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Life Cycle Assessment of Spokane Waste Management Options

Prepared for

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Acronyms

µm	micrometer
ADC	alternate daily cover
APOS	allocation at the point of substitution
BNSF	Burlington Northern Santa Fe
CAP	criteria air pollutant
CH_4	methane
Cd	cadmium
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CETA	Clean Energy Transformation Act
Ecology	Washington Department of Ecology
eGRID	Emissions & Generation Resource Integrated Database
EPA	Environmental Protection Agency
EPD	environmental product declaration
EV	electric vehicle
Finley Buttes	Waste Connections Finley Buttes Landfill
GHG	greenhouse gas
GLO	geographical location global
GWP	global warming potential
HCl	hydrogen chloride
HF	hydrogen fluoride
Hg	mercury
H_2S	hydrogen sulfide
H_2SO_4	sulfuric acid
HDPE	high-density polyethylene
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram

kWh	kilowatt-hour
Land Gem	Landfill Gas Emissions Model
LCA	life cycle assessment
LDPE	low-density polyethylene
LFG	landfill gas
MSW	municipal solid waste
MT	metric tons
MWh	megawatt-hour
N	nitrogen
NH_3	ammonia
N_2O	nitrous oxide
NOx	nitrogen oxides
NWPP	Western Electricity Coordinating Council Northwest
O_3	ozone
OPOC	other pollutant of concern
Pb	lead
PET	polyethylene terephthalate
PLA	polylactic acid
PM	particulate matter
PP	polypropylene
PS	polystyrene
PVC	polyvinylchloride
RoW	rest of world
RNG	renewable natural gas
Roosevelt	Republic Services Roosevelt Regional Landfill
SO_2	sulfur dioxide
TRACI	Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts
tpy	tons per year
VMT	vehicle miles traveled

VOC	volatile organic compound
WARM	Waste Reduction Model
WECC	Western Electricity Coordinating Council
Wenatchee	WM Greater Wenatchee Regional Landfill
WTEF	Waste-to-Energy Facility

Executive Summary

ES.1 Introduction

The State of Washington adopted the Washington Clean Energy Transformation Act (CETA) in 2019 which requires that electricity sold to Washington residents be greenhouse gas (GHG) neutral by January 1, 2030. Through December 31, 2044, a utility can provide up to 20 percent (%) of its electricity through alternative compliance options, which include electricity from an energy recovery facility using municipal solid waste as the principal fuel source, provided the facility was constructed before 1992 and is operated in compliance with federal laws and regulations and meets state air quality standards.

Additionally, an electric utility may only use electricity from an energy recovery facility, provided it results in a net reduction in greenhouse gas emissions compared to other available waste management best practices. The determination of net reduction must be based on an emissions life cycle assessment (LCA) comparing the energy recovery facility to other waste management practices available to the jurisdiction in which the facility is located. The Spokane Waste-to-Energy Facility (WTEF) was constructed in 1991, operates in compliance with federal laws and regulations and meets state air quality standards and receives approximately 250,000 short tons per year (tpy) of waste. and can generate approximately 150 gigawatt hours of electricity per year.

The Washington Department of Ecology (Ecology) hired CDM Smith to perform an emissions LCA of WTEF to determine its eligibility as an alternative compliance option under CETA. The LCA compared WTEF to three municipal solid waste (MSW) landfills in the Spokane region as landfilling was determined to be the only available best management practice alternative for managing the current waste stream going to WTEF. The three landfills are:

- The Republic Services Roosevelt Regional Landfill (Roosevelt)
- The Waste Connections Finley Buttes Landfill (Finley Buttes)
- The WM Greater Wenatchee Regional Landfill (Wenatchee)

Emissions were calculated using facility data and air emissions models for an assumed period of 30 years with 250,000 tpy being delivered to the facilities. A 30-year period was selected because it is a typical operational period of an active landfill that accounts for the cumulative effect of slow-release emissions from landfilled waste as well as the varying efficiencies of landfill gas collection over the life of a landfill.

While the main objective of the LCA was to compare GHG emissions, it also included other air pollutants regulated at the facilities including criteria air pollutants (CAPs) and other pollutants of concern (OPOC).

The LCA was not intended to provide a comprehensive assessment of environmental impacts. Other considerations for comparison of WTEF to the landfills are presented in Section 5.

ES.2 Life Cycle Assessment Scenarios

Scenario 1 (current practice) 250,000 tpy of waste from the North County Transfer Station, the Valley Transfer Station, and direct haulers is disposed of at WTEF over a 30-year period. Ash generated at WTEF is trucked to a local Burlington Northern Santa Fe (BNSF) rail spur and transported by rail to Roosevelt. The hauling distance for this scenario is 52 miles by truck and 227 miles by rail (**Figure ES.1**).

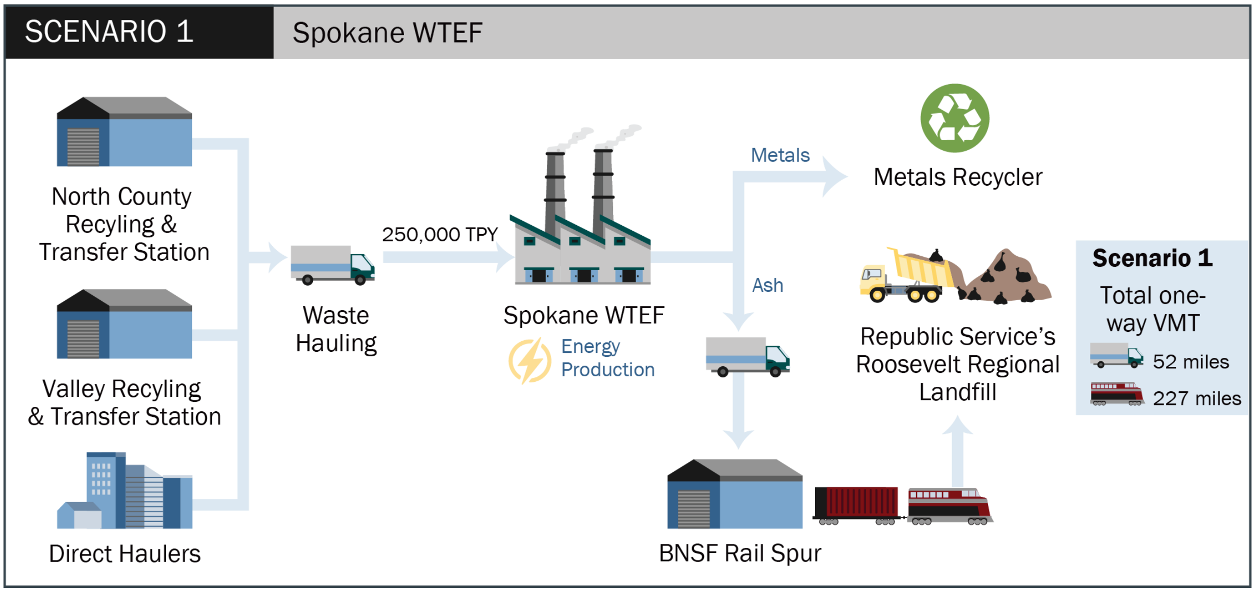

Figure ES.1. Scenario 1 Waste Disposed of at Spokane Waste-to-Energy Facility

In Scenarios 2–4, WTEF is used as a third transfer station, receiving waste from those sources that are currently making direct hauls to WTEF (**Figure ES.2**).

Scenario 2: 250,000 tpy of waste is hauled over a 30-year period by truck to a BNSF rail spur and then transported by rail to Roosevelt. The hauling distance is 37 miles by truck and 227 miles by rail.

Scenario 3: 250,000 tpy of waste is hauled over a 30-year period by truck to Finley Buttes. The hauling distance is 616 miles.

Scenario 4: 250,000 tpy of waste is hauled over a 30-year period by truck to Wenatchee. The hauling distance is 512 miles.

Figure ES.3 shows the hauling routes for Scenarios 2–4.

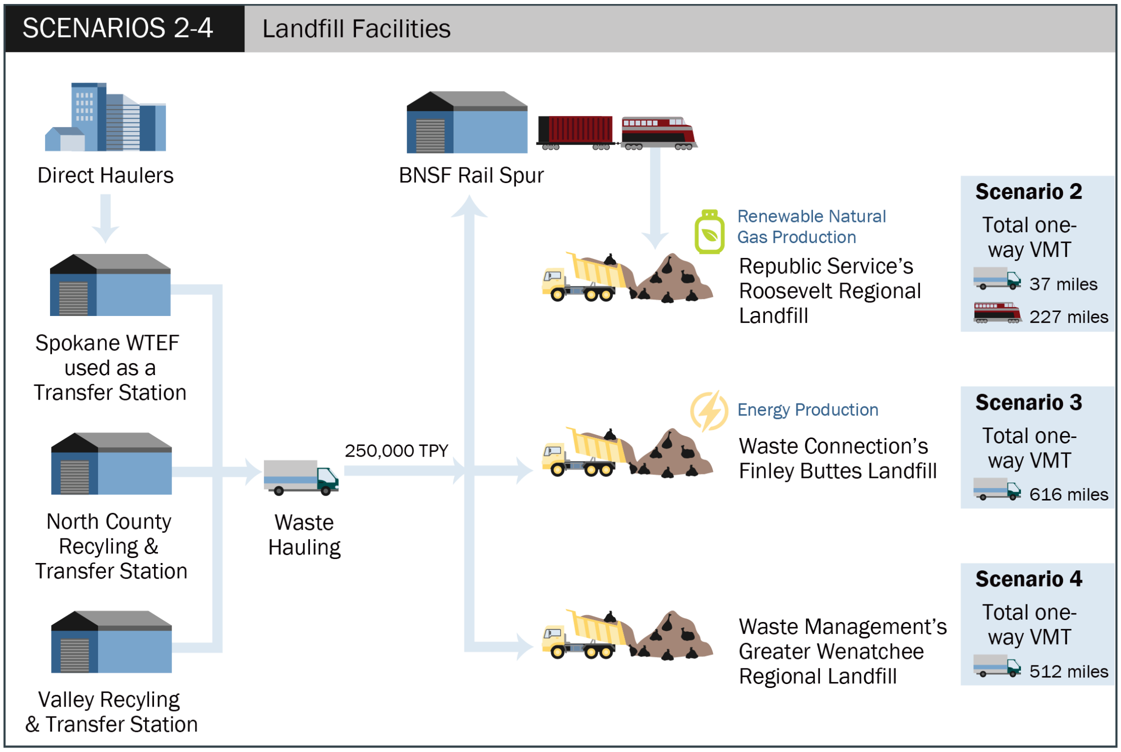

Figure ES.2. Scenarios 2–4 Waste Disposed of at Roosevelt, Finley Buttes, or Wenatchee

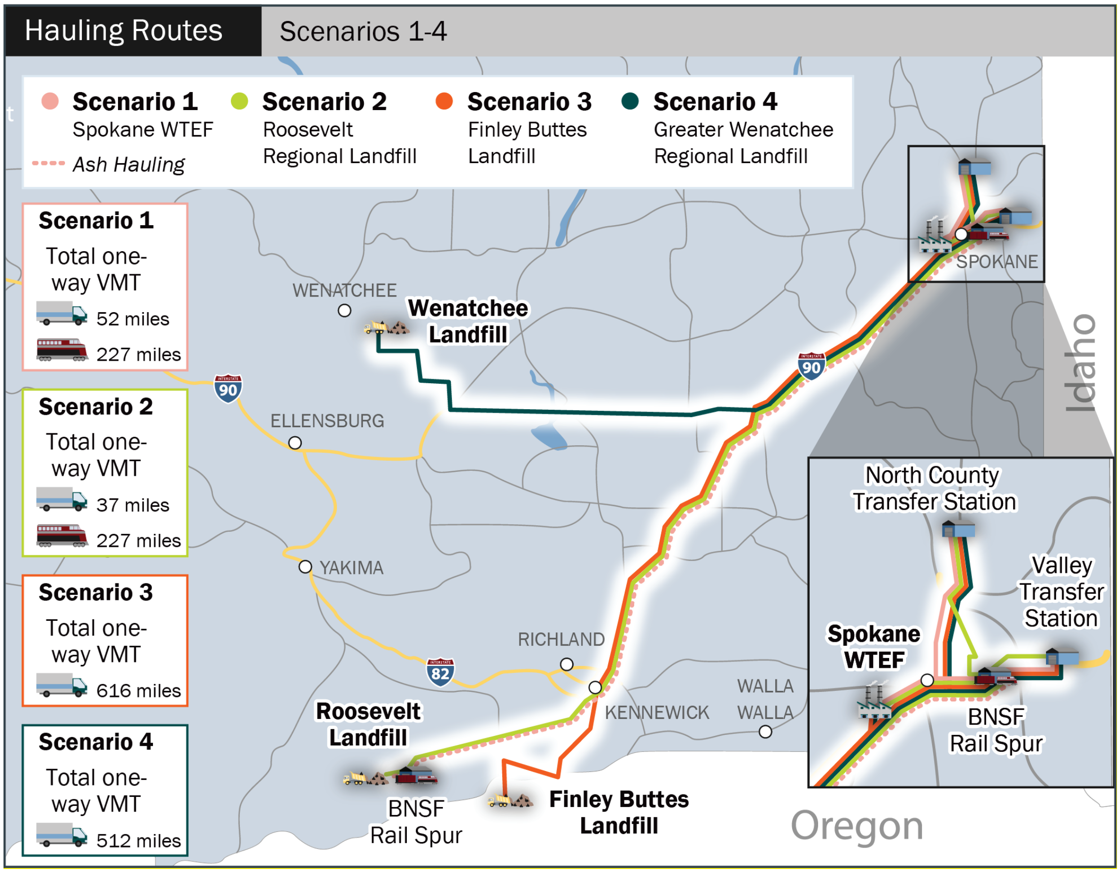

Figure ES.3. Hauling Routes

The following activities were not included in the LCA scenarios:

- Upstream activities before a material was discarded as waste (i.e., resource extraction, manufacturing, usage, maintenance)
- Collection and delivery of waste to the transfer stations and WTEF
- Any activities related to waste that is recycled or composted
- Any activities related to management of household hazardous waste

These activities are excluded because they either remain the same between the scenarios (i.e., collection and delivery to the transfer stations and WTEF) or pertain to waste materials that are not taken to WTEF. Additionally, emissions related to the construction and decommissioning of the facilities (e.g., landfill closure or demolition of WTEF) were not included in the LCA.

ES.3 Life Cycle Assessment Methodology

The LCA addresses resulting air emissions from managing 250,000 tpy of MSW over a 30-year period using waste-to-energy or landfilling.

The following pollutants were selected by Ecology for the LCA:

- **Greenhouse Gases (GHGs):** carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)
- **Criteria Air Pollutants (CAPs):** carbon monoxide (CO), lead (Pb), particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs)
- **Other Pollutants of Concern (OPOC):** hydrogen sulfide (H_2S), ammonia (NH_3), sulfuric acid (H_2SO_4), hydrogen chloride (HCl), hydrogen fluoride (HF), cadmium (Cd), mercury (Hg), and dioxins/furans

The emission pathways assumed for the LCA include:

- **Direct Emissions from Waste** includes emissions from waste combusted at WTEF or decomposed at the landfills, and emissions from landfill gas (LFG) combusted in a flare/generator.
- **Hauling** pertains to emissions produced by waste hauling vehicles.
- **Facility Use of Fossil Fuels** include emissions from fossil fuels used to power facility equipment and vehicles.
- **Facility Use of Utility Electricity** includes emissions from electricity from the grid used at the facilities.
- **Operational Materials and Chemicals** includes embodied carbon emissions of materials and chemicals that are routinely used at the facilities such as synthetic tarps and air pollution control reagents.

Global warming potentials (GWPs), listed in **Table ES.1**, were used to convert CH_4 and N_2O into CO_2-equivalent (CO_2e) values. The higher the GWP, the more potent the warming effects are of that specific GHG. The CO_2e values were calculated using 20-year and 100-year time horizons for the GWPs. These are provided in the United Nations Intergovernmental Panel on Climate Change Sixth Assessment Report, known as IPCC AR6 (IPCC 2022).

The 20-year time horizon prioritizes the climate impacts of potent, short-lived GHGs, such as CH_4 while the 100-year time horizon emphasizes longer lived GHGs such as CO_2. CH_4 is estimated to remain in the atmosphere for 10–12 years while carbon dioxide's expected life is hundreds to thousands of years. (U.S. Environmental Protection Agency [EPA] 2023j).

Table ES.1. Global Warming Potentials for 20-Year and 100-Year Time Horizons

Global Warming Potential	CO_2	CH_4	N_2O
20-year Time Horizon	1	81.2	273
100-year Time Horizon	1	27.9	273

The WTEF and landfills were credited with GHG emission offsets for power delivered to the utility grid (WTEF and Finley Buttes), ferrous metal recovery (WTEF), conversion of landfill gas to renewable natural gas (Roosevelt), and long-term storage of biogenic carbon in food and yard wastes (all three landfills). Biogenic CO_2 from wastes generated from tree products were included in the GHG tallies because of the extended duration of their biogenic cycle. Biogenic carbon dioxide from food waste, yard waste, and other nontree-based organic wastes were excluded from the GHG tallies.

ES.4 Results

Using 20-year GWPs, the Spokane WTEF GHG emissions are 20% to 58% less than the three landfills (**Figure ES.4**). Using 100-year GWPs, the Spokane WTEF GHG emissions are 21% to 166% higher than the three landfills (**Figure ES.5**).

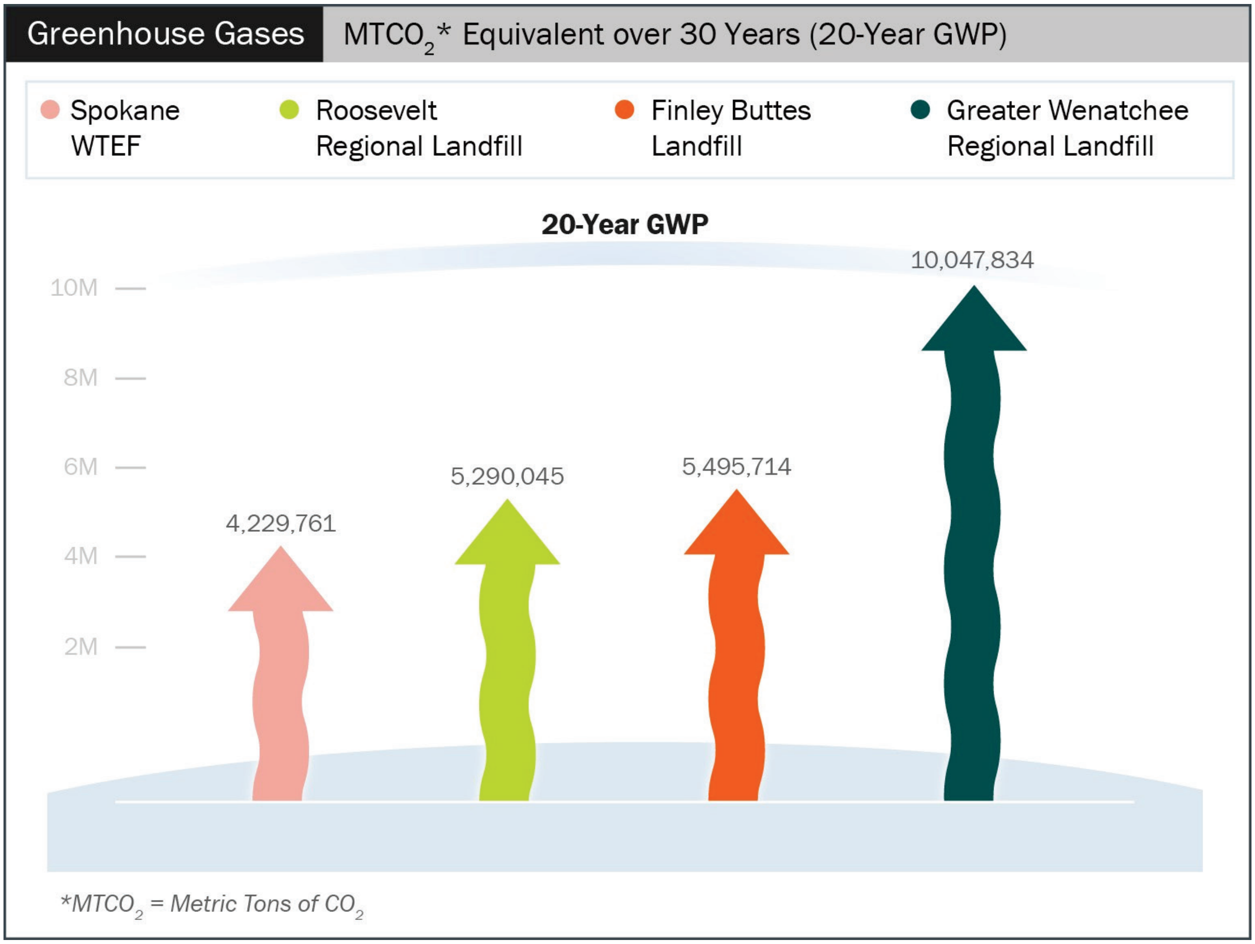

Figure ES.4. Greenhouse Gas Emissions Using 20-Year Global Warming Potentials

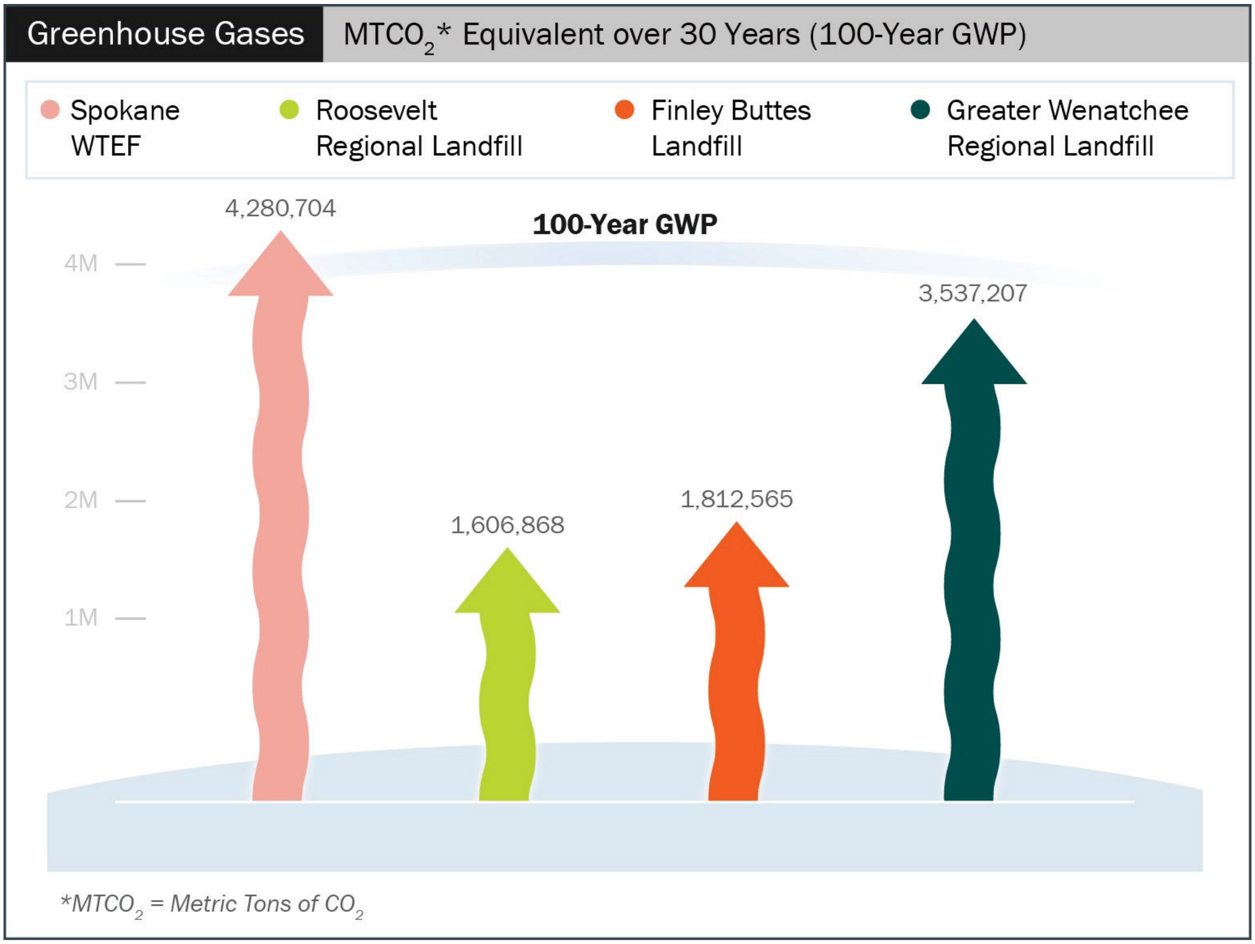

Figure ES.5. Greenhouse Gas Emissions Using 100-Year Global Warming Potentials

While EPA and Ecology uses the 100-year GWP for annual inventory requirements, CDM Smith recommends using the 20-year GWP results as they stress the importance of addressing potent GHGs, such as CH_4, in the urgent need to curb climate change. This recommendation aligns with the United Nations Environment Programme's emphasis on the importance of methane in addressing climate change. In the United Nations Environment Programme's May 6, 2021, press release, the Executive Director of the United Nations Environment Programme, Inger Andersen stated "Cutting methane is the strongest lever we have to slow climate change over the next 25 years and complements necessary efforts to reduce carbon dioxide. The benefits to society, economies, and the environment are numerous and far outweigh the cost. We need international cooperation to urgently reduce methane emissions as much as possible this decade." (UN Environment Programme 2021).

As seen in **Figure ES.6**, for CAPs emissions, WTEF, in comparison to the landfills, emits:

- 80% less VOCs
- 2 to 8 times more NO_x, SO_2, and PM_{10} and $PM_{2.5}$
- A comparable amount of CO

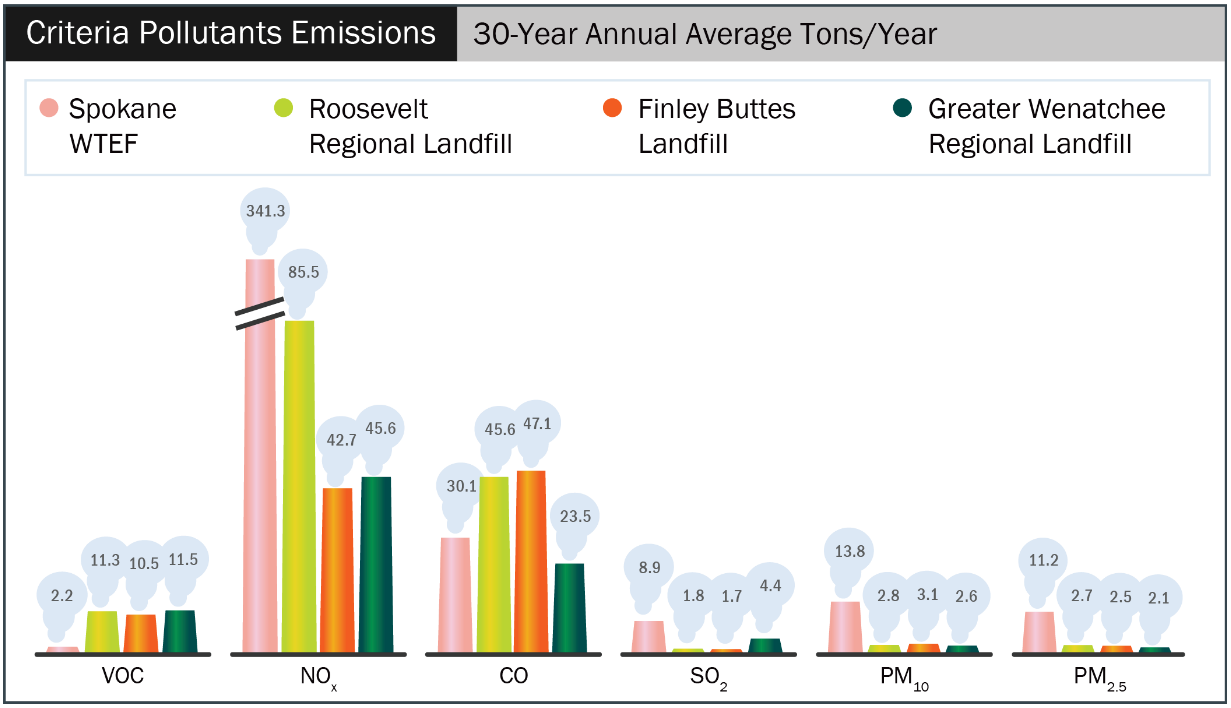

Figure ES.6. Criteria Air Pollutants Emissions

As shown in **Table ES.2**, not every facility emits all of the OPOCs included in the LCA. WTEF does not emit hydrogen sulfide (H_2S) and none of the landfills emit sulfuric acid (H_2SO_4), hydrogen fluoride (HF), or cadmium (Cd). For pollutants common to all four facilities (NH_3, HCL, Hg, and dioxins/furans) WTEF generates larger quantities than the landfills.

Table ES.2. Annual Emissions of Other Pollutants of Concern

Scenarios	**Annual Average Emissions – OPOC (tpy)**							
	H_2S	**NH_3**	**H_2SO_4**	**HCl**	**HF**	**Cd**	**Hg**	**Dioxins and Furans**
Spokane WTEF	–	7.66	4.90	7.77	0.19	4.86E-04	3.22E-03	2.23E-08
Roosevelt Landfill	0.18	0.01	–	0.95	–	–	9.57E-06	1.04E-10
Finley Buttes Landfill	0.18	0.21	–	0.95	–	–	9.60E-06	7.34E-11
Greater Wenatchee Landfill	0.18	0.16	–	0.95	–	–	9.59E-06	5.63E-11

1.0 Introduction

On May 7, 2019, Governor Jay Inslee signed into law the Washington Clean Energy Transformation Act (CETA) which commits Washington to an electricity supply that is greenhouse gas (GHG) neutral by January 1, 2030, and consisting of only non-emitting and renewable resources by January 1, 2045[1].

Under CETA, a utility can provide up to 20 percent (%) of its electricity through alternative compliance options until December 31, 2044. One of the listed alternative compliance options is electricity from an energy recovery facility using municipal solid waste (MSW) as the principal fuel source, provided the facility was constructed before 1992, and is operated in compliance with federal laws and regulations and meets state air quality standards. An electric utility may only use electricity from such an energy recovery facility if the facility provides a net reduction in GHG emissions compared to other available waste management best practices. The determination must be based on a life cycle assessment (LCA) comparing the energy recovery facility to other waste management practices available to the jurisdiction in which the facility is located.

The Spokane Waste-to-Energy Facility (WTEF), constructed in 1991, is the only operating waste-to-energy facility in Washington. It operates in compliance with federal laws and regulations and meets state air quality standards as required in its air permit. WTEF processes approximately 250,000 short tons per year (tpy) of waste and can generate approximately 150 gigawatt hours of electricity per year.[2]

Ecology funded the LCA presented in this report to determine whether WTEF qualifies as an alternative compliance option under CETA.

1.1 Life Cycle Assessment Scenarios

The LCA includes four scenarios for quantifying emissions generated from activities related to the management of 250,000 tpy of municipal solid waste (MSW) over a 30-year period. A 30-year period was chosen because it is representative of a typical active life for a landfill and is intended to capture the cumulative effects of slow-release emissions from landfilled waste and variations in landfill gas collection efficiency related to phased wellfield and final cover installation.

Scenario 1 Spokane WTEF (current practice)

In Scenario 1, as shown in **Figure 1.1**, waste generated in the City of Spokane and Spokane County is taken to the North County Recycling and Transfer Station (North County Transfer Station), the Valley Recycling and Transfer Station (Valley Transfer Station), or directly to WTEF. Waste hauls to WTEF are as follows:

- 9% of waste is hauled from North County Transfer Station to WTEF via transfer trucks with 19-ton capacities, requiring four trips per day (22 miles one-way).

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[1] Non-emitting electric generation is electricity from a generating facility or a resource that provides electric energy, capacity, or ancillary services to an electric utility and that does not emit greenhouse gases as a byproduct of energy generation.

[2] Calculated based on the Waste Reduction Model.

- 15% of the waste is hauled from Valley Transfer Station to WTEF via transfer trucks with 19-ton capacities, requiring six trips per day (18 miles one-way).
- 76% of waste is hauled directly from the waste source to WTEF by various sized vehicles.

WTEF generates electricity through the combustion of waste and recovers ferrous metals from the combusted waste (ash). Approximately 59,000 tpy of ash is disposed of at Roosevelt. Ash is hauled 12 miles one-way via transfer truck from WTEF to the BNSF (Burlington Northern Santa Fe) rail spur and then hauled by rail to Roosevelt. The ash hauling trucks have capacities of 21 tons, requiring eight trips per day from WTEF to the BNSF rail spur.

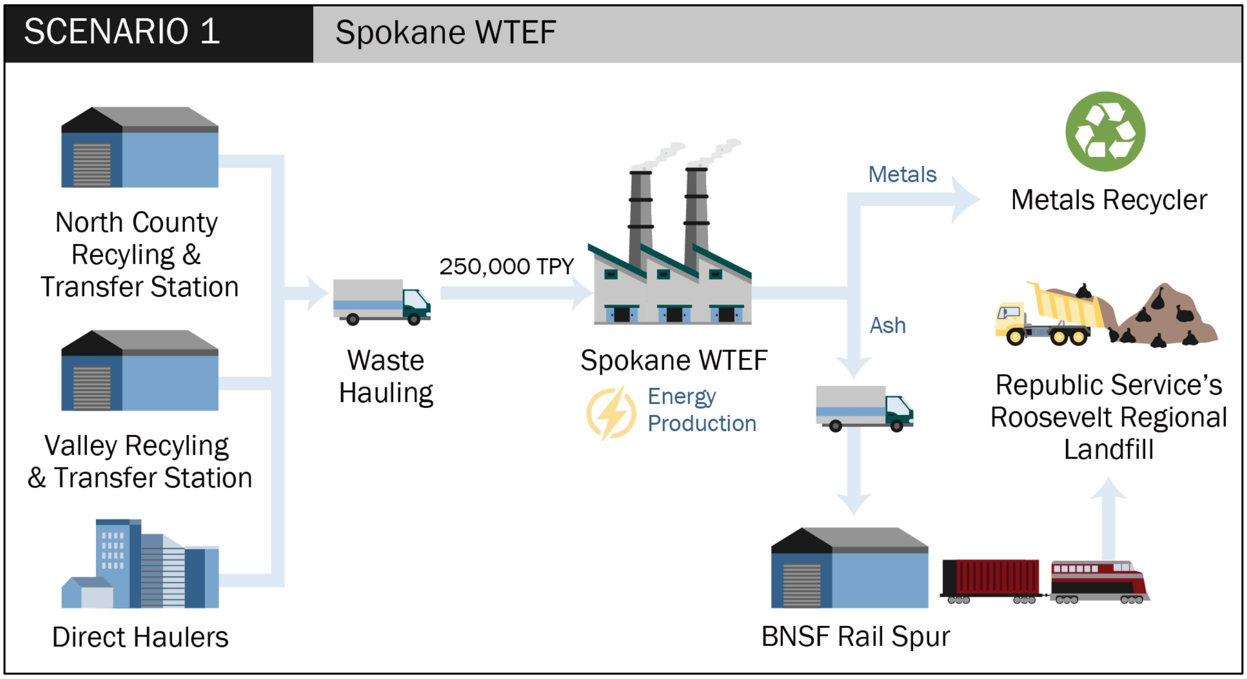


Figure 1.1. Scenario 1 Waste Disposed of at Spokane Water-to-Energy Facility

In Scenarios 2–4 (depicted in **Figure 1.2**), WTEF is assumed to have been shut down and converted to a transfer station. As such, Scenarios 2–4 assumes waste is hauled from three transfer stations to the landfills. Hauling distances are provided in **Figure 1.3**.

Scenario 2 Roosevelt

Roosevelt utilizes a phased capping approach and an active collection system consisting of horizontal and vertical wells to manage landfill gas. Collected landfill gas is converted to renewable natural gas (RNG) at an adjacent facility. Waste hauling is as follows:

- 9% of waste travels from North County Transfer Station to the BNSF rail spur via transfer trucks with 19-ton capacities, requiring four trips per day (18 miles one-way).
- 15% of waste travels from the Valley Transfer Station to the BNSF rail spur via transfer trucks with 19-ton capacities, requiring six trips per day (7 miles one-way).
- 76% of waste travels from WTEF/transfer station to the BNSF rail spur via transfer trucks with 19-ton capacities, requiring 28 trips per day (12 miles one-way).
- All waste then travels via rail from the BNSF rail spur to Roosevelt (227 miles one-way).

Scenario 3 Finley Buttes

Finley Buttes utilizes a phased capping approach and an active collection system consisting of horizontal and vertical wells to manage landfill gas. Collected landfill gas is used in a combined heat and power system to generate electricity and heat. Waste hauling is as follows:

- 9% of waste travels from North County Transfer Station to Finley Buttes via transfer trucks with 19-ton capacities, requiring four trips per day (214 miles one-way).
- 15% of waste travels from the Valley Transfer Station to Finley Buttes via transfer trucks with 19-ton capacities, requiring six trips per day (209 miles one-way).
- 76% of waste travels from WTEF, functioning as a transfer station, to Finley Buttes via transfer trucks with 19-ton capacities requiring 28 trips per day (193 miles one-way).

Scenario 4 Wenatchee

Wenatchee utilizes an active collection system consisting of horizontal and vertical wells to manage landfill gas. Collected landfill gas is flared. Wenatchee plans to cap in entirety at the end of life of the landfill. Waste hauling is as follows:

- 9% of waste travels from North County Transfer Station to Wenatchee via transfer trucks with 19-ton capacities, requiring four trips per day (179 miles one-way).
- 15% of waste travels from Valley Transfer Station to Wenatchee via transfer trucks with 19-ton capacities, requiring six trips per day (175 miles one-way).
- 76% of waste travels from WTEF, functioning as a transfer station, to Wenatchee via transfer trucks with 19-ton capacities, requiring 28 trips per day (158 miles one-way).

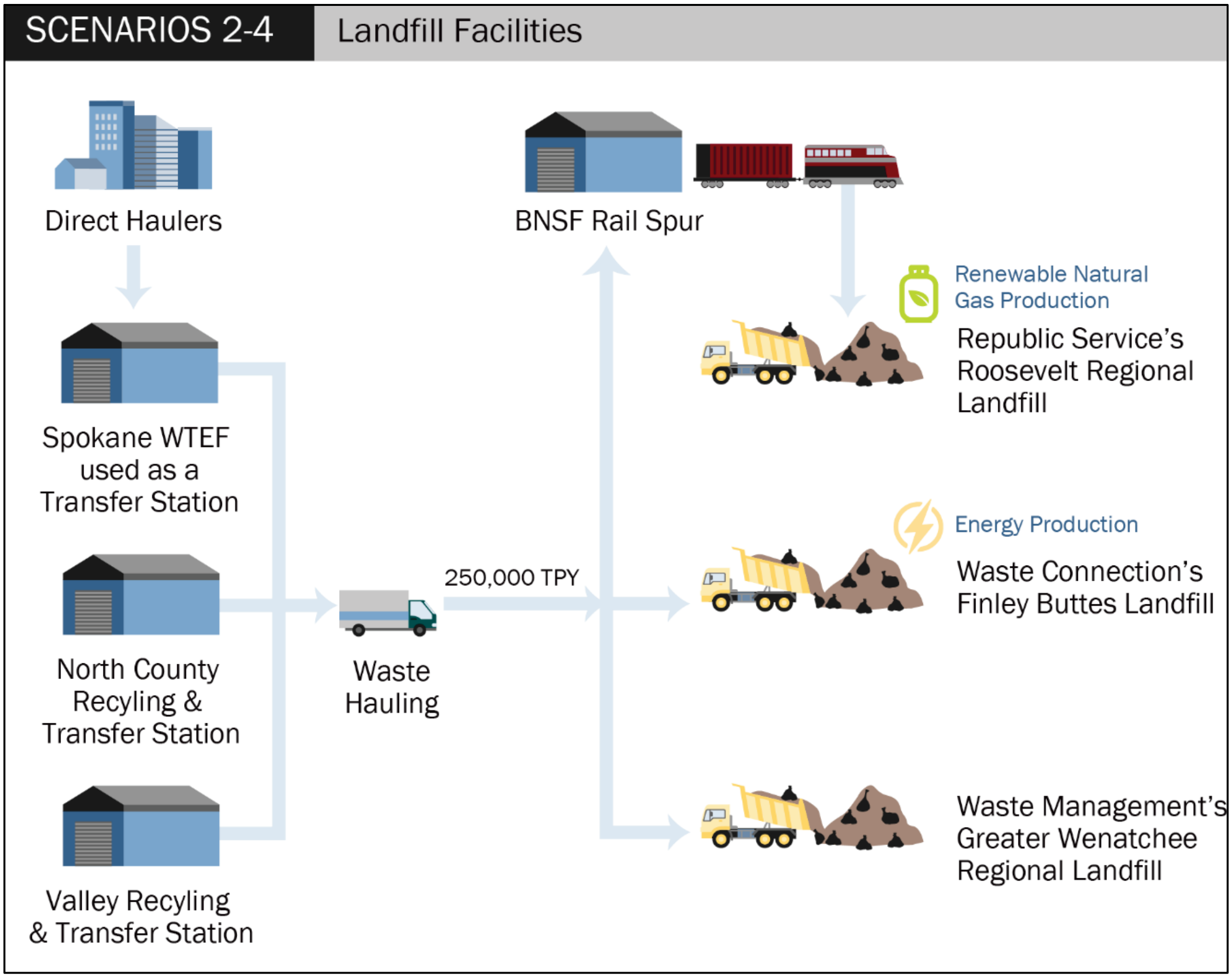


Figure 1.2. Scenarios 2–4 Waste Disposed of at Roosevelt, Finley Buttes, or Wenatchee

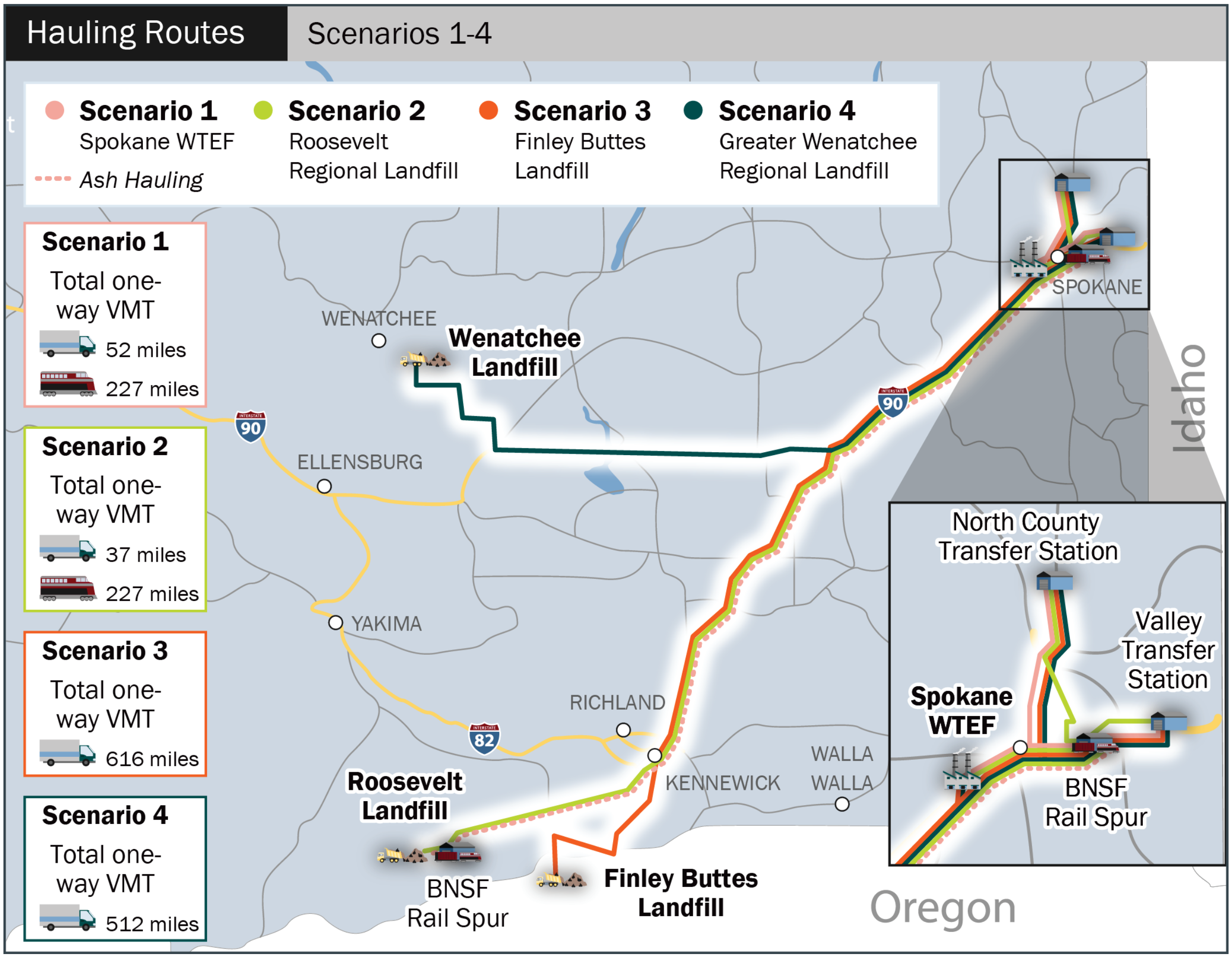


Figure 1.3. Hauling Routes and Vehicle Miles

The following activities were not included in the LCA scenarios:

- Upstream activities before a material was discarded as waste (i.e., resource extraction, manufacturing, usage, maintenance)
- Collection and delivery of waste to the transfer stations and WTEF
- Any activities related to waste that is recycled or composted
- Any activities related to management of household hazardous waste

These activities are excluded because they either remain the same between the scenarios (i.e., collection and delivery to the transfer stations and WTEF) or pertain to waste materials that are not taken to WTEF. Additionally, emissions related to the construction and decommissioning of the facilities (e.g., landfill closure or demolition of WTEF) were not included in the LCA.

1.2 Emissions Included in the Life Cycle Assessment

Ecology selected the following emission categories for the LCA:

- Greenhouse Gases (GHGs)

- Criteria Air Pollutants (CAPs)
- Other Pollutants of Concern (OPOC)

The GHG emissions are the focus of this study to address CETA requirements for alternative compliance options. The CAPs and OPOCs were included to address local air quality, providing a more complete picture of emissions from the facilities.

Ecology coordinated with local and state air authorities, Commerce, and the City of Spokane to determine which pollutants to include in the LCA. The included emissions encompass those regulated by air authorities for WTEF and the landfills.

1.2.1 Greenhouse Gases

GHGs absorb infrared radiation and trap heat in the atmosphere which is causing climate change. The LCA included carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) as these are the primary GHGs emitted from waste-to-energy facilities and landfills.

Total GHG emissions resulting from disposal of 250,000 tpy of MSW over 30 years was used for the LCA. In Scenario 1, GHG emissions occur immediately upon waste combustion and therefore the total GHG emissions occur within 30 years. In Scenarios 2–4, GHG emissions from the landfilled waste continue long past the 30-year disposal period since the emissions are dependent on the rate of waste decomposition which occurs over many decades after disposal. Landfill emissions past the 30 years are also accounted for.

Total GHG emissions (versus GHG emissions over 30 years) was selected for the LCA as it was deemed to be more representative of the impacts to climate change for each scenario (i.e., a significant quantity of GHG emissions would have been excluded from the landfill scenarios if only GHG emissions within the 30-year disposal period were counted). Total GHG emissions is more representative because a significant portion of the GHGs are long-lived, making their impacts cumulative.

1.2.2 Criteria Air Pollutants

The U.S. Environmental Protection Agency (EPA) identifies six air pollutants as CAPs. These pollutants are known to cause adverse health effects. The six pollutants are: carbon monoxide (CO), lead (Pb), particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3). CAPs are the only air pollutants that are regulated by National Ambient Air Quality Standards. The standards specify the allowable concentrations of these substances in ambient air (EPA 2023a).

O_3 is not directly emitted by sources as it is formed in the atmosphere through a series of reactions that include nitrogen oxides (NO_x) and volatile organic compounds (VOC). Therefore, this study includes NO_x and VOC emissions but does not evaluate O_3 separately. NO_2 emissions are included in the NO_x emission estimates.

CO in the atmosphere contributes to the formation of CO_2 and O_3 (Center for Science Education 2017). These downstream impacts of CO production are not included in the LCA.

CAPs were calculated as an annual average over the 30-year disposal period. An annual average is the most representative unit for determining CAP impacts (versus total emissions) because they have a shorter lifespan in the atmosphere compared to GHGs and do not accumulate over time.

1.2.2.1 Carbon Monoxide

CO is an odorless colorless gas that is created when fuels are not completely combusted. CO interacts with hemoglobin when it enters the bloodstream and causes adverse health effects. At high concentrations, CO reduces the amount of oxygen in blood. This reduction causes heart difficulties in people with chronic diseases, reduced lung capacity, and impaired mental abilities (EPA 2023b).

1.2.2.2 Lead

Lead causes adverse health effects on the nervous system, the immune system, the reproductive system, the cardiovascular system, and kidney function. Infants and young children are especially sensitive to lead exposure. Being exposed to lead can contribute to behavioral problems, difficulties with learning, and a lowered IQ (EPA 2023c).

1.2.2.3 Particulate Matter

Particulate matter consists of solid and liquid particles of dust, soot, aerosols, and other matter that are small enough to remain suspended in the air for long periods of time. PM_{10} and $PM_{2.5}$ refer to matter particles that have diameters less than or equal to (≤) 10 micrometers (µm) and 2.5 µm, respectively. (A micrometer is equal to 0.001 millimeter or about 0.000039 inch.)

PM_{10} and $PM_{2.5}$ can irritate existing respiratory conditions, increase respiratory symptoms and disease, decrease long-term lung function, and potentially cause premature death. People most sensitive to particulate matter are the elderly, individuals with cardiopulmonary disease, and children. Aside from negative health effects, particulate matter causes a reduction of visibility and damage to paints and building materials (EPA 2023d).

1.2.2.4 Sulfur Dioxide

SO_2 is formed when fuel that contains sulfur is combusted. The negative health effects of SO_2 include breathing difficulty, respiratory illness, and the irritation of existing heart and blood diseases. Children and the elderly are most vulnerable to the negative effects of exposure to SO_2 (EPA 2023e).

1.2.2.5 Nitrogen Dioxide

NO_2 is emitted when fuel is burned. Common sources are vehicles and power plants. NO_2, along with other nitrogen oxides, reacts with other chemicals to form particulate matter and ozone. NO_2 can irritate airways in the respiratory system and can worsen respiratory diseases. The elderly, children, and people with asthma are at greater risk for negative health effects from NO_2 (EPA 2023f).

1.2.2.6 Ozone

O_3 causes adverse health effects such as chest discomfort; coughing; nausea; nose, throat, and lung irritation; eye irritation; and decreased lung function. O_3 is formed when VOCs and NO_x react in the presence of sunlight. Emissions from VOCs and NO_x (called *ozone precursors*) are regulated to control the formation of O_3 (EPA 2023g).

1.2.3 Other Pollutants of Concern

The LCA included the following OPOCs: hydrogen sulfide (H_2S), ammonia (NH_3), sulfuric acid (H_2SO_4), hydrogen chloride (HCl), hydrogen fluoride (HF), cadmium (Cd), mercury (Hg), and dioxins/furans as these pollutants are known to be emitted from waste-to-energy facilities and/or landfills.

As with CAPs, OPOCs were calculated annually over the assumed 30-year disposal period to provide a 30-year annual average for comparison between scenarios.

2.0 Methodology

2.1 Data Compilation

Each of the facilities provided requested data sets. If available, 5 years of operational data were used. When not available, data from 2022 were used. If data were not available from the facilities, then it was obtained from state and federal agencies, or from research literature. The source of each data set is noted in the corresponding methodology section. Calculations, assumptions, and modeling inputs/outputs are provided in **Appendix A**.

2.2 Study Boundaries

The LCA was limited to air emissions generated from the disposal of 250,000 tpy of MSW over a 30-year period. A 30-year period of operation was selected to capture known variations in landfill gas collection efficiency related to the phased installation of landfill gas wells and final cover. A 30-year period also provides a more accurate representation of CAPs and OPOC annual emissions (i.e., the slow release of landfill gas results in increasingly higher annual emissions over the active life of a landfill).

The LCA did not attempt to forecast unknown variables such as changes in waste quantities, the “greening” of the electricity grid and haul vehicles.

The emission pathways included in the LCA are:

- **Direct Emissions from Waste** includes emissions from waste combusted at WTEF or decomposed at the landfills, and emissions from landfill gas (LFG) combusted in a flare/generator.

  Direct emissions from waste were calculated using the EPA Waste Reduction Model (WARM), EPA Landfill Gas Emissions model (LandGEM), and EPA AP-42 Compilation of Air Emission Factors (AP-42) (EPA 1995 and 2009a).

  Offsets (i.e., deductions), as described in Section 2.3.1, were credited in this category for carbon storage, electricity generation and ferrous metal recovery.
- **Hauling** pertains to emissions produced by waste hauling vehicles. Hauling emissions were calculated using the EPA Motor Vehicle Emissions Simulator (MOVES), EPA Emission Factors for Greenhouse Gas Inventories (EPA 2023h), and EPA Emission Factors for Locomotives (EPA 2009b).
- **Facility Use of Fossil Fuels** include fossil fuels used to power facility equipment and vehicles. These emissions were calculated using 40 CFR Part 98 Table C-1 and C-2, EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks Table A-92 (EPA 2022), and EPA AP-42 (EPA 1995 and 2009a).
- **Facility Use of Utility Electricity** includes electricity from the grid used at the facilities. Electricity use emissions were calculated using EPA Emissions & Generation Resource Integrated Database (eGRID) (EPA 2023i).

- **Operational Materials and Chemicals** includes materials and chemicals that are routinely used at the facilities such as synthetic tarps and air pollution control reagents. This category also includes hauling emissions related to materials (e.g., auto shredder fluff, paper pulp, and petroleum-contaminated soils) used as alternative daily cover (ADC) at landfills.

  Material and chemical use emissions were calculated using Ecoinvent emission factor databases. Ecoinvent is a nonprofit organization that maintains a database of more than 18,000 Life Cycle Inventory data sets and is updated annually. Emission factors include impacts from resource extraction, manufacturing, and transportation to the facility that uses the product.

  The Ecoinvent databases were accessed using SimaPro, an LCA modeling tool. If materials could not be found in the Ecoinvent database, environmental product declarations (EPD) were used. An EPD is a document that quantifies the environmental impact of a product or material over its lifetime.

Facility normalization factors, shown in **Table 2.1**, were applied to facility data to determine the proportional amount for the LCA waste tonnage. For example, power production data from Finley Buttes was multiplied by 31.02% (250,000/806,005) to determine the amount of power to be attributed to the power generation offset for the LCA tonnage.

Table 2.1. Impact Normalization Factors

	Spokane WTEF	Roosevelt	Finley Buttes	Wenatchee
Annual Waste Quantity (tpy)	250,000	2,400,000	806,005	292,389
Normalization Factor	NA	10.42%	31.02%	85.50%

Activities not included in the LCA are described in Section 1.1.

2.3 Greenhouse Gas Emissions

GHG emissions for the pathways listed above were summed and recorded as total GHG emissions for each of the four scenarios. Global warming potentials (GWPs), as shown in **Table 2.2**, were used to convert CH_4 and N_2O to CO_2-equivalent (CO_2e) values. GWPs are factors that are applied to GHGs other than carbon dioxide to account for the difference in radiative efficiency (i.e., warming ability). GWPs are expressed relative to CO_2. The higher the GWP, the more potent the warming effects are of that specific GHG compared to CO_2.

GWPs are based on time horizons, most commonly 20 or 100 years, meaning the GWP represents the energy absorbed by that gas over a period of 20 or 100 years. Both time horizons were used in the LCA.

The time horizon is important because GHGs have varying life expectancies in the atmosphere. For example, the life expectancy of CH_4 is 10 to 12 years while the life expectancy of CO_2 is hundreds to thousands of years (EPA 2023j). Because of its shorter time frame, the 20-year time horizon prioritizes the climate impacts of potent, short-lived GHGs such as CH_4 whereas the 100-year time horizon prioritizes long-lived GHGs such as CO_2.

Table 2.2. Global Warming Potentials for 20-Year and 100-Year Time Horizons

Global Warming Potential	CO2	CH4	N2O
20-year Time Horizon	1	81.2	273
100-year Time Horizon	1	27.9	273

Source: IPCC AR6 (IPCC 2022)

GWPs from United Nations Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6), the most recent update, are used in the LCA with the exception of the Ecoinvent database which does not allow the user to update its GWPs. Ecoinvent uses the 100-year GWPs of IPCC AR4 (the use of the older values does not have a significant impact on the results or change the LCA conclusions). The emission factors are noted in **Appendix A.1**.

2.3.1 Direct Emissions from Waste

EPA WARM Version 15 (WARM) was used to estimate GHG emissions from waste for the four scenarios. WARM calculates GHG emissions in units of metric tons (MT) of CO_2e. WARM was selected for the LCA because it is an EPA model that is widely accepted as the industry standard for estimating GHG emissions. Additionally, WARM is frequently updated and has extensive documentation. Other models that evaluate life cycle emissions from waste were deemed to be less adequate than WARM for this study because they are generally updated less frequently, and their reference documentation is not as detailed or current.

2.3.1.1 Waste Reduction Model Emissions and Offsets

WARM calculated the following emissions and offsets (i.e., deductions) for the WTEF and landfill scenarios:

- **WTEF Emissions**
  - Anthropogenic CO_2 emissions (resulting from combustion of petroleum-based materials) and N_2O emissions.
  - Exclusions:
    - WARM excludes CO_2 emissions from all biogenic sources (i.e., from organic materials). Select biogenic CO_2 emissions were included in the LCA as described in Section 2.3.1.4.
    - WARM excludes CH_4 emissions because WTEFs are not a significant source of CH_4.
- **WTEF Offsets**
  - Power Generation – based on the amount of power delivered to the utility grid. The delivered power is assumed to offset non-baseload electricity from the regional grid as described in Section 2.3.1.2. Because electricity generation emits CO_2, CH_4, and N_2O emissions, all three of these GHGs are included as offsets.
  - Recovery of Ferrous Metal – based on the avoided GHG emissions from manufacturing ferrous metal from virgin resources. Because manufacturing ferrous metal creates CO_2, CH_4, and N_2O emissions, all three of these GHGs are included as offsets.

- **Landfill Emissions**
  - Methane (CH_4) Emissions – WARM considers the anaerobic conditions of a landfill to be anthropogenic. This is because under natural conditions, organic materials decompose aerobically and do not produce CH_4 emissions.
  - Exclusions:
    - WARM excludes CO_2 emissions from landfills because they are biogenic. Select biogenic CO_2 emissions were included in the LCA as described in Section 2.3.1.4.
    - WARM excludes the portion of CH_4 that is oxidized to CO_2 as it passes through landfill cover soils. These CO_2 emissions are considered to be biogenic and therefore are excluded. WARM assumes an average CH_4 oxidation rate of 20% over the life of a landfill (ICF 2020b).
    - WARM excludes N_2O emissions because landfills are not a significant source of N_2O.
- **Landfill Offsets**
  - Power Generation – based on the amount of power delivered to the utility grid. The delivered power is assumed to offset non-baseload electricity from the regional grid as described in Section 2.3.1.2. Because electricity generation emits CO_2, CH_4, and N_2O emissions, all three of these GHGs are included as offsets. For Roosevelt, RNG produced from landfill gas was assumed to be used for power generation.
  - Carbon Storage – Carbon storage in landfills is achieved through dry entombment resulting from insufficient water for decomposition to occur. The stored carbon is considered an offset because this carbon would have been released as biogenic CO_2 under normal conditions as described in Section 2.3.1.5. Carbon storage from select biogenic CO_2 emissions were excluded for reasons described in Section 2.3.1.5.
  - Exclusions – Captured heat from the combined heat and power unit at Finley Buttes was excluded from offsets because of insufficient data.

2.3.1.2 Waste Reduction Model Inputs

Waste Composition

The waste composition used for the LCA was taken from Ecology's 2020–2021 Washington Statewide Waste Characterization Study (Department of Ecology 2021) which provides composition percentages by waste type. Note that the characterization study was performed during the COVID-19 pandemic. A comparison of this study to similar studies performed before the pandemic did not reveal any obvious anomalies in the results of the 2020–2021 study.

Composition results for the East WGA (east waste generation area) were selected for the LCA since that area was based primarily on waste sampled at WTEF. The waste categories of the 2020–2021 study were more detailed than the ones used in WARM and, as a result, did not always match up with the waste categories used in WARM.

The following assumptions were made in assigning WARM waste categories to the 2020–2021 study waste categories:

- Hazardous/special wastes, furniture, synthetic textiles, shoes/purses/belts, mattresses, remainder/composite consumer products, disposable diapers, fines/sorting/residues, gable top containers, aseptic containers, and other polycoated packaging were categorized as Mixed MSW in WARM.
- Compostable paper products, compostable paper packaging, organic textiles, and remainder/composite organics were categorized as Mixed Organics in WARM.
- Painted wood, pallets/crates, engineered wood, treated wood, and natural wood were categorized as dimensional lumber in WARM.

Construction and demolition debris (including asphalt, bricks, concrete, drywall, fiberglass insulation, fly ash, and structural steel) were not included in the LCA because they are inert materials that yield negligible emissions.

The complete listing of the 2020–2021 study waste categories and the assigned WARM waste categories is provided in **Appendix A.2**.

The percentages from the 2020–2021 study were applied to the WARM categories and multiplied by the LCA waste tonnage (250,000 tpy x 30 years) to obtain tonnage values for each waste category.

Table 2.3 lists the WARM waste categories, composition percentages, and the waste tonnages used in the LCA.

Table 2.3. Waste Types Used in Waste Reduction Model

WARM Waste Category	Percentage	Waste Quantity (tons)
Mixed MSW	12.82%	961,575
Food Waste (non-meat)	11.02%	826,698
Dimensional Lumber	8.68%	651,261
Mixed Organics	7.95%	596,155
Corrugated Containers	6.04%	452,953
Low-Density Polyethylene (LDPE)	5.63%	422,594
Mixed Paper (general)	4.79%	359,210
High-Density Polyethylene (HDPE)	3.90%	292,843
Mixed Metals	3.53%	264,569
Food Waste	3.52%	264,289
Food Waste (meat only)	3.19%	238,968
Steel Cans	2.89%	216,911
Mixed Plastics	2.80%	210,058
Glass	1.94%	145,695
Carpet	1.76%	132,031
Mixed Paper (primarily residential)	1.74%	130,812
Polyethylene terephthalate (PET)	1.37%	103,000
Grass	1.17%	87,434

WARM Waste Category	Percentage	Waste Quantity (tons)
Leaves	1.17%	87,434
Wood Flooring	1.15%	86,391
Polypropylene (PP)	0.95%	71,558
Flat-Panel Displays	0.82%	61,667
Polystyrene (PS)	0.82%	61,277
Asphalt Shingles	0.80%	60,153
Mixed Electronics	0.67%	50,621
Aluminum Cans	0.48%	35,947
Branches	0.47%	35,043
Tires	0.45%	33,518
Newspaper	0.43%	32,149
Aluminum Ingot	0.23%	17,360
Office Paper	0.22%	16,712
Magazines/Third-Class Mail	0.19%	14,465
Hard-Copy Devices	0.19%	14,453
Polylactic acid (PLA)	0.04%	2,874
Copper Wire	0.03%	2,404
Vinyl Flooring	0.02%	1,248
Polyvinyl Chloride (PVC)	0.003%	261
TOTAL WASTE INCLUDED IN ANALYSIS	93.90%	7,042,594
TOTAL WASTE EXCLUDED FROM ANALYSIS[1]	6.10%	457,406

Note:

[1] The construction and demolition material excluded from the analysis is a mix of asphalt, bricks, concrete, drywall, fiberglass insulation, fly ash, and structural steel.

Energy Grid Mix

Uploaded power to the energy grid from WTEF or the landfill gas-to-energy facility at Finley Buttes is calculated in WARM as an offset (i.e., GHG reduction). The offset is based on an emission factor for non-baseload power (baseload power plants are not affected by small power generators).

The emission factor WARM uses for calculating the offsets from non-baseload power are for the Pacific Region which includes Washington, Oregon, and California. The emission factor for non-baseload electricity in this region is 0.151 MT CO_2e/MMBtu (one million British thermal units) or 1,136 lb CO_2e/MWh (megawatt-hour) (ICF 2020b) and is representative of a combination of natural gas and coal powered plants.

The reasons renewables are not included in the non-baseload power emission factor are twofold. First, hydropower is a baseload power source and therefore is not displaced by power from a small power generator. Second, wind and solar are intermittent power sources whereas WTE and LFGTE (landfill gas to electricity) are firm power sources. Uploaded power from a firm, small power source displaces non-baseload, firm power sources (natural gas or coal). This assumption is consistent with EPA's eGRID Technical Guide 2021 (EPA 2021).

Because of the uncertainty of the resource mix on the electrical grid over the next 30 years, the emissions rate for the non-baseload electricity offset are assumed to be constant for all years in the LCA.

Landfill Gas Collection Efficiency

Landfilling waste results in anaerobic decomposition of organic waste. This produces LFG that mainly consists of CH_4 and CO_2 (ICF 2020a). LFG collection and control systems (GCCS) are installed to collect and combust the gas.

GCCS and landfill final cover are installed in phases over the operational life of a landfill. Collection efficiency is lowest in the early years of operation when there are fewer gas wells and little to no final cover. Collection efficiency is highest when the entire GCCS is installed and the entire landfill is capped with an impermeable geomembrane. Collection efficiency was selected based on local climate and operational information received from the three landfills.

All of the landfills in the LCA were assumed to have a “typical collection.” WARM considers the “typical collection” category to represent the average landfill within the United States. Collection efficiency is also affected by the amount of rainfall a landfill experiences. For arid region landfills, such as the landfills in Scenarios 2–4, WARM assigns a typical overall collection efficiency of 68.2%.

Typical collection assumes no gas collection in Year 1, 50% gas collection in Years 2 to4, 75% gas collection in Years 5 to14, 82.5% in Years 15 to 29, and 90% in Years 30 to 100. The overall landfill gas collection efficiency is calculated as follows:

> [(Year 1 LFG Generated × 0%) + (Years 2 to 4 LFG Generated × 50%) + (Years 5 to 14 LFG Generated × 75%) + (Years 15 to 29 LFG Generated × 82.5%) + (Years 30 to 100 × 90%)] / Years 1 to 100 LFG Generated]

Fate of Captured Landfill Gas

WARM inputs for captured LFG were as follows:

- **Roosevelt** captured LFG is sent to the H.W. Hill Renewable Natural Gas Facility located next to the landfill. LFG is upgraded to RNG and is injected into the Williams Northwest Pipeline. For determining the GHG offset it was assumed that the RNG is used to generate electricity.
- **Finley Buttes** captured LFG is combusted in combined heat and power system. The electricity is sold to the local utility, Pacific Corp. Recovered heat is sold to Cascade Specialties, a food processing plant. Offsets from recovered heat were not included in the LCA because of insufficient data.
- **Wenatchee** captured LFG is combusted in a flare.

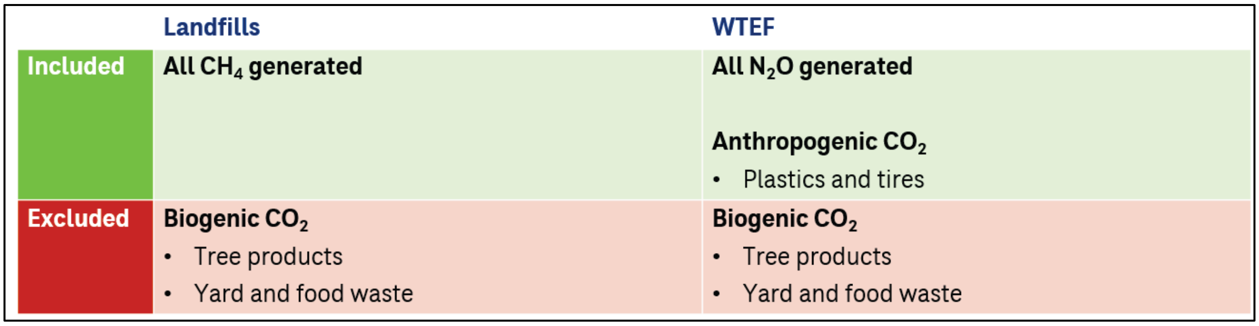
2.3.1.3 Global Warming Potentials

To calculate CO_2e emissions, WARM uses the 100-year GWPs listed in the IPCC’s Fourth Assessment Report (AR4) released in 2007. For the LCA, CO_2e emission results from WARM were revised using the 20-year and 100-year GWPs from AR6, released in 2023 (IPCC 2022).

2.3.1.4 Biogenic Carbon Dioxide and Anthropogenic Methane

Biogenic CO_2 emissions include CO_2 emissions resulting from the combustion (WTEF) or decomposition (landfill) of organic wastes. As shown in **Figure 2.1**, WARM excludes all biogenic CO_2 emissions. The exclusion is because biogenic CO_2 emissions are part of the closed-loop, natural carbon life cycle and, therefore, are not contributing to climate change (i.e., all CO_2 emitted from organic matter is later removed from the atmosphere through photosynthesis).

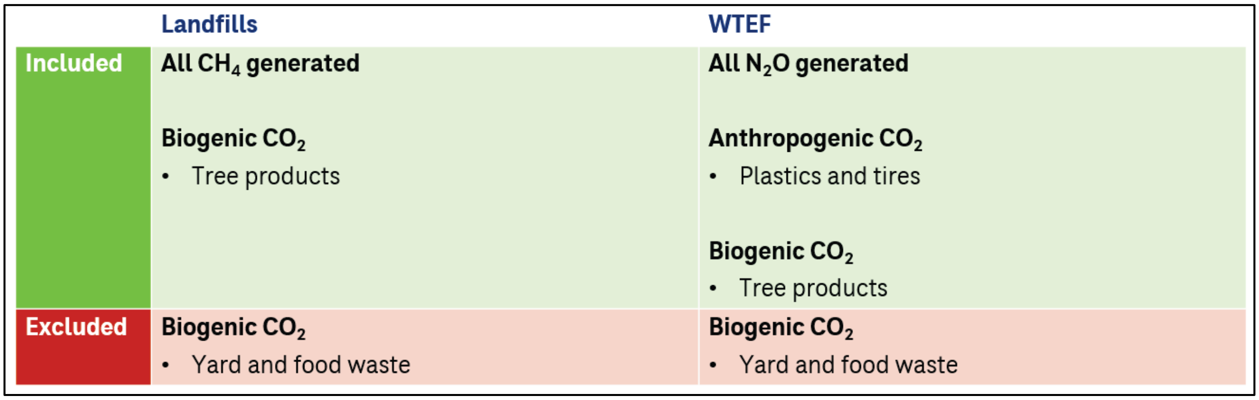
WARM includes CH_4 emissions generated from the anaerobic decomposition of waste in landfills because these emissions are considered to be anthropogenic (i.e., the anaerobic decomposition that takes place in landfills and results in CH_4 emissions would not take place in nature).



	Landfills	**WTEF**
Included	**All CH_4 generated**	**All N_2O generated** **Anthropogenic CO_2** • Plastics and tires
Excluded	**Biogenic CO_2** • Tree products • Yard and food waste	**Biogenic CO_2** • Tree products • Yard and food waste

Figure 2.1. Waste Reduction Model Assumptions for Biogenic and Anthropogenic Emissions

For this LCA, biogenic CO_2 emissions associated with tree products were included, as shown in **Figure 2.2**. Tree products have a much longer carbon life cycle than other organic wastes such as food waste and yard waste and, as such, contribute to the short-term impacts of climate change. Given the urgent need to curb further warming, it was deemed appropriate to include these CO_2 emissions.



	Landfills	**WTEF**
Included	**All CH_4 generated** **Biogenic CO_2** • Tree products	**All N_2O generated** **Anthropogenic CO_2** • Plastics and tires **Biogenic CO_2** • Tree products
Excluded	**Biogenic CO_2** • Yard and food waste	**Biogenic CO_2** • Yard and food waste

Figure 2.2. Spokane Life Cycle Assessment Inclusion of Biogenic Carbon Dioxide from Tree Products

Biogenic CO_2 from tree products was estimated by calculating the annual tonnage of tree products, which includes wood flooring, corrugated containers, dimensional lumber, mixed paper, newspaper, and compostable packaging. This value was calculated by multiplying the waste composition percentages of the tree product categories by 250,000 tpy, as shown in **Table 2.4**.

Table 2.4. Tree Product Waste Composition and Annual Tonnage for Landfill Gas Emissions Model

Tree Product Category	Waste Composition Percentage	Annual Tonnage (tpy)
Dimensional Lumber	8.7%	21,709
Wood Flooring	1.2%	2,880
Newspaper	0.6%	1,554
Mixed Paper	6.8%	16,891
Mixed Organics	5.1%	12,871
Corrugated Containers	6.0%	15,098

These annual tonnages were then input into LandGEM to calculate biogenic CO_2 emissions.

LandGEM was also used to estimate the amount of LFG that would be combusted. Combustion emissions were based on the calculated LFG from LandGEM and on emission factors from EPA 40 CFR Subpart C of Part 98.

WTEF biogenic CO_2 emissions from tree products were calculated based on the tonnage assumed from tree products shown in **Table 2.4** and emissions factors from EPA 40 CFR Subpart C of Part 98.[3] The emission factors used are provided in **Appendix A.2**.

2.3.1.5 Landfill Carbon Storage

Since organic materials do not fully decompose in landfills a portion of the carbon remains stored in the landfill indefinitely. This carbon storage would not normally occur under natural conditions, so it is counted as an offset in WARM as shown in **Figure 2.3**. The reasoning for the offset is that any carbon removed from the closed-loop, natural carbon life cycle results in an equal amount of anthropogenic carbon removed from the atmosphere.

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[3] Calculated GHG from tree products also contain small quantities of CH_4 and N_2O as they are not captured in the WARM model.

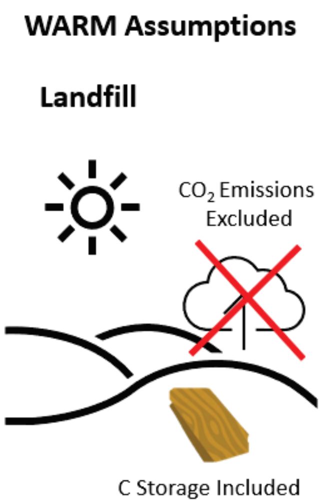


Figure 2.3. Waste Reduction Model Assumptions on Biogenic Carbon Dioxide Emissions and Landfill Carbon Storage

As described in Section 2.3.1.4, biogenic CO_2 emissions from tree products were included in this LCA because of their long carbon life cycle. By counting the CO_2 emissions, we are no longer treating these emissions as part of the biogenic closed-loop system. Therefore, to avoid double counting, the carbon storage offset for tree products was excluded, as shown in **Figure 2.4**.

The exclusion was achieved by calculating the carbon storage potential of each tree product using WARM's carbon storage factors and then subtracting the total carbon storage potential for tree products from the WARM-generated carbon storage potential. Calculations are provided in **Appendix A.2**.

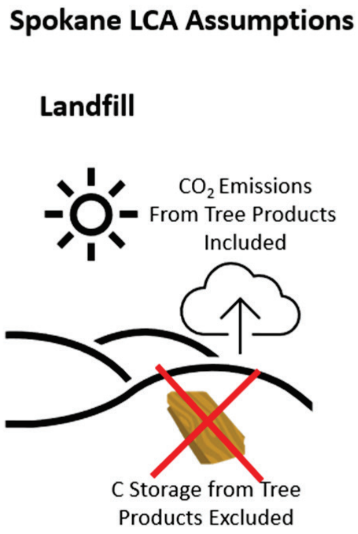


Figure 2.4. Spokane Life Cycle Assessment Assumptions on Biogenic Carbon Dioxide Emissions and Landfill Carbon Storage

The full data related to Section 2.3.1 can be found in **Appendix A.2**.

2.3.2 Greenhouse Gas Emissions from Waste and Ash Hauling

GHG emissions from truck hauling were computed using estimated vehicle miles traveled (VMT), truck hauling capacities, and emission factors from the EPA MOVES3 model. The capacities were used to determine the number of round trips the trucks would make for waste and ash hauling. The following assumptions were made for truck hauling:

- Waste is hauled by Diesel Kenworth T880 trucks with a load capacity of 19 tons
- Ash is hauled by Diesel Peterbilt 367 trucks with a load capacity of 21 tons
- Both vehicles were modeled as a diesel-combination long-haul truck in MOVES3
- Emission factors representative of 2024 in the EPA MOVES3 model were used (projections for future vehicle mixes were excluded because of uncertainty)
- Trucks use the same route when backhauling
- MOVES3 emission factors are averaged for loaded and unloaded conditions (accounting for hauling and backhaul)

The complete list of MOVES3 inputs for truck hauling is provided in **Appendix A.3**.

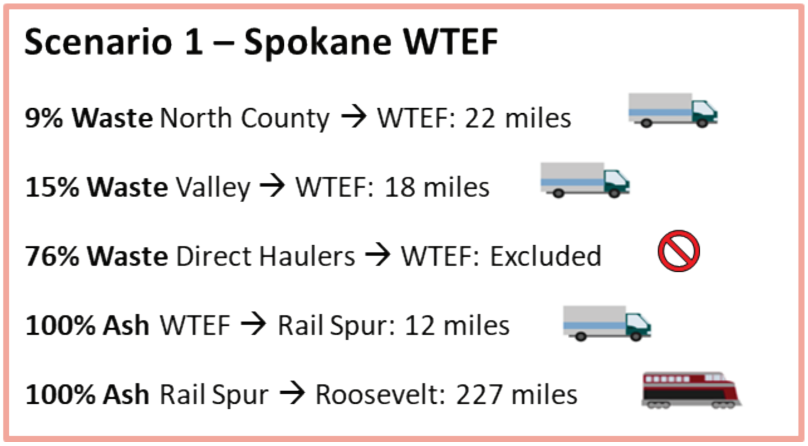
GHG emissions from rail hauling were computed using estimated rail miles traveled, weight of hauled cargo, and emission factors from the EPA 2023 GHG Emission Factors Hub (EPA 2023h).

The following assumptions were made for rail hauling:

- The EPA rail emission factors are intended for use in the distance-based method defined in the Greenhouse Gas Protocol Scope 3 Calculation Guidance (GHGP 2013). As such, the emission factors had to be multiplied by the weight of hauled cargo and the estimated VMT.
- It was assumed that the trains use the same route for return trips.
- To account for backhauling without overestimating the emissions, the estimated round-trip rail miles traveled and the average weight of the cargo being hauled and backhauled (i.e., 50% of hauled weight) were used in the calculations. The weight of cargo being backhauled is zero because there is no cargo being backhauled. In using emission factors for the distance-based method, it is not recommended to include the weight of vehicle, only the weight of the cargo (GHGP 2013).
- GHG emissions from the rail hauling were included for the two scenarios involving the BNSF railway (Scenarios 1 and 2).

Appendix A.3 provides the complete list of assumptions for calculating emissions from rail.

Figure 2.5 through **Figure 2.8** display the one-way hauling distances and modes for each scenario.



Scenario 1 – Spokane WTEF

9% Waste North County → WTEF: 22 miles 🚚

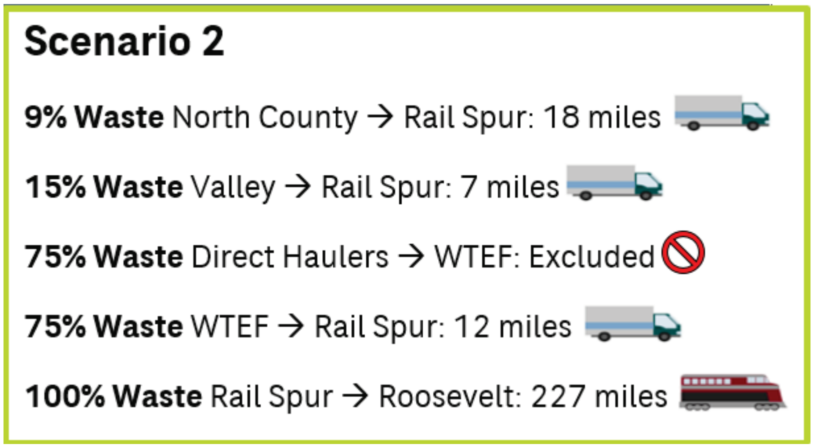
15% Waste Valley → WTEF: 18 miles 🚚

76% Waste Direct Haulers → WTEF: Excluded 🚫

100% Ash WTEF → Rail Spur: 12 miles 🚚

100% Ash Rail Spur → Roosevelt: 227 miles 🚆

Figure 2.5. Scenario 1 One-Way Hauling Distances



Scenario 2

9% Waste North County → Rail Spur: 18 miles 🚚

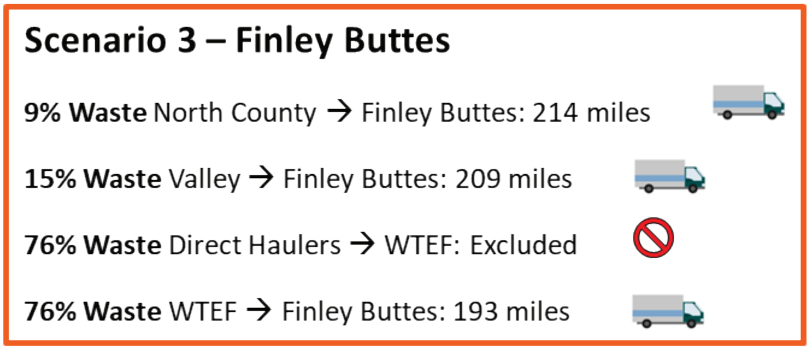
15% Waste Valley → Rail Spur: 7 miles 🚚

75% Waste Direct Haulers → WTEF: Excluded 🚫

75% Waste WTEF → Rail Spur: 12 miles 🚚

100% Waste Rail Spur → Roosevelt: 227 miles 🚆

Figure 2.6. Scenario 2 One-Way Hauling Distances



Scenario 3 – Finley Buttes

9% Waste North County → Finley Buttes: 214 miles 🚚

15% Waste Valley → Finley Buttes: 209 miles 🚚

76% Waste Direct Haulers → WTEF: Excluded 🚫

76% Waste WTEF → Finley Buttes: 193 miles 🚚

Figure 2.7. Scenario 3 One-Way Hauling Distances

Scenario 4 – Wenatchee

9% Waste North County → Wenatchee: 179 miles

15% Waste Valley → Wenatchee: 175 miles

76% Waste Direct Haulers → WTEF: Excluded

76% Waste WTEF → Wenatchee: 158 miles

Figure 2.8. Scenario 4 One-Way Hauling Distances

Appendix A.3 provides the full data related to Section 2.3.2.

2.3.3 Greenhouse Gas Emissions from Fossil Fuel Use

GHG emissions from fossil fuel use were determined by using recorded quantities of fuel usage from the facilities and emission factors for fuel combustion. The upstream emissions associated with raw material extraction, production, and transmission of the fuels were not included in this analysis as they are outside of the study boundaries.

The types of fuel used at the facilities are as follows:

- **Spokane WTEF** Diesel, propane, and natural gas
- **Roosevelt** Diesel, propane, and gasoline
- **Finley Buttes** Diesel and gasoline
- **Wenatchee** Diesel and gasoline

Fuel quantities were normalized for each facility based on annual waste tonnages received at the facility. Quantities were measured in units of fuel per ton of MSW. This number was multiplied by 250,000 tpy to calculate fuel usage for the LCA scenarios.

Assumptions for the fuel emission factors are as follows:

- **Diesel, Propane, and Gasoline** CO_2 emission factors from combustion are from 40 CFR Part 98 Table C-1. CH_4 and N_2O emission factors from combustion are from EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks Table A-92 (EPA 2022).
- **Natural Gas** CO_2 emission factors from natural gas combustion are from 40 CFR Part 98 Table C-1. CH_4 and N_2O emission factors from natural gas combustion are from 40 CFR Part 98 Table C-2.

Appendix A.4 provides the full data related to Section 2.3.3.

2.3.4 Greenhouse Gas Emissions from Utility Electricity Use

All four facilities purchase electricity from the grid. Power use for the LCA was calculated by normalizing power for each facility on a kWh (kilowatt-hour)/MSW ton basis and multiplying by 250,000 tpy.

GHG emissions were obtained by applying an emission factor that reflected the local electricity grid to the calculated electricity used. This factor was obtained from EPA's Emissions & Generation Resource Integrated Database (eGRID). The emission factors for CO_2, CH_4, and N_2O represent the 2021 operation in the Western Electricity Coordinating Council (WECC) Northwest (NWPP) grid subregion, which includes Washington, Oregon, Idaho, and portions of Montana, Wyoming, Utah, Arizona, Nevada, and California. The boundaries are drawn based on electrical grid attributes and not on strict geographical boundaries (EPA 2021). The resource mix for this grid subregion is 40.8% hydropower, 21.1% natural gas, 19% coal, 11.5% wind, 3.0% nuclear, 2.3% solar, 1.1% biomass, 0.7% geothermal, and 0.6% other fossil fuels. The emission factor used is 638.4 lb CO_2e/MWh using the 100-year GWP and 641.5 lb CO_2e/MWh using the 20-year GWP. These emission rates exclude upstream emissions associated with fossil fuel raw material extraction, production, and transmission to power plants.

Appendix A.4 provides the full data related to Section 2.3.4.

2.3.5 Greenhouse Gas Emissions from Materials, Chemicals, and Alternative Daily Cover

The scope of these emissions included the following:

- The LCA accounts for the embodied carbon (i.e., CO_2e emissions associated with a product's life cycle) of materials and chemicals used for operation and maintenance at the facilities. Examples include grate blocks, boiler tubes, and anhydrous ammonia at WTEF, and tarps used for alternate daily cover at two of the landfills. Embodied carbon for consumed materials at the Finley Butte LFGTE facility were not included because of insufficient data.
- Emissions from hauling off-site cover materials to the facilities. For example, trucking auto shredder fluff from the Portland region to Finley Buttes or contaminated soil from Seattle to Roosevelt.
- Emissions from the H.W. Hill Renewable Natural Gas Facility's purification of Roosevelt Landfill's landfill gas to RNG.

The following elements were not included in these calculations:

- All of the landfills are located in an arid climate and use evaporation ponds to manage leachate. Leachate residual in the ponds is landfilled. The LCA assumed no GHG emissions from this management practice. Any GHG emissions from electricity used to pump leachate to an evaporation pond were accounted for in Section 2.3.4.
- GHG emissions related to excavation of on-site soils for landfill cover were accounted for in fossil fuel use described in Section 2.3.3.
- Direct GHG emissions from petroleum-contaminated soils (used for alternate daily cover) were assumed to be minor and were not included in the LCA.

GHG emissions from embodied carbon were calculated by multiplying the quantity of each material or chemical by an emission factor from the Ecoinvent life cycle inventory database (Ecoinvent, Version 3.7.1, compiled in March 2021).

SimaPro was used to search the Ecoinvent database for the emission factors used in the LCA. The emission factors account for impacts from material sourcing, manufacturing, and transportation to the customer.

Where available, the 5-year average quantity of the material or chemical was used. Where a 5-year average was not available, an annual consumption value was used to represent all the years.

Emission factors with the following characteristics were chosen when possible:

- *Market* (chosen over *transformation*): *Market* processes include inputs from production as well as inputs of transport processes. *Transformation* excludes transport processes.
- *Cut-off* (chosen over *Allocation at the Point of Substitution [APOS]*): *Cut-off* emission factors consider carbon emissions as the responsibility of the first user (i.e., the polluter pays).

  For the first user of a material, the carbon footprint of the material sent to a landfill is the same as the carbon footprint of that material sent to a recycling facility. For example, oils used at WTEF have the same emission factor regardless that some is disposed and some is sent for recycling.

  For the second user of a material, the emission factor only accounts for the carbon footprint related to the recycling process. No other emissions are included (e.g., Finley Buttes' use of auto shredder fluff does not have embodied carbon impacts because the landfill is not the first user of the materials).

  APOS emission factors consider the responsibility of wastes shared between the first user and subsequent users.
- *Geographical Location Global (GLO)* (chosen over *Rest of the World [RoW]*): *GLO* emission factors represent average global production. *RoW* is representative of the global average excluding regions with emission factors specific to a certain geography.

EPA's Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI 2.1) method was used for the impact assessment. The TRACI tool displays the data directly in kg (kilograms) CO_2e. It does not display the impacts by CO_2, CH_4, and N_2O. Also, the TRACI tool uses the 100-year GWP values (EPA 2012). GHG calculations performed using the 100-year GWP values underestimate the emissions from embodied carbon compared to using 20-year GWP for reasons already mentioned.

Stainless steel did not have an Ecoinvent emission factor that could be applied as an exact match or a proxy. Therefore, an environmental product declaration (Construction Specialties 2020) was used to identify an emission factor.

To calculate emissions from hauling off-site cover materials, selected emission factors for waste hauling were multiplied by the round-trip VMTs. The methodology and emission factor sources are the same as the methodology in Section 2.3.2.

2.3.5.1 Greenhouse Gas Emissions from Renewable Natural Gas Facility

Avoided emissions from RNG's offset of electricity is accounted for in the WARM model ("Landfill Offsets" in Section 2.3.1.1).

This study includes the consumed materials that facilitate the transformation of Roosevelt's LFG into RNG. GHG emissions generated from energy and materials consumed for the H.W. Hill Renewable Natural Gas Facility (at Roosevelt) were estimated using Ecoinvent emission factors from the SimaPro model. The RNG production rate per cubic foot of LFG sent to the H.W. Hill Renewable Natural Gas Facility was used to estimate the quantity of RNG produced from 250,000 tpy of MSW. This quantity was then multiplied by the Ecoinvent emission factor for RNG production to estimate the GHG emissions.

The Ecoinvent emission factor assumes the LFG has the following characteristics:

- Composition of LFG going into the facility: CH_4: 63.3%, CO_2: 33.4%, N: 3.2%, H_2S: 0.0005%
- Composition of finished gas: CH_4: 96%, CO_2: 2%, N: 1%, H_2S: 0.0003%
- Activities included: facility's electricity consumption, raw gas compression, H_2S removal, gas conditioning, and CH_4 enrichment of the gas
- Fugitive emission rate for CH_4 is 1.25%

This emission factor is derived from information from a manufacturer of biogas upgrading plants, and the impacts are modeled off performing this process in Switzerland, as this is the only emission factor available in the SimaPro modeling software. The electricity component of the emission factor is 0.673 kg CO_2e/kWh (Switzerland). This is compared to the electricity emission factor used for this analysis of 0.290 kg CO_2e/kWh (from the NWPP eGRID subregion, as presented in Section 2.3.4). Therefore, this study limitation causes an overstatement of Roosevelt's emissions.

Appendix A.1 provides the full data related to Section 2.3.5.

2.4 Criteria Air Pollutant Emissions

2.4.1 List of Criteria Air Pollutants

CAPs include the following pollutants:

- Carbon monoxide (CO)
- Lead (Pb)
- Particulate matter (PM_{10} and $PM_{2.5}$)
- Sulfur dioxide (SO_2)
- VOC
- Nitrogen oxides (NO_x)

Note that PM emissions were only calculated for stack emissions. Fugitive PM emissions, such as windblown PM from cover soils, were not included in the LCA because of budget and schedule limitations.

2.4.2 Criteria Air Pollutants Emissions Estimates

Air emissions from landfills are released over many years as the waste slowly decomposes. Air emissions from a WTEF are released immediately upon combustion. The difference in emission rates between these two disposal methods must be carefully considered because health impacts are directly related to pollutant concentration levels at any point in time.

Emissions steadily increase in active landfills until waste is no longer received. Consequently, for the 30-year study period, emissions in Year 1 are the lowest and emissions in Year 30 are the highest.

As such, an annual average (i.e., sum emissions over 30 years and divide by 30) is the most representative unit for determining CAP impacts (versus total emissions calculated for GHGs) because they have a shorter lifespan in the atmosphere compared to GHGs and do not accumulate over time.

The methodology for estimating CAP emissions for each process considered in the LCA is described below. **Appendix A** provides detailed calculations.

- **Direct Emissions from Waste**

  For WTEF, CAP emissions were calculated using emission inventories and stack test results received from the facility for 2018 to 2022. For the landfills, CAP emissions were calculated using LandGEM for surface emissions (VOC and CO) and a combination of AP-42 and stack test results for combustion emissions.

  Appendix A.2 provides calculations. LFG collection efficiency and fate of the captured LFG assumptions are the same as those noted in Section 2.3.1.

- **Waste Hauling**

  CAP emissions associated with truck hauling were estimated using VMT and vehicle emission factors provided in EPA MOVES3. CAP emissions associated with hauling by rail were calculated using the EPA's Emission Factors for Locomotives Technical Highlights (EPA 2009). **Appendix A.3** provides calculations.

- **Fossil Fuel Use**

  CAP emissions associated with fuel use were calculated using AP-42 emission factors. **Appendix A.4** provides the specific sources from AP-42 and calculations.

- **Electricity Use**

  CAP emissions associated with electricity use were considered outside of the scope of this analysis because impacts from CAP emissions are localized and electricity generation for the grid is not necessarily local.

- **Materials, Chemicals, and Alternative Daily Cover**

  CAP emissions associated with resource extraction and manufacturing of the materials and chemicals used for facility operation were considered outside of this analysis because impacts from CAP emissions are localized. It was assumed that these materials and chemicals were manufactured outside of the region of this study. CAP emissions associated with hauling off-site ADC (by truck and rail) were calculated using the same methodology as hauling waste (see previous bullet point titled "Hauling"). **Appendix A.1** provides calculations.

2.5 Other Pollutants of Concern Emissions

2.5.1 Other Pollutants of Concern Selection

The following list of OPOCs were evaluated:

- NH_3
- Cd
- Dioxins/Furans
- HCl
- HF
- H_2S
- Hg
- H_2SO_4

OPOC for WTEF were derived from the WTEF's 5-year average Annual Emission Inventory and Stack Test reports from 2018 to 2022.

Not all OPOCs were relevant for all processes considered in the LCA.

2.5.2 Other Pollutants of Concern Emission Estimates

Methodology for calculating OPOCs was similar to the methodology used for CAPs. The 30-year annual average emissions (i.e., sum emissions over 30 years and divide by 30) were used to compare WTEF to the landfill scenarios.

The methodology for estimating OPOC emissions for each process considered in the LCA is described below. **Appendix A** provides detailed calculations.

- **Direct Emissions from Waste**

  For the WTEF, OPOC emissions (except for H_2S, which is not emitted at the WTEF) were calculated using an emission inventory and stack test results received from the facility for 2018 to 2022. For the landfills, OPOC emissions were calculated using LandGEM for surface emissions (H_2S and Hg) and AP-42 Factors for combustion emissions (HCl). **Appendix A.2** provides calculations.

- **Waste Hauling**

  OPOC emissions associated with hauling were estimated using VMT and vehicle emission factors provided in the EPA MOVES3. Ammonia emissions were not calculated for rail transport because of insufficient data. **Appendix A.3** provides calculations.

- **Fossil Fuel Use**

  Only Cd and Hg of the OPOCs are relevant for site fuel use. Cd and Hg emissions were calculated for natural gas usage at the WTEF using AP-42 emission factors. AP-42 does not provide Cd, Hg, or other OPOC emission factors for diesel or propane which are also used as fuels at WTEF. **Appendix A.4** provides the specific sources from AP-42 and calculations.

- **Electricity Use**

  OPOC emissions associated with electricity use were considered outside of the scope of this analysis because impacts from OPOC emissions are localized and electricity generation for the grid is not necessarily local.

- **Materials, Chemicals, and ADC**

  OPOC emissions associated with resource extraction and manufacturing of the materials and chemicals consumed were excluded from the LCA because impacts from OPOC emissions are localized and it was assumed that these materials and chemicals were manufactured outside of the region of this study.

  OPOC emissions associated with hauling off-site ADC (by truck and rail) were calculated using the same methodology as waste hauling. **Appendix A.1** provides calculations.

2.6 Items Not Addressed in the Life Cycle Assessment

The following analyses were not addressed in the LCA:

- **Dispersion Modeling**

  Dispersion models are used to predict concentrations of pollutants at select downwind locations and can be used to assess the impacts of CAP and OPOC emissions on local air quality.

- **Human Health Risk Assessment**

  A human health risk assessment, using the results of air pollutant dispersion modeling, can be used to quantify health risks associated with inhalation exposure from facility emissions. In 2001, the City of Spokane conducted a health risk assessment that estimated cancer and noncancer health risks to Spokane area residents resulting from long-term exposure to stack emissions from the facility. The impacts were assessed and deemed to be acceptable (Pioneer Technologies Corporation 2001).

- **On-Road Accidents**

  Fatalities, injuries, and property damage rates per VMT can be estimated for the hauling activities of each scenario using accident data from various transportation agencies.

- **Social Cost Considerations**

  Social costs can be calculated by applying social cost metrics to emission estimates and used to quantify the impacts of air emissions on quality of life. The social cost of GHG emissions quantifies the costs borne by society resulting from climate change impacts. The social costs of CAPs and OPOC can be quantified for public health impacts resulting from degradation of local air quality.

- **Environmental Justice**

  An environmental justice assessment can be conducted to determine whether disproportionate burden related to climate change and degradation of air quality is being placed on disadvantaged communities near the facilities selected for the LCA.

- **Ecological Risk Assessment**

  An ecological risk assessment could be performed to assess adverse effects on the soil, water, crops, animals, wildlife, and vegetation in the areas near the facilities.

- **Greening of the Grid**

  2021 EPA eGRID emission factors were used to calculate emissions associated with power generation for the 30-year study period. Emission factor estimates could be developed to reflect the anticipated increased use of renewables (i.e., greening of the grid) to provide a potentially more accurate estimate of GHG offsets for the LCA scenarios.

2.7 Summary of Limitations

Table 2.5 provides a summary of the LCA limitations and their assessed impact on the results. Only the exclusion of fugitive PM emissions is thought to have significantly impacted the results.

Table 2.5. Summary of Limitations

Limitation	Impact on Results
Ecoinvent database used for materials and chemicals emissions estimate uses GWPs from AR4.	No impact. The differences between AR4 vs. AR6 are insignificant.
The 2020-2021 Waste Characterization Study used for the waste composition of this study was performed during the COVID-19 pandemic.	No impact. Comparison of the 2020–2021 Study to a similar study performed in 2015–2016 did not reveal any significant anomalies.
Some of the waste categories in the 2020-2021 Waste Characterization Study do not have an exact match with the WARM waste categories.	Assumed to be minimal. An estimated 31% of waste did not have an exact match between the study and WARM waste categories. However, in nearly all cases an appropriate WARM waste category was available.
Offsets of GHGs from the heat generated from Finley Butte's combined heat and power system were not included in the LCA.	No impact. The WARM offset assumption is conservative and enough to account for power and heat at Finley Buttes.
Offsets for RNG produced from Roosevelt LFG assumed the RNG was used for power generation.	No impact. Difference between offset for power versus heat is minimal.
Consumed materials for the Finley Butte LFG to energy were not included in LCA.	Minimal. GHG emissions from material consumption were less than 2% of the total emissions.
The emission factor used in Ecoinvent for RNG production at Roosevelt is based on an RNG facility operating in Switzerland.	Minimal. Emission factors for Switzerland are slightly higher but comparable.
Fugitive PM emissions from landfill activities such as moving waste and soil, windblown dust from land disturbance, and vehicle travel on unpaved surfaces were not included.	Assumed to be significant. PM from fugitive sources are typically high in comparison to stack emissions.
Ammonia emissions were not calculated for rail transport as data was not available.	Assumed to be minimal. Ammonia emissions from locomotive diesel engines are assumed to be low based on known low ammonia emissions from truck diesel engines.

3.0 Comparative Analysis

3.1 Greenhouse Gas Emissions

Table 3.1 and **Table 3.2** present total net GHG emissions (i.e., GHG emissions minus GHG offsets) for 20-year and 100-year GWPs, respectively, and a breakdown of GHG emission sources and offsets. Landfill GHG emissions are significantly higher for the 20-year GWP time horizon because landfill emissions are driven mainly by CH_4, which is a potent short-lived GHG. For WTEF, emissions are slightly less for the 20-year GWP time horizon because the electricity offset is higher when CH_4 is considered more potent. **Appendix A** provides the full calculations.

Table 3.1. Net Greenhouse Gas Emissions Using 20-Year Global Warming Potentials

	Sources of Emissions (MT CO_2e)						Offsets (MT CO_2e)			Total (MT CO_2e)
	Anthropogenic Direct Emissions	Biogenic Direct Emissions	Hauling	Fuel Consumption	Electricity Consumption	Materials Consumption	Electricity Generation	Source Reduction and Recycling	Carbon Storage	
Spokane WTEF	3,891,830	3,261,970	17,964	60,618	8,583	40,521	-2,338,664	-713,061	0	4,229,761
Roosevelt	5,611,131	395,688	51,685	17,814	1,637	10,795	-301,171	0	-497,534	5,290,045
Finley Buttes	5,611,131	395,688	253,573	14,392	949	18,686	-301,171	0	-497,534	5,495,714
Wenatchee	9,917,420	395,688	208,787	24,182	2,512	410	0	0	-501,165	10,047,834

Note: GHG emissions are representative of the disposal of 250,000 tpy of MSW for a 30-year period. For landfills, the total GHG emissions from decomposition, regardless of when they are released, are included. For Roosevelt, the electricity required for upgrading LFG to RNG is included under "Material Use" and not "Electricity" because it is done off-site.

Key: MTCO_2e = metric tons of carbon dioxide equivalent

Table 3.2. Net Greenhouse Gas Emissions Using 100-Year Global Warming Potentials

	Sources of Emissions (MT CO_2e)						Offsets (MT CO_2e)			Total (MT CO_2e)
	Anthropogenic Direct Emissions	Biogenic Direct Emissions	Hauling	Fuel Consumption	Electricity Consumption	Materials Consumption	Electricity Generation	Source Reduction and Recycling	Carbon Storage	
Spokane WTEF	3,891,830	3,244,838	17,924	60,519	8,542	40,521	-2,270,409	-713,061	0	4,280,704
Roosevelt	1,927,963	395,172	51,530	17,721	1,629	10,767	-300,379	0	-497,534	1,606,868
Finley Buttes	1,927,963	395,172	253,408	14,317	944	18,674	-300,379	0	-497,534	1,812,565
Wenatchee	3,407,586	395,172	208,651	24,053	2,500	410	0	0	-501,165	3,537,207

Note: GHG emissions are representative of the disposal of 250,000 tpy of MSW for a 30-year period. For landfills, the total GHG emissions from decomposition, regardless of when they are released, are included. For Roosevelt, the electricity required for upgrading LFG to RNG is included under "Material Use" and not "Electricity" because it is done off-site.

Key: MTCO_2e = metric tons of carbon dioxide equivalent

3.1.1 Greenhouse Gas Emission Sources

The largest source of GHG emissions for all scenarios is anthropogenic direct emissions. For the landfill scenarios, the anthropogenic direct GHG emissions are significantly higher for the 20-year GWP in comparison to the 100-year GWP because the 20-year GWP for CH_4 (methane is the only contributor to anthropogenic direct emissions for landfills) is nearly three times higher than its 100-year GWP.

For WTEF, the anthropogenic direct emissions include N_2O emissions and CO_2 emissions resulting from the combustion of plastic packaging, rigid plastics, carpeting, tires, asphalt shingles, vinyl flooring, and various parts of electronic devices. The anthropogenic direct GHG emissions for WTEF do not increase when comparing 20-year GWP to 100-year GWP because CO_2 and N_2O are both long-lived gases and, therefore, their potencies are not impacted by varying time horizons.

The second largest source of GHG emissions for all scenarios is biogenic direct emissions. This constitutes the GHG emissions from the combustion of tree products (biogenic CO_2 for WTEF) and from decomposition of tree products (biogenic CO_2 for landfills). The biogenic direct emissions for landfills are nearly ten times lower than WTEF due to the dry tombing effect in the arid climate landfills (i.e., a portion of the food and yard waste carbon remains stored in the landfills as a result of incomplete decomposition).

Hauling emissions are the next highest source of emissions overall. The hauling emissions for Finley Buttes and Wenatchee scenarios are more than an order of magnitude higher than the hauling emissions for WTEF and 4 to 5 times more than the Roosevelt scenario. Finley Buttes and Wenatchee scenarios both require significant trucking to dispose of waste, whereas the Roosevelt scenario relies on rail. WTEF is local to Spokane and does not require significant trucking; therefore, it has the lowest hauling emissions.

GHG emissions for fuel, materials, and electricity consumption are all significantly lower than the previously mentioned categories. For fuel consumption, WTEF has more than double the emissions than the landfill scenarios because of the higher natural gas consumed at WTEF. The landfill scenarios consume more diesel than WTEF, but this does not outweigh the large quantity of natural gas used at WTEF. For electricity, WTEF uses the most electricity and the landfill scenarios have roughly 3 to 9 times less GHG emissions and electricity consumption than WTEF. WTEF has the highest emissions for materials consumption as there are more consumables used in WTEF than in landfill scenarios.

3.1.2 Greenhouse Gas Emission Offsets

The largest emissions offset for WTEF is electricity generation, whereas the largest emissions offsets for landfills is carbon storage. **Table 3.3** shows the total expected electricity generation calculated by WARM for all scenarios. WTEF is expected to generate roughly 8 times more electricity than the landfill scenarios with LFG capture for electricity generation (Roosevelt and Finley Buttes). As a result, the emissions offset for electricity generation for WTEF is much higher than the landfill scenarios. WTEF has an additional offset in terms of source reduction and recycling because of ferrous metals recovery.

The largest emissions offset for the landfill scenarios is landfill carbon storage. For Roosevelt and Finley Buttes, which both have LFG capture for electricity generation, the landfill carbon storage offset is within the same order of magnitude as the electricity offset.

The emissions offsets do not change significantly when looking at a 20-year GWP compared to a 100-year GWP because most of the emissions offsets are composed of CO_2 emissions. The slight difference between the two time horizons come from CH_4 emissions.

Table 3.3. Waste Reduction Model Calculated Electricity Generation

Scenario	Total Expected Electricity Generation from WARM (MWh)	Annualized Expected Electricity Generation from WARM (MWh/year)
Spokane WTEF	4,510,944	150,365
Roosevelt	583,025	19,434
Finley Buttes	583,025	19,434
Wenatchee	0	0

3.2 Criteria Air Pollutant Emissions

CAPs estimate for the four scenarios are presented in **Table 3.4**. CAP emissions are presented as a 30-year annual average for the reasons described in Section 1.2.2.

Table 3.4 shows that the VOC emissions from the landfill scenarios are greater than the WTEF. The NO_x, PM_{10}, $PM_{2.5}$, and SO_2 emissions are greater in the WTEF than the landfill scenarios. Note that PM values are based on stack emissions only (i.e., do not include fugitive emissions at the facilities). The CO emissions from the WTEF are comparable to the CO emissions of the landfills. Pb emissions only occur in the WTEF combustion process. Notably, Wenatchee has no CAP emissions associated with materials hauling because all cover materials used at the facility come from on-site.

Table 3.4. Criteria Air Pollutants Emissions

Emission Source	Annual Average Emissions – CAPs (tpy)						
	CO	NO_x	SO_2	PM_{10}	$PM_{2.5}$	Pb	VOC
Spokane WTEF							
Combustion	25.73	324.84	8.30	12.90	10.32	5.91E-03	1.18
Site Fuel	3.14	11.44	0.57	0.71	0.71	7.79E-06	0.78
Waste and Ash Hauling	1.22	4.98	4.01E-03	0.16	0.14	–	0.23
Total Emissions	***30.09***	***341.27***	***8.87***	***13.77***	***11.17***	***5.92E-03***	***2.18***
Republic Service's Roosevelt Regional Landfill							
Surface Emissions	2.02	–	–	–	–	–	8.44
Combustion	35.77	49.11	0.74	1.02	1.02	–	0.51
Site Fuel	3.45	15.87	1.04	1.11	1.11	–	1.39
Waste and Ash Hauling	4.05	18.86	0.01	0.58	0.53	–	0.86
Materials Hauling	0.32	1.68	1.16E–03	0.05	0.05	–	0.08
Total Emissions	***45.61***	***85.52***	***1.80***	***2.76***	***2.71***	***–***	***11.27***
Waste Connection's Finley Buttes Landfill							
Surface Emissions	2.02	–	–	–	–	–	8.44
Combustion	29.48	3.90	0.75	1.02	1.02	–	0.81
Site Fuel	2.97	13.69	0.90	0.96	0.96	–	0.10
Waste Hauling	11.77	23.38	0.03	1.02	0.47	–	1.04
Materials Hauling	0.87	1.72	2.30E–03	0.07	0.03	–	0.08
Total Emissions	***47.10***	***42.70***	***1.68***	***3.07***	***2.48***	***–***	***10.47***
WM's Greater Wenatchee Regional Landfill							
Surface Emissions	2.02	–	–	–	–	–	8.44
Combustion	6.77	3.52	2.85	0.14	0.14	–	0.06
Site Fuel	4.99	22.84	1.50	1.60	1.60	–	2.18
Waste Hauling	9.69	19.25	0.03	0.84	0.38	–	0.86
Materials Hauling	–	–	–	–	–	–	–
Total Emissions	***23.47***	***45.61***	***4.37***	***2.58***	***2.13***	***–***	***11.54***

Notes: NO_x, SO_2, and PM emissions are emitted when landfill gas is combusted at the flare and/or generator. Totals may not be exact because of rounding. Note that fugitive PM emissions were not included in the LCA.
Key: ADC = alternative daily cover, VOC = volatile organic compound, CO = carbon monoxide, NO_x = nitrogen oxides, PM_{10} = particulate matter that have diameters ≤10 micrometers, $PM_{2.5}$ = particulate matter that have diameters ≤2.5 micrometers, SO_2 = sulfur dioxide, "–" = no emissions

3.3 Other Pollutants of Concern Emissions

OPOC emissions were estimated for the four scenarios and are presented in **Table 3.5**. As with CAPs, OPOCs are presented as a 30-year annual average.

Table 3.5. Other Pollutants of Concern Emissions

Emission Source	Average Annual Emissions – OPOC (tpy)							
	H_2S	NH_3	H_2SO_4	HCl	HF	Cd	Hg	Dioxins/ Furans
Spokane WTEF								
Combustion	–	7.66	4.90	7.77	0.19	4.69E-04	3.22E-03	2.23E-08
Site Fuel	–	–	–	–	–	1.71E-05	4.05E-06	–
Waste and Ash Hauling	–	0.01	–	–	–	–	8.66E-09	2.23E-11
Total Emissions	***–***	***7.66***	***4.90***	***7.77***	***0.19***	***4.86E-04***	***3.22E-03***	***2.23E-08***
Republic Service's Roosevelt Regional Landfill								
Surface emissions	0.18	–	–	–	–	–	9.54E-06	–
Combustion	–	–	–	0.95	–	–	–	–
Site Fuel	–	–	–	–	–	–	–	–
Waste and Ash Hauling	–	0.01	–	–	–	–	3.06E-08	8.77E-11
Materials Hauling	–	–	–	–	–	–	5.16E-09	1.61E-11
Total Emissions	***0.18***	***0.01***	***–***	***0.95***	***–***	***–***	***9.57E-06***	***1.04E-10***
Waste Connection's Finley Buttes Landfill								
Surface emissions	0.18	–	–	–	–	–	9.54E-06	–
Combustion	–	–	–	0.95	–	–	–	–
Site Fuel	–	–	–	–	–	–	–	–
Waste Hauling	–	0.19	–	–	–	–	6.29E-08	6.84E-11
Materials Hauling	–	0.01	–	–	–	–	2.59E-09	5.04E-12
Total Emissions	***0.18***	***0.21***	***–***	***0.95***	***–***	***–***	***9.60E-06***	***7.34E-11***
WM's Greater Wenatchee Regional Landfill								
Surface emissions	0.18	–	–	–	–	–	9.54E-06	–
Combustion	–	–	–	0.95	–	–	–	–
Site Fuel	–	–	–	–	–	–	–	–
Waste Hauling	–	0.16	–	–	–	–	5.18E-08	5.63E-11
Materials Hauling	–	–	–	–	–	–	–	–
Total Emissions	***0.18***	***0.16***	***–***	***0.95***	***–***	***–***	***9.59E-06***	***5.63E-11***

Note: Totals may not be exact because of rounding.
Key: ADC = alternative daily cover, H_2S = hydrogen sulfide, NH_3 = ammonia, H_2SO_4 = sulfuric acid, HCl = hydrogen chloride, HF = hydrogen fluoride, Cd = cadmium, Hg = mercury, "–" = no emissions

Table 3.5 shows that not all OPOCs are emitted in every scenario. For example, H_2S emissions are only found in the surface emissions of the landfill scenarios. Likewise, H_2SO_4, HF, and Cd are all found in the WTEF scenario but none of the landfills.

For the OPOCs generated by all four scenarios (NH_3, HCl, Hg, and dioxins/furans), the quantities produced by the WTEF are orders of magnitude larger than the quantities produced by the landfill scenarios. As with CAPs, Wenatchee has no OPOC emissions associated with materials hauling because all cover materials used at the facility come from on-site.

4.0 Summary of Results and Conclusions

An LCA of the Spokane WTEF and three landfills in eastern Washington and Oregon was performed for the following pollutants:

- Total GHG emissions representative of 30 years of operation (MT)
- 30-year annual average emission rate of CAPs (tpy)
- 30-year annual average emission rate of OPOCs (tpy)

4.1 Greenhouse Gas Emissions

Figure 4-1 presents total net GHG emissions for 20-year GWP. As noted in Section 3.1, the GWP time horizon has a major impact on the results. Using the 20-year GWP time horizon, the WTEF has the lowest GHG emissions of all the facilities in the LCA. This is explained by the fact that:

- Landfills generate CH_4, a highly potent GHG with a 20-year GWP that is 81 times higher than CO_2
- Landfills are not able to capture and destroy all the CH_4 generated (nearly a third of CH_4 is emitted to the atmosphere due to the inefficiencies of landfill gas management)
- On a per-ton basis, power generation at WTEF is 8 times higher than at the landfills. Accordingly, WTEF was credited with a much larger GHG offset for power generation
- WTEF received a sizeable offset for ferrous metal recovery whereas none of the landfills recover metal

The landfills are located much farther away from the waste generators and, therefore, require longer hauling distances which equates to GHG emissions that are three to 14 times higher than WTEF.

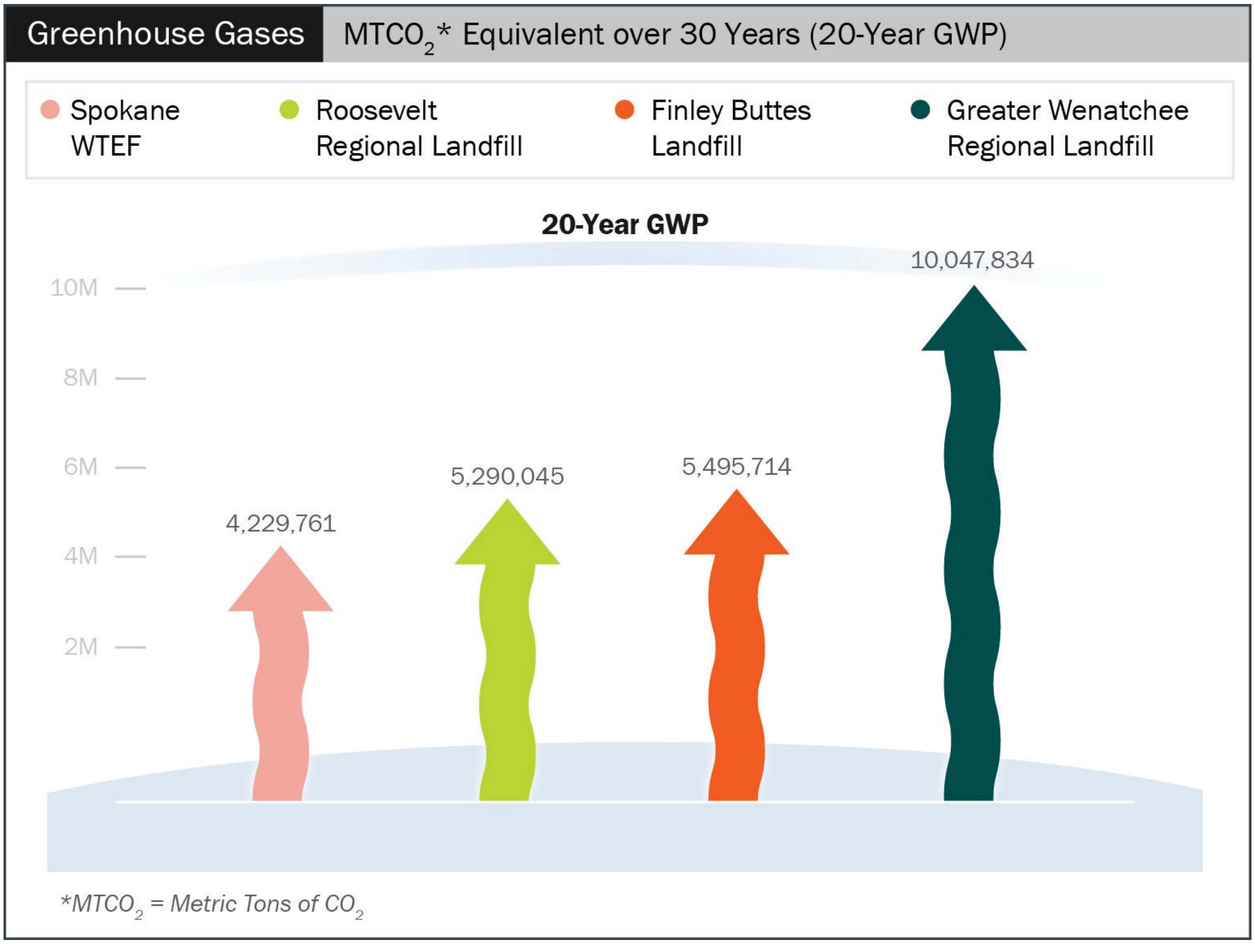


Figure 4.1. Net Greenhouse Gas Emissions (in Metric Tons of Carbon Dioxide Equivalent) Using 20-Year Global Warming Potentials

As shown in **Figure 4.2**, using the 100-year GWP time horizon, Roosevelt has the lowest GHG emissions of all facilities for several reasons, including the lower GWP for CH_4 compared to the 20-year GWP. Other major differences include:

- The arid climate results in lower CH_4 generation at the landfills compared to regions with more rainfall, resulting in overall lower GHG emissions for these landfills comparably (i.e., higher carbon storage).
- Fate of LFG at the landfills creates variation in the results for the landfills (i.e., Wenatchee flaring all of its CH_4 and receiving no offsets from electricity generation, compared to Roosevelt and Finley Buttes receiving offsets for LFG utilization).
- The difference in hauling methods (i.e., hauling by rail has much lower emissions compared to hauling by truck).
- The emission factor for non-baseload power in the Pacific region is lower than many other regions of the United States because of a greater usage of natural gas as opposed to coal for power generation in this region, resulting in less advantage for WTEFs in terms of power offsets.

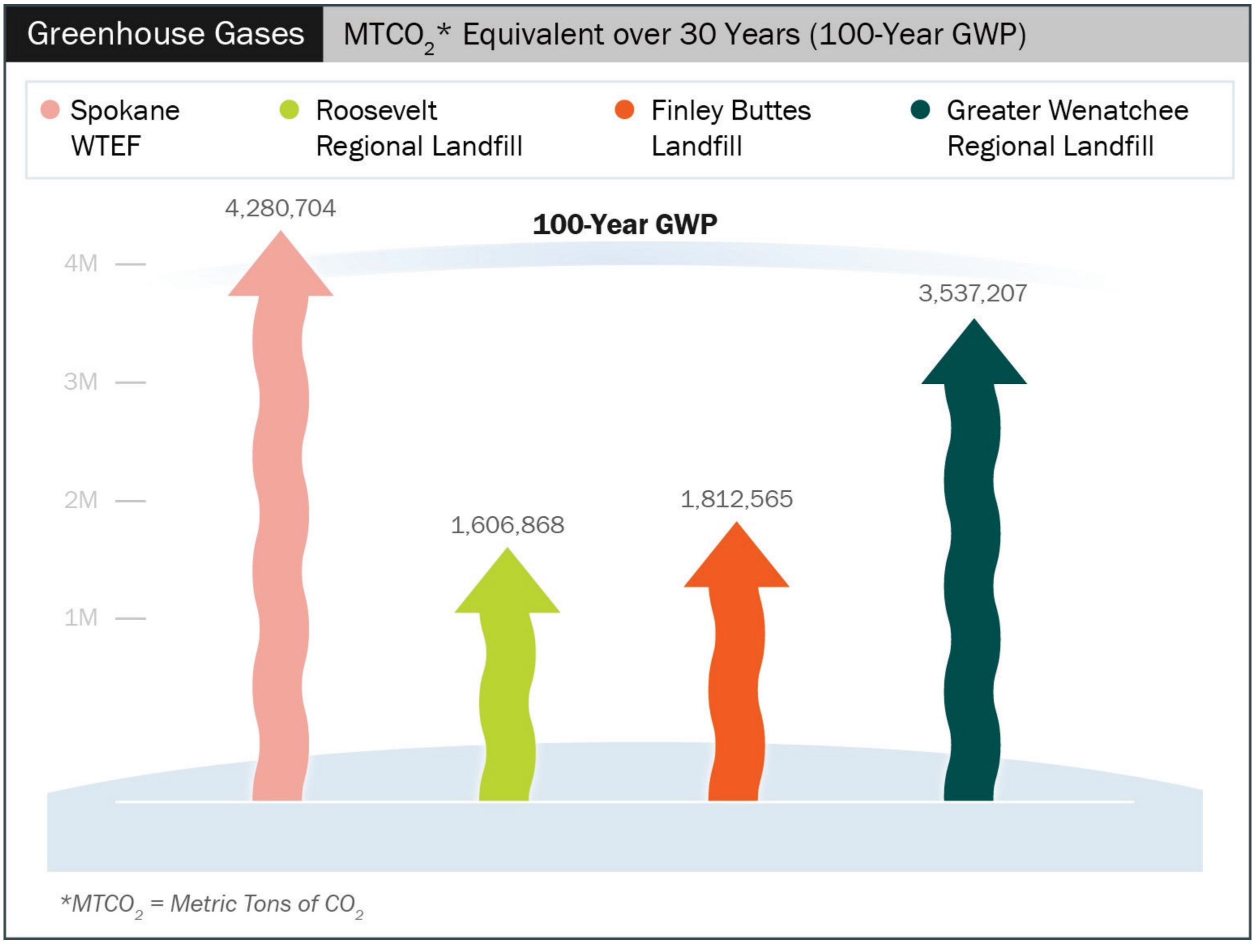


Figure 4.2. Net Greenhouse Gas Emissions (in Metric Tons of Carbon Dioxide Equivalent) Using 100-Year Global Warming Potentials

While EPA and Ecology uses the 100-year GWP for annual inventory requirements, CDM Smith recommends using the 20-year GWP time horizon results as they highlight the importance of addressing potent GHGs such as CH_4 in the urgent need to curb climate change. This recommendation is not intended to minimize concern about CO_2 emissions but rather stress the importance of addressing all types of GHGs (particularly those that are highly potent). This recommendation aligns with the United Nations Environment Programme's emphasis on the importance of methane in addressing climate change. In the United Nations Environment Programme's May 6, 2021, press release, the Executive Director of the United Nations Environment Programme, Inger Andersen stated "Cutting methane is the strongest lever we have to slow climate change over the next 25 years and complements necessary efforts to reduce carbon dioxide. The benefits to society, economies, and the environment are numerous and far outweigh the cost. We need international cooperation to urgently reduce methane emissions as much as possible this decade." (UN Environment Programme 2021).

4.2 Criteria Air Pollutants

As shown in **Figure 4.3**, WTEF emits the most NO_x, SO_2, PM_{10} and $PM_{2.5}$, while the largest emitters of CO are Finley Buttes and Roosevelt. All three landfills produce about five times more VOCs than the WTEF.

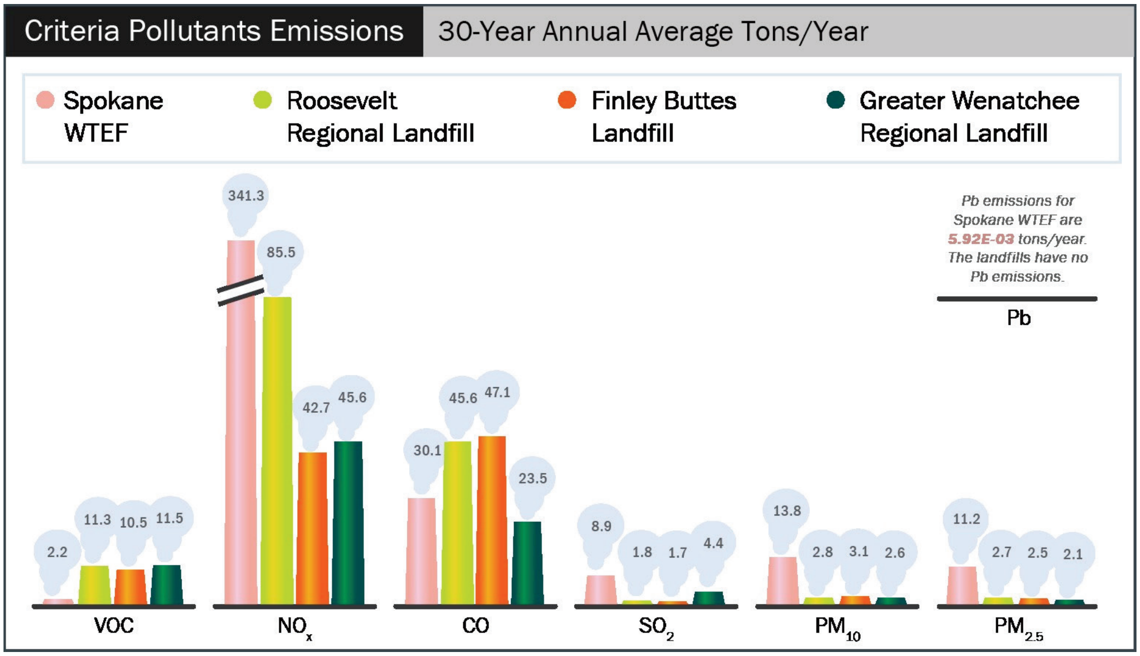


Figure 4.3. Criteria Air Pollutants Emissions

4.3 Other Pollutants of Concern

Of the eight pollutants selected for OPOCs, four of them are not emitted at every facility in the LCA. As shown in **Table 4.1**, Spokane WTEF does not generate H_2S emissions whereas H_2SO_4, HF, are Cd are not emitted at the three landfills.

Due to its combustion process, WTEF emits more of the four pollutants common to all of the facilities (NH_3, HCl, Hg, and Dioxin/Furans) than any of the landfills.

Table 4.1. Annual Emissions of Other Pollutants of Concern

Scenarios	Annual Average Emissions – OPOC (tpy)							
	H_2S	NH_3	H_2SO_4	HCl	HF	Cd	Hg	Dioxins and Furans
Spokane WTEF	–	7.66	4.90	7.77	0.19	4.86E-04	3.22E-03	2.23E-08
Roosevelt Landfill	0.18	0.01	–	0.95	–	–	9.57E-06	1.04E-10
Finley Buttes Landfill	0.18	0.21	–	0.95	–	–	9.60E-06	7.34E-11
Wenatchee Landfill	0.18	0.16	–	0.95	–	–	9.59E-06	5.63E-11

5.0 Other Considerations

There are numerous factors that can be considered when comparing sustainability of waste management options. However, schedule and budget constraints require that a prioritized list of factors be selected. For this study, air emissions pertaining to climate change and human health were chosen by Ecology to assess sustainability and in particular, net GHG emissions. The following sustainability factors that were not included in the LCA are offered for further consideration:

- **Land Use:** Landfills are more land resource intensive than WTEFs because the ash produced by a WTEF results in 90% less volume compared to landfilling MSW.
- **Management of Sensitive Wastes:** Sensitive wastes from law enforcement agencies and pharmaceutical waste are sent to WTEF for destruction. If WTEF were to cease operations the waste would need to be sent to a hazardous waste incinerator, increasing the need for that resource. Additional hauling emissions would also be incurred, as the nearest hazardous waste incinerators are in western Oregon and northern Utah.
- **Facilitation of *Zero Waste to Landfill* Goals:** Some corporations with *Zero Waste to Landfill* sustainability goals choose to take their waste to a WTEF rather than landfill it.
- **Long-Term Care:** Landfilled ash from WTEF is more stable than landfilled MSW resulting in reduced monitoring and maintenance activities during long term care (i.e., the 30-year period after closure). For example, the prolonged operation of leachate and gas collection systems in MSW landfills requires electricity and fuel that result in GHG emissions.
- **Longer Haul Routes:** If the WTEF were to cease operations, waste currently being hauled to the WTEF would need to travel much longer distances to the landfills. While the emissions associated with this change were considered in this study, the impact on traffic and potential accidents were not. It is possible that this additional distance could result in greater impacts on local communities living along the hauling routes because of the traffic and potential accidents.
- **Review of Air Permits**: Air permit limits are set for each of the facilities that are deemed protective of human health; therefore, qualitative statements could be made about health impacts of facilities their permits.

6.0 Recommendations for Carbon Reduction

Recommendations for reducing carbon emissions for the scenarios in the LCA include:

- **Hauling:** Use rail instead of trucks where available. Switch to electric vehicle (EV) trucks if trucks are the only viable option.
- **Electricity:** Use electricity generated from renewable sources by either siting solar panels and/or wind turbines or selecting green power options available from power utilities.
- **Fossil Fuel Use:** Consider transitioning from equipment using petroleum-based fuels to battery powered equipment that can be charged from renewable sources.
- **Landfill Gas Management:** Utilize landfill gas for power and heating to displace fossil fuels (Wenatchee is only flaring their landfill gas). Implement more frequent capping of landfill areas that have reached final grades to reduce GHG surface emissions.
- **Recycling:** Expand metals recovery at WTEF from ferrous metals to ferrous and nonferrous metals.
- **Organics Ban:** Ban the landfilling of food and yard waste to reduce methane emissions as these waste types decompose quickly – releasing methane prior to installation of gas collection wells.

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