TETRA TECH CASCADIA CONSULTING GROUP

MEMO

To:	King County Natural Resources and Parks Solid Waste Division	Date:	January 23, 2024
Cc:		Memo No.:	5
From:	Tetra Tech Project Team	File:	197-2022-0133

Subject:	King County Long-Term Waste Disposal Options Study Environmental Impact Factors and Assumptions for County Consideration and Approval

1.0 INTRODUCTION

The Tetra Tech Team (TT Team) was retained by King County (County) to conduct a Long-Term Waste Disposal Options Study (Study) to evaluate disposal options for the Cedar Hills Regional Landfill after it closes. The goal of this Study is to provide information to the County and their stakeholders on potential long-term waste disposal options and their respective costs and benefits.

As we progress in evaluating disposal options based on the criteria established for the study, we have certain assumptions and modeling input parameters that have been developed for the environmental and social criteria analysis. The purpose of this memo is to provide the County with a list of environmental impact factors and assumptions that are proposed to be used in the comparative analysis for the long-term waste disposal options. This includes an Approval Check List containing the environmental parameters that will be used to create the various outputs for the five (5) different long-term disposal option scenarios.[1] Section 2 contains the Approval Checklist that the County can use to approve the environmental parameters and/or leave comments for each parameter. Sections 3 through 11 document each of the environmental parameters that the County will be reviewing from the Checklist provided in Section 2.

We are requesting the County review and approve and/or provide comments back to the TT Team within two (2) weeks of receipt of the memo.

2.0 APPROVAL CHECKLIST

Below is the summary of items for King County's approval. Columns, "KC Approved" and "KC Comments", are provided to document acknowledgement of each data item.

[1] This also includes the Environmental Impact Factors Data Sources MS Excel Workbook which is attached to the email.

Tetra Tech
21700 Copley Drive, Suite 200
Diamond Bar, CA 91765
Tel 909.960.7777

Table 1. Environmental Impact Factors Approval Checklist

Item	File Location	KC Approved?	KC Comments
Environmental Impact Factors Data Sources	Excel file: *KingCountyApprovalWorkbook_100523* *Tab: Data Source Matrix*		
Environmental Impacts Evaluation Results Reporting	This document		
Energy Grid Assumptions	This document		
Train Assumptions	This document		
Miles Assumptions: Trains & Trucks	This document		
Fuel Consumption Assumptions: Trains & Trucks	This document		
Landfill Gas Management Assumptions	This document		
BTUs Assumptions	This document		
FTE Assumptions	This document		

3.0 ENVIRONMENTAL IMPACT FACTORS

Environmental impact factors use data from life cycle assessments and other studies to estimate the amount of emissions, energy use, or other impacts associated with a specified quantity of an activity, such as a gallon of diesel used in a truck. For reference, Table 2 shows the environmental impact factors that King County previously approved to be used for this study.

We have attached an Excel file with the proposed data sources for each pathway and material on King County's list. Please note:

- Material types that are not suitable for pathways are noted by the shading in the matrix. We plan to rely on MSW-DST/SwolfPy for most emission factors, supplemented with other sources including WARM, literature, and life cycle inventory databases such as from Ecoinvent. Note that MSW-DST and SwolfPy draw from the same background data sources and are used interchangeably.
- Definitions of Data Sources:

Database	Definition
MSW-DST	The Municipal Solid Waste Decision Support Tool (MSW-DST) can be used to identify and evaluate cost and environmental aspects associated with specific waste management strategies or existing systems. It can also be used to identify costs and environmental aspects of proposed strategies such as those designed to meet recycling and waste diversion goals, quantify potential environmental benefits associated with recycling, identify strategies for optimizing energy recovery from MSW, and evaluate options for reducing greenhouse gases, air pollutants, and environmental releases to water bodies or ecosystems.
swolfpy	SwolfPy is a free open-source solid waste management (SWM) life-cycle assessment (LCA) optimization framework with built-in parametric and Monte Carlo sensitivity and uncertainty analysis capabilities.
ecoinvent	Ecoinvent database provides users with information on the environmental impact of their products and services.
GREET	The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model is a life-cycle model from the Argonne National Laboratory.

4.0 ENVIRONMENTAL IMPACTS EVALUATION RESULTS REPORTING

The approach will be to report each environmental impact in their corresponding units presented in the previously provided memorandum titled Final Evaluation Criteria Definitions and Metrics, dated March 27, 2023. Impact categories, units, and methodologies are listed in 2 below.

Table 2. Environmental Impact Factors

Impact/Inventory Category and Description	Unit	LCIA/LCI Methodology
Total energy demand. Measures the total energy from point of extraction; results include both renewable and non-renewable energy sources	MJ	Cumulative energy inventory
Non-renewable energy demand. Measures the fossil and nuclear energy from point of extraction	MJ	Cumulative energy inventory
Water consumption. Freshwater withdrawals which are evaporated, incorporated into products and waste, transferred to different watersheds, or disposed into the sea after usage	L H_2O	Cumulative water consumption inventory
Acidification potential (air quality). Quantifies the acidifying effect of substances on their environment. Important emissions: SO_2, NO_x, NH_3, HCl, HF, H_2S	kg SO_2 equivalents (eq)	TRACI v2.1

Eutrophication potential (water quality). Assesses impacts from excessive load of macro-nutrients to the environment. Important emissions: NH_3, NO_x, COD and BOD, N and P compounds	kg N eq	TRACI v2.1
Global warming potential. Represents the heat trapping capacity of the greenhouse gases. Important emissions: CO_2 fossil, CH_4, N_2O	MT CO_2 eq	IPCC (2013) GWP 100a
Smog formation potential (air quality). Determines the formation of reactive substances (e.g., tropospheric ozone) that cause harm to human health and vegetation. Important emissions: NO_x, BTEX, NMVOC, CH_4, C_2H_6, C_4H_{10}, C_3H_8, C_6H_{14}, acetylene, Et-OH, formaldehyde	kg O_3 eq	TRACI v2.1
Human Health Toxicity—Cancer Potential. The comparative toxic unit (CTU) characterizes the probable increase in cancer related morbidity (from inhalation or ingestion) for the total human population per unit mass of chemical emitted.	CTUh	USEtox™ 2.02
Human Health Toxicity—Noncancer Potential. A CTU for noncancer characterizes the probable increase in noncancer related morbidity (from inhalation or ingestion) for the total human population per unit mass of chemical emitted.	CTUh	USEtox™ 2.02

Using these environmental impact factors, tonnage scenarios, and transport distances, the Tetra Tech Team will produce a table summarizing the potential environmental impacts of each option.

5.0 ENERGY GRID ASSUMPTIONS

- King County-specific energy grid resources that include 2040 to 2060 projections are not available. Instead, we plan to use regional data from the US Energy Information Administration (EIA) for the current and projected grid mixes.
- Additionally, renewable energy is grouped into one category, so we plan to assume a constant energy mix of 88% hydroelectric, 10% wind, 2% biomass, 1% solar. Numbers rounded to the nearest decimal place.

6.0 TRAIN ASSUMPTIONS

RECOMMENDATIONS

The Tetra Tech project team's recommendation to the County is to model the locomotive power assumptions on the following assumptions, which are based on discussions with the railroads on where they currently are and where they are forecast to be in the foreseeable future with electric locomotive technology for use in mainline service operations:

- Do not assume any all-electric powered mainline locomotives.

Assume locomotives are powered by a combination of low sulfur diesel and 30% biodiesel blend fuel.

- NOTE: The railroads may continue to increase their use of renewable biofuels over the next several decades. On April 22, 2022, the Federal Railroad Administration (FRA) announced its Rail Industry Climate Challenge (Challenge). The agency is asking owners and operators along the national rail network, and manufacturers of rail equipment, to commit to reach net-zero greenhouse gas emissions (GHG) by 2050. This is not a law and is up to the railroads to comply with. It is difficult to predict the exact percentage that the locomotive fuel blend will be when CHRLF closes in 2040 (e.g., 30%-40% or higher, etc.) but the Tetra Tech believes an estimate of 30% biodiesel blend fuel is conservative based on existing UPRR-stated forecasts for the foreseeable future.

SUPPORTING DISCUSSION

For the County's consideration, here is the most current (September 2023) status of the Union Pacific (UP) Railroad's recent information on their ESG initiatives. Our recommendations are based on this information.

Union Pacific Target: Reduce absolute Scope 1 and Scope 2 GHG emissions and GHG emissions on a well-to-wheel basis from locomotive operations by 26% by 2030 from a 2018 baseline.

Locomotives: Nearly 175 high- and low-horsepower locomotives were overhauled in 2020, meaning they were completely rebuilt to meet more stringent emissions standards. Each modernization results in an approximate 53% reduction in emissions and an additional 5% reduction in fuel consumption per engine. These overhauls improved the reliability of UP's locomotive fleet, which resulted in a 14% increase in locomotive productivity compared to 2019 while reducing emissions through better fuel efficiency. The UP completed approximately 100 modernizations in 2021 and around 120 in 2022. They anticipate continuing this pace of modernization in future years.

- Progress Rail approved the use of up to 20% biodiesel blend in the vast majority of Electro-Motive Diesel (EMD) locomotives that UPRR operates.
- The UPRR has introduced Genset and Green Goat locomotives for service in California, Texas, and Chicago, with fuel-savings of more than 20% compared to diesel locomotives in similar use.
- $100M investment in 20 new battery-electric locomotive operations and technology. These are not for mainline rail service, but rather only in local railroad facilities for repositioning railcars and only in select locations.
- Increasing the percentage of low-carbon fuels consumed to 10% of total diesel consumption by 2025 and pushing that number to 26% by 2030.

Similar to car manufacturers adding more hybrids and electric vehicles to their lineups, railroads are also exploring the use of low- and zero-emission technology.

- **Battery-Electric Locomotives:** Railroads are testing and piloting battery-powered locomotives in switching yards to potentially replace over-the-road diesel engines at some point in the future.
- **Hydrogen Fuel Cell Locomotives:** Railroads are also researching the use of hydrogen fuel cell locomotives for long-haul shipments and switching as well. One day these could replace diesel locomotives altogether.

[3] Oregon DEQ RMA Overview of Scenario Modeling 2023

7.0 MIILES ASSUMPTIONS: TRAINS AND TRUCKS

Facility_Name	Landfill_Name	Transport Segment	TransportMode_Name	Miles
WEBR	*All*	*Garbage TS to Railyard*	*Truck*	*20*
WEBR	*Columbia*	*Railyard KC to Landfill*	*Rail*	*325*
WEBR	*Roosevelt*	*Railyard KC to Landfill*	*Rail*	*330*
WEBR	*Finley Buttes*	*Railyard KC to Landfill*	*Rail*	*352*
WEBR	*Columbia*	*Garbage Rail to Landfill Face*	*Shuttle*	*2*
WEBR	*Roosevelt*	*Garbage Rail to Landfill Face*	*Shuttle*	*6*
WEBR	*Finley Buttes*	*Garbage Rail to Landfill Face*	*Shuttle*	*9*
All	*-*	*Garbage TS to Processing facility*	*Truck*	*20*
All	*-*	*Processing facility to Railyard*	*Shuttle*	*20*
Mass Burn	*Roosevelt*	*Ash Disposal – Processing facility to ash landfill*	*Rail*	*330*
Mass Burn	*-*	*Metal Residuals - processing facility to local metal recycling facility*	*Truck*	*20*
*Pyrolysis / Gasification**	*Roosevelt*	*Ash Disposal – Processing facility to ash landfill*	*Rail*	*330*
RDF	*-*	*RDF - processing to distributor*	*Truck*	*TBD*

* Note: Quantity of ash estimated to be approximately 5% greater than Mass Burn.

8.0 FUEL CONSUMPTION ASSUMPTIONS: TRAINS AND TRUCKS

RECOMMENDATION

TransportMode_Name	Vehicle type (make or model if known)	Fuel or energy type	Fuel/energy used per ton-mile
Electric Truck in KC	Class 8 Kenworth T680E	Electric	3 kWh/mi Total Load: 20 tons 2.5 MPGe
Diesel Truck	Class 8 Kenworth T800	Diesel	3.5 MPGe Total Load: 28 tons 96,000 Gross Combined Weight Rate (GCWR)
Rail	General Electric (GE) Evolution Series Locomotive, now owned by Wabtec.	Diesel	1 ton of freight around 500 miles on 1 gallon of fuel
Diesel Drayage Shuttles at Landfill	Class 8 Trucks - Peterbilt's	Diesel	1 ton of freight around 130 miles on 1 gallon of fuel

SUPPORTING DISCUSSION

Outlined below are the fuel consumption assumptions for each type of truck or train identified above:

- Diesel gallon equivalent (DGEs) for the Class 8 Electric Trucks is based on limited information as of 2023, since these vehicles are still new on the market.
- On November 29, 2021, Washington State's Department of Ecology adopted the California Air Resources Board (CARB)'s Advanced Clean Trucks (ACT) rule, which requires truck manufacturers to increase their sales of zero-emission, medium- and heavy-duty trucks in the state. This rule goes into effect with the 2025 truck model year. Diesel Trucks account for the case in which an out-of-state disposal option is considered.
- Drayage Shuttles are modeled to drive on highways as this is the current state of the Finley Buttes and Roosevelt Landfills. Therefore, on-road diesel will be used.

9.0 LANDFILL GAS MANAGEMENT ASSUMPTIONS

Information was gathered on the three potential landfills and used to create average landfill input assumptions (see table below). Contacts from the three landfills being considered in the study (Columbia Ridge, Roosevelt and Finley Buttes) provided the information used to develop the assumptions.

Characteristic	Input Assumptions
Landfill gas collection efficiency (from EPA WARM model options)	Typical: Years 0-1: 0%; Years 2-4: 50%; Years 5-14: 75%; Years 15 to 1 year before final cover: 82.5%; Final cover: 90%
Moisture conditions (from EPA WARM model options)	Dry (k=0.02) = Less than 20 inches of precipitation per year
Percentage of collected gas captured versus flared	99% to 100% captured
Use of captured gas	Three methods: ▪ Sent to PUD #1 of Klickitat County, which processes it into renewable natural gas (RNG) and sends it to Puget Sound Energy's regional pipeline. ▪ Filtered and used to power Caterpillar engines to create electricity that is fed directly into the grid. Heat from engines is used to dry onions at a neighboring onion plant. ▪ Half is captured for electricity and half is converted to renewable natural gas.

Source: Responses from WM on Columbia Ridge, Republic Services on Roosevelt, and Waste Connections on Finley Buttes landfills.

10.0 BTU ASSUMPTIONS

RECOMMENDATIONS

Alternative	Energy	Describe energy or fuel type produced	Where is the fuel or energy used?	Low-tonnage Scenario	Mid-tonnage Scenario	High-tonnage Scenario	Energy Replaced
Mass Burn WTE	Electricity	Electricity KWh	Utility grid, self-consumption	551 KWh/ton	551 KWh/ton	551 KWh/ton	Grid Electricity (see Electricity Grid Assumptions section)
RDF	Fuel Type	Refuse Derived Fuel	Industry (i.e. cement)	9,200,000 BTU/ton	9,200,000 BTU/ton	9,200,000 BTU/ton	Equivalent BTU of Coke/Coal
Gasification	Syngas	Methane, hydrogen	Electrical production, methane/hydrogen sale	None	None	None	Assume same energy value in Natural Gas. End value is then 4,416,000 Btu/T in equivalent energy[4]
Gasification	Heat Energy	High & low pressured steam, hot water	District energy, industry	4,416,000 BTU/ton	4,416,000 BTU/ton	4,416,000 BTU/ton	Equivalent BTU of Natural Gas
Pyrolysis	Heat Energy	High & low pressured steam, hot water	District energy, industry	4,416,000 BTU/ton	4,416,000 BTU/ton	4,416,000 BTU/ton	Equivalent BTU of Natural Gas
Pyrolysis	Syngas	Converted to hydrocarbons fuel	Oil and gas users	None	None	None	Assume same energy value in Natural Gas. End value is then 4,416,000 Btu/T in equivalent energy[3]

Source: Assumptions obtained from existing WtE technology operators and suppliers who wished to remain confidential and information from conference notes, public domain and other confidential work undertaken by Tetra Tech for clients.

[4] Hydrogen would then be converted into methane.

SUPPORTING DISCUSSIONS

Mass Burn Assumptions

- For the purpose of estimating eventual energy generation and usage, it is estimated that waste has a range from 4,000 to 5,200 Btu/lb. The difference in tonnages of the various materials is captured in this variance. This is important as WtE plants are typically thermally limited, therefore the design for a facility has to account for the thermal cap based on the variation of waste input.
- Given that at this time we do not know where a WtE plant would be located, it is difficult to assess whether the plant could supply thermal energy to neighbors (via steam or District Heating whereby hot water is pushed through a series of pipes). Tetra Tech therefore will assess using the thermal energy to generate electricity. We will use an industry average of 551 KWh/ton of waste for net export (accounts for internal consumption).
- For the purpose of estimating energy loss, it is assumed that the conversion of combustion to steam/hot water will be 60%. Similarly, for the conversion of steam to electrical energy it is assumed to also be 60%.
- Most WtE facilities in the U.S. and Europe are mass burn. The primary reason is that mass burn attains the maximum amount of energy from the waste. In addition, mass burn technologies are simple, well understood (have been used over the last 40 years), and when aligned to proper air pollution technologies produce low amounts of pollutants.

Gasification and Pyrolysis

- According to the United States Department of Agriculture, Pyrolysis is the heating of an organic material, such as biomass, [typically] in the absence of oxygen.[5] On the other hand, Gasification is a thermochemical pathway to transform solid feedstocks to gases in the medium of oxygen, air, or steam.[6]
- Gasification uses some oxygen in the thermal conversion process (pyrolysis can occur with no oxygen although it can be added) and thereby may not use the total thermal content of the waste. For the purpose of estimation, it is assumed that both technologies yield 80% of the energy generated compared to mass burn.
- Ash residue from both processes is assumed to contain a higher level of carbon, thereby, residue rates are typically higher than mass burn. This accounts for any pre-processing prior to material being fed to the thermal conversion unit. The amount of residue is dependent on the extent of preprocessing done prior to being fed into the thermal conversion unit.

- At this time, the Tetra Tech project team is not aware of any plants in the United States (U.S.) that process the amount of waste contemplated in King County for the low to high tonnage scenarios. Given this, there is very little history of plant operations.
- Gasification and Pyrolysis typically are used where the end product is important. For both processes, the end uses are typically biochar, hydrogen and methane, and in some cases the

[5] What is Pyrolysis? : USDA ARS
[6] Gasification - an overview | ScienceDirect Topics

biogases are used as an intermediate toward other products such as ethanol. Gasification is typically focused on producing a rich biogas stream whereas pyrolysis may be more focused on producing a solid residual stream but in effect they can produce similar end-products. .

- Both gasification and pyrolysis work best with a narrow band of fuel sources (i.e., wood, wastewater, plastics, etc.). It is believed that the thermal conversion of general garbage toward biogas also carries other compounds such as tars which may be problematic in the environment.

- There has been some back and forth from the EPA on whether or not pyrolysis and gasification are considered combustion technologies. On August 31, 2020, the EPA proposed amendments to the Other Solid Waste Incineration (OSWI) New Source Performance Standards (NSPS) and Emissions Guidelines (EG) rule. The proposal provided technical clarifications on pyrolysis units and stated that pyrolysis is not combustion and thus, pyrolysis units are not regulated under the OSWI rule. Environmental groups submitted adverse comments on EPA's proposed clarifications regarding pyrolysis, arguing that pyrolysis and gasification are indeed combustion technologies and therefore, units using such technologies should be regulated under CAA section 129.[7]

- In May of 2023, the EPA agreed with the environmental groups and reversed the 2020 proposal and decided to continue applying the current Clean Air Act requirements for pyrolysis - leaving pyrolysis in the "other solid waste incineration" definition, therefore considering it to be a combustion technology.[8] [9]

Refuse Derived Fuel (RDF)

- According to the EPA, Refuse Derived Fuel systems use mechanical methods to shred incoming MSW, separate out non-combustible materials, and produce a combustible mixture that is suitable as a fuel in a dedicated furnace or as a supplemental fuel in a conventional boiler system.[10] During the RDF process (sorting the materials and turning them into a fuel source), no combustion is occurring.
- Typically, RDF generated from municipal solid waste must have a consistent range of energy depending on the end user needs. In most cases RDF is used in Europe for cement plants and electrical generation facilities to offset the use of fossil fuels such as from coal, coke and natural gas. In the U.S., RDF typically is most often used in cement plants.
- To attain a consistent energy range, the RDF process includes sorting and screening, with the ability to add or subtract waste types. Inert materials such as sand, grit or metals are extracted within the process, and high combustion materials like plastics and paper are re-blended to create consistent fuel. Furthermore, RDF is often dried to increase the energy content of organics.
- The manufacture of RDF is typically done in conjunction with other processes (i.e., from mixed waste processing MRFs), whereby usable recyclable materials are extracted.

[7] Fact Sheet: Advance Notice of Proposed Rulemaking on Pyrolysis and Gasification Units (epa.gov)
[8] EPA opts to maintain existing pyrolysis air rules (resource-recycling.com)
[9] Microsoft Word - Pyrolysis Proposed Provision Withdrawal Notice_ ADMIN+DISC.docx (epa.gov)
[10] Energy Recovery from the Combustion of Municipal Solid Waste (MSW) | US EPA

- Chlorides in waste are problematic in cement plants - thereby limiting the amount of material that they combine with the fossil fuels (maximum 10 to 20% RDF to the fossil fuels).

- RDF facilities in Washington may be considered waste processors (based on the feedstock content – if it includes MSW components such as plastic vs. just wood waste) and, thereby, need to obtain solid waste facility permits. Historically, the financial benefit of using RDF has not been enough to justify the permitting costs for cement plants.
- Limitations on the volume of RDF that can be used due to chlorides and permitting requirements have been an impediment for RDF markets. RDF can and has been produced in King County and sold to cement kilns outside the state (i.e., in Canada). It should be noted that the RDF that was produced was from construction and demolition waste and not from MSW.

11.0 FTE ASSUMPTIONS

RECOMMENDATIONS

Category	Mass Burn Low	Mass Burn Mid	Mass Burn High	RDF Low	RDF Mid	RDF High	Gasification Low	Gasification Mid	Gasification High	Pyrolysis Low	Pyrolysis Mid	Pyrolysis High
Minimal skill	4	5	6	4	5	6	4	5	6	4	5	6
Technical skill	24	26	28	18	20	22	24	26	28	24	26	28
Advanced skill	15	17	20	15	17	19	15	17	20	15	17	20

SUPPORTING DISCUSSIONS

- The number of FTEs for the study's three tonnage scenarios are assumed not to differ over a twenty-year span.
- There are few Gasification and Pyrolysis plants in either North America or Europe, and none that could be identified at the sizes needed to compare to the requirements for King County. The few known operations are small and typically work with focused feed sources (i.e., wood). Tetra Tech assumed the FTEs would be similar to a Mass Burn facility as the operations are similar: front-end material handling, some pre-processing, loading, operating the combustion unit(s), post processing and residue

management. Depending on the combustion units needed, there may be higher FTEs required for Gasification and Pyrolysis but that is unknown at this time.

- Skill levels.
    - Minimal skill: Requires no prior skill and minimal on-the-job training. This category includes cleaning staff, spotters, and general maintenance.
    - Technical skill: Requires associate degree, technical certificate, or similar level of on-the-job technical training. This category includes loader operators, crane operators, electricians, millwrights, and mechanical maintenance.
    - Advanced skill: Requires Bachelors, Masters, or other advanced degree or equivalent level of on-the-job training and experience. This category includes stationary engineers (boiler operators), APC experts, instrumentation/Scada, regulator staff, operations/facility manager, and Professional Engineers.