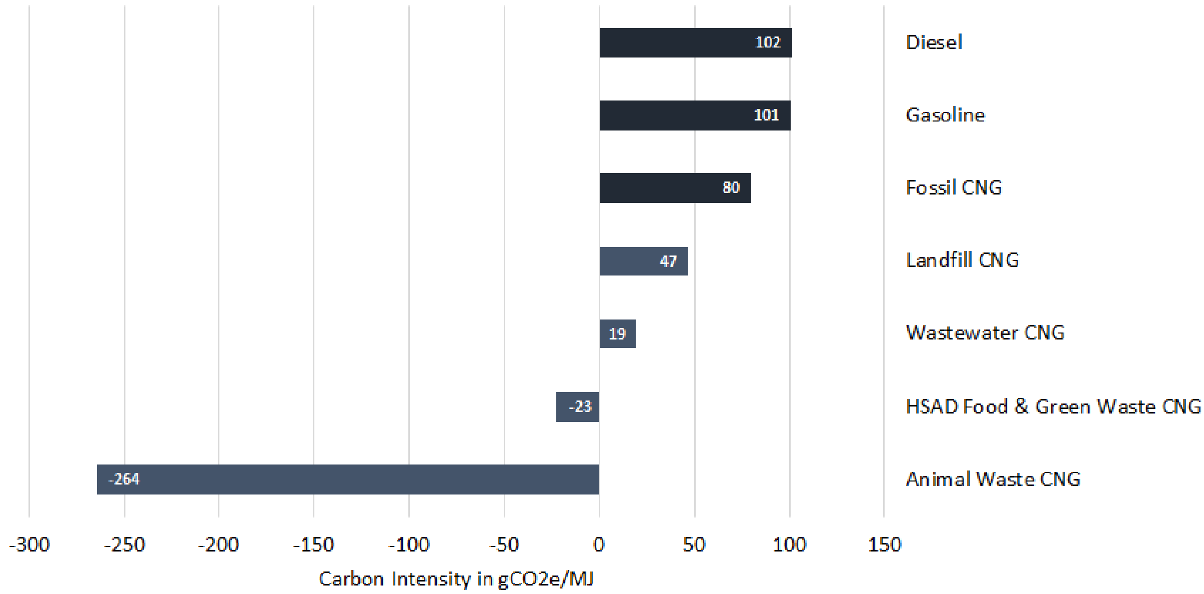
Air pollution from vehicle emissions contribute to smog and poor air quality, which have detrimental effects on the environment and public health. Air toxics such as benzene, formaldehyde, and particulate matter are compounds known or suspected to cause cancer or other serious health and environmental effects.

The particulate matter from diesel exhaust is particularly dangerous. PM2.5 is small enough to be inhaled into the lungs, absorbed into the blood stream, and can cross the blood-brain barrier (ODEQ 2015). It is recognized by the U.S. Department of Health and Human Services as "reasonably suspected to be a human carcinogen" and labeled a "likely" human carcinogen by the U.S. EPA (Downing 2015). The ODEQ recognizes diesel particulate matter as a human carcinogen (Downing 2015). RNG was analyzed as an alternative to diesel fuel to assess the greatest feasible reductions in air pollutants from diesel exhaust.

Greenhouse Gases: GHG emissions from transportation fuel use in Oregon produced 24 MTCO2e emissions in 2016, or around 39 percent of the State's total emissions profile. Gasoline fuel use constituted 13.2 MTCO2e emissions, while diesel (distillate) fuel use caused 6.9 MTCO2e emissions (ODEQ 2016). The two fuel sources combined amount to about 83 percent of all transportation sector-related emissions across Oregon.

RNG as an Alternative Transportation Fuel: RNG can serve as an alternative fuel in transportation. The combustion of RNG can have a much lower air pollution and GHG profile, especially when life-cycle accounting is taken into consideration. Based on the individual feedstock source, RNG can exhibit negative carbon intensity (CI) values as seen in the figure below. For comparison, gasoline has a CI of around 101, diesel 102, and traditional natural gas about 80 gCO2e/MJ.

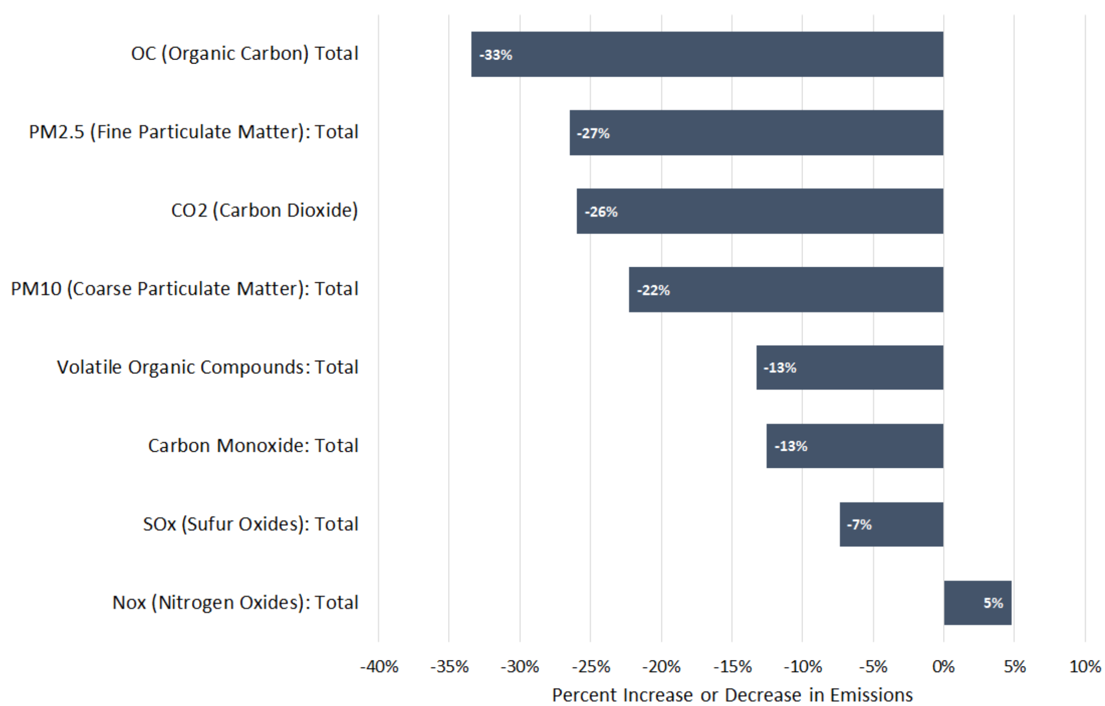
Figure 21. Carbon Intensity of CARB LCFS-Approved RNG Pathways (2018).



California Air Resources Board Low Carbon Fuel Standard. 2018.

RNG has the potential to reduce air pollution and GHG emissions when used as an alternative to diesel in transportation vehicle applications. Since RNG is identical to conventional natural gas on a molecular basis, the combustion of both fuels results in similar air toxics emissions.

Figure 22. Percent Change in Emissions with State RNG Potential vs. Equivalent Amount of Diesel.



Oregon Department of Environmental Quality. 2018.

RNG used as an alternative to diesel fuel can produce significant reductions in air pollutants. The analysis shows reductions of 20 percent or more for GHGs, CO2, fine particulate matter 2.5 (PM2.5 and PM 10), and greater than 30 percent decrease in the amount of organic carbon emissions. There was a 5 percent increase in nitrogen oxide emissions. However, the lifecycle analysis did not include the latest near-zero nitrogen oxide engines being employed in today's CNG fleets.

Lifecycle Analysis Caveat: The data above is from part of a lifecycle analysis and not a tailpipe emissions analysis for comparing natural gas to diesel combustion emissions. Tailpipe emissions do not include emissions resulting from the extraction, processing, and transport of the fuel. Therefore, using RNG as an alternative to an equivalent amount of diesel fuel produced emissions reductions which are lower than those of a simple tailpipe emissions analysis. It should also be noted that the model used for the lifecycle analysis (CAL GREET) utilizes diesel engines that meet current federal emissions standards. However, many diesel engines in Oregon vehicles are not compliant with these federal emissions standards and consequently emit higher rates of harmful emissions.

RNG used as an alternative to diesel fuel could produce significant GHG reductions. When used as an alternative for an equivalent amount of diesel fuel, the state's total RNG production potential from anaerobic digestion reduced net GHG emissions by 2,265,00 MTCO2e. This is a 33 percent reduction in diesel fuel's total GHG contributions to the transportation sector, or a nine percent reduction in the total emissions from the sector's total emissions of 24 million MTCO2e in 2016.

CHAPTER 5: GENERAL MARKET ANALYSIS AND CAPACITY

RNG-related activity is in its earliest stages in Oregon, leaving much to learn about the associated industries and markets in its economic orbit. One of the advisory committee members used an economic model called IMPLAN to take a high-level look at this market. That analysis captures generalized patterns and learnings of the still-unfolding details of the RNG market.

Because the price of RNG relative to conventional gas is more immediately relevant to individual households and businesses than its absolute price effect on the economy, there are less obvious cost factors that play important roles in terms of net economic effect. First, it is widely expected that both Oregon and Washington will implement new legislation and/or regulatory measures that place a price on GHG emissions, effectively increasing the price of conventional natural gas and other fossil fuels to homes and businesses. In contrast, the life-cycle emissions of RNG are very low, and in the case of sources like dairies and livestock feedlots, can even be negative. Therefore, the emissions-related costs associated with RNG that are felt by consumers would be reduced under future policy scenarios. The second price factor stems from the fact that much of the in-state RNG resource would be produced on or near the existing natural gas infrastructure in Oregon. Such "on-system" resources provide energy that does not need to be transported via interstate pipelines from distant basins, and may support localized gas distribution systems that would otherwise require system upgrades. Like a price on emissions, these "avoided costs" further shrink the effective price difference between conventional gas and locally-sourced renewable substitutes.

The use of RNG as a low carbon fuel is driven by the available market. The market can be divided into two primary uses: transportation fuels and stationary fuels. In the former, RNG can be used to fuel vehicles, mostly medium and heavy duty vehicles like garbage trucks and transit buses. For the latter, RNG can be used for electricity generation, space heating, cooking, process heat, and, in some cases, cooling. Currently it is the transportation market that is advancing the RNG market in Oregon.

RNG is currently valued in three transportation-related markets for its low carbon environmental attributes: the Oregon Clean Fuels Program (OCFP), the California Low Carbon Fuels Standard program (LCFS), and the U.S. EPA's Renewable Fuel Standard (RFS). There are no similar markets for RNG use in the stationary markets.

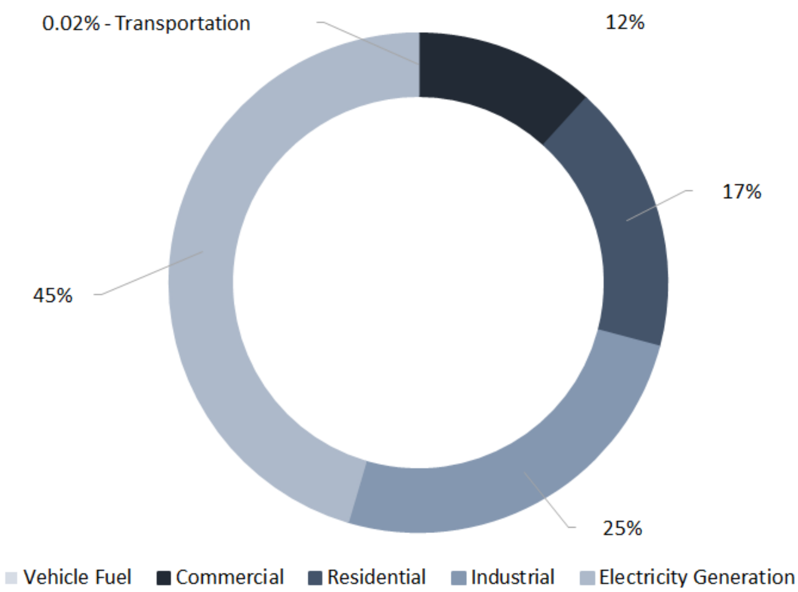
How Biogas is Produced and Used in Oregon

Biogas is produced at multiple locations in Oregon. These facilities include landfill gas sites as well as digesters utilizing source-separated food waste, food processor waste, animal manure, and municipal wastewater processing facilities. Oregon's biogas facilities convert waste streams from local, regional, and in some cases statewide sources into a productive resource. Under Oregon's Renewable Portfolio Standard, biogas is considered a renewable energy source when used to generate electricity or useful thermal heat, and is eligible to generate Thermal or standard Renewable Energy Certificates (T-REC/REC) (ODOE 2018).

Conventional Natural Gas Use in Oregon

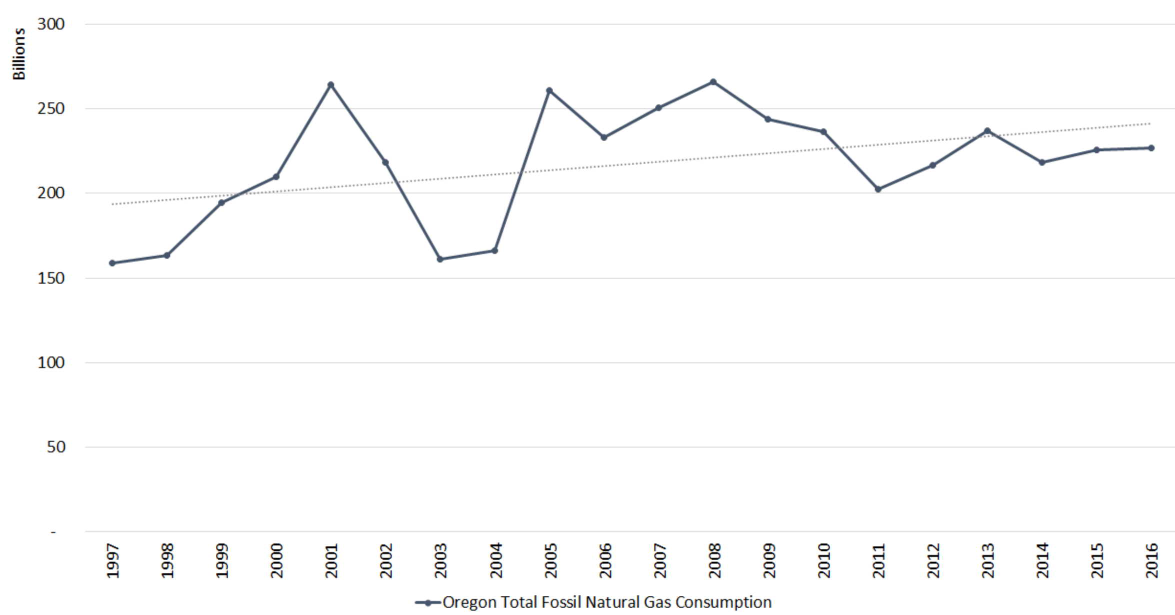
Natural gas in the state of Oregon is used in a variety of applications across the electricity, residential, commercial, industrial, and transportation sectors. Oregon imports 99 percent of the natural gas its citizens and businesses use (US EIA 2016). The only natural gas field in the Pacific Northwest is located in Oregon, and can be found northwest of Portland near the unincorporated town of Mist.

Figure 23. Oregon's Sector-Based Fossil Natural Gas Consumption (2016).



United States Energy Information Administration Natural Gas Annual Responded Query System. 2016.

Figure 24. Trend in Oregon Natural Gas Consumption (1997-2016).



United States Energy Information Administration Natural Gas Annual Responded Query System. 2016.

Oregon's natural gas consumption has grown 43 percent since 1997 and has averaged a 3 percent year-over-year increase since 1997 (US EIA 2016). This trend is portrayed in Figure 24. The State's dominant end-uses of natural gas have gradually shifted since 1997 from industrial consumption to electricity generation consumption as of 2016 (US EIA 2016). Pictured in Figure 23 is Oregon's natural gas consumption by sector. Oregon's seven natural gas-fueled electricity generating plants consume about 45 percent of the state's total, and are the largest end-use of gas in the state. Residential, industrial, and commercial make up the remaining 55 percent of natural gas consumption while transportation use of natural gas constitutes 0.02 percent of Oregon's total natural gas use.

RNG Stationary Fuel Market

RNG is suitable for stationary fuel applications of conventional natural gas in the electricity generation, residential, commercial, and industrial sectors. As a whole, Oregon's entire RNG potential in standard cubic feet could meet around 22 percent of current annual natural gas consumption needs. However, not all of this potential is feasible as 79 percent is derived from thermal gasification potential – a technology that is not operational anywhere in the U.S. Some thermal gasification applications exist but stop at syngas and do not produce to RNG.

There are currently no state or federal financial incentives available to encourage stationary fuel use of renewable natural gas. Additionally, it is challenging for RNG to compete with the low cost of natural gas due to the inherent capital intensity of RNG developments. A program which successfully facilitates the use of RNG as a stationary fuel is British Columbia's Carbon Tax. The B.C. carbon tax is discussed later in this report.

RNG Transportation Fuel Market

The state's current CNG transportation needs could consume 100 percent of the RNG potential available from anaerobic digestion. Several drivers in this market are actively encouraging adoption of RNG in Oregon and production of Oregon RNG sources, including a number of programs that can facilitate the production and utilization of RNG as a transportation fuel at the state, federal, and potentially international levels.

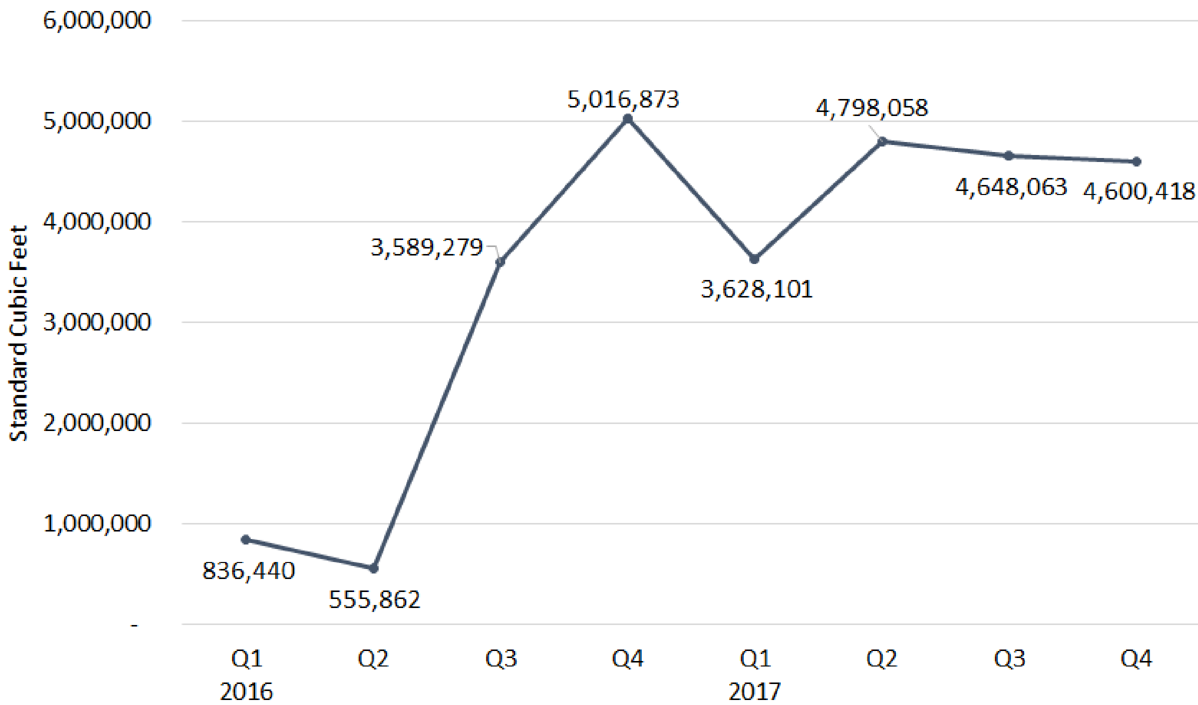
Oregon Clean Fuels Program (OCFP)

The OCFP encourages adoption of low carbon fuels as an alternative to traditional fuels consumed in the transportation sector. Lower carbon fuels include hydrogen, biodiesel, renewable diesel, ethanol, liquefied petroleum gas (LPG), CNG, liquefied natural gas (LNG), and RNG.

The program is generating interest in producing and consuming RNG in the transportation sector of Oregon. RNG produced in the state must be dispensed within the state in order to generate credits under the OCFP. Out-of-state producers may also generate credits under the program if their fuel is dispensed within the state.

As of the first reporting quarter of 2016 for the OCFP, over 800,000 standard cubic feet of RNG was used as a transportation fuel. By the program's fourth reporting quarter of 2017, over 4.6 million standard cubic feet of RNG were imported and used as fuel in the State's transportation sector.

Figure 23. Oregon Consumption of RNG as a Transportation Fuel (2016-2017).



Oregon Department of Environmental Quality Clean Fuels Program Quarterly Data Summary. 2016-2017.

California Low Carbon Fuels Standard (LCFS)

The LCFS is similar to the OCFP and works to encourage low carbon transportation fuel alternatives. This program encourages production of RNG in Oregon but does not assist in consumption of RNG within the State. Like the OCFP, RNG must be consumed by approved transportation vehicles within the State of California in order to generate LCFS credits. Oregon RNG producers selling fuel to California vehicle users may generate LCFS credits.

National Renewable Fuel Standard (RFS)

The U.S. EPA administers the nation's RFS, which uses a Renewable Identification Number (RIN) to track and apply a monetary value to each gallon (or gasoline equivalent) of domestically-manufactured renewable fuels. Producers of RNG can generate RINs if their RNG is used as a transportation fuel anywhere in the U.S. There are different types of RINs, which are based on the originating feedstock for the renewable fuel. The value of the RINs is different for each of the different RIN types. For RNG, the D3 and D5 RINs are primary the focus. The D3 RINs originate from cellulosic, hemicellulose or lignin feedstocks and meet a 60 percent lifecycle GHG reduction. The D5 RINs originate from non-corn starch renewable biomass and meet a 50 percent lifecycle GHG reduction. Actual classification of RINs is a very complex process. Furthermore, RINs are traded like commodities and the daily price can fluctuate dramatically. For more information about RINs and how they are generated, visit the EPA's website: https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard

Selling RNG as a Transportation Fuel

The transportation fuels market is the primary financial driver behind RNG production today. RNG has low carbon characteristics that are environmentally beneficial and can be sold into any low carbon fuels market in the U.S. As mentioned above, Oregon and California have state markets and the federal government has a nationwide market. When selling RNG as a transportation fuel, a producer can add the state and federal credits together to maximize the return for the RNG.

Table 7 shows four different scenarios and the potential value when fuels and the associated credits for those fuels are added together and then sold. The OR1 and OR2 scenarios represent trading of RNG in Oregon and use of the OCFP credits, as well as two different types of federal credits (D3 and D5 RINs. D3 RINs are more valuable). Scenarios CA1 and CA2 represent similar trades, but in the California LCFS market. A carbon Intensity of 30 was chosen as an average of what could be expected from low-carbon fuels. Carbon intensity determines the credit price within the state programs, but not the federal program. As seen in Figure 4 (from the CARB table/graphic) carbon intensity can range from the high 90s down to around -250 gCO2e/MJ. The lower the CI number, the more valuable the gas is in the state-level low carbon/clean fuel markets.

Table 7. Scenarios and Potential Values of Fuels and Environmental Credits. 2018.

Values for 1,027,000 Btu (1,000 cubic feet or 1 MMBtu)	OR 1	OR 2	CA 1	CA 2
Value of Gas (if NG = RNG)	$2.76	$2.76	$2.76	$2.76
Value of D3 Federal Credit (1 RIN = $2.20) 7/18 price))	$28.49		28.49	
Value of D5 Federal Credit (1 RIN = $0.39 7/18 price)		5.05		5.05
Value of OR Credit (OCFP = $61.01 MT (7/18 price) (Avg. CI 30)	$4.40	$4.40		
Value of CA Credit (LCFS = $180 /MT 7/7/18 price)) (Avg. CI 30*)*			$13.54	$13.54
Total Value	$35.65	$12.21	$44.79	$21.35

Other Carbon Markets

British Columbia Carbon Tax

British Columbia's Carbon Tax helps support RNG demand within the Canadian Province. Consumption of RNG can help mitigate the cost of consuming fossil fuel for stationary or transportation applications under the Province's $35/metric ton carbon tax. The British Columbia Carbon Tax successfully diminished the cost difference between fossil fuel and renewable natural gas by improving the value of RNG's environmental attributes. The Province's natural gas utility, Fortis BC, enacted an RNG program in 2011 and has over 7,000 utility customers voluntarily requesting RNG as of 2016 (Canadian Biogas Association).

CHAPTER 6: POTENTIAL BARRIERS TO RNG DEVELOPMENT, PRODUCTION, AND UTILIZATION

There are a number of barriers to developing, producing, and using biogas and renewable natural gas as a means to reducing greenhouse gas emissions and improving air quality. Barriers were identified by conducting a literature review of known RNG development barriers, as well as through discussion with a diverse group of representatives from the RNG Advisory Committee who are familiar with RNG production and utilization. The barriers identified fell into the following categories: finance, information, transportation and stationary fuel markets, existing statutes and rules governing the Oregon Public Utility Commission, and a general category of "other," which includes an examination of barriers around pipeline access, contract language, competition for feedstocks, out-of-state producers, and incentives.

ODOE and its advisory committee members initially produced a list of 100 barriers, which was consolidated into a list of 30. Using the list of 30 identified barriers, ODOE conducted a survey through the advisory committee to determine how members would prioritize each barrier within a certain category.

For this report, ODOE further reduced the overall number of barriers to 13 by focusing on the key barriers ranked highest by advisory committee members, and those that generated significant discussion. The key barriers listed below are grouped by type of barrier, but are not in priority order. The completed and ranked survey of barriers can be found in Appendix E.

Finance Barriers

Finance barriers include the ability to obtain financing, the magnitude of capital costs of initial project development, and the lack of value attributed to RNG environmental benefits.

1. **Access to project financing.** Because RNG is unfamiliar to traditional financial institutions like banks and credit unions, they may view these projects as risky and may be reluctant to lend to RNG producers or developers. There are no financial mechanisms to help offset financial risk. This barrier affects municipalities and private entities.
2. **Higher capital cost of gas upgrading requirements to remove impurities and increase heat content of RNG to meet utility pipeline standards.** The technology required to clean and upgrade biogas to RNG is capital intensive, and it increases as the requirements for gas treatment and volumes of gas requiring treatment are increased. This barrier affects all participants. Smaller independent producers (from all types of pathways) could be shut out of the RNG market due to the high cost of entry.
3. **High cost of pipeline interconnection and testing.** Pipeline injection points may require several pieces of infrastructure, such as compressors and pipeline extensions, and are capital intensive. Testing creates ongoing costs that can differ significantly based on the pipeline company, and there is no standardized tariff language on biogas testing requirements. Effects from this barrier affect producers, developers, and pipeline companies.

4. **High production and capital costs, and no valuing of the environmental benefits.** It costs more per Btu to produce RNG than it does fossil natural gas, and the value of the environmental benefits of RNG (e.g., lower carbon emissions, reduced methane emissions, and use of local waste streams as fuel stocks) are not included in the economics of a project. This barrier affects all participants and the end user.

Information Barriers

Information barriers include uninformed perceptions of the technology, fuel sources, and supply chains; the lack of information about incentive programs; and the impact of certain contract language on the ability to get financing.

5. **Perception of risk due to the unfamiliarity with the technology, the fuel source, and the fuel supply chain.** Most people are not familiar with biogas or RNG, and are therefore not informed about the beneficial properties of biogas and RNG, especially its interchangeability with fossil fuel natural gas and the quality of the gas. This barrier could affect producers, developers, and the gas companies.

Market Barriers

Market barriers include challenges associated with creating stable long term in-state markets, because without them there will likely only be a few RNG producers that will sell their RNG into out-of-state markets. Fueling infrastructure is an essential step for the creation of a transportation market. In addition, the commercial stationary market can be a key market as manufactures that use process heat desire to have their products associated with renewable, low-carbon fuels like RNG.

6. **Lack of natural gas vehicles or fleets.** There is modest current demand for RNG as a transportation fuel in Oregon, partly due to a relatively small number of natural gas vehicles and fleets.
7. **Lack of natural gas fueling infrastructure.** There are only 17 natural gas fueling sites (12 private and five public) in Oregon, and all of them are clustered along the I-5 corridor.

Policy and Regulatory Barriers

Policy and regulatory barriers include existing state rules and statutes that prohibit the purchase and rate-basing of RNG projects, and the lack of policy that would promote access to feedstocks.

8. **Existing state rules prevent Oregon utilities from making ratepayer-funded capital investments in RNG infrastructure.** Capital investments into extensions of pipelines or pipeline interconnection points with RNG projects cannot be rate-based under current statutes.
9. **Natural gas utilities are prohibited from purchasing or selling RNG.** Current statute requires utilities to purchase only the least-cost resource, and because RNG is more

expensive than fossil natural gas, it does not meet the least-cost purchase requirement rule.

10. **Inability to utilize most food waste streams in the state.** Access to municipal food waste is limited, because no statewide policy exists requiring the separation of food waste from municipal solid waste streams, or prohibiting food waste from entering landfills.
11. **Lack of financial incentives for natural gas fueling infrastructure.** Fueling infrastructure is expensive, and the lack of incentives keeps its cost high.
12. **Lack of financial incentives for natural gas vehicles and fleet conversions.** Fleet conversion and new CNG vehicles can be expensive, and a lack of incentives keeps the cost high.

Other Barriers

Other barriers include pipeline access, contract language, competition for feedstocks, out-of-state producers, and lack of incentives.

13. **Limited number of RNG production sites close to natural gas pipelines.** It is very capital-intensive to construct pipelines, so it is essential to site RNG projects near a pipeline injection point to lower costs and ensure a cost-effective RNG project. This barrier affects all sectors and all participants.

Advisory Committee Member Perspectives on Barriers

Some advisory committee members contributed less formal comments through the work group meeting process, and their views are captured in the full list of barriers above. However, seven committee members produced written statements stating their industry sector's perspective of the barriers, and included potential options for policy-based solutions to a number of the above barriers. The individual letters can be found in Appendix C.

CHAPTER 7: RECOMMENDATIONS

As part of the SB 334 requirements, ODOE asked members of the RNG Advisory Committee to make recommendations for removing barriers to producing and utilizing biogas and RNG in Oregon. These recommendations would provide the greatest feasible reductions in greenhouse gas emissions and improvements in air quality. Recommendations were submitted by a number of different sectors represented on the advisory committee, sometimes with competing perspectives.

Several changes would promote the development of RNG projects including: allowing gas companies to buy RNG and sell it to their customers, allowing gas companies to recover pipeline interconnection costs from their customers, expanding transportation fueling infrastructure, creating a common RNG quality standard, and expanding and securing access to feedstock supplies. Taking into consideration the expertise and observations provided by the Advisory Committee, ODOE conducted its own research and analysis and makes the following recommendations:

1. **Allow the natural gas companies to buy and sell RNG to and for their customers.** Currently natural gas companies must purchase and sell only least-cost resources, which include fossil natural gas. RNG is not considered a least-cost resource, and statutes would need to be changed to allow RNG purchases.
2. **Allow local gas distribution companies to recover pipeline interconnection costs through their rates.** Connecting to the pipeline is cost prohibitive for all but the largest projects. Without the ability of utilities to rate-base the pipeline interconnection capital costs, those costs must be borne by the project developer, thereby increasing the project's cost.
3. **Study how best to expand natural gas transportation fueling infrastructure.** Key medium and heavy truck transportation corridors need adequate and publicly-accessible compressed RNG (CRNG) and compressed natural gas (CNG) fueling facilities. Without fueling infrastructure, there is little motivation to convert commercial and fleet vehicles to CRNG/CNG. A study could determine where in Oregon fueling stations should be constructed to grow and strengthen the CRNG/CNG market, how to fund this new infrastructure, and how to construct and support repair facilities.
4. **Explore development of voluntary gas quality standards for injection of RNG into the natural gas pipeline.** Quality standards for injection of RNG would identify acceptable levels of impurities and heat content for safety and environmental purposes, including ensuring pipeline integrity, while providing reasonable and predictable access to pipeline transmission and distribution facilities. ODOE should consult with industry stakeholders and identify industry best practices for gas quality standards.
5. **Explore financial incentives to help drive the nascent industry forward.** Near-term financial incentives would reduce the cost of RNG projects, stimulate demand for RNG, and help reduce the future cost of RNG projects, pipeline interconnections, and fueling infrastructure.
6. **Coordinate with RNG stakeholders and state agencies to develop a tracking and accounting protocol for production and use of RNG.** Any protocol would need to mesh with

current state and federal tracking in the Oregon Clean Fuels Program, the California Low Carbon Fuels Standard Program, and the U.S. EPA Renewable Fuels Program. A protocol would assist in the accurate accounting and tracking of current and future RNG credits that can be traded in current and future markets.

Finally, some members of the RNG Advisory Committee submitted formal recommendations for policy proposals. These recommendations were taken into account in the development of the above recommendations. A summary document of the compiled recommendations and copies of the submitted documents can be found in Appendix C.

CHAPTER 8: DATA GAPS AND NEXT STEPS

This report is the first of a series of periodic reports on biogas and renewable natural gas resources and opportunities in Oregon. During the initial investigation into this topic, numerous questions and information resources were identified but not fully pursued due to scope, time, and financial constraints. ODOE has assembled a brief list of data gaps and ideas that could help guide the development of the next report.

1. Practical Statewide RNG Potential

The purpose of the RNG Inventory report is to accurately inform the State of Oregon of the potential production, practical utilization, and benefits of RNG within the state. ODOE's objective for this iteration of the report included theoretical statewide RNG potential. In the next version of this report, ODOE intends to describe the practical statewide RNG production potential.

2. Lifecycle Economic Analysis of RNG Production Pathways

This analysis will estimate, under a given set of conditions, the minimum project size and maximum distance to an interconnection point by which a project can be economically feasible. This includes an evaluation of feedstock accessibility. A detailed analysis of RNG production pathways will first analyze carbon intensities of RNG production pathways across the lifecycle of the fuel, from the point of raw feedstock acquisition to gas production to its final end-use in either the transportation or the stationary fuels sectors. The second step will be to assign industry average costs to each step in the supply chain.

3. Tracking and Accounting for RNG in Transportation & Stationary Fuel Use

This project would develop a tracking and accounting process for RNG when used as either a transportation or stationary fuel. This includes developing a standard protocol, identifying requirements for accounting, and identifying accounting technologies capable of this type of tracking. This protocol and mechanism should mesh seamlessly with the Oregon Clean Fuels Program, California Low Carbon Fuels Standard, and U.S. EPA Renewable Fuels Program tracking mechanisms.

4. Future Carbon Policy

A carbon policy study would provide data and analysis to inform Oregon's efforts to reduce greenhouse gases. Because of its lower carbon intensity, there are likely opportunities for RNG within the context of a carbon pricing or cap and trade policy. This and future iterations of this inventory can inform carbon policy discussions with data on available resources and economic and technical feasibility. RNG can manage persistent waste streams that are likely to continue into our future. Converting these waste streams to useful fuel, generating local jobs, and supporting local energy resiliency and economies all fall into Oregon's present and future discussions.

5. Detailed Analysis of Market Economics & Drivers

ODOE would provide a detailed market analysis that characterizes current markets and their drivers, as well as analysis of potential markets and their drivers. This information is the basis for determining the revenue potential from RNG potentials, and will assist in informing the economic feasibility of future projects.

6. More Comprehensive Feedstock Inventory and Other Biogas Production Pathways

ODOE would expand the current inventory to include other potential feedstocks like food processor residuals and slaughterhouse waste products. Along with new feedstocks, ODOE would examine new production technologies such as high-solids digesters, which would enable the use of additional feedstocks like corn stover and straw for anaerobic digestion.

APPENDIX A: SB 334 ADVISORY COMMITTEE LISTS

The Oregon Department of Energy is grateful to the stakeholders who participated in its SB 334 Advisory Committee. A core group of members, listed below, attended most meetings and actively participated in developing this report.

In addition to the core group of members, ODOE sent meeting notices, agendas, and materials to a variety of additional stakeholders who expressed interest in staying informed about the advisory committee process, but did not regularly attend meetings.

Meeting information and materials were also available on ODOE's website: https://www.oregon.gov/energy/Get-Involved/Pages/RNG-Advisory-Committee.aspx

SB 334 Advisory Committee Core Members

NAME	AFFILIATION
Alex Schay	Carbon Solutions Northwest
Allison Spector	Cascade Natural Gas
Bill Edmonds	NW Natural
Brian Trice	Columbia-Willamette Clean Cities Coalition
Conner Reiten	Northwest Gas Association
Cory Ann Wind	Oregon Department of Environmental Quality
Dan Avery	Oregon Department of Energy
Dan Kirschner	Northwest Gas Association
Dave Madsen	Williams Northwest Pipeline
Dave Modal	Energy Trust of Oregon
David Allaway	Oregon Department of Environmental Quality
Elizabeth Ebel	Oregon Department of Environmental Quality
Gary Bauer	NW Natural
Holly Stirnkorb	Metro
Jay Story	TransCanada Gas Trans. Northwest
Jim Jensen	Washington State University Energy Program
Jody Morehouse	Avista
Josh Newman	Oregon Association of Clean Water Agencies
Laura Leebrick	Dry Creek Landfill
Lee Fortier	Rogue Disposal & Recyling
Marcus Gillette	Coalition for RNG
Mary Moerlins	NW Natural
Michael S. Graham	Oregon Department of Energy
Pamela Anderson	Perkins Coie LLP
Paul Suto	City of Portland
Peter Moulton	Washington Department of Commerce

Ryan Bracken	NW Natural
Tim Logan	DMT Clean Gas
Tim Robinson	Clean Methane systems
Wym Williams	ODA

SB 334 Advisory Committee - All Members

NAME	AFFILIATION
Alex Schay	Carbon Solutions NW
Allison Spector	Cascade Natural Gas
Anna Chittum	NW Natural
Bill Edmonds	NW Natural
Blake Shelide	ODOE
Brian Dunn	ODOT
Brian Trice	Columbia-Willamette Clean Cities Coalition
Bruce Cordon	Clean Water Service
Colin McConnaha	ODEQ
Conner Reiten	NW Gas Association
Cory Ann Wind	ODEQ
Dan Avery	ODOE
Dan Kirschner	NW Gas Assoc.
Dave Madsen	Williams NW Pipeline
David Modal	Energy Trust of Oregon
David Allaway	ODEQ
Elizabeth Ebel	ODEQ
Gary Bauer	NW Natural
Heath Curtis	OFIC
Holly Stirnkorb	Metro
Ian Howell	Travel Card
Jay Story	TransCanada Gas Trans. Northwest
Jim Jensen	WSU Energy Program
Jody Morehouse	Avista
Josh Newman	OR ACWA
Kathryn Williams	NW Natural
Laura Leebrick	Dry Creek Landfill
Lee Fortier	Rogue Disposal
Lisa Gorsuch	OPUC
Marcus Gillette	Coalition for RNG
Marty Myers	Threemile Canyon Farm

Mary Moerlins	NW Natural
Matt Tomich	Energy Vision
Michael Briesh	NWEC
Michael S. Graham	ODOE
Nina Kapoor	RNG Coalition
Pamela Anderson	Perkins Coie
Paul Suto	City of Portland
Peter Christeleit	GE Power
Peter Moulton	WA Dept. Commerce
Rhett Lawrence	Sierra Club
Ryan Bracken	NW Natural
Seth Barns	OFIC
Tami Kerr	Oregon Dairy Farmers Assoc.
Tammy Dennee	Oregon Dairy Farms Assoc.
Tim Robinson	Clean Methane systems
Tim Logan	DMT Clean Gas
Taylor Lucey	OFIC
Tracy Rutten	League of Oregon Cities
Troy Downing	OSU Extension
Wym Matthews	ODA

APPENDIX B: THEORETICAL COUNTY-SCALE RNG POTENTIALS

POULTRY - BROILERS

County	Capturable Manure Produced (LBS/YR)	Capturable Volatile Solids Produced (LBS/AU/YR)	Methane Potential from Capturable Volatile Solids (SCF/YR)
BAKER	-	-	-
BENTON	-	-	-
CLACKAMAS	37,152,228	7,177,135	34,522,019
CLATSOP	-	-	-
COLUMBIA	-	-	-
COOS	-	-	-
CROOK	-	-	-
CURRY	-	-	-
DESCHUTES	-	-	-
DOUGLAS	-	-	-
GILLIAM	-	-	-
GRANT	-	-	-
HARNEY	-	-	-
HOOD RIVER	-	-	-
JACKSON	-	-	-
JEFFERSON	-	-	-
JOSEPHINE	-	-	-
KLAMATH	-	-	-
LAKE	-	-	-
LANE	8,698,577	1,680,407	8,082,757
LINCOLN	-	-	-
LINN	92,601,906	17,889,005	86,046,112
MALHEUR	-	-	-
MARION	30,610,074	5,913,310	28,443,020
MORROW	-	-	-
MULTNOMAH	-	-	-
POLK	39,270,068	7,586,263	36,489,925
SHERMAN	-	-	-
TILLAMOOK	-	-	-
UMATILLA	-	-	-
UNION	-	-	-
WALLOWA	-	-	-
WASCO	-	-	-
WASHINGTON	-	-	-
WHEELER	-	-	-
YAMHILL	-	-	-
TOTAL	**208,332,853**	**40,246,119**	**193,583,834**

POULTRY - LAYERS

County	Capturable Manure Produced (LBS/YR)	Capturable Volatile Solids Produced (LBS/AU/YR)	Methane Potential from Capturable Volatile Solids (SCF/YR)
BAKER	-	-	-
BENTON	-	-	-
CLACKAMAS	87,981,994	16,978,981	92,535,448
CLATSOP	-	-	-
COLUMBIA	-	-	-
COOS	-	-	-
CROOK	-	-	-
CURRY	-	-	-
DESCHUTES	-	-	-
DOUGLAS	-	-	-
GILLIAM	-	-	-
GRANT	-	-	-
HARNEY	-	-	-
HOOD RIVER	-	-	-
JACKSON	-	-	-
JEFFERSON	-	-	-
JOSEPHINE	-	-	-
KLAMATH	-	-	-
LAKE	-	-	-
LANE	13,144,474	2,536,653	13,824,758
LINCOLN	-	-	-
LINN	-	-	-
MALHEUR	-	-	-
MARION	57,217,828	11,042,037	60,179,101
MORROW	-	-	-
MULTNOMAH	-	-	-
POLK	-	-	-
SHERMAN	-	-	-
TILLAMOOK	-	-	-
UMATILLA	-	-	-
UNION	-	-	-
WALLOWA	-	-	-
WASCO	-	-	-
WASHINGTON	-	-	-
WHEELER	-	-	-
YAMHILL	-	-	-
TOTAL	**158,344,296**	**30,557,671**	**166,539,308**

CATTLE - BEEF

County	Capturable Manure Produced (LBS/YR)	Capturable Volatile Solids Produced (LBS/AU/YR)	Methane Potential from Capturable Volatile Solids (SCF/YR)
BAKER	178,530,625	11,810,488	62,477,479
BENTON	-	-	-
CLACKAMAS	7,041,580	465,828	2,464,228
CLATSOP	-	-	-
COLUMBIA	-	-	-
COOS	13,950,300	922,866	4,881,961
CROOK	79,250,990	5,242,758	27,734,189
CURRY	-	-	-
DESCHUTES	-	-	-
DOUGLAS	-	-	-
GILLIAM	14,049,945	929,458	4,916,832
GRANT	-	-	-
HARNEY	830,375	54,933	290,593
HOOD RIVER	-	-	-
JACKSON	2,856,490	188,968	999,640
JEFFERSON	63,473,865	4,199,040	22,212,923
JOSEPHINE	-	-	-
KLAMATH	61,447,750	4,065,005	21,503,876
LAKE	141,761,620	9,378,076	49,610,024
LANE	1,660,750	109,865	581,186
LINCOLN	-	-	-
LINN	62,244,910	4,117,740	21,782,846
MALHEUR	1,497,265,770	99,051,014	523,979,862
MARION	42,780,920	2,830,122	14,971,347
MORROW	1,612,621,465	106,681,112	564,343,084
MULTNOMAH	-	-	-
POLK	20,759,375	1,373,313	7,264,823
SHERMAN	-	-	-
TILLAMOOK	51,748,970	3,423,393	18,109,751
UMATILLA	886,906,930	58,672,305	310,376,491
UNION	-	-	-
WALLOWA	42,481,985	2,810,347	14,866,734
WASCO	-	-	-
WASHINGTON	5,447,260	360,357	1,906,290
WHEELER	-	-	-
YAMHILL	145,016,690	9,593,412	50,749,148
TOTAL	**4,932,128,565**	**326,280,399**	**1,726,023,308**

CATTLE - DAIRY

County	Gross Manure Produced (LBS/YR)	Capturable Volatile Solids Produced (LBS/AU/YR)	Methane Potential from Capturable Volatile Solids (SCF/YR)
BAKER	-	-	-
BENTON	87,962,242	9,222,969	35,416,202
CLACKAMAS	91,783,032	6,988,244	26,834,859
CLATSOP	77,698,056	3,349,573	12,862,361
COLUMBIA	8,956,959	462,641	1,776,540
COOS	195,588,602	11,478,224	44,076,380
CROOK	1,665,872	28,833	110,719
CURRY	-	-	-
DESCHUTES	17,242,144	1,044,959	4,012,642
DOUGLAS	-	-	-
GILLIAM	-	-	-
GRANT	-	-	-
HARNEY	-	-	-
HOOD RIVER	-	-	-
JACKSON	9,530,439	638,371	2,451,346
JEFFERSON	12,533,124	462,084	1,774,402
JOSEPHINE	88,264,820	6,827,734	26,218,499
KLAMATH	361,005,183	37,510,529	144,040,430
LAKE	-	-	-
LANE	140,923,890	15,659,804	60,133,647
LINCOLN	-	-	-
LINN	164,627,857	14,527,676	55,786,277
MALHEUR	193,806,731	21,817,613	83,779,634
MARION	689,274,450	73,089,849	280,665,019
MORROW	2,193,859,287	253,509,870	973,477,902
MULTNOMAH	1,361,222	94,875	364,320
POLK	258,192,012	30,854,104	118,479,757
SHERMAN	-	-	-
TILLAMOOK	1,449,499,134	119,191,135	457,693,960
UMATILLA	136,336,107	11,944,147	45,865,523
UNION	-	-	-
WALLOWA	-	-	-
WASCO	-	-	-
WASHINGTON	121,083,205	12,414,338	47,671,057
WHEELER	-	-	-
YAMHILL	404,675,664	33,851,276	129,988,899
TOTAL	**6,705,870,032**	**664,968,848**	**2,553,480,375**

FOOD WASTE

County	***Disposed*** Food Waste Methane Potential (SCF/YR)	***Recovered*** Food Waste Methane Potential (SCF/YR)	***Generated*** Food Waste Methane Potential (SCF/YR)
BAKER	5,861,009	5,422	5,866,431
BENTON	31,027,024	1,515,410	32,542,433
CLACKAMAS	192,595,742	35,277,736	227,873,478
CLATSOP	16,274,510	104,511	16,379,021
COLUMBIA	13,218,901	35,218	13,254,118
COOS	21,430,630	235,877	21,666,507
CROOK	8,550,726	-	8,550,726
CURRY	8,652,223	-	8,652,223
DESCHUTES	72,883,023	2,606,974	75,489,997
DOUGLAS	37,656,693	36,211	37,692,904
GILLIAM	989,051	-	989,051
GRANT	1,926,852	-	1,926,852
HARNEY	1,966,060	2,435	1,968,496
HOOD RIVER	9,413,098	203,481	9,616,579
JACKSON	82,982,795	2,240,799	85,223,594
JEFFERSON	6,270,063	7,356	6,277,419
JOSEPHINE	31,432,444	629,072	32,061,516
KLAMATH	26,740,854	-	26,740,854
LAKE	2,998,161	3,686	3,001,847
LANE	141,746,256	10,661,039	152,407,295
LINCOLN	22,106,793	295,667	22,402,460
LINN	46,460,103	724,934	47,185,037
MALHEUR	10,601,791	583,721	11,185,512
MARION	124,780,981	9,766,129	134,547,110
MORROW	8,428,659	-	8,428,659
MULTNOMAH	192,595,742	35,277,736	227,873,478
POLK	21,619,174	1,632,814	23,251,987
SHERMAN	672,972	-	672,972
TILLAMOOK	11,701,338	8,451	11,709,790
UMATILLA	38,253,821	840,117	39,093,938
UNION	10,263,953	517,618	10,781,571
WALLOWA	1,963,569	2,327	1,965,895
WASCO	8,867,078	8,676	8,875,754
WASHINGTON	192,595,742	35,277,736	227,873,478
WHEELER	211,468	-	211,468
YAMHILL	38,903,514	70,505	38,974,019
TOTAL	**1,444,642,814**	**138,571,656**	**1,583,214,471**

LANDFILLS

			ODEQ Data		*ODOE Landfill Survey Data*	
Landfill Name	**City**	**County**	***Modelled*** Methane Collected (SCF/YR)	***Reported*** Methane Collected (SCF/YR)	Methane at 50% (SCF/YR)	Methane at 55% (SCF/YR)
Coffin Butte Landfill	Corvallis	GILLIAM	891,581,364	288,804,728	525,600,000	578,160,000
Columbia Ridge Landfill Co.	Arlington	GILLIAM	1,526,004,295	445,316,613	1,681,920,000	1,850,112,000
Crook County Landfill	Prineville	CROOK	No Data	66,399,285	No Data	No Data
Dry Creek Landfill	Eagle Point	JACKSON	757,038,849	93,530,997	451,945,000	497,139,500
Finley Buttes Landfill	Boardman	MORROW	382,689,205	102,758,666	No Data	No Data
Hillsboro Landfill Inc.	Hillsboro	WASHINGTON	304,764,114	No Data	252,288,000	277,516,800
Knott Pit Landfill	Bend	DESCHUTES	146,489,192	67,083,333	210,765,600	231,842,160
Riverbend Landfill Co.	McMinnville	YAMHILL	961,658,109	256,546,738	762,120,000	838,332,000
Roseburg Landfill	Roseburg	DOUGLAS	255,772,749	180,862,627	9,900,000	10,890,000
Rossman's Landfill	Oregon City	CLACKAMAS	No Data	50,651,165	No Data	No Data
Short Mountain Landfill	Eugene	LANE	515,355,663	222,391,219	6,250,000	6,875,000
South Stage Landfill	Jacksonville	JACKSON	54,886,805	2,731,978	42,213,600	46,434,960
St. Johns Landfill	Portland	MULTNOMAH	161,613,317	87,230,221	12,500,000	13,750,000
Wasco County Landfill	The Dalles	WASCO	No Data	147,510,476	No Data	No Data
STATE TOTAL:			**5,957,853,661**	**2,011,818,044**	**3,955,502,200**	**4,351,052,420**
AVERAGE			**3,984,835,853**		**4,153,277,310**	

WASTEWATER TREATMENT PLANTS

Plant Name	City	County	***Calculated*** *Methane Potential (60% Methane SCF/YR)*	***Metered*** *Methane Potential (60% Methane SCF/YR)*
ALBANY-MILLERSBURG WRF	ALBANY	LINN	23,163,843	23,469,199
ASHLAND STP	ASHLAND	JACKSON	8,790,751	8,906,635
ASTORIA STP	ASTORIA	CLATSOP	4,134,201	4,188,700
BAKER CITY WWTP	BAKER CITY	BAKER	4,200,026	4,255,392
BEND WRF	BEND	DESCHUTES	32,982,305	33,417,094
BROOKINGS WWTP	BROOKINGS	CURRY	2,800,725	2,837,645
CANBY STP	CANBY	CLACKAMAS	7,075,069	7,168,336
CITY OF TROUTDALE WPCF	TROUTDALE	MULTNOMAH	6,824,511	6,914,475
COLUMBIA BOULEVARD STP	PORTLAND	MULTNOMAH	254,804,391	258,163,345
COOS BAY STP NO. 1	COOS BAY	COOS	3,527,979	3,574,487
COOS BAY STP NO. 2	COOS BAY	COOS	3,527,979	3,574,487
CORVALLIS STP	CORVALLIS	BENTON	24,943,226	25,272,040
COTTAGE GROVE STP	COTTAGE GROVE	LANE	4,212,766	4,268,301
DALLAS STP	DALLAS	POLK	6,612,174	6,699,339
DURHAM STP	TIGARD	WASHINGTON	104,172,528	105,545,781
FOREST GROVE STP	FOREST GROVE	WASHINGTON	20,030,598	20,294,651
GRANTS PASS STP	GRANTS PASS	JOSEPHINE	15,770,268	15,978,160
GRESHAM WWTP	PORTLAND	MULTNOMAH	50,111,530	50,772,125
HERMISTON STP	HERMISTON	UMATILLA	7,637,762	7,738,446
HILLSBORO-WESTSIDE STP	HILLSBORO	WASHINGTON	17,007,344	17,231,543
HOOD RIVER STP	HOOD RIVER	HOOD RIVER	3,378,282	3,422,816
KELLOGG CREEK WWTP	MILWAUKIE	MULTNOMAH	33,039,636	33,475,180
KLAMATH FALLS WTRF	KLAMATH FALLS	KLAMATH	4,622,576	4,683,513
LA GRANDE STP	LA GRANDE	UNION	5,624,807	5,698,956
LEBANON WWTP	LEBANON	LINN	7,100,549	7,194,152
LINCOLN CITY STP	LINCOLN CITY	LINCOLN	3,679,800	3,728,309
MCMINNVILLE WRF	MCMINNVILLE	YAMHILL	14,296,650	14,485,115
MEDFORD RWRF	CENTRAL POINT	JACKSON	84,085,449	85,193,904
MOLALLA STP	MOLALLA	CLACKAMAS	4,081,117	4,134,916
EUGENE/SPRINGFIELD MWMC	EUGENE	LANE	107,731,296	109,151,462
NEWBERG STP	NEWBERG	YAMHILL	9,971,345	10,102,792
NORTH BEND STP	NORTH BEND	COOS	4,161,805	4,216,668
OAK LODGE WATER SERVICES WRF	MILWAUKIE	CLACKAMAS	11,890,872	12,047,623
ONTARIO STP	ONTARIO	MALHEUR	4,868,887	4,933,071
PENDLETON STP	PENDLETON	UMATILLA	7,172,744	7,267,298
R.U.S.A. ROSEBURG STP	ROSEBURG	DOUGLAS	10,198,546	10,332,988
ROCK CREEK STP	HILLSBORO	WASHINGTON	91,022,923	92,222,831
SALEM WILLOW LAKE STP	KEIZER	MARION	97,250,343	98,532,343
SOUTH SUBURBAN STP	KLAMATH FALLS	KLAMATH	4,622,576	4,683,513
ST. HELENS STP/BOISE CASCADE	ST HELENS	COLUMBIA	5,622,684	5,696,804
STAYTON STP	STAYTON	MARION	3,299,717	3,343,215
SWEET HOME STP	SWEET HOME	LINN	3,860,287	3,911,175
THE DALLES STP	THE DALLES	WASCO	6,210,857	6,292,732
TRI-CITY WPCP	OREGON CITY	CLACKAMAS	30,576,527	30,979,601
TRYON CREEK WWTP	LAKE OSWEGO	CLACKAMAS	25,480,439	25,816,334
WILSONVILLE STP	WILSONVILLE	CLACKAMAS	10,325,948	10,462,070
WINSTON-GREEN WWTF	ROSEBURG	DOUGLAS	2,297,486	2,327,773
WOODBURN WWTP	WOODBURN	MARION	10,483,077	10,621,270
STATE TOTAL			**1,209,287,200**	**1,225,228,606**
AVERAGE			**1,217,257,903**	

AGRICULTURAL RESIDUALS

County	Total Residuals (BDT/YR)	Methane Potential (SCF/YR)	Assuming 50% Recovery Rate
BAKER	33,838	508,058,220	254,029,110
BENTON	87,557	1,069,027,198	534,513,599
CLACKAMAS	21,107	280,048,405	140,024,203
CLATSOP	-	-	-
COLUMBIA	642	9,634,872	4,817,436
COOS	-	-	-
CROOK	2,174	32,634,245	16,317,123
CURRY	-	-	-
DESCHUTES	2,958	44,410,201	22,205,100
DOUGLAS	3,056	39,411,435	19,705,718
GILLIAM	248,931	3,737,605,303	1,868,802,651
GRANT	-	-	-
HARNEY	3,249	41,166,362	20,583,181
HOOD RIVER	189	2,831,755	1,415,877
JACKSON	1,240	18,747,979	9,373,989
JEFFERSON	47,914	662,399,877	331,199,939
JOSEPHINE	296	4,588,432	2,294,216
KLAMATH	41,322	620,430,532	310,215,266
LAKE	-	-	-
LANE	115,290	1,407,472,019	703,736,010
LINCOLN	-	-	-
LINN	312,132	3,750,652,569	1,875,326,284
MALHEUR	158,780	2,434,044,401	1,217,022,201
MARION	237,389	2,940,675,811	1,470,337,906
MORROW	362,953	5,464,771,796	2,732,385,898
MULTNOMAH	5,214	74,769,905	37,384,952
POLK	123,331	1,534,909,151	767,454,575
SHERMAN	295,739	4,440,398,454	2,220,199,227
TILLAMOOK	-	-	-
UMATILLA	699,505	10,346,484,489	5,173,242,244
UNION	82,540	1,198,585,032	599,292,516
WALLOWA	33,539	503,568,853	251,784,426
WASCO	132,372	1,987,511,877	993,755,939
WASHINGTON	68,925	928,912,475	464,456,238
WHEELER	-	-	-
YAMHILL	100,706	1,289,798,627	644,899,314
TOTAL	**3,222,882**	**45,373,550,275**	**22,686,775,137**

FORESTRY RESIDUALS

County	Total Residuals (BDT/YR)	2016 Methane Potential (SCF/YR)
BAKER	11,967	106,635,564
BENTON	56,935	507,340,372
CLACKAMAS	81,649	727,565,418
CLATSOP	138,569	1,234,771,057
COLUMBIA	83,126	740,724,309
COOS	131,838	1,174,797,053
CROOK	1,715	15,282,535
CURRY	47,888	426,725,323
DESCHUTES	12,954	115,433,822
DOUGLAS	307,960	2,744,199,160
GILLIAM	-	-
GRANT	18,596	165,708,356
HARNEY	2,116	18,854,020
HOOD RIVER	21,051	187,579,319
JACKSON	48,717	434,108,673
JEFFERSON	7,680	68,435,644
JOSEPHINE	15,929	141,940,871
KLAMATH	37,697	335,912,079
LAKE	15,514	138,244,277
LANE	274,680	2,447,643,564
LINCOLN	89,911	801,187,842
LINN	152,576	1,359,591,897
MALHEUR	-	-
MARION	34,635	308,632,135
MORROW	393	3,498,772
MULTNOMAH	9,107	81,153,980
POLK	59,887	533,644,681
SHERMAN	-	-
TILLAMOOK	105,981	944,386,218
UMATILLA	7,385	65,805,149
UNION	20,740	184,814,733
WALLOWA	27,451	244,610,376
WASCO	15,395	137,183,525
WASHINGTON	59,182	527,361,648
WHEELER	2,749	24,495,683
YAMHILL	48,638	433,403,572
2016 TOTAL	**1,950,610**	**17,381,671,628**
AVERAGE 2010-2016		**16,998,108,771**

APPENDIX C: POLICY CONCEPTS

Policy Suggestions by Members of the SB 334 RNG Advisory Committee

- The Committee identified the need for a policy that directs the OPUC to allow gas utilities to purchase and sell RNG for their customers.
- The Committee identified the need for a policy that allows gas utilities to recover capital expenses associated with connecting RNG production facilities to the common carrier gas grid.
- Some Committee members recommended a policy to develop a bio-energy electricity feed-in tariff for biogas-derived electricity that sets a fixed price and a required level of electricity purchase over time (similar to the California SB 1122 Bioenergy Feed-in tariff Program).
- Some Committee members recommended a policy that lowers and fixes wheeling charges for bio-energy electricity across various private and public utilities.
- All members agree that there needs to be a protocol for tracking and accounting for the production and use of RNG.

Policy Suggestions from Other Stakeholders

Select stakeholder comments are summarized below, with attribution.

Incentives Policy

1. Greater proliferation of grants and other incentives for natural gas fueling infrastructure would likely support the development of RNG. ***(CASCADE Natural Gas)***
2. NGV vehicle incentives - Covering all or a portion of the incremental cost of CNG vehicles would reduce a severe cost barrier, and would accelerate cost parity between CNG and diesel engines. ***(NW Alliance for Clean Transportation)***
3. Alternative fuel infrastructure grants - The creation of a grant program to support refueling infrastructure in key corridors would reduce or eliminate a major up-front cost barrier to potential fleet owners. ***(NW Alliance for Clean Transportation)***
4. Establish certain categorical environmental exemptions for MSW landfills that produce RNG. ***(Dry Creek Landfill)***
5. Establish alternative fuel vehicle purchase requirements and incentives. ***(Dry Creek Landfill)***
6. Establish funding sources for building CNG fueling stations. ***(Dry Creek Landfill)***
7. Provide incentives for local colleges to provide CNG vehicle maintenance training. ***(Dry Creek Landfill)***
8. Provide funding for building or retrofitting state vehicle fleet maintenance facilities to service CNG vehicles. ***(Dry Creek Landfill)***
9. Provide grant funding to private fleet operators to offset the higher costs of purchasing CNG vehicles. ***(Dry Creek Landfill)***

10. Provide incentives to regulated gas utilities to participate with RNG project developers by offsetting the high cost of connecting RNG projects to pipelines with rate based financing- the intent of SB 844. ***(Dry Creek Landfill)***
11. Establish grant and loan programs and other financial incentives for RNG project development. ***(Dry Creek Landfill)***
12. Fund ODOE's Small-Scale Local Energy Loan Program (SELP). Currently SELP is not accepting new applications. Like the RED program, loan funding and project specific maximum loan funds need to be significantly increased to support RNG projects. ***(Dry Creek Landfill)***
13. Local property tax exemptions should be considered for RNG project infrastructure. ***(Dry Creek Landfill)***
14. Production and or investment tax waivers (or "credits") to defray interconnection costs, regardless of the end use of the RNG product, so as to not create policy incongruence. ***(RNG Coalition)***
15. Create incentives for the Conversion of Medium- and Heavy-Duty Vehicle Fleets from Diesel to Ultra-low NOx and Natural Gas Engines. ***(RNG Coalition)***

Market Facilitation Policy

1. Create a credit marketplace consisting of Renewable Identification Numbers (RINs). RINs would be individual numbers for every gallon or gallon-equivalent of RNG sold that displaces fossil natural gas with RNG. ***(Dry Creek Landfill)***
2. A state program that would guarantee all or a portion of financiers' investment in an RNG project that has all finalized contracts in place would add a layer of financial security that would help to drive RNG project financiers and developers to pursue projects in Oregon. ***(RNG Coalition)***

Regulatory Policy

1. Policy supporting the recovery of cost-effective utility investments in RNG infrastructure would help support increased engagement and coordination on RNG activities between utilities and producers. ***(CASCADE Natural Gas)***
2. The company encourages the Energy Trust of Oregon to continue its discussion on inclusion of RNG pilots in future program activities. ***(CASCADE Natural Gas)***
3. Cascade supports regulation and policy that maintains the reliability and cost-effectiveness of the natural gas supplied to our customers. It will need to be determined from a regulatory standpoint if there is a method of valuation of RNG resources that captures additional value or benefits that would qualify it under least-cost procurement. ***(CASCADE Natural Gas)***
4. Amplified clean air regulations - Natural gas vehicles have nearly non-existent NOx, SOx, and particulate matter (PM) emissions. Advancing clean air requirements is likely to benefit natural gas vehicles as diesel becomes untenable under those regulations. ***(NW Alliance for Clean Transportation)***
5. Government fleet procurement guidelines requiring alternative fuels. ***(NW Alliance for Clean Transportation)***
6. Vehicle length exemptions - Oregon has a rule that essentially disallows triple tractor trailer orientations with CNG due to the small amount of length added by the refueling system. By

working with the Federal Government, the State could encourage greater penetration of CNG in trucking by exempting that added length. ***(NW Alliance for Clean Transportation)***

7. HOV/Parking exemptions for CNG vehicles. ***(NW Alliance for Clean Transportation)***
8. Assure availability of quality feed stocks through policies including:
    a. Supporting and encouraging the development of programs that source separate and collect high quality food waste. High quality feed stocks produce quality end products.
    b. Developing a "food waste only" collection standard for local government commercial collection programs
    c. Food waste only collection standards should include food scraps only and should not include "food-related" materials (e.g., soiled cardboard, napkins, plates and compostable food service ware or other non-food items).
    d. The collection standard should have a list of the specific types of items that are and are not accepted.
    e. Collection programs should include appropriate and effective compliance mechanisms. ***(Metro)***
9. Current language in proposed Cap and Invest legislation SB 1507 exempts closed MSW landfills from compliance with the bills' requirements.
    a. Active MSW landfills that currently have GTE (gas to energy) facilities or RNG facilities should also be exempt.
    b. The MSW landfill's exemption should be conditioned upon the deployment of temporary plastic covers, which should be considered the Best Management Practices (BMPs) for all landfills.
    c. The MSW landfills must be required to capture and destroy landfill gas at a minimum 70% level. ***(Dry Creek Landfill)***
10. MSW landfills provide a significant role in protecting both public health and the environment, and should not be taxed for their efforts.
    a. Any tax on MSW landfills must be passed directly to their customers- the public. ***(Dry Creek Landfill)***
11. Require all state vehicle fleet managers to purchase a certain percentage of new vehicles that run on CNG where fueling infrastructure is currently in place. ***(Dry Creek Landfill)***
12. Establish a Renewal Portfolio Standard (RPS) for natural gas.
    a. Natural gas RPS could be modeled after the electricity RPS program. Under the program regulated gas utilities would be required to provide a certain percentage of RNG to their customers, increasing over time.
    b. The PUC would need to be on board with the RPS approach, as the gas utilities would need the ability to pass the added cost of purchasing RNG on to their customer base.
    c. The natural gas RPS would benefit the entire spectrum of natural gas uses, including heat, electricity and transportation. ***(Dry Creek Landfill)***
13. Open ODOE's Renewal Energy Development (RED) grant program to RNG projects Increase the total allocable RED grant funding and project specific maximum grant funds significantly to support RNG projects. ***(Dry Creek Landfill)***

14. Legislative and or regulatory measures that permit and shift the burden of interconnection costs from the RNG project developer to the gas corporation. ***(RNG Coalition)***

Feedstock Policy

1. Support and encourage policies and programs that promote diverse and robust end markets for the digestion co-products produced from anaerobic digestion through:
    a. Increased use of digestate co-products in the agricultural industry. Developing partnership with Oregon Department of Agriculture, US Department of Agriculture and Oregon State University Extension Service to research barriers and opportunities to increasing the agricultural use of digestate co-products. Adopting and establishing state purchasing requirements and standards for using digestate co-products for landscaping projects. Promote the co-benefits of pesticide and water reduction. ***(Metro)***
2. Support Development of AD Processing Capacity through:
    a. Researching use of existing AD infrastructure at wastewater treatment facilities to process waste food. Convene wastewater treatment plant advisory group to discuss potential to directly receive food waste.
    b. Researching small-scale, on-site processing AD technologies for commercial and industrial generators. Consider life-cycle impacts compared to centralized processing.
    c. Providing micro-grants/loans to pilot technologies.
    d. Providing assistance to help overcome barriers to siting processing facilities that are related to land use issues including land use, zoning and permitting. ***(Metro)***
3. Support and encourage the development of a collection and processing infrastructure that is flexible and allows for an efficient and effective recovery system that reduces the cost differential compared to other processing options.
    a. Facilitate a statewide workgroup to identify opportunities and barriers to establishing food waste collection programs.
    Examine how local agreements (e.g., intergovernmental to combine collection programs) could facilitate aggregation of collection amounts to make AD facilities more feasible. ***(Metro)***
4. Create a state Renewable Natural Gas Procurement Program. ***(RNG Coalition)***

Full submitted stakeholder letters are reproduced in the following pages:

Comments submitted by stakeholder who wished to remain anonymous:

1. Since the existing policy framework influencing the RNG market drives RNG toward the vehicle fuels market, gas utilities are much less able to purchase RNG for their stationary sales customers (such as Oregon homes and businesses), because they must compete with the cost of the environmental credits in the vehicle fuel market. In order to increase the amount of potential buyers of RNG, gas utilities would need a policy pathway that allows them to purchase RNG and value the benefits for their customers. This would allow them to potentially offer RNG projects longer term, lower-priced contracts, which may be more attractive to some RNG project developers than relying on the much more volatile vehicle fuels credit markets. It is unlikely that a future near-term Oregon carbon emission reduction policy, such as cap-and-trade, will by itself drive substantial utility purchases of RNG in the near term. Some gas utilities will want to begin to decarbonize their product faster, and the overall benefit to the climate is greater if more RNG can be brought online earlier. Because the RNG market is nascent, a policy that creates a clear regulatory pathway for gas utilities to purchase RNG could be optional to individual gas utilities, recognizing that not every gas utility is experiencing customers asking for a decarbonized product. The program supported by such a policy should include a reasonable cost-containment mechanism to protect customers, and should clarify that various interconnection costs (metering, pipe to interconnect and monitoring) are part of utility service.

2. To ensure a vibrant and growing RNG market, it will be necessary over time to develop an accounting and tracking system for environmental attributes that flow to stationary gas customers. A RNG program should ensure the transparent and reliable transfer of environmental attributes and should allow purchases from a broad geographic area (over time allowing for a national market). Various Oregon state agencies (ODOE, ODEQ, and OPUC) should take a role in making sure this system develops and that it works for stakeholders within the state. The tracking of environmental attributes can and should be handled contractually in the interim, while this more structured regional and national trading system is developed.

Metro

600 NE Grand Ave.
Portland, OR 97232-2736
oregonmetro.gov

July 26, 2018

Mr. Daniel Avery Senior Policy Analyst
Oregon Department of Energy 550 Capitol Street N.E., 1st Floor Salem, OR 97301

RE: Comments to SB 334 Advisory Committee Dear Mr. Avery:

Thank you for the opportunity to provide a local government perspective on anaerobic digesters to the SB 334 Advisory Committee. Holly Stirnkorb, our representative on the committee, found the meetings useful and informative, and appreciated your leadership. Our comments below are focused on how to enable more food waste from our municipal waste stream to be processed at anaerobic digestion facilities.

We believe that expanding the amount of anaerobic digesting (AD) capacity in Oregon will require overcoming a number of barriers and pursuing policies that enable the use of existing facilities and the construction of additional facilities. There is a need to focus on approaches targeting the collection and aggregation of feed stocks adding the most value to the anaerobic digestion process. We recommend that targeted feed stocks should be food waste that has been source separated from industrial, commercial and institutional sectors (ICI) of the solid waste stream.

Barriers

Development of AD capacity for food waste requires addressing several key barriers:

1. Availability of sufficient quantities of quality food waste – facilities need sizable amounts and assured delivery of high value feed stocks.
2. Lack of robust end-markets for by-products from AD process (liquid and solid digestate).
3. Need for research on utilizing existing AD systems, employing smaller scale technologies and addressing facility siting issues including land use, zoning and permitting.
4. Anaerobic digestion can be more costly than other available options such as composting or landfilling. Development of additional AD capacity will require reducing that differential.

Policies to Address Barriers and Expand AD Capacity

1. Assure availability of quality feed stocks through policies including:

    - Supporting and encouraging the development of programs that source separate and collect high quality food waste. High quality feed stocks produce quality end products.
    - Developing a "food waste only" collection standard for local government commercial collection programs:
        - "Food waste only" collection standards should include food scraps only and should not include "food-related" materials (e.g., soiled cardboard, napkins, plates and compostable food service ware or other non-food items).
        - The collection standard should have a list of the specific types of items that are and are not accepted.
        - Collection programs should include appropriate and effective compliance mechanisms.
    - Convening and facilitating a statewide workgroup to develop collection standards and identify additional opportunities and barriers to quality feedstock.
    - Developing model regulations that expand compost/AD permit requirements to include quality standards (contamination thresholds) for incoming loads and finished products.
    - Legislation to require food stickers that rapidly break down in the composting processes.

2. Support and encourage policies and programs that promote diverse and robust end markets for the digestion co-products produced from anaerobic digestion through:

    - Increased use of digestate co-products in the agricultural industry.
    - Developing partnership with Oregon Department of Agriculture, US Department of Agriculture and Oregon State University Extension Service to research barriers and opportunities to increasing the agricultural use of digestate co-products.
    - Adopting and establishing state purchasing requirements and standards for using digestate co-products for landscaping projects. Promote the co-benefits of pesticide and water reduction.

3. Support Development of AD Processing Capacity through:

    - Researching use of existing AD infrastructure at wastewater treatment facilities to process waste food. Convene wastewater treatment plant advisory group to discuss potential to directly receive food waste.
    - Researching small-scale, on-site processing AD technologies for commercial and industrial generators. Consider life-cycle impacts compared to

centralized processing.

- Providing micro-grants/loans to pilot technologies.
- Providing assistance to help overcome barriers to siting processing facilities that are related to land use issues including land use, zoning and permitting.

4. Support and encourage the development of a collection and processing infrastructure that is flexible and allows for an efficient and effective recovery system that reduces the cost differential compared to other processing options.

    - Facilitate a statewide workgroup to identify opportunities and barriers to establishing food waste collection programs.
    - Examine how local agreements (e.g., intergovernmental to combine collection programs) could facilitate aggregation of collection amounts to make AD facilities more feasible.

Thank you again for the opportunity to provide our perspective on these issues. We look forward to continuing to work with you and the stakeholders on the committee to advance the production of this important renewable energy within Oregon.

Sincerely,

Paul Slyman
Director, Property & Environmental Services

cc: Matt Korot, Program Director
Holly Stirnkorb, Sr. Planner

SB 334 COMMENTS OF THE COALITION FOR RENEWABLE NATURAL GAS:
BARRIERS & POLICY SOLUTIONS FOR RNG DEVELOPMENT IN OREGON

This document outlines comments from the Coalition for Renewable Natural Gas (RNG Coalition) in response to Oregon Department of Energy (ODOE)'s request for input regarding the barriers study conducted by ODOE, the corresponding barriers discussed by the SB 334 Committee of biogas and renewable natural gas (RNG) stakeholders, and recommended policy solutions to overcome those barriers.

I. INTRODUCTION

The RNG Coalition is a nonprofit organization dedicated to the advancement of renewable natural gas (biogas-derived biomethane or "RNG") throughout North America as a clean, ultra-low-carbon, renewable energy resource that can be utilized in the generation of renewable electric power, thermal heat and transportation fuel. Our diverse membership is representative of the entire RNG value-chain, including waste collection, waste management and recycling companies, renewable energy developers, engineers, financiers, manufacturers, service and technology providers, gas marketers and transporters, environmental advocates, non-profit research organizations, organized labor, law firms, municipalities, ratepayers, universities and utilities.

The following comments represent the RNG industry across North America and are based on our collective experience working to overcome similar policy and market barriers and implement solutions nationally, and regionally at the state and local levels.

Oregon can focus on a variety of solutions to spur increased development, deployment and utilization of biogas-derived renewable natural gas (RNG) in the state. In so doing, Oregon would simultaneously realize a host of environmental and economic benefits. Policies supporting a market that enables RNG projects to be developed attract hundreds of millions of dollars of private investment and create hundreds of new clean energy sector jobs.

RNG development, deployment and utilization improves the environment by redeeming methane from society's waste streams for sustainable and productive end-use, including as an ultra-low carbon fuel and power source that can blend with or substitute for gas or electricity derived from limited natural resources. Approximately 28% of the U.S. municipal waste stream is comprised of organics (food scraps, yard clippings, etc.) - 187,000 metric tons a day or close to

68 million metric tons per year. RNG production turns the costly environmental burden of effectively managing solid waste into a renewable energy solution.

II. FINANCING & INVESTMENT BARRIERS

Due to the high capital costs of developing RNG projects that cost between $10-$70+ million per project, RNG project developers must be able to generate and monetize environmental credits for the commodity they produce on related markets (RFS, LCFS, RPS, AEPS, etc.) in order for RNG projects to be economically viable. Thus, access to such markets, and market certainty and predictability are prerequisites for most RNG project developers to be able to access investment capital and or debt financing. Access to investment capital or other financing is only a barrier if there are insufficient policies in place to promulgate markets that support the increased development, deployment and utilization of RNG in perpetuity.

To the extent there is uncertainty surrounding existing markets, whether due to a new Presidential Administration or EPA Administrator, or because of lawsuits levied against administering regulatory agencies, confidence in the perpetuity of such markets can make it difficult for RNG project developers to access investment capital and financing.

Fortunately, the current value of monetized environmental credits associated with RNG production and utilization as a transportation fuel make it possible for developers to amortize and realize a return on investments made in their projects in shorter timeframes. This reality, along with improved industry advocacy and education efforts, have assisted in increasing investor and financier understanding of the innate volatility that comes with markets that are underwritten by public policy – and they are eager to invest in viable RNG projects.

III. PROJECT DEVELOPMENT & INTERCONNECTION COST BARRIERS

RNG projects are capital intensive, with significant up-front costs. A dairy-to-RNG project, depending on the size of the project or cluster, can cost as much as $10 million to develop, while an RNG production facility developed at a larger landfill or anaerobic digestion facility can cost between to $50-$100 million.

The proximity between the RNG production facility and the point of interconnect with the nearest common carrier pipeline can also be a barrier – as interconnection estimates range between $1.5-$3 million per mile in some regions**.** Interconnection costs are incurred and typically borne by a project developer prior to injection and can equal and even exceed the total costs of developing the RNG production facility.

Due to its population size and density, the corresponding density of Oregon's natural gas pipeline infrastructure is less than many other states. This is especially true east of the Cascade Mountains, where population density is much lower. For some potential RNG projects, particularly those at or near farms and dairies that plan to use manure or other agricultural waste feedstocks, their proximity to the nearest common carrier pipeline and correlating interconnection costs can represent a significant barrier.

However, it is worth noting that the availability and product offerings of virtual or mobile pipeline solutions are increasing, and being used where an RNG project is too far from the nearest common carrier pipeline to justify the cost of interconnection. In some cases, utilizing a virtual or mobile pipeline solution creates a closed-loop, where medium- and heavy-duty CNG trucks fueled by RNG, pick-up, transport and deliver RNG from the production facility to the end-use customer.

IV. MARKET DEMAND BARRIERS

Since 2014, the volume of RNG that has been produced for the transportation fuel market has increased more than ten-fold. With the number of operating projects already producing and delivering RNG to the transportation fuel market, and the number of new RNG projects under construction and in development, there is a legitimate concern that supply could outpace demand in the foreseeable future. Nationwide, findings indicate between 20-38% of all natural gas vehicles are fueled by RNG. In California, for example, we expect nearly 90% of all natural gas vehicles to be fueled by RNG by year's end.

In order to deploy RNG as an ultra-low carbon transportation fuel in Oregon, and across the country, we need a greater deployment of natural gas vehicles. We recognize that there are not as many vehicles – much less natural gas vehicles – in Oregon as there are in many other states. We also understand that the cost of converting diesel fleets or replacing diesel engines with cleaner burning natural gas engines that are fueled by RNG is expensive. The RNG Coalition supports policies that provide incentives and direct funding to offset these costs, so that economics is not a barrier to improved air quality and public health.

The lack of access to RNG transportation fuel users has a direct impact on the ability of RNG developers to access investment or financing for the development of projects in Oregon. Because RNG must be used as a transportation fuel in order for the developer to generate environmental credits that are relied upon during project financing, RNG projects that are being considered or constructed in Oregon are often forced to consider off-take agreements in markets outside the state: projects can get a better price for the RNG they produce where market demand is higher, both due to more fleets and or larger natural gas vehicle fleets, and due to low-carbon fuel programs that fetch a higher value for the environmental attributes of RNG (E.g. California's Low Carbon Fuel Standard vs. Oregon's developing Clean Fuels Program).

The limited existing number of natural gas stations in Oregon is not as much of a barrier in itself – it is just a reflection of the lack of natural gas vehicles in the state. Natural gas or RNG fueling stations can be developed in conjunction with an RNG production facility if the end-use customer or fleet requires it.

V. LEGISLATIVE & REGULATORY SOLUTIONS TO OVERCOME BARRIERS

A. Reducing Cost of Interconnection

The RNG Coalition – including common carrier pipeline member companies in certain states – support policy that would enable gas corporations to invest in and recover from their rate base the cost of interconnecting RNG production facilities to their system.

Policy solutions include, but are not limited to:

1. Legislative and or regulatory measures that permit and shift the burden of interconnection costs from the RNG project developer to the gas corporation. Shifting these costs to the gas corporations, and allowing a utility to recover the cost from their rate base would enable projects to be developed and benefit the general public through realized economic and environmental benefits associated with increased biomethane development, deployment and utilization regardless of the projects proximity to the nearest pipeline.

   Such programs would be in the ratepayers' long-term interest, because interconnection of RNG facilities results in: carbon sequestration, methane mitigation and decarbonization of the natural gas pipeline system; improved air quality and public health; reduction of related negative health and environmental impacts from air pollution; reduction of greenhouse gas emissions related to electricity generation and fuel production derived from fossil sources; energy efficiency savings; and, finally, increased availability and use of alternative, ultra-low carbon fuels.

   The California State Legislature is considering two RNG Coalition-sponsored bills in its 2018 legislative session. An original component of one of these measures, Senate Bill 1440 (SB 1440), would have required the California Public Utilities Commission (CPUC) to "allow recovery in rates, or other alternatives as appropriate, of the costs of reasonable and prudent investments for infrastructure that provides direct benefits to ratepayers".[1] As of the submission of these comments, SB 1440 has been approved by the State Senate and both policy committees in the State Assembly. SB 1440 is now undergoing fiscal review by the Assembly Appropriations committee prior to being voted on by the entire

[1] *SB 1440 Biomethane Procurement Program Fact Sheet*, 2018. Attached to these comments, we are submitting the official SB 1440 Fact Sheet for the record. For current bill language and status, please visit https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB1440.

State Assembly and transmitted to the Governor for signature.

2. Production and or investment tax waivers (or "credits") to defray interconnection costs, regardless of the end use of the RNG product, so as to not create policy incongruence.[2]

B. Spurring Demand for RNG in State Clean Energy Programs

1. Create a state Renewable Natural Gas Procurement Program. Similar to the manner in which a state Renewable Portfolio Standard (RPS) works to increasingly require the procurement of electricity from renewable resources, California's SB 1440 would create an RNG procurement program to decarbonize and reduce GHGs from the natural gas sector. SB 1440 would require the California Air Resources Board (CARB), in consultation with the CPUC, to establish an RNG procurement program for investor-owned natural gas utilities of at least a certain size, in furtherance of the state's GHG, short-lived climate pollutant reduction, and organic waste diversion goals. The bill would require annually increasing targets for procurement of RNG by natural gas utilities, resulting in the annual procurement of 32 billion cubic feet of RNG by the year 2030. Under SB 1440, the same gas corporations would be required to enter into procurement contracts of no less than ten-years for a purchase price not to exceed $15 per MMBtu above indexed price for natural gas. SB 1440 does not stipulate how the gas corporations are to use the gas, other than they are not to unfairly compete with RNG marketers. Enacting an identical or comparable Renewable Natural Gas Procurement Program would address barriers associated with project development and interconnection costs and market demand limitations in Oregon.

   Displacing even a fraction of conventional natural gas used for residential and commercial heating and cooking has dramatic environmental benefits. A new study from Navigant Consulting found that using RNG to replace just 16 percent of the geologically-sourced natural gas in California could achieve similar GHG reductions as electrifying 100 percent of the state's buildings.[3]

2. Create incentives for the Conversion of Medium- and Heavy-Duty Vehicle Fleets from Diesel to Ultra-low NOx and Natural Gas Engines.
   Due to the modest number and limited size of fleets in Oregon currently running on natural gas engines, a policy proposal to create an RNG procurement program for utilities would be aided by a corresponding program to increase conversion of medium and heavy-duty vehicles in Oregon to run on natural gas engines.

[2] Policy incongruence: for example, facilities that produce RNG for electricity markets are eligible for the Federal Production Tax Credit (PTC), whereas facilities producing RNG for the transportation fuel market are not.
[3] "Analysis of the Role of Gas for a Low Carbon California Future," Navigant Consulting Inc., 2018. https://www.socalgas.com/1443741887279/SoCalGas_Renewable_Gas_Final-Report.pdf

A new CNG truck costs $30,000 to $100,000 more than a comparable diesel truck. While the fuel savings to the fleet from fueling with natural gas compared to diesel makes up a portion of that difference[4], the savings alone will not provide full payback on the increased vehicle cost. A solution is to offer grants to repower existing diesel trucks to natural gas engines.

C. Loan Guarantees to Increase Investor Certainty & Reduce Perceived Investor Risk

The U.S. Department of Energy (DOE) AgSTAR program has historically made a limited quantity of loan guarantees available for anaerobic digestion projects across the nation.[5] However, DOE grant programs with a focus on environmental benefits are annually at risk of being cut in the federal appropriations process. Draft appropriations proposals from the majority political party have eliminated them from the DOE budget in recent years. The program has also had a limited impact, perhaps due to the routinely retroactive or concurrent manner in which the federal appropriations process has occurred in recent years. When financing a project in real time, it can be challenging to plan on utilizing a loan guarantee program that is not put in place until summer of that year.

A state program that would guarantee all or a portion of financiers' investment in an RNG project that has all finalized contracts in place would add a layer of financial security that would help to drive RNG project financiers and developers to pursue projects in Oregon. Such a program would help alleviate policy risk by significantly reducing perceived uncertainty, such as that associated with a change in federal RFS policy.

When an RNG project in development reaches the stage of breaking ground on construction, many of the risks have been significantly reduced. At this phase, they have obtained permits, and they have contracts in place for financing, acquisition and installation of equipment, off-take (purchase) of the RNG product, and, most often, a contract in place for marketing and/or sale of the renewable credits attached to each unit of production.

Therefore, provided a loan guarantee program is setup and implemented with a process that consults RNG project stakeholders and results in sufficient underwriting due diligence, any financial liability of such a program to the state should be minimal.

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[4] At current prices, which reflect recent increases in the average price of diesel. Transportation fuel prices, diesel more-so than natural gas, are variable.

[5] "Funding On-Farm Anaerobic Digestion." September 2012. United States Environmental Protection Agency Office of Air and Radiation. https://www.epa.gov/sites/production/files/2014-12/documents/funding_digestion.pdf

The NW Alliance for Clean Transportation, on behalf of its Oregon members, is keenly interested in expanding the use of natural gas engines in the transportation sector. NGVs are capable of significantly reducing air quality pollutants and carbon emissions when used in most medium and heavy duty applications. This is the most efficient way to reduce Oregon's environmental footprint, and the technology is ready for wide scale adoption. As with many emerging technologies aiming to replace an entrenched incumbent, there are hurdles that will need to be addressed to clear the way for NGVs.

There is an immeasurable societal benefit to eliminating diesel emissions, and creating clean air in our most populated areas. Additionally, a growing CNG market creates a larger demand for renewable natural gas. As such, the NW Alliance submits the following as a sample of potential policy avenues to support increased adoption of natural gas vehicles. The listing of these policies does not represent an endorsement from the NW Alliance for Clean Transportation or any of our members.

- NGV vehicle incentives
  - Covering all or a portion of the incremental cost of CNG vehicles would reduce a severe cost barrier, and would accelerate cost parity between CNG and diesel engines.
- Amplified clean air regulations
  - Natural gas vehicles have nearly non-existent NOx, SOx, and particulate matter (PM) emissions. Advancing clean air requirements is likely to benefit natural gas vehicles as diesel becomes untenable under those regulations.
- Alternative fuel infrastructure grants
  - The creation of a grant program to support refueling infrastructure in key corridors would reduce or eliminate a major up-front cost barrier to potential fleet owners.
- RNG for transportation programs
  - California's LCFS has provided additional funds to support renewable product for transportation fleets. This has attracted a great deal of RNG into the state, and has facilitated a near total penetration of RNG in the NGV market. Oregon currently has a clean fuel program that mirrors California's policy, except the credits currently trade at roughly half the price.
- Government fleet procurement guidelines requiring alternative fuels
  - The use of CNG in government fleets would increase the availability of refueling infrastructure while reducing pollution from those fleets.
- Vehicle length exemptions
  - Oregon has a rule that essentially disallows triple tractor trailer orientations with CNG due to the small amount of length added by the refueling system. By working with the Federal Government, the State could encourage greater penetration of CNG in trucking by exempting that added length.

- Vehicle weight exemption
    - In the 2016 legislative session, Oregon passed a law allowing up to a 2,000-pound weight exemption to account for the additional weight of CNG fueling systems. While this is a significant step forward, other states have stumbled over implementation of similar laws by attempting to exempt the exact weight of each fueling system as opposed to applying a blanket 2,000-pound exemption. Supplementing Oregon's exemption by administrative rulemaking or a law dictating a blanket 2,000-pound exemption would significantly reduce the difficulty of compliance for the user and the state, and would go further in achieving the law's intended effect: encouraging CNG adoption.
- HOV/Parking exemptions for CNG vehicles
    - While CNG makes most sense for medium and heavy duty vehicles, there is still some benefit to allowing CNG vehicles access to HOV lanes and preferred parking in government targeted lots (this could include rest stops, government buildings, etc.). Additionally, it appears congestion pricing is coming to the Portland-area. Exemptions for CNG vehicles would provide an added incentive for fleet owners, and would have positive effects across weight classes.

Oregon Department of Energy
SB 334 Barriers Importance Survey
Comments of Williams Northwest Pipeline and TransCanada - GTN
March 9, 2018

Regulatory/Operational Barriers

Interstate natural gas pipelines are open access pipelines that are regulated by the Federal Energy Regulatory Commission (FERC) and deliver natural gas from supply regions to market centers. Natural gas transported through interstate pipelines travel at high pressures (pressures anywhere from 200 to 1,500 pounds per square inch) and must meet specific gas quality measures so as to provide uniform quality gas across their systems to local distribution companies, end-users and interconnecting pipelines.

A potential regulatory barrier for a RNG producer to inject product into an interstate pipeline is the producer's ability to meet the interstate pipeline's (a) FERC approved tariff gas quality limits (e.g., BTU limits and thresholds for a number of specific contaminants) and (b) current prevailing mainline pressures. If met, the interstate pipeline, as an open access transporter, must accept the RNG product into its system.

Financial Barriers

A potential financial policy barrier for a RNG producer to inject product directly into an interstate pipeline is the cost per unit to connect to an interstate pipeline. If the RNG facility is not near an existing interstate pipeline mainline/lateral, then, in addition to the meter/compression cost, additional piping costs would be incurred to connect the RNG facility (unless the product is trucked to a central injection point). This additional cost, along with potential costs to bring the RNG product into spec, may become too high given the volume of RNG product being produced.

Oregon Department of Energy
SB 334 Barriers and Policy Comments
Cascade Natural Gas Corporation
August 13, 2018

Is production variation of RNG a barrier to developing RNG?

Yes. Consistency of the quality of RNG entering the pipeline is important for the health and safety of our customers and to ensure the reliability of the natural gas we deliver.

Is the OPUC regulation requiring the procurement of the least-cost resource by Oregon utilities a barrier to developing RNG?

Cascade supports regulation and policy that maintains the reliability and cost-effectiveness of the natural gas supplied to our customers. It will need to be determined from a regulatory standpoint if there is a method of valuation of RNG resources that captures additional value or benefits that would qualify it under least-cost procurement.

Is a lack of incentivization of biogas (or RNG) as a fuel under the Renewable Portfolio Standard a barrier to developing RNG?

Biogas and RNG should be recognized as a viable renewable energy source. However, supply and cost have not yet reached a point where it would be appropriate to mandate inclusion of this resource in an LDC's portfolio.

Are rigorous tariffs for RNG a barrier to developing RNG?

Rigorous, clearly articulated standards are important to maintaining the safety and reliability of the gas entering the pipeline. Therefore tariffs ensuring the quality of RNG should not be perceived as a barrier.

Are gas upgrading costs to remove impurities, and increase heat content of biogas, barriers to developing RNG?

As unrefined RNG starts with a very low heating value and is high in impurities, meeting pipeline quality standards is essential for RNG entering the system. Communication is essential to ensure that expectations are understood in advance so that costs can be managed.

Is the Energy Trust of Oregon encouraging biogas-to-electricity production projects rather than RNG fuel projects a barrier to developing RNG?

The Company encourages the Energy Trust of Oregon to continue its discussion on inclusion of RNG pilots in future program activities.

Is existing policy that prevents Oregon utilities from making ratepayer-funded capital investments in RNG infrastructure, such as extension of pipelines or connection points for RNG producers, as well as the requirement for Utilities to purchase the least cost resource, a barrier to developing RNG?

Policy supporting the recovery of cost-effective utility investments in RNG infrastructure would help support increased engagement and coordination on RNG activities between utilities and producers.

Is the low cost of cost differential between fossil natural gas and RNG a barrier to developing RNG?

Under the current valuation methodology applied to RNG, the cost differential between fossil and renewable natural gas does preclude RNG as a least cost resource from an LDC perspective.

Is a lack of natural gas fueling infrastructure a barrier to developing RNG?

Greater proliferation of grants and other incentives for natural gas fueling infrastructure would likely support the development of RNG.

drycreeklandfill.com

Recommendations for Advancement of RNG Projects

The Oregon legislature has been considering ways to reduce greenhouse gases (GHG) for some time now and during the 2013 legislative session passed Senate Bill (SB) 844. SB 844 allows the Oregon Public Utility Commission (PUC) to establish a program for utilities that furnish natural gas to propose projects that could reduce GHG gas emissions and provide benefits to their customers. This should include funding for connector pipelines that transport biogas and renewable natural gas (RNG) from often distant facilities to existing CNG pipelines. However, rules to implement this bill have not been written.

SB 334, passed during the 2017 legislative session, requires the Oregon Department of Energy (ODOE) to complete a detailed inventory related to biogas and RNG resources in the state. The bill directs ODOE to form an advisory committee to provide input on barriers for developing and utilizing biogas and RNG. The committee is requested to offer policy recommendations to promote RNG. This narrative is intended for that purpose.

We represent Dry Creek Landfill (DCL), a regional municipal solid waste landfill (MSW) landfill located outside of Medford, Oregon. Cells 2 through 7 at Dry Creek Landfill have been lined and have received municipal solid waste. The site development plan proposes an additional 14 cells. A total of 74 acres have been lined to date, with a permitted landfill footprint of 250 acres. Total remaining site life is approximately 100 years.

In 2007, DCL built a landfill gas to energy (GTE) facility that produces 3 MW of power that is put onto PacifiCorp’s grid. Unfortunately, the conductor sizing of PacifiCorp power line is insufficient to allow more power to be produced and put on the grid. The GTE plant now bums approximately 50% on the landfill gas captured at the site. The remaining gas is flared in enclosed flame flares. With a site that has the potential to produce gas for another 130+ years, it is essential that DCL find another beneficial use for our gas.

We believe that production of RNG is the best possible option. However, the barrier that DCL is facing is primarily an economic one. The cost of these facilities, when adding on the cost of a connecting pipeline, is enormous and prohibitive without legislative support.
The legislative support that we believe would encourage the advancement of RNG projects includes the following:

- Establish certain categorical environmental exemptions for MSW landfill's that produce
  RNG
    - Current language in proposed Cap and Invest legislation SB 1507 exempts closed MSW landfills from compliance with the bills' requirements
    - Active MSW landfills that currently have GTE facilities or RNG facilities should also be exempt
    - The MSW landfill's exemption should be conditioned upon the deployment of temporary plastic covers, which should be considered the Best Management Practices (BMPs) for all landfills
    - The MSW landfills must be required to capture and destroy landfill gas at a minimum 70% level
    - MSW landfills provide a significant role in protecting both public health and the environment, and should not be taxed for their efforts
    - Any tax on MSW landfills must be passed directly to their customers- the public
- Establish alternative fuel vehicle purchase requirements and incentives
    - Establish funding sources for building CNG fueling stations
    - Require all state vehicle fleet managers to purchase a certain percentage of new vehicles that run on CNG where fueling infrastructure is currently in place
    - Provide incentives for local colleges to provide CNG vehicle maintenance training
    - Provide funding for building or retrofitting state vehicle fleet maintenance facilities to service CNG vehicles
    - Provide grant funding to private fleet operators to offset the higher costs of purchasing CNG vehicles
- Establish a Renewal Portfolio Standard (RPS) for natural gas
    - Natural gas RPS could be modeled after the electricity RPS program
    - Under the program regulated gas utilities would be required to provide a certain percentage of RNG to their customers, increasing over time
    - The PUC would need to be on board with the RPS approach, as the gas utilities would need the ability to pass the added cost of purchasing RNG on to their customer base
    - The natural gas RPS would benefit the entire spectrum of natural gas uses, including heat, electricity and transportation

- Provide incentives to regulated gas utilities to participate with RNG project
- developers by offsetting the high cost of connecting RNG projects to pipelines with rate based financing- the intent of SB 844
- Create a credit marketplace consisting of Renewable Identification Numbers (RINs). RINs would be individual numbers for every gallon or gallon-equivalent of RNG sold that displaces fossil natural gas with RNG

- Establish grant and loan programs and other financial incentives for RNG project development
    - Open ODOE's Renewal Energy Development (RED) grant program to RNG projects
    - Increase the total allocable RED grant funding and project specific maximum grant funds significantly to support RNG projects
    - Fund ODOE's Small-Scale Local Energy Loan Program (SELP). Currently SELP is not accepting new applications. Like the RED program, loan funding and project specific maximum loan funds need to be significantly increased to support RNG projects
    - Local property tax exemptions should be considered for RNG project infrastructure

Special thanks go to the Washington State University Energy Program. Their publication "Harnessing Renewable Natural Gas for Low-Carbon Fuel: A roadmap for Washington State" (December 2017) was very insightful and educational. Some of their thoughts were used herein.

March 27, 2018

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The following document constitutes NWGA's comments regarding ODOE's SB 334 Barriers Importance Study. NWGA's comments represent the views of NWGA's LDC members with service territory in the State of Oregon. This includes Avista Utilities, Cascade Natural Gas, and NW Natural Gas. Please contact Connor Reiten at creiten@nwga.org with any questions.

Finance Barriers:

We agree with previous group discussion stating that access to financing is one of the primary economic barriers to RNG proliferation. Primarily, what makes financing so difficult is:

- Real and perceived risks related to revenue streams tied to low-carbon/renewable fuel programs that are volatile and subject to ongoing regulatory and public policy risk
- No long-term ability to hedge the cost of RNG production (e.g., by being able to enter long-term offtake arrangements with gas utilities or major gas consumers)

Information Barriers:

During discussions with the SB 334 Advisory Group, a concern has surfaced regarding the utilities' role as interconnection gatekeepers.

It is important to remember that the distribution system is funded by customers, and that utilities are obligated to maintain its safety and reliability. Therefore, utilities must ensure an appropriate balance of volume and demand can be maintained when placing RNG on the system. Additionally, it is imperative and incumbent on the utilities to ensure appropriate standards are in place that will protect customer health and the integrity of the distribution system. Policy needs to take into consideration the liability and risks associated with accepting RNG onto the system, thus maintaining strong, clearly understood standards. The utilities welcome the opportunity to have earnest discussions with developers and pipeline companies to identify ways to bring more RNG systems online while maintaining safety and reliability. This means exploring whether there are components of such standards upon which we can all agree. There is also an opportunity to gain greater familiarity with the risks and benefits of various feedstocks and biomass technologies, paired with the purpose behind the individual elements of current pipeline specifications.

Market Barriers:

The utilities agree that lack of clarity on future price/market stability of various credits is a barrier to the development of RNG.

In the short term, we agree that a lack of CNG vehicles and fueling infrastructure is also a barrier. Additional incentives are needed to support natural gas fueling infrastructure. This is relevant to short-term market fundamentals facing RNG rather than longer term ones. For RNG to truly thrive as an industry, it will need to be supported by demand beyond the vehicle market, especially as those vehicle markets reach RNG saturation (as is becoming the case in California).

Over the long term, the differential between the cost of conventional gas and the cost of RNG is our #1 market barrier. Regulated utilities in Oregon cannot currently purchase gas that is more expensive than our least expensive gas, which is conventional gas. Additionally, current policy does not fully reflect the “best and highest use” of renewable natural gas. Preliminary policy tends to tilt toward the vehicle market, rather than the direct-use of natural gas (such as the use of natural gas for furnaces, water heaters, etc.) Both are important to the proliferation and maturation of the RNG market. Additionally, policy tilted solely to vehicle usage could result in the lockout of RNG supplies to utilities for sale to end-use customers or for use as a supply stream for the purpose of decarbonization of the natural gas system.

- There is a disconnect between consumer interest and the value RNG can command in the market. For instance, while there is a high policy-driven market value for RNG that is used in a vehicle, there is very little market value (e.g., revenue potential) for that same RNG used for direct-use, such as in a furnace. This means that certain analyses will find that RNG’s “highest and best use” is in a vehicle, due only to the existence of a particular policy that favors it going into vehicles. This market construct does not reflect the benefits of RNG going into a furnace or hot water heater.

Policy Barriers:

We agree that an inability to make ratepayer-funded capital investments in all aspects of RNG, including basic interconnection of existing RNG systems, is a major barrier. While many RNG projects would offer customers significant emissions reductions; stimulate local economic development; and support local energy resources; we cannot currently make any investment in RNG project components because RNG does not constitute the “least cost” resource that we must procure. OR SB 844 attempts to incentivize utilities and create a pathway to investment recovery, but doesn’t go far enough as a mechanism to allow the PUC to give “pre-approval,” which is important because RNG projects have a long germination period. Further, moving a project through the SB 844 process has significant transaction costs, and customers might be better served by policy that gives clearer high-level guidance on RNG projects and does not require customized project-by-project analysis of each RNG opportunity.

Another highly ranked barrier for us is the fact that biogas-focused incentives and services in Oregon are available only for projects generating electricity. This is true both for the Energy Trust of Oregon's incentives and services, as well as the recently announced round of ODOE's Renewable Energy Development Grant program. Even though there are many good projects that could produce RNG for direct use, the above-mentioned incentive programs are only available to projects that use RNG for electric generation. This is a major barrier that fails to maximize the use of renewable energy (both gas and electric) within our economy by not promoting the most efficient use of RNG. Significantly, the Energy Trust of Oregon has a long history of providing high-value early-stage feasibility assessments for a variety of technologies, and those capabilities and services are greatly needed by facilities considering whether RNG is a viable path forward. The utilities appreciate preliminary conversations that have taken place with the Energy Trust regarding consideration of RNG market development for direct-use, and encourage continued consideration and regulatory support for this direction.

Finally, while there is a state-level incentive program focused in part on growing the supply of RNG in Oregon (the Clean Fuels Program), there is no complementary policy to encourage demand of that fuel, such as policies designed to encourage CNG vehicle adoption. We believe this is also a highly-ranked policy barrier.

Regulatory Barriers:

RNG is not currently prioritized for its direct use value from a regulatory standpoint. Clear guidance is required regarding the Commission's guidance or authority to approve the purchase of RNG for delivery to residential and commercial end-use customers. This regulatory policy might take a variety of forms including Commission authority to approve (as in the case with low income bill pay assistance programs), an allowance for RNG purchases under a set price cap, or other legislative or regulatory policy options.

Other Barriers:

In general, we believe the proximity to tie-in points can be one of the more challenging of the barriers listed in this section. There are proposals under consideration in Oregon to move RNG via truck to an interconnection point. This model will increase costs of interconnection but may be one way around this barrier.

<u>Re: adjacency study</u>:

After some discussion, the utilities have concluded that a simple analysis of how far a project is from the gas system is insufficient to making a first-cut determination of whether an RNG project is economically viable. This is because, while a project may be located close to a natural gas utility line, the volume and other characteristics of the gas generated by the RNG plant may not be well-suited to the size, pressure, and design of the nearby pipe. To make a first-cut assessment of whether nearby pipes are well-suited to interconnection of a particular project, the following items must be assessed:

- For the RNG project:
  - Volume of gas generated per minute
  - Seasonal performance characteristics
  - Potential future volume (e.g., as at a wastewater treatment plant with a new input of organic wastes)
- For the adjacent pipeline:
  - Size
  - Pressure
  - Direction of gas flow in different seasons

And while this analysis will be important for determining if a project can physically and economically interconnect with the natural gas infrastructure, it may not be critical in determining the “technical potential” for RNG in the state. There are proposals within Oregon that would involve trucking RNG to a point of interconnect, suggesting that pipeline adjacency may not be a critical barrier and should not be used to limit the overall technical potential within the state.

APPENDIX D: BIOGAS PRODUCTION PATHWAY METHODOLOGIES

Agricultural Residuals Methodology

Overview: Agricultural residuals were analyzed at the county level using county crop harvest data for wheat, grass seed, and grain corn. Wheat was analyzed for its wheat straw byproduct, grass seed for its grass seed straw byproduct, and grain corn for its corn stover byproduct. Wheat straw and grass seed straw were both analyzed because other large acreage produced. Grain corn on the other hand was analyzed due to its high residual production rate per acre planted rather than total acres planted.

Data for the number of acres harvested was collected from the USDA Census of Agriculture for the most recent year data was available, 2012, for each crop type at the county level (United States Department of Agriculture 2012). Oregon Agripedia 2017 was not consulted due to a lack of county scale data. Outside literature was consulted in order to analyze residual production from these crop types as Oregon Agripedia 2017 data did not portray the amount of residuals produced from each crop.

Information Required for Analysis:

- **Acres Planted:** number of acres planted for each crop type
- **Conversion Rate:** number of Bone Dry Tons (BDT) of residuals produced per acre planted for each crop type
- **Energy Content:** number of Btu's per BDT for each crop type *(or Btu/lb * 2,000)*
- **Recovery Rate:** the *percentage* of residuals recovered from the field during or after harvest
- **Methane Conversion:** the energy content (Btu's) of one cubic foot of methane

Assumptions					
Crop Type	Acres Harvested	Conversion Factor	Recovery Rate	British Thermal Units *(Btu's/BDT)*	Energy Content of Methane *(Btu/1ft³ CH_4)*
Wheat (Straw)	905,362	2.3	0.5	15,420,000	1,027
Grain Corn (Stover)	51,178	4	0.5	15,920,000	1,027
Total Grass Seed	445,637	2.1	0.5	12,000,000	1,027

Equation: Theoretical Annual Cubic Feet of Methane Potential

$$\frac{[(\textit{Number of Acres Harvested} * (\textit{Btu per Acre} * \textit{Recovery Rate})\ x\ (\textit{Btu per lb} * 2{,}000)]}{1027\ \textit{Btu}} = \textit{theoretical annual } ft^3 \textit{ of } CH_4$$

Example: Wheat Straw Methane Potential
$\frac{[(905{,}362 * (2.3 * 0.5) * (7{,}710 * 2{,}000)]}{1027}$ ***= 15,632,701,408 ft³ of CH₄ annually***

Analysis: The number of acres harvested per crop type was multiplied by the respective rate of crop residue production per acre. The resulting figure was the total tons of bone dry residuals for each crop type, per acre, and at the county scale. These three numbers were then multiplied by the number of Btu's per ton of bone dry residual for their respective crop type. The final figures for each crop type were divided by 1,027 BTU's to reach a theoretical cubic foot of methane value for each crop type (Hofstrand 2014, 1).

Agricultural Residual Methodology References: The rate of BDT/acre produced for crop type was sourced from Manitoba Agriculture's Agriculture: Corn Stover and Silage for Corn Stover and also mentioned a cap of 4 BDT/acre planted for yields over 140+ bushels per acre; Oregon's yield for 2017 was 230 bushels per acre according to Oregon Agripedia 2017 (Manitoba Agriculture n.d., 1) (Oregon Department of Agriculture 2017, 3). The National Renewable Energy Laboratory's (NREL) An Evaluation of the Potential for Ethanol Production in Oregon Using Cellulose-Based Feedstocks was used for grass seed straw and wheat straw (Graf & Koehler 2000, 11). A recovery rate of 50% for residuals was sourced from *Potential Production of Methane from Canadian Wastes* (Abboud et al. 2010).

The energy content per pound of residuals was sourced from the Ontario Ministry of Agriculture, Food, and Rural Affairs' *Biomass Burn Characteristics* for both corn stover and wheat straw, while the NREL study *Potential for on-Farm Conversion of Straw to Bioenergy in Seed Producing Operations* was consulted for the energy content of grass seed straw (Clarke & Preto 2011, 1) (Banowetz, Steiner, Boateng & El-Nashaar 2005, 75). The number of BTUs in a cubic foot of methane was sourced from the Iowa State University Extension and Outreach's *Natural Gas and Coal Measurements and Conversions* (Hofstrand 2014, 1).

References

- **Corn Stover Residual Rate Reference:** Manitoba Agriculture. (n.d.). Corn Stover and Silage. Retrieved from https://www.gov.mb.ca/agriculture/crops/production/grain-corn/corn-stover-and-silage.html
- **Wheat Straw Residual Rate Reference:** Graf, Angela, and Tom Koehler. 2000. "An Evaluation of the Potential for Ethanol Production in Oregon Using Cellulose-Based Feedstocks." *Oregon Cellulose-Ethanol Study*, no. June: 1–36. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:An+evaluation+of+the+potential+for+ethanol+production+in+Oregon+using+cellulose-based+feedstocks#1.
- **Grass Seed Residual Rate Reference:** Graf, Angela, and Tom Koehler. 2000. "An Evaluation of the Potential for Ethanol Production in Oregon Using Cellulose-Based Feedstocks." *Oregon Cellulose-Ethanol Study*, no. June: 1–36.

http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:An+evaluation+of+the+potential+for+ethanol+production+in+Oregon+using+cellulose-based+feedstocks#1.

- **Average Corn Bushel Yield Data Reference:** Oregon Department of Agriculture. (2017). Oregon Agripedia, 2017 Editi, 228.
- **County Grass Seed Data Reference:** United States Department of Agriculture. 2012. "Census of Agriculture." http://quickstats.nass.usda.gov/?source_desc=CENSUS.
- **BTU Content for Corn Stover & Wheat Straw:** Clarke, S., & Preto, F. (2011). Biomass Burn Characteristics. Ontario Ministry of Agriculture, Food, and Rural Affairs. Retrieved from http://www.omafra.gov.on.ca/english/engineer/facts/11-033.htm
- **BTU Content of Methane:** Hofstrand, Don. 2014. "Natural Gas and Coal Measurements and Conversions." Iowa State University Extension and Outreach. 2014.
- **Grass Seed Btu Content:** Banowetz, GM, JJ Steiner, A Boateng, and H. El-Nashaar. 2005. "Potential for on-Farm Conversion of Straw to Bioenergy in Seed Producing Operations." *Seed Production Research at Oregon State University, USDA-ARS Cooperating. Ext/CrS* 124: 75–78. http://cropandsoil.oregonstate.edu/seed-ext/Pub/2004/30.pdf.
    - Abboud, Salim, Kevin Aschim, Brennan Bagdan, Partha Sarkar, Hongqi Yuan, Brent Scorfield, Christian Felske, Shahrzad Rahbar, and Louis Marmen. 2010. "Potential Production of Methane from Canadian Wastes." ResearchGate.

Animal Manure Methodology

Overview: Confined Animal Feed Operations (CAFOs) were analyzed on a site-by-site basis and aggregated at the county level in summary tables and maps. CAFOs were considered for their RNG potential because of their ability to capture manure in large quantities. Grazing operations were excluded due to poor manure capturability. The goal of this analysis was to portray the county-scale RNG potential of animal manures for Oregon's largest CAFO types: dairy cows, beef cows, and poultry in broilers and layers. These operations were analyzed using data and methods which were sourced and developed in close coordination with the Oregon Department of Agriculture (ODA).

Dairy CAFOs: The largest potential came from Dairy CAFOs. This CAFO type required the most detail l of the four CAFO animal manure types due to cow management and cow variety. The ODA and ODOE separated the 244 Dairy CAFOs into three regions; Coastal, (Willamette) Valley, and East. The CAFOs were further separated into three size categories based on herd counts, being Large (700+), Medium (200-699) and Small (<200). The ODA provided spatial and on-farm data for individual CAFOs. This information detailed a breakdown of three dairy cow types: milking cows, dry cows, and heifers as these subsets of dairy cows varied in weight, manure and volatile solids production. ODA also supplied state-specific typical animal masses (TAMs) for the three dairy cow types so Oregon-unique animal units (AU) could be developed.

Collaborative efforts also created a manure capture rate for Dairy CAFOs in order to account for the widespread variability in climate, number of Dairy CAFOs, and consequent variability in manure capturability. The rate took into account the total number of days a Dairy CAFO grazed its cows to account for the number of days manure was deemed uncapturable. This number of days was subtracted from the total number of days in a year (365), with the resulting number being divided by 365 to provide the final rate of manure capture.

Equation: Manure Capture Rate
$((Days\ in\ One\ Year - Days\ Grazed)/365)$ = ***Manure Capture Rate***
Example: Manure Capture Rate
$((365 - 125)/365)$ = ***65.76% Manure Capture Rate***

This rate details the number of days dairy cows were housed on a surface which could support manure recovery, as well as the life stage of the dairy cows (i.e. cows being milked, dry cows and heifers. Calves were not included in the analysis by ODA and ODOE).

Beef & Poultry CAFOs: Oregon-specific values for the TAM of Beef, Broilers and Layers (Poultry) were provided by ODA. These CAFOs were likewise divided into categories of Coastal, Valley, or East.

Information Required for Analysis:

- **Animal Type:** type of animal manure being analyzed
- **Animal Unit (AU):** typical animal mass in pounds divided by 1,000. Poultry are calculated by dividing 1,000 by the weight of the Broiler or Layer.
- **Manure Production Rate:** gross production rate in pounds per animal unit
- **Volatile Solids (VS) Production Rate:** gross production rate in pounds per animal unit
- **Capture Rate:** an industry-specific rate which, in this case, was derived from ODA surveys of CAFO operators
- **Methane Potential:** theoretical methane potential per pound of volatile solids

Assumptions					
Animal Type	**Typical Animal Mass** *(TAM in lbs)*	**Manure rate** *(lbs Manure/AU)*	**Volatile Solids Rate** *(lbs VS/AU)*	**Capture Rate**	**Methane Potential** *(ft^3 CH_4 per lb VS)*
Dairy: ➢ Milk Cow ➢ Dry Cow ➢ Heifer	 1,250 1,250 970	 108 51 56	 11 11 11	*Varies by Dairy CAFO*	3.84 ***(Dairy)***
Beef	1,400	63.9	640	100%	5.29
Broiler	2.6	88	17	100%	4.81
Layer	3	57	11	100%	5.45

Equation: Theoretical Annual Cubic Feet of RNG from Capturable Volatile Solids

Animal Units = $\frac{(\boldsymbol{Typical\ Animal\ Mass\ x\ Herd\ Size})}{\mathbf{1{,}000}}$

Annual Manure Production = $(((\boldsymbol{AU} * \boldsymbol{Manure\ Rate}) * \boldsymbol{Capture\ Rate}) * \mathbf{365})$

Annual Volatile Solids Production & Methane Potential = $((\boldsymbol{AU} * \boldsymbol{Pounds\ VS} * \boldsymbol{Recovery\ Rate}) * \boldsymbol{Methane\ Potential}) * \mathbf{365}$

Example: Dairy (Milk Cows)

Animal Units = $\frac{\mathbf{1250*578)}}{\mathbf{1{,}000}}$ **= 722.5 AU**

Manure Production = $((\mathbf{722.5} * \mathbf{108}) * \mathbf{0.71}) * \mathbf{365}$ ***= 20,221,474.5 lbs manure capturable annually***

Volatile Solids Production & Methane Potential = $(\mathbf{722.5} * \mathbf{11} * \mathbf{0.71}) * \mathbf{3.84}) * \mathbf{365}$ ***= 7,908,843.36 ft^3 CH_4 annually***

Analysis: The fourth chapter of the USDA Agricultural Waste Management Field Handbook as well as Discussion 7 of the *EPA States Workbook* were employed for the analysis of RNG potential from Oregon CAFOs for each animal type: Dairy Cows, Beef Cows, and Broilers and Layers for Poultry (USDA 2008), (EPA 1992). All Volatile Solids (VS) Production rates, Manure Production rates, Animal Units, were sourced from the *USDA Agricultural Waste Management Field Handbook* for Dairy Cows, Beef Cows, and Poultry (USDA 2008, 4-13), (USDA 2008, 4-16), (USDA 2008, 4-20). The Volatile Solids (VS) Production rate and the Methane Potential for each animal type were sourced from the *EPA States Workbook* (EPA 1992, D7-8), (EPA 1992, D7-7).

The AUs were first calculated by multiplying the number of head in the herd by their TAMs, provided by ODA, and dividing this product by 1,000.

For manure production, the AU of the heard was then applied to the manure production rate, the manure capture rate, and the number of days in a year for the respective animal type. For methane potential, the AU of the heard was then applied to the volatile solids production rate, the manure capture rate, the methane potential of the animal type, and the number of days in a year.

References

1. EPA. 1992. "EPA State Workbook: Methodologies For Estimating Greenhouse Gas Emissions," 1–344.
    a. **Citation for VS Production:** (EPA 1992, D7-8)
    b. **Citation for CH4 Production**: (EPA 1992, D7-7)
2. USDA. 2008. "Part 651 Handbook Chapter 4 Agricultural Waste Characteristics." *Waste Management*, no. March.
    a. **VS, AU, Manure Figures**
        i. **Dairy** (USDA 2008, 4-13)
        ii. **Beef VS, AU, Manure Figures:** (USDA 2008, 4-16)
        iii. **Poultry VS, AU, Manure Figures:** (USDA 2008, 4-20)

Food Waste Methodology

Overview: Food wastes were analyzed at the county scale for their RNG potential using data provided by the Oregon Department of Environmental Quality (ODEQ). The original data was portrayed in waste sheds, with all counties being considered waste sheds except for Metro and Milton-Freewater. These outliers were divided by the number of counties they spanned, in the case of Metro, or added to their county's prior total, in the case of Milton-Freewater. Data was provided in three categories: Disposed, Recovered or Generated. Only food waste classified as Recovered was used to estimate methane potential as summing all three would involve double-counting the methane potential of food waste which was already sent to landfills.

Information Required for Analysis:

- **Recovered Food Waste:** amount of food waste diverted and recovered from municipal solid waste (MSW)
- **Methane Potential:** standard cubic feet of methane possible from one wet ton of food waste

Assumptions	
Methane Potential	**3,300 ft^3 Methane/1 wet ton of food waste**

Equation: Theoretical Annual Cubic Feet of Methane Potential
$(\boldsymbol{Wet\ Tons\ of\ Food\ Waste * Methane\ Potential})$ = theoretical annual ft^3 CH_4 potential
Example: Benton County Food Waste Methane Potential
$(\mathbf{459 * 3,300})$ = 1,515,409.50 ft^3 CH_4 annually

Analysis: The number wet tons of food waste Recovered for each county was multiplied by 3,300 cubic feet of methane – a rate sourced from (Suto, Peck and Gray 2008, 33). The final figure is representative of the theoretical RNG potential in annual standard cubic feet of methane for all food waste classified as Recovered in the State of Oregon.

References

1. **Conversion Reference:** (Suto, Peck and Gray 2008, 33)
    a. Suto, Paul, Cara Peck, and Donald Gray. 2008. "Anaerobic Digestion of Food Waste." *USEPA No. EPA-R9-WST-06*, no. March. http://www.epa.gov/Region09/organics/ad/EBMUDFinalReport.pdf.
2. Blatt, Elaine. 2017. "Oregon Strategic Plan for Preventing the Wasting of Food."
3. Xu, Fuqing, Yangyang Li, Xumeng Ge, Liangcheng Yang, and Yebo Li. 2018. "Anaerobic Digestion of Food Waste – Challenges and Opportunities." *Bioresource Technology* 247 (July 2017): 1047–58. https://doi.org/10.1016/j.biortech.2017.09.020.

Forest Residuals Methodology

Overview: Forest harvest residuals were analyzed at the county scale using commercial timber harvest data collected by the Oregon Department of Forestry (ODF). Harvest data was broken out by county but was separated by geographic region during the analysis due to differences in tree species, with west of the Cascade (Mountain) Range and east of the Cascade Range being the two regions. The predominant tree type west of the Cascades is the Douglas Fir while the Ponderosa Pine dominates slopes east of the Cascades. Each species has a different energy content, expressed in British Thermal Units (Btu), and it was assumed for this analysis that all trees harvested in counties west of the Cascades were Douglas Fir and all trees harvested in counties east of the Cascades were Ponderosa Pine.

A review of literature determined the average Btu values for the potential residual parts of the trees, tops and branches, which would be the primary source of feedstock material. After further conversation with ODF and consultation of literature (Howard, 1988 4, Simmons et al, 2016), it was determined that for every 1,000 board feet harvested between 1.6 and 2 tons of wet timber residuals are generated. We applied a 50% Recovery Rate to determine the base amount of feedstock and converted the wet green tons to bone dry tons based on (Glass et al 2010). Finally we took the average yearly harvest value from 2010 to 2016 for each county.

Information Required for Analysis:

- **Commercial Harvest Volume:** total volume of timber harvested for commercial purposes (excludes forest restoration)
- **Residual Production Rate:** amount of residuals in bone dry tons (BDT) produced per million board-foot (MBF) of timber harvested
- **Tree Type Energy Content:** number of British Thermal Units (Btu's) per Bone Dry Ton (BDT)
- **Thermal Gasification Conversion Rate:** conversion of bone dry tons (BDT) timber residual energy content to cubic feet of methane
- **Methane Conversion:** the energy content (Btu's) of one cubic foot of methane

Assumptions					
Tree Type	**Residual Production Rate** *(Green Ton/MBF)*	**Recovery Rate**	**Bone Dry Material Content**	**Energy Content** *(Btu/BDT)*	**Thermal Gasification Conversion to Methane** *(Btu/1ft^3 CH_4)*
Douglas Fir	1.6	50%	63%	9,000,000,000	990.1
Ponderosa Pine	1.6	50%	60%	9,000,000,000	990.1

Equation: Theoretical Annual Cubic Feet of Methane Potential

$$\left[\left(\left((MBF\ Harvested * Residual\ Production\ Rate) * Recovery\ Rate\right) * Dry\ Material\ Content\right) * Energy\ Content\right] * TG\ Conversion\ to\ Methane = \text{theoretical annual } ft^3 \text{ of } CH_4$$

Example: Baker County Methane Potential

$$\left[\left(\left((24,931 * 1.6) * 0.5\right) * .63\right) * 9\right] * 990.1 = 106,635,564 \text{ theoretical annual } ft^3 \text{ of } CH_4$$

Analysis: The amount of timber harvested in commercial operations for the years 2010 through 2016 was provided by ODF (Oregon Department of Forestry 2018). The residual production rate of 1.6 green tons per 1,000 Board Feet was located in the *Green Ton Converter* (Forest Operations Research Unit, US Forest Service, and Forest Business Network. n.d.). A recovery rate of 50% was applied using industry and inter-agency knowledge, while the moisture content (Bone Dry Material Content) was sourced from the *Wood Handbook: Wood as an Engineering Material* and the energy content of residuals from the *Energy Values for Whole Trees and Crowns of Selected Species* (USDA, US Forest Service, and Forest Products Laboratory 2010, 4-2), (Howard 1988, 4). Conversion to methane estimates for thermal gasification Conversion to Methane was produced through discussions with NW Natural Scientist Chris Galati.

Methane potential from commercial forest harvesting residuals are estimated by multiplying the Residual Production Rate of 1.6 by the total commercial forest harvest for a given year, expressed in Million Board Feet. This figure is then multiplied by the Recovery Rate of 50% and subsequently by the Bone Dry Material Content of the tree species, which itself is the difference between 100% and the Moisture Content percentage for the tree species. The final figure is then multiplied against the Energy Content of the tree, which in this case is 9, and by the Thermal Gasification Conversion to Methane rate in order to arrive at the theoretical annual cubic feet of methane potential for commercial timber harvest residuals.

References:

- **Conversion of Green Tons to Bone Dry Tons:** (Forest Operations Research Unit, US Forest Service, and Forest Business Network. n.d.)
  - Forest Operations Research Unit, US Forest Service, and Forest Business Network. n.d. "Green Ton Converter." https://www.forestbusinessnetwork.com/green-ton-converter/.
- **Average Moisture Content of Green Wood:** (USDA, US Forest Service, and Forest Products Laboratory 2010, 4-2)
  - USDA, US Forest Service, and Forest Products Laboratory. 2010. "Wood Handbook : Wood as an Engineering Material." https://doi.org/10.2737/FPL-GTR-190.
- **Energy Values of Whole Trees/Crowns:** (Howard 1988, 4)
  - Howard, James O. 1988. "Energy Values for Whole Trees and Crowns of Selected Species." Forestry Sciences.
- **Conversion of BDT to MMBTU:** (NW Natural Scientist Chris Galati)
- **Timber Harvest Data:** (Oregon Department of Forestry 2018)
  - Oregon Department of Forestry. 2018. "Timber Harvest Data 1942-2016." 2018. https://data.oregon.gov/Natural-Resources/Timber-Harvest-Data-1942-2016/9cuv-nijj.

Landfill Methodology

Overview: Landfills were analyzed for their modeled methane potential as well as their annual metered methane data on a site-specific basis and aggregated at the county level in summary tables and maps. The goal of these analyses was to provide theoretical-modeled and actual-reported metered datasets.

Modeled: The Oregon Department of Environmental Quality (ODEQ) Solid Waste Management Program provided data for modeled values of methane as carbon-dioxide-equivalent gas generation, oxidation, and emissions. The reported ODEQ data was converted from carbon dioxide to methane using the US EPA's definition of methane's warming potential as a greenhouse gas, being 25 times that of carbon dioxide's on a pound-for-pound 100-year basis (EPA 2015). This is also the IPCC AR rate (United Nations IPCC 2007, 2.10.2). This figure was then converted from metric tonnes, to British Thermal Units, and then to cubic feet of methane.

Reported: The second data set is composed of information collected by ODOE staff via a written survey along with written and oral follow-up interviews with all 13 landfill operators. This data provides an additional on-the-ground perspective of biogas and methane potential in comparison to the modeled data developed by ODEQ. It is important to remember the survey-generated dataset does not take into account all variables in considering the methane potential of these landfills, such as generation, oxidation and emission (as was done in the ODEQ model). Additionally, this data hinges on the efficiency of landfill gas collection systems and the accuracy of gas metering systems.

Information Required for Analysis:

Generation: total amount of gas generated from the anaerobic decomposition of waste in place within the landfill

- **Oxidation:** a portion of the total generated methane which, upon migrating to the upper biologic layer of the landfill, reacts to form other gases
- **Emission:** a portion of the total generated methane which migrates out of the landfill and escapes to the atmosphere
- **Collection:** assumed to be collected by the landfill's collection system and is calculated by subtracting the total generated methane from the sum of the oxidized and emitted methane.

Equation: Modeled Annual Metric Tonnes of Methane Potential
$(\boldsymbol{Generation} - (\boldsymbol{Oxidation} + \boldsymbol{Emissions})$ = **Collected Annual Metric Tonnes CH_4 Potential**
Example: Rossman's Landfill Methane Potential
$(\mathbf{2,102} - (\mathbf{210} + \mathbf{1,892})$ = **0 Collected Annual Metric Tonnes CH_4 Potential**

Analysis: The modeled data was summed using the above formula. A methane content of 50% and 55% was applied to the *reported* data to portray a final RNG potential.

References

1. **Methane Warming Potential:** (EPA 2015)
    a. EPA. 2015. "Methane Emissions." Greenhouse Gas Emissions. 2015. https://www.epa.gov/ghgemissions/overview-greenhouse-gases.
2. **Methane Warming Potential** (United Nations IPCC 2007, 2.10.2)
    a. United Nations Intergovernmental Panel on Climate Change. 2007. "Climate Change 2007: Working Group I: The Physical Science Basis." Fourth Assessment Report. 2007. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html.

Wastewater Treatment Plant Methodology

Overview: Wastewater treatments plants (WWTPs) across Oregon were analyzed on a plant-by-plant basis and their RNG potentials aggregated at the county level in summary tables and maps. The goal of these analyses was to determine a metered value as reported by plants as well as a calculated value derived from plant-based inputs to produce a theoretical biogas value. The rationale for two methods is as follows: the advisory committee and other industry stakeholders informed ODOE of inaccuracies associated with metering biogas. Therefore, it was important to account for this possibility with a theoretical value for comparison. The penultimate goal was to describe the on-the-ground biogas production potential as well as the theoretical production potential.

Plants were initially selected for their amount of inflow, with a lower boundary was set at one-million gallons of inflow. A small number of plants near this boundary, such as those with 800,000 or 900,000 gallons of daily inflow. Primary plant information included name, geographic coordinates, and county location information and was collected from two sources: the US EPA Clean Watershed Needs Survey and the Oregon Department of Environmental Quality's National Pollutant Discharge Elimination System (NPDES) database (US EPA 2012), (ODEQ n.d.). These plants were then surveyed in order to determine their *metered* and *calculated* biogas potentials.

Plant Operator Survey: The plant operator survey was developed in close coordination between the ODOE and The Oregon Association of Clean Water Agencies (ORACWA). The survey covered several pieces of information required for the two separate analyses: the *metered* and *calculated* biogas values.

> **Calculated Method**: It was determined through close coordination with ORACWA that biogas potential from WWTPs is dependent upon the amount of volatile solids present in the wastewater. Therefore, it was important to understand the amount of volatile solids processed by plants to arrive at a calculated biogas figure.
>
> The calculated method required questions concerning specific plant details, such as the total solids loading to solids stabilization process in dry tons (DT) annually, percentage of solids which are primary, percentage of solids which are secondary/waste-activated-sludge, and the total percentage of solids destroyed in the plant's anaerobic digester(s). ORACWA provided the biogas production rate of 30,000 ft^3 biogas/DT volatile solids.
>
> **Metered Method:** These values were derived from survey responses concerning plant's amount of metered biogas in standard cubic feet, annually.
>
> **Data Limitations:** Some plants could not provide information at the level of detail required by the survey. A final method was introduced to fill these holes. While the survey also asked of plant's their biogas methane content this value was seldom included in survey responses and a methane content of 60% was used instead.

Per Capita Method: A third method was employed due to incomplete survey responses. This method developed an annual per capita biogas production rate for Oregon WWTPs which was then applied to all plants included within the one-million gallons of daily flow boundary. The per capita biogas production rate was developed using the largest plants in the state, which serviced over 50,000 people. Plants above this threshold were contacted to determine their service area population.

> **Data Limitations:** Corvallis and Albany-Millersburg were not contacted and the population of Albany and Millersburg was summed. Portland State University (PSU) Certified Population Estimates for July 1 were used in place of this information for these plants. In developing per capita biogas production rates for the *metered* and *calculated* values, *calculated* data was not available for the plants in the cities of Salem and Medford, while *metered* data was not available for the City of Medford. These plants were not factored into the creation of a per capita biogas production rate.

The largest plants' data for *metered* and *calculated* biogas production rates were summed together for their respective classes, either *metered* or *calculated*. The separately-summed values for *metered* and *calculated* data were then divided by the collected population data for the largest plants. These rates were then averaged to produce per capita *metered* and a per capita *calculated* values. The two values were applied to the plants assessed in the prior analyses to provide both *calculated* and *metered* values.

Information Required for Analysis:

- **Primary Solids Loading:** amount of dry tons (DT) of solids sent to primary process annually
- **Secondary Solids Loading:** amount of bone dry tons (DT) of solids sent to secondary process annually
- **Primary Volatile Solids (pVS) Content:** percentage of primary solids sent to digester which are volatile solids
- **Secondary Volatile Solids (sVS) Content:** percentage of secondary solids sent to digester which are volatile solids
- **Volatile Solids (VS) Destruction Rate:** percentage of volatile solids destroyed in solids stabilization processes or anaerobic digester(s)
- **Biogas Production Rate:** standard cubic feet of biogas produced per dry ton (DT) of volatile solids destroyed in anaerobic digester(s)
- **Population Served by Plant:** number of people receiving service from a wastewater treatment plant

Assumptions	
Biogas Production Rate	**30,000 ft^3 biogas/1 dry ton volatile solids destroyed** *(15 scf/lb VS * 2,000lbs/DT)*

Equation: Theoretical Annual Cubic Feet of Biogas Potential

$$\left(\left((\boldsymbol{BDT\ Primary\ Solids} * \boldsymbol{pVS\ Content}) + (\boldsymbol{BDT\ Secondary\ Solids} * \boldsymbol{sVS\ Content})\right) * \boldsymbol{VS\ Destruction}\right) * \mathbf{30,000}\boldsymbol{scf}$$

= theoretical annual ft^3 of biogas

Example: City of Roseburg

$$\left(\left((\mathbf{107.45} * \mathbf{0.88}) + (\mathbf{199.55} * \mathbf{0.86})\right) * \mathbf{0.55}\right) * \mathbf{30,000}\ \boldsymbol{scf}$$ ***= 4,391,755.50 ft^3 biogas annually***

Analysis: The number of people serviced by each WWTP was multiplied by the average per capita biogas production values for *calculated* and *metered* to arrive at per capita *metered* and per capita *calculated* biogas production potentials for each plant. These data sets provide the most accurate representation of the State's wastewater treatment plant sector RNG potential using the most current and available data. The population data was derived from contacting the largest plants and was augmented at times using PSU Certified Population Estimates for July 1 – the most current year data was available (PSU 2017). For smaller plants, population data from the same PSU source was employed.

References

- **Oregon Population Data Reference:** (PSU 2017)
  - Portland State University. 2017. "Certified Population Estimates, July 1, 2017." https://www.pdx.edu/prc/population-reports-estimates.
- **Rate for Biogas Generation Reference:** (Water Environment Federation; American Society of Civil Engineers; Environmental and Water Resources Institute 2009)
  - Water Environment Federation; American Society of Civil Engineers; Environmental and Water Resources Institute (2009) Design of Municipal Wastewater Treatment Plants, 5th Edition; WEF Manual of Practice No. 8; ASCE Manuals and Reports on Engineering Practice No. 76; McGraw-Hill: New York.
- **Rate for Biogas Generation Reference:** (Metcalf and Eddy, Inc. 2003)
  - Metcalf and Eddy, Inc. (2003) Wastewater Engineering: Treatment and Reuse, 4th Edition; Tchobanoglous, G., Ed; McGraw-Hill: New York.
  - 30,000ft^3/ton VS destroyed referred by OR ACWA
- **Data Source:** (US EPA 2012) ; (ODEQ n.d.)
  - US EPA. 2012. "CWNS 2012 Data and Reports." Clean Watersheds Needs Survey. 2012. https://ofmpub.epa.gov/apex/cwns2012/f?p=134:4::::RP.
  - Oregon Department of Environmental Quality. n.d. "Water Quality Permitted Facilities." https://www.deq.state.or.us/wq/sisdata/facilitylist.asp.
    - Data from ODEQ was sourced for latitude and longitude, along with MGD parameters as plants below 1 MGD were excluded from this analysis due to methane production limitations. EPA CWNS data was used to provide average daily flows from WWTPs. These sources were cross referenced to combine attributes and compare missing inputs on either list.

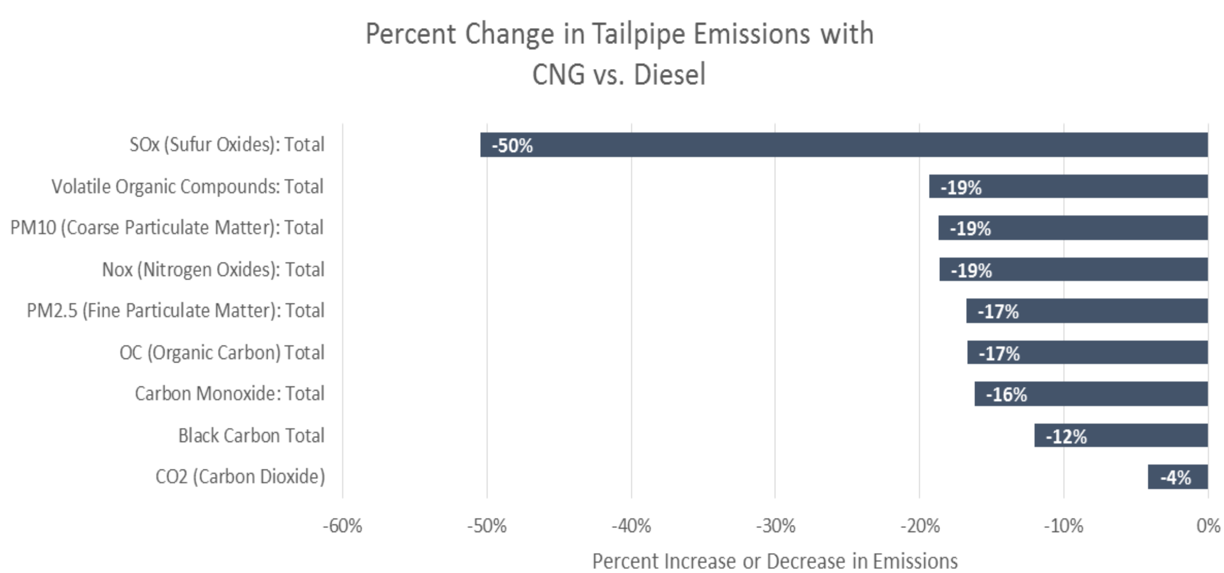
APPENDIX E: SUPPORTING ANALYSES METHODOLOGIES

Renewable Natural Gas Transportation Fuel Emissions Analysis

Overview: SB334 tasked the ODOE with finding the potential for RNG to improve air quality and reduce greenhouse gases within the state of Oregon. Detailed below is the methodology supporting the analysis of the tailpipe and lifecycle emissions of the State's RNG Potential, as CNG, when compared as an alternative to an equivalent amount of diesel fuel. This analysis informs ODOE of the potential for greenhouse gas reductions and improvements in State air quality when considering the State's RNG Potential for use as an alternative to diesel fuel in the transportation sector.

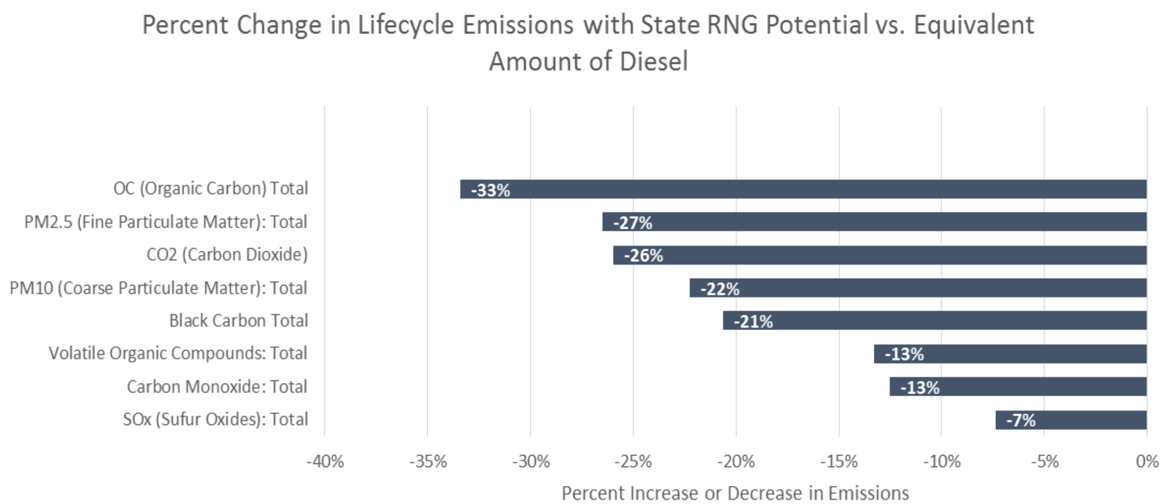
The data is based off of the CAL GREET 3.0 model data. ODEQ pulled emission factors for CNG and Diesel fuel. This information encompassed emissions from the fuels' feedstocks, the fuel itself, vehicle operation, and its total lifecycle. The lifecycle emissions analyzed included volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxides (Nox), sulfur oxides (SOx), black carbon, organic carbon (OC), and fine particulate matters 2.5 and 10 (PM2.5, PM10). Total lifecycle is a well-to-wheel analysis, from the well (point of extraction), through processing, transportation, distribution, and combustion (wheel).

Tailpipe Emissions: This graphic is a comparison between tailpipe emissions of CNG and Diesel fuel and is copied from CAL GREET 3.0 (grams/mmbtu). See the copied data supporting this graphic below.



Vehicle Operation g/mmbtu	CNG	Diesel	% Lower
CO2 (Carbon Dioxide)	299.43	312.38	-4%
Volatile Organic Compounds: Total	50.91	63.14	-19%
Carbon Monoxide: Total	620.47	740.37	-16%
Nox (Nitrogen Oxides): Total	41.06	50.43	-19%
PM10 (Coarse Particulate Matter): Tota	4.63	5.70	-19%
PM2.5 (Fine Particulate Matter): Total	1.87	2.25	-17%
SOx (Sufur Oxides): Total	0.27	0.54	-50%
Black Carbon Total	0.35	0.40	-12%
OC (Organic Carbon) Total	0.68	0.82	-17%

Lifecycle Emissions: The following graphic details the percent change in lifecycle emissions of the State's RNG Potential vs. an equivalent amount of diesel fuel. Only carbon dioxide emissions were assumed to change when using RNG vs. CNG. Therefore, all emissions factors for CNG were employed except for carbon dioxide. For carbon dioxide, we inserted a unique average carbon intensity for each anaerobic digestion pathway of RNG. These averages are derived from averaging the approved pathway carbon intensities for RNG under the California LCFS. These carbon intensities were converted from grams/MJ to grams/Btu.



The diesel-equivalent to the State RNG Potential was calculated by converting the theoretical RNG potential for anaerobic digestion pathways into Btus and dividing by the number of Btus in a diesel gallon equivalent (DGE).

Lifecycle emission factors from CAL GREET were converted from g/mmbtu into either g/SCF or g/DGE by multiplying the emission factor by the number of Btus in the respective fuel and dividing by 1,000,000. This number was consequently applied to the volume of fuel (either RNG or DGE) to arrive at the lifecycle emissions for the respective fuel in g/unit of fuel. The final number was divided by 1,000,000 to arrive at metric tonnes of emissions/unit of fuel.

Equation: Converting State RNG Potential to a Diesel Gallon Equivalent (DGE)
$\frac{Theoretical\ RNG\ Potential\ for\ Oregon * Energy\ Content\ of\ Methane}{Energy\ Content\ of\ 1\ DGE}$ = *DGE to State RNG Potential*
Example
$\frac{1000scf\ rng * 1027btus}{128{,}488btus}$ = 7.99 DGE
Equation: Calculating Grams of Pollutants per Unit of Fuel
$\frac{Emission\ Factor * Fuel\ Energy\ Content}{1{,}000{,}000}$ = *Grams of Pollutant per Unit of Fuel*
Example
$\frac{\frac{0.60g}{mmbtu} black\ carbon * 1{,}027btu}{1{,}000{,}000}$ = *0.0006 g/SCF CNG Black Carbon*
Equation: Calculating Metric Tonnes of Emissions per Unit of Fuel
$\frac{(Grams\ of\ Pollutant\ per\ Unit\ of\ Fuel * Amount\ of\ Fuel)}{1{,}000{,}000}$ = *Metric Tonnes of Emissions per*
Example
$\frac{\frac{0.006g}{scf} CNG * 100{,}000{,}000scf\ CNG}{1{,}000{,}000}$ = *0.6 Metric Tonnes of Black Carbons*

Barriers Ranking from SB 334 AC Meeting on 2-13-2018

Finance Barriers

- Is access to financing a barrier to developing RNG? 4.1/5
- Are gas upgrading costs to remove impurities, and increase heat content of biogas, barriers to developing RNG? 3.8/5
- Are interconnection costs for testing, verification, and pipeline construction barriers to developing RNG? 3.7/5
- Is the cost to produce RNG at certain scales a barrier to developing RNG? 3.4/5
- Is the cost of producing biogas a barrier to developing RNG? 3.0/5.0

- Are regulatory costs, such as permitting, barriers to developing new stationary sources of RNG? 1.7/5.0

Information Barriers

- Is the perception of risk due to unfamiliarity with biomass technologies and fuel supply chains a barrier to developing RNG? 2.3/5.0
- Is a lack of knowledge surrounding potential incentives for RNG a barrier for developing RNG? 2.1/5.0
- Is a lack of standard purchase agreements a barrier to developing RNG? 13/50

(Note: The concern here was about contract language that could potentially kept RNG from a known source off line for a long period of time while gas quality was being retested after a quality failure that resulted in that RNG being declined by the pipeline operator.)

Market Barriers

- Is a lack of natural gas vehicles or fleets a barrier to developing RNG? 3.0/5.0
- Are mismatches between biogas producers and consumers a barrier to developing RNG? 2.7/5.0
- Is the cost differential between fossil natural gas and RNG a barrier to developing RNG? 2.6/5.0
- Is a lack of natural gas fueling infrastructure a barrier to developing RNG? 2.5/5.0

Policy Barriers

- Is existing policy that prevents Oregon utilities from making ratepayer-funded capital investments in RNG infrastructure, such as extension of pipelines or connection points for RNG producers, as well as the requirement for Utilities to purchase the least cost resource, a barrier to developing RNG? 3.3/5.0
- Is a lack of policy encouraging or mandating the source separation of wastes (such as food wastes) a barrier to developing RNG? 3.3/5.0
- Is a lack of financial incentives for natural gas fueling infrastructure a barrier to developing RNG? 3.1/5.0

- Is a lack of financial incentives for natural gas vehicles and fleet conversions a barrier to developing RNG? 2.75/5.0
- Is the Energy Trust of Oregon encouraging biogas-to-electricity production projects rather than RNG fuel projects a barrier to developing RNG? 2.5/5.0
- Is a lack of incentive for implementation of biogas systems as resiliency infrastructure a barrier to developing biogas? Incentives need not be monetary. 2.4/5.0
- Is a lack of incentive for implementation of RNG systems as resiliency infrastructure a barrier to developing RNG? Incentives need not be monetary. 2.4/5.0
- Are rigorous tariffs for RNG a barrier to developing RNG? 2.3/5.0
- Is the concern for pipeline discrimination against RNG, even if it meets pipeline standards, a barrier? 2.3/5.0
- Is an inability to incorporate hydrogen into the pipeline through policy a barrier to developing RNG? 1.3/5.5
- Is an unwillingness to incorporate hydrogen into the pipeline a barrier? 1.3/5.0

Regulatory Barriers

- Is the OPUC regulation requiring the procurement of the least-cost resource by Oregon utilities a barrier to developing RNG? 3.6/5.0
- Is a lack of incentivization of biogas (or RNG) as a fuel under the Renewable Portfolio Standard a barrier to developing RNG? 2.5/5.0

Other Barriers

- Is proximity to tie-in points for the RNG/CNG grid a barrier to developing RNG? 3.7/5.0
- Are contracting risks a barrier to developing RNG? 2.3/5.0
- Is production variation of RNG a barrier to developing RNG? 2.3/5.0
- Are market competition risks for feedstock supplies (such as food waste for composting vs. anaerobic digestion) a barrier to developing RNG? 2.1/5.0
- Are out-of-state producers of RNG a barrier in developing in-state RNG? 1.4/5.0

APPENDIX F: REFERENCES

1. Abbasi, T., Tauseef, S.M. and S.A. Abbasi. 2012., Biogas Energy, SpringerBriefs in Environmental Science 2, 11
DOI 10.1007/978-1-4614-1040-9_2

2. British Columbia. n.d. "British Columbia's Carbon Tax." Climate Planning & Action. https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/carbon-tax.

3. California Air Resources Board. 2018 "Carbon Intensity Values of Current Certified Pathways (2017) Retrieved from
https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm

4. California Air Resources Board. 2018. "Low Carbon Fuel Standard Pathway Certified Carbon Intensities." https://www.arb.ca.gov/fuels/lcfs/lcfs.htm.

5. Downing, Kevin. 2015. "The Concerns about Diesel Engine Exhaust" 1–8.

6. G4 Insights. 2018. http://www.g4insights.com/about.html.

7. Gerstle, Brandon, Amanda Singh, Cheryl Cox, Cheryl Lee, and Judith Iklé. 2018. "Padilla Report: Costs and Cost Savings for the RPS Program (Public Utilities Code 913.3)." Vol. 66. https://doi.org/10.1111/1475-4932.12386.

8. International Renewable Energy Agency. 2018. "Renewable Power Generation Costs in 2017." http://www.irena.org/publications/2018/Jan/Renewable-power-generation-costs-in-2017.

9. Luna-delRisco, M, Noormak, and K. Orupold. 2011. Biochemical methane potential of different organic wastes and energy crops From Estonia, Agronomy Research 9 (1-2), 332-342)

10. Lyford-Pike, E.J., and National Renewable Energy Laboratory. 2003. "An Emission and Performance Comparison of the Natural Gas C-Gas Plus Engine in Heavy-Duty Trucks." Contract, no. April.

11. Oregon Department of Energy, and Energy Facilities & Safety. n.d. "Facilities Under EFSC." https://www.oregon.gov/energy/facilities-safety/facilities/Pages/Facilities-Under-EFSC.aspx?View=%7B1f58a115-e64c-474d-9fb5-a33c2e035f9b%7D&SortField=Facility_x0020_Type&SortDir=Asc.

12. Oregon Department of Energy. n.d. "Renewable Portfolio Standard." https://www.oregon.gov/energy/energy-oregon/Pages/Renewable-Portfolio-Standard.aspx.

13. Oregon Department of Environmental Quality. 2016. "Oregon Greenhouse Gas Statewide Sector-Based Inventory Statewide Greenhouse Gas Emissions," 1–5.

14. Oregon Department of Environmental Quality.ODEQ. 2017. Oregon DEQ Strategic Plan for Preventing the Wasting of Food. Retrieved from https://www.oregon.gov/deq/FilterDocs/foodstrategic.pdf

15. Oregon Department of Environmental Quality. 2018. "Oregon Clean Fuels Program." https://www.oregon.gov/deq/aq/programs/Pages/Clean-Fuels.aspx.

16. Ostrem, Karena. 2004. "Greening Waste: Anaerobic Digestion for Treating the Organic Fraction of Municipal Solid Waste." Department of Earth and Environmental Engineering Fu Foundation of School of Engineering and Applied Science, Columbia University, no. The Earth Engineering Center and the Henry Krumb School of Mines: 1–59.

17. Persson, Tobias, Jerry Murphy, Anna-Karin Jannasch, Eoin Ahern, Jan Liebetrau, Marcus Trommler, and Jeferson Toyama. 2015. "A Perspective on the Potential Role of Biogas in Smart Energy Grids." Renewable Energy 78: 648–56. https://doi.org/10.1016/j.renene.2015.01.048.

18. Sadaka, Sammy. 2010. "Gasification, Producer Gas and Syngas." University of Arkansas System

19. Snowden-Swan, LJ, Y Zhu, SB Jones, DC Elliott, AJ Schmidt, RT Hallen, JM Billing, TR Hart, SP Fox, and GD Maupin. 2016. "Hydrothermal Liquefaction and Upgrading of Municipal Wastewater Treatment Plant Sludge: A Preliminary Techno-Economic Analysis," PNNL-25464.

20. Suto, Paul, Cara Peck, and Donald Gray. 2008. "Anaerobic Digestion of Food Waste." USEPA No. EPA-R9-WST-06, no. March. http://www.epa.gov/Region09/organics/ad/EBMUDFinalReport.pdf.

21. United Nations Intergovernmental Panel on Climate Change. 2007. "Climate Change 2007: Working Group I: The Physical Science Basis." Fourth Assessment Report. 2007. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html.

22. U.S. Department of Agriculture. 2008. “Part 651 Handbook Chapter 4 Agricultural Waste Characteristics.” Waste Management, no. March.

23. U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Department of Energy. 2014. “Biogas Opportunities Roadmap: Voluntary Actions to Reduce Methane Emissions and Increase Energy Independence,” no. August: 28. http://www.usda.gov/oce/reports/energy/Biogas_Opportunities_Roadmap_8-1-14.pdf.

24. U.S. Energy Information Administration. 2016. “Oregon Electricity Profile 2016.” State Electricity Profiles. 2016. https://www.eia.gov/electricity/state/oregon/.

25. U.S. Environmental Protection Agency. 1992. “EPA State Workbook: Methodologies For Estimating Greenhouse Gas Emissions,” 1–344.

26. U.S. Environmental Protection Agency. 2015. “Methane Emissions.” Greenhouse Gas Emissions. 2015. https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

27. U.S. Environmental Protection Agency. 2018. “Renewable Fuel Standard Program.” https://www.epa.gov/renewable-fuel-standard-program.

28. U.S. National Energy Technology Laboratory. n.d. “History of Gasification.” https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/history-gasification.

29. Williams, Robert B, Stephen R Kaffka, and Robert Oglesby. 2014. “DRAFT Comparative Assessment of Technology Options for Biogas Clean‐up.”

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