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# Technical Memorandum

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**Technical Memorandum No. 1**

Subject: Preferred Conceptual Alternative Selection

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| | |
|---|---|
| ˚F | degree(s) Fahrenheit |
| ATAD | autothermal thermophilic aerobic digestion |
| bhp | brake horsepower |
| BOD | biochemical oxygen demand |
| $CH_4$ | methane |
| CHP | combined heat and power |
| City | City of Bellingham |
| CNG | compressed natural gas |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| CVRD | Comox Valley Regional District |
| D | day(s) |
| DC | direct current |
| gal | gallon(s) |
| GBT | gravity belt thickener |
| GE | General Electric |
| GHG | greenhouse gas |
| EPA | U.S. Environmental Protection Agency |
| FBI | fluidized bed incinerator |
| FOG | fats, oils, and grease |
| g | gram(s) |
| $H_2S$ | hydrogen sulfide |
| hr | hour(s) |
| HTL | hydrothermal liquefaction |
| IPCC | Intergovernmental Panel on Climate Change |
| kg | kilogram(s) |
| kW | kilowatt(s) |
| kWh | kilowatt-hour(s) |
| LEED | Leadership in Energy and Environmental Design |
| LWWSD | Lake Whatcom Water and Sewer District |
| $NO_x$ | nitrogen oxide |
| NWCAA | Northwest Clean Air Agency |
| mgd | million gallon(s) per day |
| MHF | multiple-hearth furnace |
| MW | megawatt(s) |
| O&M | operations and maintenance |
| ppcd | pound(s) per capita per day |
| ppd | pound(s) per day |
| psi | pound(s) per square inch |
| psig | pound(s) per square inch gauge |
| RFS | Renewable Fuel Standard |
| RIN | renewable identification number |
| ROI | return on investment |
| scfd | standard cubic foot/feet per day |
| SCWO | supercritical water oxidation |
| SIU | significant industrial user |
| SWEET | Solids-Water-Energy-Evaluation Tool |
| TBL+ | triple-bottom-line plus |
| TCR | The Client Registry |
| THP | thermal hydrolysis process |
| TM | technical memorandum |
| TPAD | temperature-phased anaerobic digestion |
| TSS | total suspended solids |
| UGA | urban growth area |
| VFA | volatile fatty acid |
| VOC | volatile organic compound |
| VSS | volatile suspended solids |
| WAS | waste activated sludge |
| WERF | Water Environment Research Foundation |
| WT | wet ton(s) |
| WGB | waste gas burner |

# Section 1: Introduction, Purpose, and Approach

The City of Bellingham (City) currently utilizes multiple-hearth furnaces (MHFs) to incinerate the wastewater residual solids recovered from the Post Point Wastewater Treatment Plant (Post Point). Because of the age of the existing MHFs and the desire to employ a more sustainable solids management solution, the City has initiated investigations into alternative means of managing its solids. CDM Smith completed initial studies in 2010 and 2012 to investigate and evaluate a limited number of biosolids management alternatives, with the conclusion that anaerobic digestion coupled with thermal drying is the preferred alternative that meets the City's objectives the best. The purpose of the current Post Point Biosolids Planning project is to further evaluate and develop solids management options to select a preferred alternative for implementation.

This technical memorandum (TM) is the first of two documents that will describe the alternatives considered as part of the project, and identify the preferred alternative for solids management. This first TM (TM 1) describes Phase 1 of the project, which includes the initial screening and first round of evaluations of all possible alternatives and selection of a preferred conceptual alternative. In Phase 2 of the project, the preferred conceptual alternative will be further developed, specific processes will be evaluated, and the preferred final alternative will be identified. Results of Phase 2 will be summarized in TM 2 following completion of Phase 1 of the project.

To develop and select the preferred conceptual alternative, the following steps were completed in Phase 1 and are documented in the following sections:

1. Establish the basis for the analysis, including pass/fail and triple-bottom-line plus (TBL+) evaluation criteria based on the City's established "Legacies and Strategic Commitments," solids projections for sizing new facilities, and the regulatory framework for biosolids and biogas applications (Section 2:)
2. Identify the world of possible alternatives for the City to consider and screen to only the viable alternatives using the pass/fail criteria for solids stabilization (Section 3:), biosolids end use (Section 4:), and biogas end use (Section 5:) alternatives
3. Develop conceptual alternatives based on the screened alternatives (Section 6:)
4. Evaluate the solids, energy, and greenhouse gas (GHG) balances of the conceptual alternatives (Section 7:)
5. Evaluate the conceptual alternatives based on the TBL+ criteria (Section 8:)
6. Undertake the public involvement plan and incorporate the feedback from community workshops into the evaluation (Section 9:)
7. Identify the preferred conceptual alternative for further development (Section 10:)

Figure 1-1 summarizes the work flow for Phase 1 of the project.

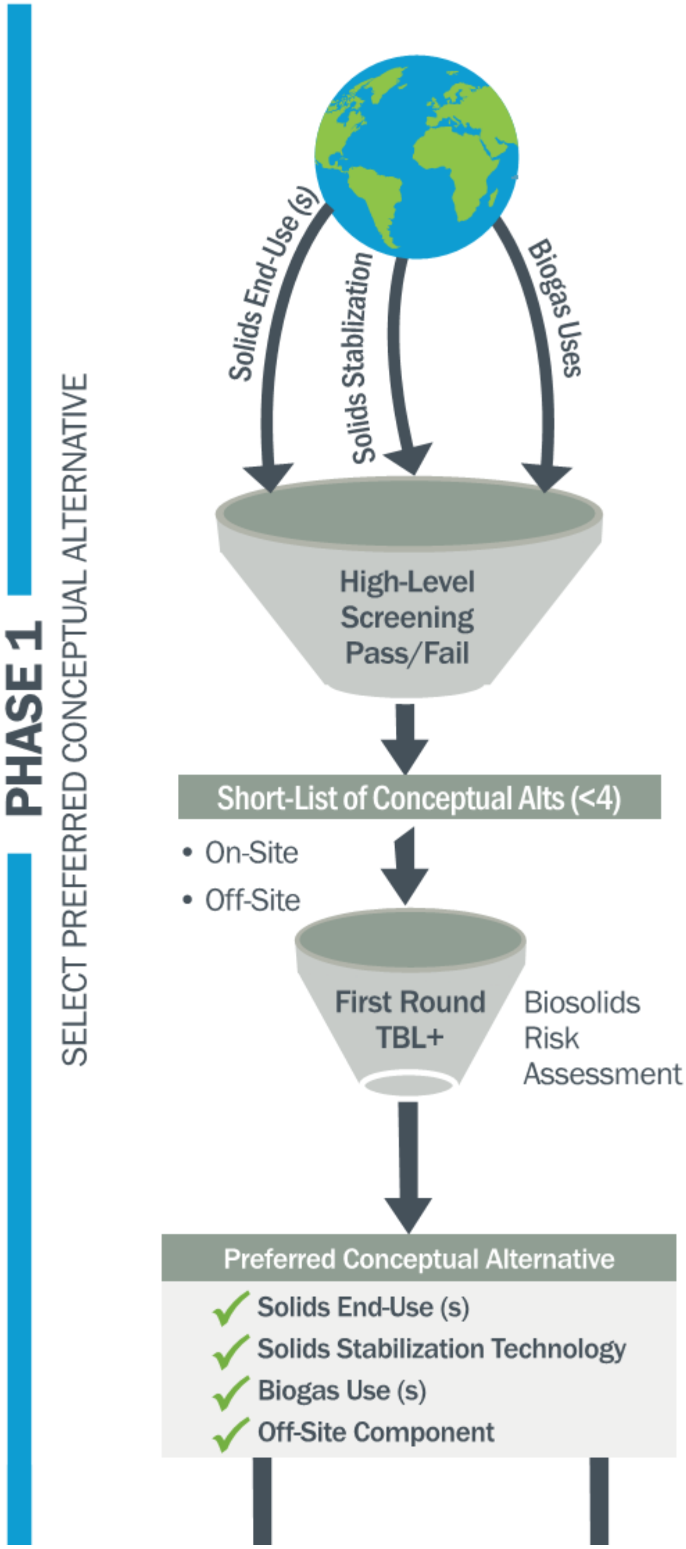


**Figure 1-1. Work flow for Phase 1 of the project**

# Section 2: Basis of Analysis

The following sections describe the basis upon which alternatives were analyzed. These include the evaluation methodology, projected solids loadings to a new solids facility at Post Point, the regulatory framework that any new system would need to meet, and the stakeholder involvement efforts.

## 2.1 Evaluation Methodology

The process for evaluating alternatives is illustrated in Figure 1-1 and includes screening the world of potential alternatives down to a short list of conceptual alternatives (using pass/fail criteria) and then using a TBL+ approach to identify the preferred conceptual alternative. Pass/fail criteria were used for the initial screening to identify viable alternatives and to screen out alternatives and technologies that do not meet the City's basic requirements.

The following sections describe how the City's documented Legacies and Strategic Commitments were used to develop the pass/fail criteria used for the initial screening, and the evaluation criteria used in the TBL+ evaluation.

### 2.1.1 City's Commitments and Legacies

The City has a strong commitment to sustainability and has received awards for its Climate Protection Action Plan and "Green Government." These values are reflected in the City's Public Works Department's mission statement, which is to:

> Enhance Bellingham's quality of life through the construction and operation of a safe, effective physical environment; to protect public health & safety and the natural environment; and to provide our neighborhoods, our businesses and our visitors with the efficient, quality services necessary to meet the demands of our growing, diverse community.

To support this mission statement, the City Council adopted and continues to implement the following nine Legacies and Strategic Commitments (summarized in Figure 2-1):

- Clean, safe drinking water
- Healthy environment
- Vibrant sustainable economy
- Sense of place
- Safe and prepared community
- Mobility and connectivity options
- Access to quality-of-life amenities
- Quality, responsive City services
- Equity and social justice

The 2009 Legacies and Strategic Commitments represent the values of the community and the Public Works Department. In addition, the City Council adopted several resolutions and programs that enforce these values and objectives, including:

- Environmentally Preferable Purchasing Program
- Cities for Climate Protection Program
- Resource Conservation Management Program
- Sustainable Buildings/Leadership in Energy and Environmental Design (LEED®)

***"We are working today so future generations will benefit from…"***

**Clean, Safe Drinking Water**

- Protect & improve drinking water sources
- Limit development in Lake Whatcom watershed
- Use efficient, ecological treatment techniques
- Maintain reliable distribution system
- Promote water conservation

**Healthy Environment**

- Protect & improve the health of lakes, streams & bay
- Protect & restore ecological functions & habitat
- Reduce contributions to climate change
- Conserve natural & consumable resources

**Vibrant Sustainable Economy**

- Support a thriving local economy across all sectors
- Promote inter-dependence of environmental, economic & social interests
- Create conditions that encourage public & private investment
- Foster vibrant downtown & other commercial centers
- Preserve farmland & the agricultural economy

**Sense of Place**

- Support sense of place in neighborhoods
- Encourage development within existing infrastructure
- Preserve historic & cultural resources
- Protect natural green settings & access to open space
- Support people-to-people connections

**Safe & Prepared Community**

- Prevent and respond to emergencies
- Prevent and respond to crime
- Ensure safe infrastructure
- Increase community readiness and resilience

**Mobility & Connectivity Options**

- Provide safe, well-connected mobility options for all users
- Maintain & improve streets, trails & other infrastructure
- Limit sprawl
- Increase infrastructure for bicycles, pedestrians & non-single-occupancy vehicle modes of transportation
- Reduce dependence on single-occupancy vehicles

**Access to Quality of Life Amenities**

- Maintain & enhance publicly owned assets
- Foster arts, culture & lifelong learning
- Provide recreation & enrichment opportunities for all ages & abilities
- Ensure convenient access to & availability of parks & trails citywide

**Quality, Responsive City Services**

- Deliver efficient, effective & accountable municipal services
- Use transparent processes & involve stakeholders in decisions
- Provide access to accurate information
- Recruit, retain & support quality employees

**Equity & Social Justice**

- Provide access to problem-solving resources
- Support safe, affordable housing
- Increase living wage employment
- Support services for lower-income residents
- Cultivate respect & appreciation for diversity

**Legacies and Strategic Commitments**

**Adopted by Bellingham City Council**
**July 13, 2009**

CITY OF BELLINGHAM • WASHINGTON •

**Figure 2-1.City Legacies and Strategic Commitments**

*Source: City Council 2009.*

### 2.1.2 Pass/Fail Criteria

The pass/fail criteria, based on the City's Legacies and Strategic Commitments, represent "must haves" for any potential solution the City would implement. Potential alternatives that did not meet all these criteria were dropped from further consideration.

The pass/fail criteria were developed in a collaborative workshop setting with the City's "core team", using the City's Legacies and Strategic Commitments as a guide. Table 2-1 describes each criterion along with the specific legacy goals and strategic commitments that it supports.

### 2.1.3 TBL+ Evaluation Criteria

A TBL+ approach compares and evaluates alternatives based on the four considerations that impact any project or program delivered by a municipal utility: (1) environmental, (2) financial, (3) social, and (4) technical impacts. By including considerations for all four categories, the impacts to, and values of, a variety of stakeholders are included within the evaluation (e.g., ratepayers, neighbors, regulators, City staff, and others). The TBL+ approach has been implemented to successfully facilitate community input and communicate decisions in a clear and defensible manner for the City's largest public works projects in recent years.

For the evaluation of solids management alternatives at Post Point, TBL+ evaluation criteria were developed for each of the four categories based on the City's values (represented by the Legacies and Strategic Commitments) Figure 2-1). To facilitate evaluation of the alternatives, each criterion identified is further defined by a corresponding parameter that serves as a qualitative or quantitative metric for achieving the criterion.

The following sections describe the criteria in further detail, organized by category (Figure 2-2). Although the number of criteria are different between the categories, the total number of points allowable for each category remains equal (i.e., 25 percent per category). This approach results in no single category having more weight or influence than another.

**Environmental** *(Healthy Environment)*
**E1** – Minimize Carbon Footprint
**E2** – Protect Air Quality
**E3** – Maximize Resource Recovery
**E4** – Minimize Energy Usage
**E5** – Protect Local Habitat

**Financial** *(Quality, Responsive Services, Vibrant Sustainable Economy)*
**F1** – Optimize System Value
**F2** – Maintain Affordability
**F3** – Minimize Market Sensitivity

**Social** *(Sense of place, Safe and Prepared Community)*
**S1 –** Minimize Noise
**S2** – Minimize Odor
**S3** – Minimize Truck Traffic
**S4** – Minimize Visual Impacts
**S5** – Minimize Toxin Exposure

**Technical** *(Quality, Responsive City Services)*
**T1** – Proven Reliability
**T2** – Minimize Post Point Impacts
**T3** – Maintain Flexibility
**T4** – Minimize Complexity

**Figure 2-2. TBL+ criteria**

**Table 2-1. Pass/Fail Criteria**

| Objective | Criterion | Importance | Legacy Goals | Strategic Commitments |
|---|---|---|---|---|
| Meets current regulatory requirements | Meets biosolids disposal permit and regulations. | Required by the state and federal government. Helps to protect the health of the environment. | Healthy environment | Protect and improve the health of lakes, streams, and bays |
| | Meets air quality permit and regulations. | | Healthy environment | Reduce contribution to climate change |
| Utilizes a proven technology while allowing for innovation | Stabilization process technology meets "established" criteria. Non-critical components meet either "established" or "innovative" technology requirements. 1 | Allows for incorporation of innovative technology while minimizing risk of being a process that is not well understood without long-term performance data. | Quality, responsive City services | Deliver efficient, effective, and accountable municipal services |
| | Stabilization process technology operates successfully in at least 5 similar-sized plants (average flow > 10 mgd) for more than 7 years in North America. | | | |
| Maintains reliable end-use options | Maintains a minimum of 1 end-use or readily available backup alternative capable of handling the full biosolids flow under control of the City. | Reduces risk to the City of loss of market or disposal option for its biosolids. | Quality, responsive City services | Deliver efficient, effective, and accountable municipal services |
| | Does not require importing materials (not including incidental chemicals, fuel) to site as part of the main stabilization treatment process. | | | |
| Maintains safe working environment | Does not require specialized licensing to operate the system beyond current wastewater operator license | Protects worker and public health and safety. | Safe and prepared community | Prevent and respond to emergencies |
| | Does not require hazardous chemicals or steam as an integral part of the stabilization treatment or energy recovery process. | | | |
| Meets the goals of the climate action plan | Compared to current practice, reduces GHG emissions.<br>Beneficially uses inherent biosolids nutrient and energy resources.<br>Substantially reduces use of non-renewable resources compared to current practice. | Supports City's strategic climate action plan. Reduces global environmental impact. | Clean, safe drinking water | Use efficient, ecological treatment techniques |
| | | | Healthy environment | Reduce contribution to climate change |
| Minimizes social impacts | Compared to current practice, technology does not increase untreatable odors at the fence line. | Minimizes impacts to neighbors. | Sense of place | Support sense of place in neighborhoods |

[1] *The EPA has defined the following descriptions for current and upcoming treatment technologies:*

*Embryonic: developmental stage and/or tested at laboratory or bench scale; demonstrated viability overseas but not considered well established there; high risk*

*Innovative: tested at full-scale in the United States; established technology overseas and some full-scale implementation in the United States (less than 5 years, less than 25 utilities); moderate risk*

*Established: widely used (generally at least 25 utilities in US); low risk*

#### 2.1.3.1 Environmental Criteria

Five environmental criteria were identified to support the City's goal of maintaining a healthy environment, summarized in Table 2-2.

**Table 2-2. Environmental Criteria**

| Criterion | Parameter | Supports these Legacy Goals |
|---|---|---|
| E1. Minimizes carbon footprint | Pursues alternatives that emit the lowest levels of GHG | • Healthy environment (reduce contribution to climate change) |
| E2. Protects air quality | Reduces air pollutant discharge to minimize human exposure | • Healthy environment (protect and restore ecological functions and habitat) |
| E3. Maximizes opportunities for resource recovery | Maximizes beneficial reuse of resources | • Health environment (conserve natural and consumable resources) |
| E4. Minimizes net energy usage | Minimizes the City's energy use | • Health environment (conserve natural and consumable resources) |
| E5. Protects and improves local habitat | Maximizes protection of local environmental assets | • Health environment (protect and restore ecological functions and habitat) |

These criteria reflect the City's strong environmental ethics and priority to improving the local environment. As an example of the preference for local beneficial impacts, a biosolids end use that could be utilized and benefit the local area would be considered more compatible with the City's goals than end uses that benefitted distant communities (e.g., eastern Washington agriculture).

#### 2.1.3.2 Social Criteria

Five social criteria were identified to support the City's goal of maintaining a sense of place and preserving access to quality-of-life amenities, summarized in Table 2-3.

**Table 2-3. Social Criteria**

| Criterion | Parameter | Supports these Legacy Goals |
|---|---|---|
| S1. Minimizes public exposure to noise | Minimize public exposure to noise | • Sense of place (support sense of place in neighborhoods) |
| S2. Minimizes public exposure to odor | Minimize public exposure to odors | • Sense of place (support sense of place in neighborhoods) |
| S3. Minimizes public exposure to truck traffic | Minimize neighborhood exposure to truck traffic | • Sense of place (support sense of place in neighborhoods) |
| S4. Minimizes local visual impacts | Minimizes impact on view corridors and line of sight | • Access to quality-of-life amenities (maintain and enhance publicly owned assets)<br>• Sense of place (support sense of place in neighborhoods) |
| S5. Minimizes exposure to toxins | Minimizes neighborhood exposure to toxins | • Sense of place (support sense of place in neighborhoods) |

These criteria focus on minimizing impacts to the neighborhoods surrounding Post Point, an area that currently supports social amenities available within the city. For this evaluation, any facilities located off the current Post Point site is assumed to be located in a less sensitive area that's appropriately zoned for the use (e.g., a site without immediate neighbors or in a heavy industrial area).

#### 2.1.3.3 Financial Criteria

Three financial criteria were identified to support the City's goal of providing quality, responsive services, and supporting a vibrant and sustainable economy, identified in Table 2-4.

Table 2-4. Financial Criteria

| Criterion | Parameter | Supports these Legacy Goals |
|---|---|---|
| F1. Optimizes system value | Provides balanced ROI using TBL+ criteria over 50-year life | • Quality, responsive City services (deliver efficient, effective, and accountable municipal services) |
| F2. Affordability | Consistent with long-term financial, environmental, and social goals of utility | • Vibrant sustainable economy (support a thriving local economy across all sectors and promote inter-dependence of environmental, economic, and social interests) |
| F3. Minimizes risk of end-use market sensitivity | Limits risk or maximizes benefits from commodity market changes of end-use products | • Quality, responsive City services (deliver efficient, effective, and accountable municipal services) |

These criteria represent the City's commitment to implementing a solution that effectively meets its financial capabilities while minimizing commodity market risks.

#### 2.1.3.4 Technical Criteria

Four technical criteria were identified to support the City's goals of providing quality responsive services, described in Table 2-5.

Table 2-5. Technical Criteria

| Criterion | Parameter | Supports these Legacy Goals |
|---|---|---|
| T1. Incorporates reliability and proven performance | Utilizes a proven process technology | • Quality, responsive City services (deliver efficient, effective, and accountable municipal services)<br>• Safe and prepared community (increase community readiness and resilience) |
| | Meets technology reliability | |
| | Maximizes use of stable long-term market or disposal options | |
| T2. Minimizes existing process impacts | Minimizes the solids and nutrient return impact to the liquid stream | • Quality, responsive City services (deliver efficient, effective, and accountable municipal services) |
| T3. Provides flexibility for future | Minimizes current space requirements | • Quality, responsive City services (deliver efficient, effective, and accountable municipal services)<br>• Sense of place (protect natural green settings and access to open space) |
| | Technology allows the City flexibility to adapt to future requirements | |
| T4. Minimizes implementation complexity | Implementation complexity related to permitting, public acceptance, and land acquisition, etc. | • Quality, responsive City services (deliver efficient, effective, and accountable municipal services) |

These parameters reflect the City's preference for a reliable treatment process and end use, while also maintaining flexibility, operability, and innovation for resource recovery.

## 2.2 Solids Projections

To develop and analyze alternatives, a common basis for sizing systems is required. To accomplish this, solids loading projections from the current Post Point liquid stream treatment process to a future solids management process were developed. These projections were developed based on population growth forecasts, observed influent flows and loads, and modeled performance of the liquid stream treatment process.

### 2.2.1 Population Growth Forecasts

The 2016 Bellingham Comprehensive Plan provides a summary of the City's population from 1980 through 2015 and the urban growth area's (UGAs) population from 2000–15. The 2016 Bellingham Comprehensive Plan also provides growth projections for the City and UGA population for the year 2036 as shown in Figure 2-3. Consistent with the 2009 Comprehensive Sewer Plan, it was assumed that the City and UGA populations are currently 86 and 47 percent sewered, respectively, and that both will become 100 percent sewered by 2036.

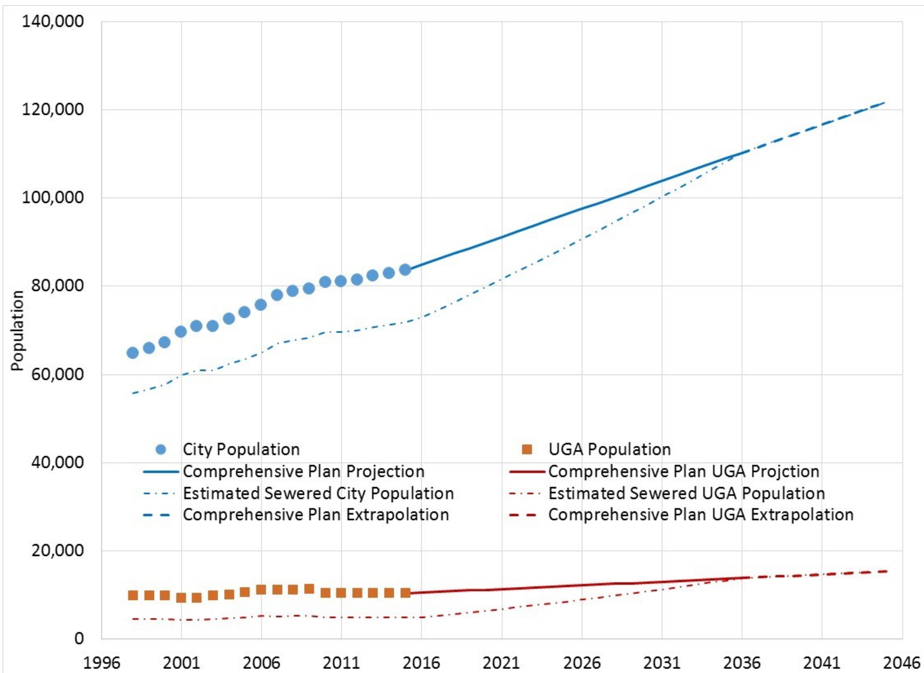


**Figure 2-3. City and UGA population projections**

The solids management alternatives are based on a 20-year planning cycle, so the population forecasts for both the City and UGA were linearly extrapolated from 2036–45 (assuming any new facilities would become operational in approximately 2025). In addition to the City and UGA population contributions, Post Point also receives flow and loads from the Lake Whatcom Water and Sewer District (LWWSD). In the 2009 Comprehensive Sewer Plan, the LWWSD population was estimated to be 9,190 in the year 2004 and 14,235 in the year 2026. These values were also linearly extrapolated to the year 2045.

### 2.2.2 Influent Flow and Load Projections

The average annual residential influent loads were projected based on a constant per capita load of 0.20 pound per capita per day (ppcd) for biochemical oxygen demand (BOD) and 0.23 ppcd for total suspended solids (TSS). These per capita loads are the average of measured values for the years 2014–16. The load contribution from the significant industrial users (SIUs) was measured by the City to be approximately 9 percent of the influent load in April 2011 (or approximately 2,100 pounds per day [ppd] for BOD and 2,800 ppd for TSS). The loads from the SIUs were assumed to be constant through 2016 and then increased proportional to the employment growth estimated by the 2016 Bellingham Comprehensive Plan. The total average annual influent BOD and TSS loads were then determined by adding the residential and industrial loads.

Maximum month loads were projected based on a 1.24 peak factor for BOD and 1.23 peak factor for TSS. These maximum month peak factors were the maximum observed from 2014–16. Table 2-6 summarizes the current and projected average annual and maximum month influent BOD and TSS loads to Post Point through 2045.

| Table 2-6. Load Projections | | | | |
|---|---|---|---|---|
| Year | Average Annual BOD (ppd) | Maximum Month BOD (ppd) | Average Annual TSS (ppd) | Maximum Month TSS (ppd) |
| 2016 | 20,600 | 23,300 | 25,500 | 30,700 |
| 2025 | 24,800 | 30,700 | 30,100 | 36,900 |
| 2045 | 34,400 | 42,500 | 37,700 | 51,100 |

### 2.2.3 Treatment Process Performance

To determine the solids loadings to a new solids management system, a dynamic model was developed in BioWin version 5.0 and calibrated to 1 year of influent, primary effluent, and waste activated sludge (WAS) load data from April 25, 2016, through April 24, 2017. This model was used to develop combined sludge projections for the years 2025 and 2045 assuming that the existing plant configuration and operation continues. The sludge projections in terms of TSS and volatile suspended solids (VSS) at a range of peak periods are shown in Table 2-7.

| Table 2-7. Combined Sludge Projections | | | | | | |
|---|---|---|---|---|---|---|
| Year | Average Annual | Maximum Month | Maximum 2-week | Maximum Week | Maximum 3-day | Maximum Day |
| TSS Load (ppd) | | | | | | |
| 2025 | 40,800 | 46,900 | 48,500 | 53,700 | 61,000 | 84,800 |
| 2045 | 56,300 | 64,500 | 66,800 | 73,800 | 83,100 | 117,600 |
| VSS Load (ppd) | | | | | | |
| 2025 | 35,700 | 40,200 | 40,200 | 40,900 | 50,900 | 68,800 |
| 2045 | 49,100 | 55,400 | 56,700 | 55,200 | 68,000 | 93,400 |

To determine the hydraulic loads to the new solids management system, a solids content of 3.20 percent was assumed for primary sludge and 0.55 percent was assumed for WAS (resulting in a combined sludge solids content of approximately 1.1 percent). These values were based on observed solids content in the primary and WAS between April 25, 2016, and April 24, 2017.

## 2.3 Regulatory Framework

There are two major categories of regulations that impact the implementation of solids management and biogas end-use alternatives. Each is described in the following sections.

### 2.3.1 Biosolids Regulations

The U.S. Environmental Protection Agency (EPA) has established regulations defining the specific levels of stabilization required before biosolids can be beneficially used on both public and private lands (Title 40 of the Code of Federal Regulations, Part 503; i.e., “Part 503”). These regulations establish requirements for a reduction in pathogens within the biosolids and a reduction in the attractiveness of the solids to vectors of disease-carrying organisms (e.g., flies, mosquitoes, rats, etc.). Together, these two criteria define stabilization of the solids.

Part of the definition of stabilization requirements in the Part 503 rules includes the definition of Class A and B biosolids. Class B biosolids are stabilized sufficiently to be safely applied to permitted agricultural land, subject to certain setback and loading restrictions and reporting requirements. Class A biosolids are solids that have received more treatment to further reduce pathogens compared to Class B biosolids. Thus, Class A biosolids have fewer restrictions on their application and are deemed by EPA to be suitable for public distribution for use on home gardens and landscaping. The Part 503 rules define the process requirements for biosolids to be classified as Class A, which generally fall under two groupings: (1) time-temperature requirements (i.e., maintaining the temperature of the solids at a specific temperature for a defined amount of time), and (2) pH-temperature requirements (i.e., maintaining the temperature of the solids at a specific temperature and pH).

In the development of stabilization and biosolids end-use requirements, consideration for the regulatory requirements and product classification are included.

### 2.3.2 Air Permitting

The addition of biogas end-use systems owned and operated by the City would require a new air permit from the local air authority (Northwest Clean Air Agency). At this phase of the project, detailed evaluations of air permitting requirements were not completed, but the biogas end-use alternatives described in subsequent sections include a description of typical permitting needs for the different technologies.

## 2.4 Stakeholder Involvement

As part of the development and evaluation of solids management alternatives, key stakeholders were involved and provided essential feedback to inform the results.  These stakeholders includes City staff and the greater Bellingham community.  A “core team” of City staff was formed that was composed of engineering, operations, maintenance, natural resources, and public outreach staff.  This team was involved in frequent workshops to discuss the methodology, development, and results of the alternatives analysis at each stage of the process.  In addition, the City staff included briefings to the City Council to keep them informed of the progress of the study and the key outcomes.

Community input is a critically important factor to confirm that evaluation criteria and TBL+ evaluation results reflect the values of the City and the impacted stakeholders. To support project development, the City proactively identified and met with key partner representatives, potentially impacted landowners, and other stakeholders to inventory project opportunities and concerns. A public involvement plan was developed specific for the biosolids project with the following overall project goals:

- Inform residents and stakeholders within the surrounding neighborhoods (e.g., Fairhaven, Happy Valley, Edgemoor, and South Hill) and throughout the City about the project and planned phases, including upcoming and potential activities
- Engage interested stakeholders (using multiple tools and forums) to solicit their perspectives and values regarding project alternatives being considered.
- Reflect the City’s core values expressed in the Legacies and Strategic Commitments as alternatives are developed and screened
- Create project ambassadors who will help disseminate project-related information to their communities/constituents and voice support for elements relevant to their interests

- Avoid project-related surprises by ensuring that other City staff, elected officials, and decision-makers understand the project and hear directly from the project team about updates and issues
- Identify a community-supported alternative by creating a transparent and collaborative evaluation process

A description of the community workshops held and how they informed the results of the analysis is included in Section 9:.

# Section 3: Solids Stabilization Alternatives

Solids stabilization is the process in which residual solids from the wastewater treatment process are treated to allow for safe beneficial use or disposal. As described in Section 2.3.1, stabilization is defined by a reduction in pathogens and in the attractiveness of the solids to vectors of disease-carrying organisms (e.g., flies, mosquitoes, rats, etc.). In addition, depending on the level of treatment and pathogen reduction, solids stabilization can result in either Class A or B biosolids.

The following sections give a brief overview of the world of solids stabilization alternatives, divided between biological and chemical processes and thermochemical processes. This section concludes with a screening of all the stabilization alternatives using the pass/fail criteria defined in Section 2.1.2 to identify the feasible solids stabilization alternatives.

## 3.1 Biological and Chemical Processes

The first group of stabilization processes described are processes using biological and/or chemical processes to stabilize solids. These include digestion (e.g., anaerobic and aerobic), alkaline, lagoons, and composting.

### 3.1.1 Anaerobic Digestion

Anaerobic digestion has been the primary process used to stabilize wastewater solids for the last 50 years. Anaerobic digestion is a natural, biological process that breaks down organic materials using microorganisms to produce biosolids and biogas. The microorganisms used for the breakdown require an oxygen-free environment and release both methane ($CH_4$) and carbon dioxide ($CO_2$) during respiration. The digestion process contains four stages:

1. Hydrolysis: insoluble organic materials are broken down into soluble materials
2. Acidogenesis: soluble organic material is converted into volatile fatty acids (VFAs)
3. Acetogenesis: VFAs are converted to acetic acid, carbon dioxide, and hydrogen
4. Methanogenesis: acetates and hydrogen are converted to methane and carbon dioxide

Anaerobic digestion typically operates within one of two temperature regimes, mesophilic (90 to 100 degrees Fahrenheit [˚F]) and thermophilic (120 to 135˚F), and generally requires 10 to 20 days (d) of retention time to achieve stabilization requirements. Of the two temperature regimes, mesophilic is most commonly applied at municipal wastewater treatment facilities. Configured appropriately, operation at thermophilic temperatures can result in a Class A product while mesophilic digestion results in a Class B product.

The solids fed to an anaerobic digestion process are typically -thickened to roughly 3 to 6 percent total solids. The biosolids produced by an anaerobic digestion process are typically dewatered after digestion to about 20 to 30 percent total solids. This process results in stabilization of the solids, a reduction in the mass of solids (i.e., volatile solids reduction), and the generation of methane. The resulting biosolids have a high macro- and micro-nutrient content that can be used to support plant growth and organic matter, which improves soil tilth.

Maintaining consistent feed, temperature, and mixing within the digester is key for the anaerobic digestion process. Active mixing occurs to maintain uniformity within the digester and helps to promote the degradation of organic materials. Digesters are frequently heated by combusting the methane produced by the process. Figure 3-1 shows an anaerobic digester at the King County Brightwater Treatment Plant in Woodinville, Washington.

**Figure 3-1. Anaerobic digester at Brightwater Treatment Plant**

A recent development in the anaerobic digestion process is the thermal hydrolysis process (THP), an optional pretreatment step before anaerobic digestion in which the hydrolysis phase is completed using high-pressure and -temperature steam. The hydrolysis step is often the rate-limiting phase in the overall digestion process, so by completing this step outside of the digestion tanks, the solids are more readily degradable within the digester. Therefore, digesters coupled with THP can be smaller while maintaining the same processing capacity. Figure 3-2 illustrates the Cambi THP installed at the Blue Plains Advanced Wastewater Treatment Plant in Washington, D.C.

Dewatering of the solids to 15 to 20 percent total solids occurs prior to THP to facilitate efficient operation, and a second dewatering process is required following digestion. The solids are held at 320˚F and 60 to 90 pounds per square inch (psi) for at least 30 minutes in a batch process (satisfying Class A time-temperature requirements). The pressure is released quickly, rupturing the cell walls of organic material. The hydrolyzed solids then require dilution and cooling prior to being fed to a digester. Mesophilic anaerobic digestion is used after THP because the same high-rate digestion achieved with thermophilic digestion with normal feeds can be achieved with the hydrolyzed sludge. The benefits of this process are its ability to achieve a Class A product, reduced digester volume requirements, and the excellent dewaterability of the final digested biosolids. The drawbacks of this process are the complexity of the THP, the need for high-pressure steam, and the need for additional sludge cooling and dewatering steps.

Figure 3-2. THP (foreground) and Anaerobic Digesters at the Blue Plains Advanced Wastewater Treatment Plant

### 3.1.2 Aerobic Digestion

Aerobic digestion is a biological process like anaerobic digestion, except that it uses microorganisms that consume oxygen. The aerobic bacteria stabilize and reduce the mass of volatile material in the solids, converting them into carbon dioxide, water, and other minor constituents. The aerobic process is similar to the activated sludge process: oxygen must be provided to maintain the process (either as air or high-purity oxygen) and microorganisms will consume available degradable organic material before consuming themselves as the availability of external substrates is depleted (i.e., endogenous respiration).

Sludge thickening and biosolids dewatering typically occur before and after digestion, like anaerobic digestion. Unlike anaerobic digestion, aerobic digestion does not require an outside source of heat. In fact, a type of aerobic digestion (autothermal thermophilic aerobic digestion [ATAD]) utilizes the heat released from the exothermic oxidation process to maintain thermophilic temperatures in the digester. The ATAD process also occurs in a shorter time frame (5 to 10 days of retention time) allowing for smaller tanks and reduced capital cost.

Whereas the aerobic digestion process produces biosolids that are stable and suitable for beneficial land application, the process requires significant amounts of energy to supply the required oxygen and there is no associated useable biogas production.

Aerobic digestion can be coupled with anaerobic digestion to take advantage of the benefits from the two systems. Aerobic digestion can be used as a pre-processing step to an anaerobic process or as a post-anaerobic digestion step to enhance volatile solids destruction. The City of Tacoma uses an ATAD system ahead of a temperature-phased anaerobic digestion (TPAD) system at its Central Treatment Plant in Tacoma, Washington. This combination produces Class A biosolids and minimizes odors. The ATAD system at the City of Tacoma's Central Treatment Plant is shown in Figure 3-3.

**Figure 3-3. ATAD and TPAD Facilities at the City of Tacoma's Central Treatment Plant**

### 3.1.3 Alkaline Stabilization

Alkaline stabilization is the process of adding alkaline chemicals to biomass—reducing harmful pathogens. The added lime or alkaline chemicals raise the pH levels of the biomass, creating unfavorable conditions for the growth of organisms. The types of chemicals traditionally used are hydrated lime and quicklime.

Class A biosolids can be achieved through alkaline stabilization by maintaining the pH at greater than 12 for at least 72 hours, maintaining the temperature above 125˚F for at least 12 hours within that period, and drying the solids to greater than 50 percent total solids. This short time frame and exothermic reaction of adding quicklime to a wet product results in shorter detention times and less heating than is required for anaerobic digestion. This can lead to lower initial capital costs.

This process does not result in any reduction in the mass of the solids. In fact, the addition of a significant amount of lime would increase the mass of the resulting biosolids. In addition, there is no $CH_4$ by-product from alkaline stabilization; thus, ongoing annual costs are typically higher for alkaline stabilization systems when compared to anaerobic digestion.

The stabilized product can be used for a variety of end uses such as landscaping, agriculture, mine reclamation, and landfill cover. Depending on the soil to which the product is applied, the final product can be more favorable for some vegetation as it can improve soil pH due to the added alkaline chemicals. However, extensive odor control may be required to treat ammonia and other off-gases. Figure 3-4 illustrates the contrasting appearance of alkaline stabilized biosolids compared to anaerobically digested biosolids.

Figure 3-4. Lime-stabilized biosolids (bottom) compared to anaerobically digested biosolids (top)

### 3.1.4 Lagoons

Lagoons provide a form of stabilization that is inexpensive and requires little energy. The constructed lagoons or ponds are typically 4 to 8 feet deep and are not mechanically mixed or aerated. Because the process is natural, the organic material decomposes at a slow rate, on the order of 1 to 5 years. Thus, this process requires a significant volume and is extremely land-intensive. Sludge accumulation occurs at the bottom of the lagoon, which requires dredging periodically.

The lagoon surface contains dissolved oxygen and algae, making it a favorable environment for aerobic organisms. The oxygen produced by the algae and surface aeration is used by the bacteria to stabilize organic material in the upper layer of water. The intermediate layer is known as the "anoxic layer" or the "facultative zone," which contains aerobic and anaerobic bacteria. The bottom layer contains mostly anaerobic organisms and contains most of the sludge deposits. Anaerobic fermentation is the dominant process at the bottom layer of the lagoon. Because the lagoon is open to the atmosphere, it emits a large amount of GHGs (e.g., methane) and odors.

Lagoons can treat raw or digested solids, but most existing systems are fed either digested solids or aerobic solids from extended aeration plants. The process reduces volatile solids and pathogens, but is more efficient in warm weather as microbial activity slows in cold weather.

Most lagoons are large multi-cell systems that can be enclosed, but are typically open to the atmosphere. An image of one of the lagoons operated by the City of Everett at its water pollution control facility is shown in Figure 3-5.

**Figure 3-5. Lagoon at the City of Everett's Water Pollution Control Facility**

### 3.1.5 Raw Solids Composting

Raw solids composting is a biological process to decompose organic material to produce humus. Active composting accelerates the natural process by controlling the carbon-to-nitrogen ratio, temperature, moisture content, and oxygen supply. After active composting, the material is cured and stored until ready for transport. The resulting product is rich in nutrients and suitable for promoting soil tilth and plant growth.

Composting is typically applied to dewatered solids that have already been digested, but can be used on unstabilized (i.e., raw) solids as well. Solids are typically dewatered to between 14 and 30 percent total solids before mixing with a bulking agent such as wood chips, sawdust, or yard waste. Retention times of 10 to 30 days are required to sufficiently stabilize the material; additional time is often needed to air-dry the solids to allow for beneficial use.

There are three different compost methods typically available for wastewater solids: (1) aerated static pile, (2) windrow, and (3) in-vessel. All methods can produce Class A biosolids; the decomposition of organics matter is exothermic and if controlled properly can lead to the appropriate level of pathogen reduction. The major differences between the different methods is how the solids are aerated (e.g., either through forced aeration or by mixing). The Comox Valley Regional District (CVRD) on Vancouver Island stabilizes its solids using aerated static piles. An image of the covered piles is shown in Figure 3-6.

**Figure 3-6. Aerated static pile operated by CVRD**

The composting process uses little energy, but does not generate an energy by-product such as biogas from anaerobic digestion. The process results in some reduction in wastewater solids, but the mass of the final product is increased by the amount of bulking agent used. The process can also be land-intensive and odorous, depending on the method used and materials processed.

## 3.2 Thermochemical Processes

The second group of stabilization processes described oxidize the organic material present in wastewater solids using thermochemical processes. The technologies described include incineration, gasification, pyrolysis, hydrothermal liquefaction (HTL), and supercritical water oxidation (SCWO).

### 3.2.1 Incineration

Incineration is a process that completely oxidizes organic materials to eliminate pathogens and reduce the mass of solids. To reduce the mass of water requiring evaporation, combustion is typically used for dewatered solids that are 20 to 35 percent total solids. Combustion of unstabilized solids can be autogenous if the total solids is above about 28 percent, where the volatile content of the material is sufficient to provide the necessary energy to maintain combustion. Combustion of digested solids typically requires the solids to be dewatered or dried to 35 to 40 percent total solids to maintain combustion autogenously.

The resulting products of complete incineration are water vapor, carbon dioxide, sulfur dioxide, and an inert ash not suitable for agricultural use (i.e., it contains no nutrient value). Instead, the ash is usually sent to a landfill but can also be reused for cement production, road construction material, or landfill cover.

Two types of incinerators are typically used for biosolids combustion: (1) MHFs and (2) fluidized bed incinerators (FBIs). MHFs operates at temperatures ranging between 1,400 and 1,700˚F and consist of three zones: (1) top, (2) middle, and (3) bottom. The solids burn in the middle zone, and the ash produced is cooled in the bottom zone. The exhaust gas is scrubbed in the top hearth to remove particulates and meet air permit requirements. Figure 3-7 shows a typical picture of a MHF at Post Point.

Figure 3-7. MHF at Post Point

FBIs contain a fluidized sand bed at the bottom of the vertical shell cylinder, which serves as a heat sink to promote uniform combustion. Dewatered sludge is heated and injected into the fluidized sand bed while fluidizing, and combustion air is dispensed throughout the vessel. Supplemental heat is often required and brings overall internal temperatures between 1,400 and 1,800˚F. Organic materials are broken down and combusted in the sand bed while the liquid components are evaporated. The ash and water vapor produced are removed through a scrubber at the top of the FBI. Figure 3-8 shows a picture of a FBI at the City of Vancouver's Westside Treatment Plant in Vancouver, Washington.


Figure 3-8. FBI at the City of Vancouver's Westside Treatment Plant

Both incinerator types require constant air emission monitoring to ensure that no toxic substances are released to the atmosphere and to meet air permitting regulations. Different types of scrubbers are available to clean the flue gas. The composition of the exhaust will vary depending on the amount of excess air provided to the incinerator. If not enough air is provided, complete combustion will not be achieved.

Heat recovery is available during the incineration process. The heat in the exhaust can be captured and used in a waste heat boiler or to generate steam and produce electricity. The heat recovered is not significant enough for a facility's total heat demand but could be used to heat the combustion air, reducing the demand on the overall incineration process. The City's existing MHFs do not include a heat recovery process.

### 3.2.2 Gasification

Gasification is a thermal oxidation process that oxidizes dried solids under high-temperature sub-stochiometric conditions. The resulting products are an inert ash (i.e., biochar) and a mixture of carbon monoxide (CO), methane, hydrogen, and other volatile components (i.e., syngas). To sustain the process, a portion of the syngas is used to dry the feed solids (required); the remaining syngas requires significant treatment before being used as a renewable fuel source.

Gasification has a long history of being used with fossil fuels to convert coal to a gaseous fuel, but its use to stabilize wastewater solids is still in development. Whereas several gasification projects have been developed in North America, most have been mothballed due to poor economics and operational issues. Only one small operating facility has been identified as currently operating in a wastewater treatment plant in North America. Gasification on biosolids requires an additional feedstock to properly process solids, such as wood waste or used tires. Figure 3-9 shows a downdraft gasifier at a wastewater treatment facility in Lebanon, Tennessee, that is used for biosolids and wood and yard waste from the area's solid waste stream.

Figure 3-9. Downdraft gasifier in Lebanon, Tennessee

### 3.2.3 Pyrolysis

Pyrolysis is a thermal conversion process similar to gasification, but it is accomplished at a lower temperature and does not require the presence of oxygen. Similar to gasification, drying is required upstream of the pyrolysis system to sustain the process and produce a usable final product.

There are varying by-products of pyrolysis depending on different heating rates. The products of the pyrolysis process are biochar and bio-oil (a condensed liquid fuel). The liquid nature of the bio-oil makes it more useful as a fuel, but this end product requires further processing to be used beneficially. Of the bio-oil produced, typically 40 percent can be recovered in this manner. In addition, a significant amount of energy is required to dry the feed solids prior to the pyrolysis process, reducing the overall net energy produced.

Pyrolysis is a process widely used in the chemical industry that has not been successfully applied to manage wastewater solids.

### 3.2.4 Hydrothermal Liquefaction

HTL is an emerging technology that has been studied at the bench scale. The process directly converts biomass under high pressure (3,000 psi) and temperatures (700°F) into a liquid oil, mimicking the naturally occurring process that results in fossil fuel generation. HTL is different from the other oxidation processes described because the process does not require a dry biomass, instead requiring a feed with a high water content. At the pressures and temperatures used, the water is below the thermodynamic critical point and acts as a catalyst. In these conditions, the water disintegrates the organic materials that reform into hydrocarbons. The resulting highly viscous, liquid biocrude requires further processing within a refinery to remove oxygen and refine the fuel to a product useable as a vehicle fuel. Figure 3-10 illustrates the typical process flow diagram.

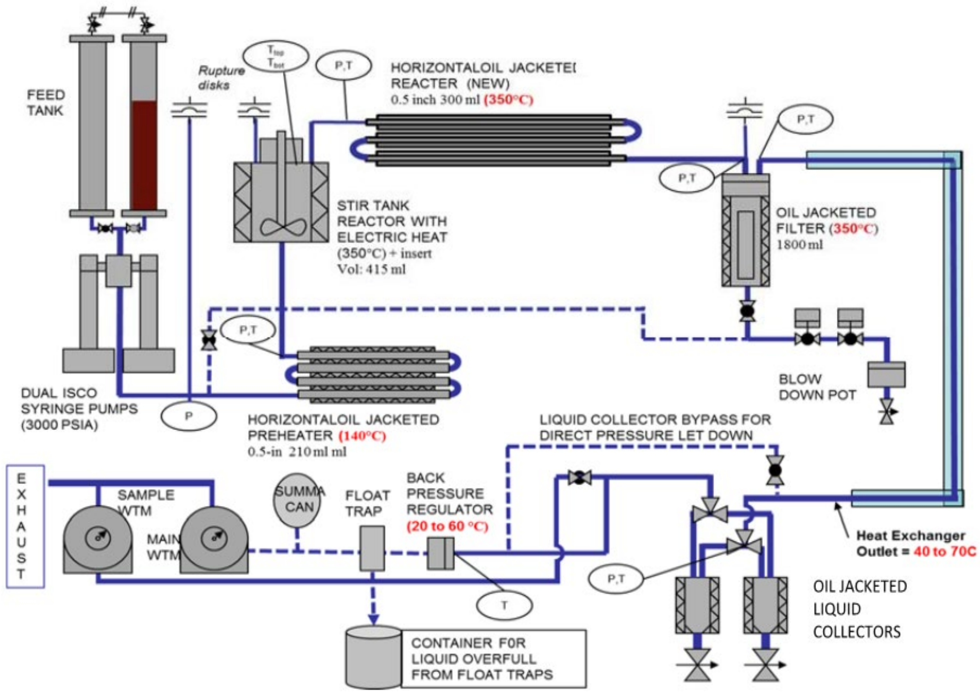


**Figure 3-10. HTL process flow diagram**

HTL is still under research and development and faces challenges surrounding its ability to scale up to full-scale operations cost effectively, prove a sustainable energy balance between the energy required to refine the biocrude and the amount of useable fuel produced, and reliably process the varying qualities of municipal wastewater solids. The Water Environment Research Foundation (WERF) recently received grant funding from the U.S. Department of Energy to implement a pilot-scale test of an HTL process in the Bay Area of California—but there are no known installations of this process in full-scale wastewater treatment plants at this time.

### 3.2.5 Supercritical Water Oxidation

SCWO is like HTL except that the pressures and temperatures used are beyond the thermodynamic critical point for water. In this supercritical state, water has unique properties resembling both a liquid and a gas. The organic compounds within the solids become soluble and readily available to oxidation through the addition of an oxidant (e.g., oxygen). The process destroys all organic compounds within 30 to 90 seconds, resulting in the generation of carbon dioxide, nitrogen, oxygen, water, and inorganic residues.

The oxidation process is exothermic, resulting in a significant release of heat. The excess heat can be captured and used to generate steam for use in a steam turbine. SCWO has been implemented at the bench and pilot scale but has not been successfully implemented at full scale to treat wastewater solids. Thus, there are no known installations of this process in full-scale wastewater treatment plants.

## 3.3 Pass/Fail Criteria Screening

Each of the stabilization technologies was evaluated based on the pass/fail criteria described in Section 2.1.2. Table 3-1 summarizes the results of this initial screening. The following technologies were identified as non-acceptable based on one or more of the criteria:

- **Thermal hydrolysis**: Is not an established technology with sufficient similar installations in North America, and requires high-temperature steam as an integral part of the process
- **Aerobic digestion**: Does not meet the climate action plan goals by reducing GHG emissions as it requires a large amount of energy to provide the oxygen or air, and does not produce a useable biogas
- **Alkaline stabilization**: Requires significant import and use of alkaline chemical, does not meet the climate action plan goals by reducing GHG emissions, and would result in untreatable odor increases
- **Lagoon**: Does not meet the climate action plan goals by reducing GHG emissions, and would result in untreatable odor increases
- **Raw Solids Composting:** Requires significant import of additional organic matter, does not meet the climate action plan goals by reducing GHG emissions, and would result in untreatable odor increases
- **Incineration**: Does not meet the climate action plan goals by recovering nutrients in the biosolids and would not reduce GHG emissions without the use of a steam energy recovery system
- **Gasification**: Is not an established technology with sufficient similar installations, requires additional feedstock to maintain consistent operation, and does not meet the climate action plan goals by recovering the nutrients in the biosolids
- **Pyrolysis**: Is not an established technology with sufficient similar installations and does not meet the climate action plan goals by recovering the nutrients in the biosolids
- **HTL**: Is not an established technology with sufficient similar installations and does not meet the climate action plan goals by recovering the nutrients in the biosolids
- **SCWO**: Is not an established technology with sufficient similar installations, requires the import and use of liquid oxygen as part of the process, requires a steam system to recover energy, and does not meet the climate action plan goals by recovering the nutrients in the biosolids

Thus, anaerobic digestion is the only solids stabilization technology that meets the City's pass/fail criteria.

**Table 3-1. Initial Pass/Fail Screening of Solids Stabilization Technology Alternatives**

| Objective | Criterion | Anaerobic Digestion | Thermal Hydrolysis | Aerobic Digestion | Alkaline Stabilization | Lagoon | Raw Solids Composting | Incineration | Gasification | Pyrolysis | HTL | SCWO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Meets current regulatory requirements | Meets biosolids disposal permit and regulations. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Meets air quality permit and regulations. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Utilizes proven process technology while allowing for innovation | Stabilization process technology meets established criteria. Non-critical components meet either established or innovative technology requirements. | ✓ | X | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | X |
| | Stabilization process technology operates successfully in at least 5 similar-sized plants (average flow > 10 mgd) for more than 7 years in North America. | ✓ | X | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | X |
| Maintains reliable end-use options | Maintains minimum of 1 end use or readily available backup alternative capable of handling the full biosolids flow under control of the City. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Does not require importing materials (not including incidental chemicals, fuel) to site as part of the main stabilization treatment process. | ✓ | ✓ | ✓ | X | ✓ | X | ✓ | X | ✓ | ✓ | X |
| Maintains safe working environment | Does not require specialized licensing to operate system beyond current wastewater operator license. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Does not require hazardous chemicals or steam as an integral part of the stabilization treatment or energy recovery process. | ✓ | X | ✓ | X | ✓ | ✓ | X | ✓ | ✓ | ✓ | X |
| Meets the goals of the climate action plan | Compared to current practice, reduces GHG emissions. Beneficially uses inherent biosolids nutrient and energy resources. Substantially reduces use of non-renewable resources compared to current practice. | ✓ | ✓ | X | X | X | X | X | X | X | X | X |
| Minimizes social impacts | Compared to current practice, technology does not increase untreatable odors at the fence line. | ✓ | ✓ | ✓ | X | X | X | ✓ | ✓ | ✓ | ✓ | ✓ |

# Section 4: Biosolids End Use Alternatives

This section describes end-use options for the biosolids produced by the stabilization technologies described in Section 3:. It includes descriptions of successful practices adopted by other agencies with a focus on Washington state, but also discusses common practices in other places.

As described in Section 2.3.1, Part 503 rules and state regulations define the Class A and B treatment requirements, performance monitoring, and end-use limitations. Class A biosolids are treated to the extent that direct sale to the public and use on public lands is acceptable. Class B biosolids have greater restrictions, including:

- Additional permitting
- Buffer requirements
- Limited public access
- Crop harvesting restrictions

Potential end uses for both Class A and B biosolids are discussed in the following sections. This section concludes with a screening of the alternatives identified using the pass/fail criteria established in Section 2.1.2.

## 4.1 Direct Land Application

Biosolids applied to soil can offset the use of conventional fertilizers to increase plant yield. Biosolids also provide additional benefits to the soil while requiring less energy for production. These advantages over conventional fertilizers are outlined in Table 4-1.

**Table 4-1. Comparison of Chemical Fertilizer and Biosolids**

| Fertilizer Attribute | Chemical Fertilizer | Biosolids |
|---|---|---|
| Provides nitrogen | ✓ | ✓ |
| Supplies micronutrients | X | ✓ |
| Slowly releases nutrients | Occasionally | ✓ |
| Introduces organic matter | X | ✓ |
| Increases soil water holding capacity | X | ✓ |
| Emits GHGs during production[1] | X | X |
| Rehabilitates damaged soil | X | ✓ |
| Sequesters carbon | X | ✓ |

*[1]Commercial nitrogen uses a large quantity of natural gas for production of fertilizer. Biosolids emit small amounts of GHG but is offset by production and beneficial use of biogas.*

Biosolids contain plant nutrients, such as nitrogen, phosphorus, and sulphur, in organic and inorganic forms. The inorganic forms are immediately available to plants. Nutrients in the organic form are released slowly as the biosolids decompose in the soil, providing plants with nutrients throughout the year when additional fertilizer application is prohibited. The slow release of nutrients gives biosolids an advantage over chemical fertilizers, which only supply nutrients for a short period. Biosolids also supply needed micronutrients such as zinc, copper, boron, molybdenum, manganese, and iron. Studies have shown that the availability of these nutrients results in plant growth yields much higher than what can be achieved through conventional fertilizers.

Digested biosolids meeting either Class A or B treatment standards are suitable for direct land application for reclaiming disturbed land or to improve forest and agricultural land productivity. Because of the limited public exposure to the biosolids used in these applications, most Washington agencies practicing land application produce a Class B biosolids product. (A Class A product is just as applicable but requires additional processing that is not generally necessary in land application end uses.)

Smaller agencies may produce a digested liquid slurry (3 to 5 percent dry solids) for land application, but larger agencies typically use mechanical dewatering (e.g., belt press, screw press, or centrifuge) to produce a dewatered "cake" in the 18 to 25 percent dry solids range. The advantage of a dewatered product is that the dryer cake holds less water; therefore, transportation costs are reduced. This is important for agencies in western Washington as most land-applied biosolids in Washington require transport to central or eastern Washington. Because of the wet winters in western Washington, the only way to apply biosolids locally is to either provide seasonal storage for the biosolids during the winter or to combine a seasonal local end use with a year-long remote end use. Storage facilities typically cost more than transport to arid locations, so most western Washington agencies choose to transport biosolids year-round to agricultural land application sites east of the Cascade Range.

The following sections describe land application options, and focus is on operations that are common for western Washington treatment facilities.

### 4.1.1 Mine Sites

Mining activities degrade soil, producing large areas of disturbed land. Re-vegetation of cleared areas is necessary to improve aesthetics and reduce spreading of mine tailings and soil erosion. Re-establishment of vegetation on disturbed sites proves difficult for many reasons, including:

- Lack of nutrients because of low cation exchange capacity
- Disturbed soils have poor water-holding capacity, creating drought conditions for plants
- Phytotoxicity because of the presence of metals and acidic pH drainages
- Little to no soil biological activity

Biosolids have a documented success record as an amendment in mine remediation operations. Biosolids contain 50 to 60 percent organic matter and high nutrient concentrations necessary for re-establishment of plant life. Addition of organic matter improves the water-holding capacity of the soil and provides a matrix to bind and store nutrients. Slow release of nutrients from the biosolids matrix supports the plants for longer than conventional fertilizers, keeping the mine site stabilized. Biosolids are applied at rates much higher than agronomic levels because the biosolids are used to establish a soil-like system instead of merely supplementing an already productive agricultural soil system. Figure 4-1 shows photographs of the Sechelt Gravel Mine site in British Columbia before and after remediation with biosolids.

Figure 4-1. Before and after reclamation at Sechelt Gravel Mine

A major advantage of remediating mine sites with biosolids is the potential for GHG credits. A large carbon sequestration credit can be achieved by re-establishing a productive land site. One disadvantage of reclamation as an end-use option is that a disturbed site requires a limited number of solids applications to restore the site. Once a site has been rehabilitated, another site must be identified for continued biosolids reuse.

Mine reclamation with biosolids has been successfully practiced on a large scale in British Columbia. The proximity of Metro Vancouver within a reasonable trucking distance to mining operations was key to the success of its program.

### 4.1.2 Forest Lands

Forest application of biosolids also results in carbon sequestration, increased land use productivity, and recycling of organic matter. Used in silvicultural practices to fertilize tree plantations, biosolids nutrients can significantly increase tree growth where poor soil conditions exist. Figure 4-2 demonstrates the benefits of applying biosolids to forest lands. After biosolids application, the width between growth rings increases drastically, indicating an increase in biomass production.

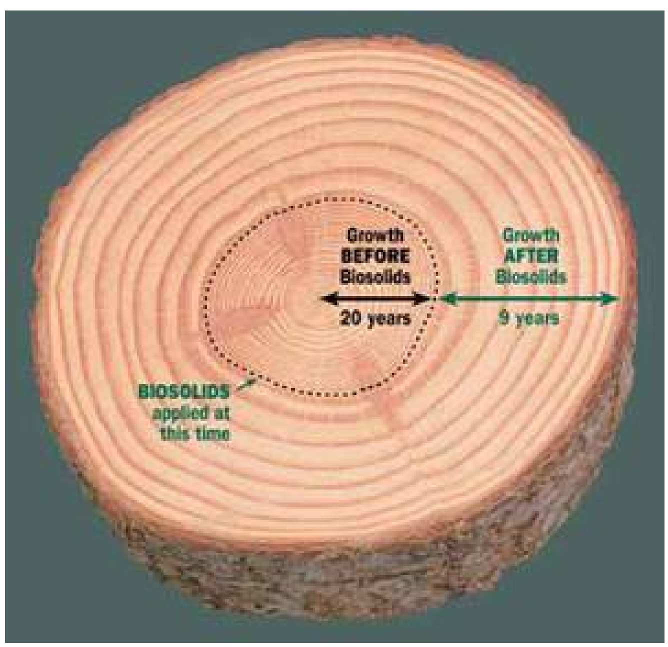


Figure 4-2. Tree growth before and after biosolids application

Forest application is conducted at a controlled rate with buffers and monitoring to ensure that there are no adverse environmental effects. Because biosolids used in silvicultural are not used to grow food for human consumption, some agencies have found this end use to be easier to implement if public perceptions are opposed to biosolids end uses. One disadvantage of this end use compared to agriculture use is that commercial fertilizers are not generally used in silvicultural systems, and thus would not be displaced by using biosolids.

At one time King County directed a significant portion of its biosolids to privately held Douglas fir tree farms in east King County. However, this use has been reduced considerably in recent years due to changes in forest land ownership and increased demand from the agricultural sector.

Like silvicultural application, biosolids can be used to fertilize new tree crops, planted for wood chip production. The trees are grown in a rotation and new trees are propagated from the stumps of the previously harvested trees. The underground biomass or roots remain and decompose, adding carbon to the soil and resulting in an overall carbon-neutral production of wood chips for fuel. In the Pacific Northwest, Poplar is generally the tree species favored in these types of operations. A large multi-year demonstration project involving Poplar grown for chip production is under way in the Pilchuck forest. This demonstration has already conducted its first harvest of trees to produce wood chips, but no market has been found for the chips yet and they remain at the farm site.

### 4.1.3 Agricultural Land

Another end-use option is to land-apply the biosolids on private agricultural land as a fertilizer and soil conditioner. The agronomic biosolids application rate can be customized to supply the optimal amount of nutrients for the planned cropping system to minimize environmental impacts due to nutrient runoff. The benefits of land application on agricultural land have been demonstrated in numerous research and full-scale projects. The advantages and disadvantages of land application are outlined in Table 4-2.

**Table 4-2. Advantages and Disadvantages of Land Application of Biosolids**

| Advantages | Disadvantages |
|---|---|
| Offset commercial fertilizer use, expense, and reduce GHG emissions from inorganic fertilizer production | Transporting the solids to a rural land application site, especially when crossing mountain passes during the winter. |
| Sequester carbon in soil | Strict regulatory standards limit application (EPA Part 503) |
| Improved plant yield due to presence of essential macro- and micro-nutrients | Potential for odor |
| Slow release of nutrients from organic forms allowing fertilization for longer periods | Public perception |
| Increase soil organic matter, which improves soil structure and water holding capacity | Large land area required |
| Increased earthworm and soil microbial activity | Permitting requirements |

Use of biosolids as an agricultural soil amendment is widely practiced in the Pacific Northwest. Contract land application in central and eastern Washington has been especially successful because the drier climate allows operations year-round to grow dryland wheat, canola, hops, alfalfa, and rangeland grasses. Hauling distances from population centers in the Puget Sound region can be as much as 200 miles one-way, but ongoing demand for the product and avoided storage costs make this an attractive option.

### 4.1.4 Landfill

Some communities haul their biosolids product to a landfill either for disposal or for use as an alternative daily cover. This application can be low cost compared to other alternatives, and the use as an alternative daily cover can provide benefit by improving the $CH_4$ capture of the landfill's gas recovery system. In general, this end use is not considered beneficial as it does not provide any improvement to the local soils, recycling of the organic matter and nutrients, or offset of other fertilizers. Thus, the Washington State Department of Ecology has previously indicated that this end use would not be permitted as a primary end use unless the utility can show that there is no other economically feasible alternative available.

Landfilling biosolids is widely used as an emergency end use for communities when their primary end use is suddenly unavailable for a short-term period. Landfills typically require that the solids be stabilized and dewatered before they are received. The EPA-defined "paint filter test" is typically used to determine if the solids have been dewatered sufficiently before they can be disposed of in a landfill. This typically works out to an 18 percent dry solids.

## 4.2 Further Processing and Product Development

Beyond direct application of biosolids to land, further processing can be implemented to develop other biosolids end products. These products and the associated processing are described in the following sections.

### 4.2.1 Biosolids Composting

Biosolids can be composted with waste or debris material to make excellent mulches and topsoils for horticultural and landscaping purposes. Some waste or debris material includes sawdust, wood chips, yard clippings, storm debris, food waste, manure or crop residues, or food processing wastes. While these materials have traditionally been viewed as waste, they can play a valuable role as soil amendments in urban and agricultural settings. Many professional landscapers and master gardeners use composted biosolids for landscaping new homes and businesses. Home gardeners also find composted biosolids to be an excellent addition to planting beds and gardens.

Similar to the process requirements described for the composting of unstabilized solids, composted biosolids must meet certain criteria, which include meeting pathogen reduction limits, complying with required sampling and analysis protocols, maintaining compost temperature and retention time records, and product labeling requirements. Compost products provide nutrients and organic matter and sequester carbon, thereby conserving resources, restoring soils, and combating climate change. Because of site constraints at Post Point, an offsite location would be required for this type of system.

Composting is the most common method used to produce Class A biosolids, and is a good alternative for processing biosolids from small or large wastewater treatment plants, whether on site or at another permitted facility. Many large and small communities in the Pacific Northwest have active composting operations. Demand for these products usually exceeds the available supply. Figure 4-3 illustrates utilities in Washington that produce compost.

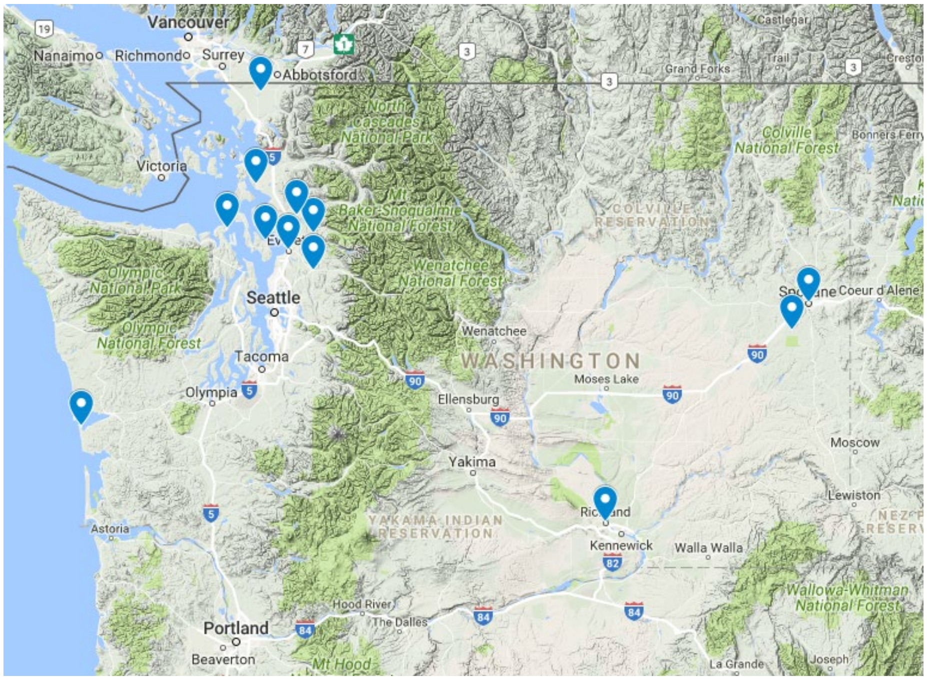


**Figure 4-3. Biosolids composting sites in Washington**

Private composting companies in some areas receive biosolids from multiple communities and market their products to landscapers and home gardeners. Local delivery programs return a portion of the composted material to the communities from which they originated. However, private biosolids composters are very limited in the state of Washington.

### 4.2.2 Soil blending

While Class B biosolids may be composted to produce Class A material with certain technologies, producing manufactured soils is a specialized class of biosolids product development. To be suitable for use by the public, the feedstock for this production is Class A biosolids cake. Class A biosolids are blended with a mixture of sawdust/bark and sand to produce a product that can be publicly distributed in bag or bulk form. The TAGRO product produced by the City of Tacoma is a manufactured soil comprising two parts Class A dewatered cake, two parts sawdust, and one part sand. Manufactured soils could potentially be custom-tailored to meet certain landscaping needs. As examples, TAGRO products include potting soil and a green roof blend in addition to the classic topsoil blend. Figure 4-4 is an example of the TAGRO topsoil blend product being delivered to a customer. An offsite location would be required to conduct the soil blending operation due to site constraints at Post Point.


Figure 4-4. TAGRO topsoil blend product produced by the City of Tacoma

### 4.2.3 Thermally Dried Product

Various thermal drying technologies can be employed to reduce the moisture content of dewatered biosolids and produce a Class A biosolids product. Thermal dryer technologies include direct dryers (e.g., drum dryers and belt dryers) and indirect dryers (e.g., paddle dryers). Some communities in arid areas can dry solids using solar energy by spreading the solids outdoors in drying beds. The major benefits of drying biosolids are the ability to convert Class B biosolids in to a Class A product, and the significant reduction in material by removing almost all the moisture (greatly reducing transportation costs). The major disadvantage of the thermal drying process is the significant amount of energy required to evaporate the water in a dewatered cake.

The different dryer types produce different qualities of dried product. The dry product from a drum dryer system is a pellet that can be graded to various size standards depending on the market it will be directed to (see Figure 4-5). For example, a small pellet may be suitable for application on the greens of golf courses, while a large pellet may be better used in agricultural or forest operations. Pierce County uses a drum dryer system at the Chambers Creek Regional Wastewater Treatment Plant. Indirect dryers and belt dryer technologies produce a granulated product on a batch basis that may be dusty and less marketable. Examples of indirect dryer facilities are in Sumner, La Center, and Burlington; while Shelton, Alderwood, and Camas all use belt dryers.

**Figure 4-5. Dried biosolids pellets produced by a drum dryer**

*Source: Andritz.*

Dried biosolids can be used in the same land application end uses as other Class A biosolids products, but can also be sold as a fertilizer for individual or bulk use. An example of a fertilizer sold in individual bags is Milorganite, the dried product produced by the Milwaukee Metropolitan Sewerage District and sold in hardware stores across the United States. An example of bulk sale of a dried fertilizer product is the SoundGRO® product produced by Pierce County, Washington, and sold to a bulk end user in Oregon.

In addition to use as a fertilizer, a dried product could be used as a fuel source in some applications. Because most of the moisture in the biosolids have been removed in the drying process, dried biosolids typically retain enough volatile content to facilitate autogenous combustion (i.e., combustion without supplemental fuel). Thus, the dried biosolids can be combusted as a carbon-neutral source of fuel, potentially offsetting the use of fossil fuels. The use of a dried product fuel supplement in coal-fired cement kilns has been considered in Vancouver, British Columbia, and California; however, this market has never been fully developed.

## 4.3 Pass/Fail Criteria Screening

Each of the biosolids end-use options was evaluated based on the pass/fail criteria described in Section 2.1.2. Table 4-3 summarizes the results of this initial screening. The following end uses were identified as non-viable:

- **Landfill**: unlikely to receive a permit as the primary end use and does not beneficially recover the nutrients in the biosolids
- **Dried fuel product**: no communities are currently known to use this end use, does not beneficially recover the nutrients in the biosolids

As a result, three groups of beneficial end uses meet the City's pass/fail criteria:

- Land application: can be for agricultural use, silviculture, or mine reclamation
- Soil amendment: as a compost product or a topsoil blend
- Dried fertilizer

Each group will be considered in further detail in the following sections.

**Table 4-3. Initial Pass/Fail Screening of Biosolids End Use Alternatives**

| Objective | Criterion | Mine Sites | Forest Lands | Agricultural Fields | Landfill | Biosolids Composting | Topsoil Blend | Dried Fertilizer Product | Dried Fuel Product |
|---|---|---|---|---|---|---|---|---|---|
| Meets current regulatory requirements | Meets biosolids disposal permit and regulations as a primary end use. | ✓ | ✓ | ✓ | X | ✓ | ✓ | ✓ | ✓ |
| | Meets air quality permit and regulations. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Uses proven process technology while allowing for innovation | Stabilization process technology meets established criteria. Non-critical components meet either established or innovative technology requirements. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X |
| Maintains reliable end-use options | Maintains minimum of 1 end use or readily available backup alternative capable of handling the full biosolids flow under control of the City. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Maintains safe working environment | Does not require specialized licensing to operate system beyond current wastewater operator license. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Does not require hazardous chemicals or steam as an integral part of the stabilization treatment or energy recovery process. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Meets the goals of the climate action plan | Compared to current practice, reduces GHG emissions. Beneficially uses inherent biosolids nutrient and energy resources. Substantially reduces use of non-renewable resources compared to current practice. | ✓ | ✓ | ✓ | X | ✓ | ✓ | ✓ | X |
| Minimizes social impacts | Compared to current practice, technology does not increase untreatable odors at the fence line. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

# Section 5: Biogas Utilization Alternatives

This section evaluates alternative biogas end uses for anaerobic digestion based alternatives. Four end uses were identified: (1) flaring, (2) boilers, (3) combined heat and power (CHP), and (4) biogas upgrading. Each is described in the following sections followed by a discussion on the initial screening of alternatives using the pass/fail criteria.

## 5.1 Flaring

The simplest means of disposing of biogas from the digestion process is to combust the gas in a flare. For safety reasons, a flare is needed as a backup to any alternative to ensure a means of biogas disposal at all times. The flaring alternative considered here assumes flares would be used as the primary and only end use for digester gas at the facility.

A flare provides combustion of the flammable gas prior to discharge to the atmosphere. Flares can either be installed so that the flame is unshielded and visible (e.g., candlestick type) or enclosed. While candlestick flares are common throughout the United States, enclosed waste gas burners (WGBs) are common in new installations in Washington (see Figure 5-1 for an example of candlestick at Metro Vancouver's Lulu Island Wastewater Treatment Plant in Richmond, British Columbia; and WGBs at Brightwater Treatment Plant). Enclosed WGBs are typically more expensive and require substantial additional testing and monitoring compared to a candlestick flare, but come with a significantly improved GHG profile as candlestick flares have been shown to allow more methane to slip through the flame than an enclosed WGB. At this level of analysis, it has been assumed that an enclosed WGB will be implemented.

The flaring system at Post Point would require an air permit from the Northwest Clean Air Agency (NWCAA).

**Figure 5-1. Candlestick flares at Lulu Island Wastewater Treatment Plant and enclosed WGBs at Brightwater Treatment Plant**

## 5.2 Boilers

At almost every treatment plant using anaerobic digestion, a portion of the digester gas produced is recovered and utilized as fuel to fire a boiler and meet plant heating needs. Hot water boilers are the most common technology used for this purpose, but CHP systems are also common (see Section 5.3). Even plants with CHP systems typically include hot water boilers as a backup system to ensure that sufficient heat to maintain the digestion process is always available.

A hot water boiler typically heats water to approximately 200°F, and this injects water into a plant-wide hot water supply loop that operates at a lower temperature (e.g., between 130 and 180°F). The hot water from the boiler can be used to meet space heating needs (via hydronic heating coils) and to meet digestion heating needs (via a water-to-sludge heat exchangers). The boilers often have the capability to utilize natural gas also (using dual fuel burners) in case digester gas becomes unavailable.

The boilers will require an air permit from NWCAA. Low nitrogen oxide ($NO_x$) and ultra-low $NO_x$ burners are required more frequently in areas of the country with stringent air quality requirements. Figure 5-2 is an image of a hot water boiler at the Brightwater Treatment Plant.


**Figure 5-2. Hot water boiler at Brightwater Treatment Plant**

## 5.3 Combined Heat and Power

A CHP system burns fuel to create electricity and capture the heat produced for beneficial use. Wastewater treatment plants typically use the generated heat to maintain target digester temperature and for space heating, while using the electricity to run other plant processes and reduce electricity demands from the electric utility. Three types of CHP technologies are available: (1) reciprocating internal combustion engines, (2) turbines, and (3) fuel cells. The following section summarizes each of the technologies.

### 5.3.1 Reciprocating Internal Combustion Engines

The most common technology for a CHP system is an engine-generator. A reciprocating internal combustion engine combusts the digester gas in a series of combustion chambers to drive a rotating shaft connected to an electric generator. The gas engines used for this purpose at wastewater treatment facilities have historically been rich-burn engines in which the mixture of fuel and air includes more fuel than is necessary for combustion (i.e., above the stochiometric fuel-to-air ratio). Recent technology improvements coupled with more stringent air emission limits have resulted in a shift to lean-burn engines in which more air is included in the fuel-air mixture than necessary (i.e., the mixture is sub-stochiometric).

Several lean-burn reciprocating engine suppliers have new-generation, high-efficiency, low-emission units designed for use with biogas, including Cummins; Caterpillar; and General Electric (GE)/Jenbacher. These engines have overall efficiencies of approximately 80 percent and typically operate between 70 and 100 percent of full engine load. Approximately 35 to 40 percent of the fuel (as a percentage of fuel input energy content) is converted to electrical output, and 40 to 45 percent can be recovered as heat using heat exchangers on the engine cooling water and exhaust. A typical cogeneration unit is shown in Figure 5-3.

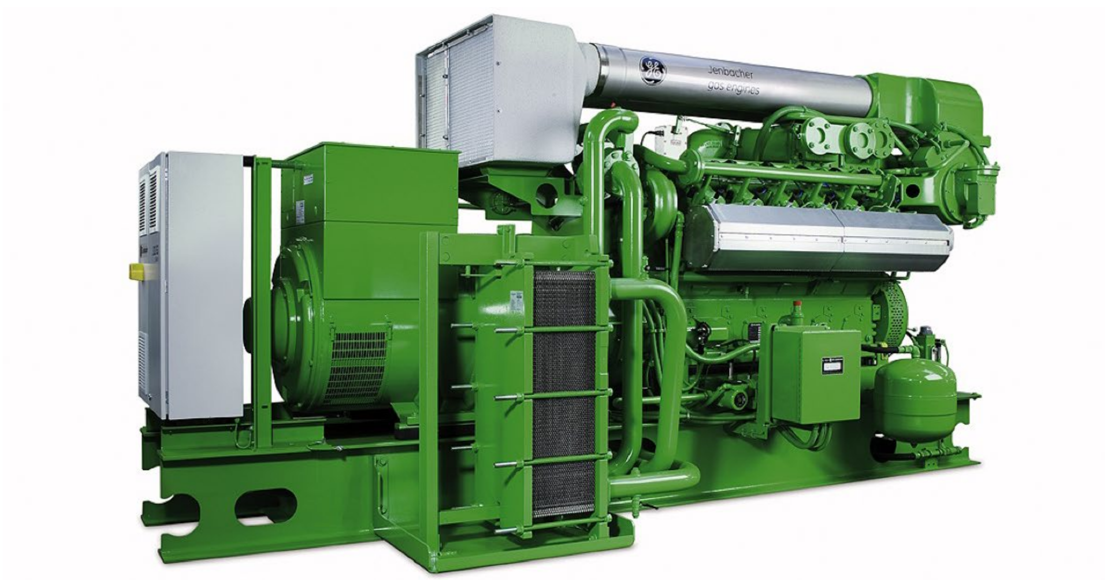


**Figure 5-3. GE Jenbacher engine**

A CHP system would require an air permit from NWCAA. A lean-burn engine can be fit with exhaust after-treatment equipment to control $NO_x$ and CO emissions, if required. These after-treatment systems (e.g., catalysts) require pretreatment of the biogas used in the engine to remove hydrogen sulfides ($H_2S$) and siloxanes that would otherwise damage the equipment. This type of biogas conditioning may be required by the engine manufacturer as well to increase the performance and reliability of the engine while reducing engine operating and maintenance costs. A typical gas treatment schematic for a CHP system is presented in Figure 5-4.

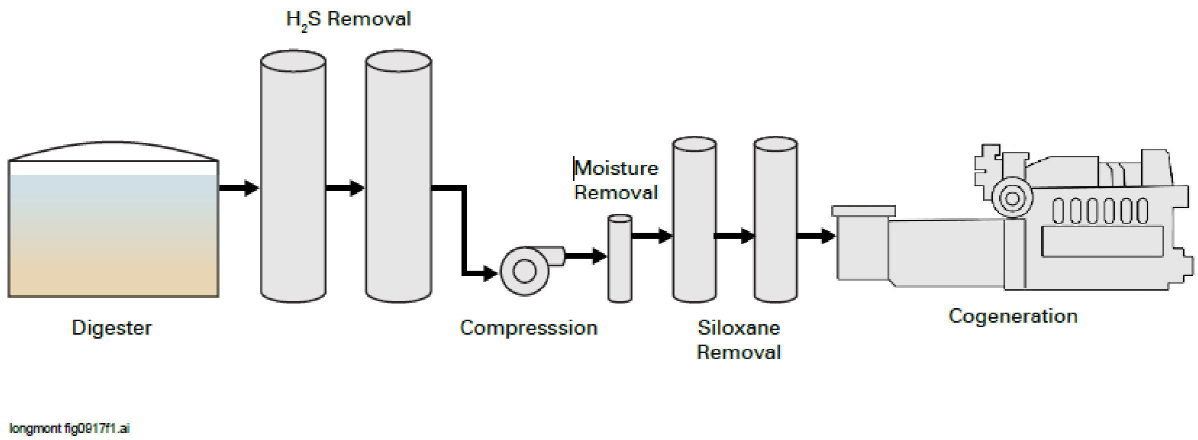


**Figure 5-4. Typical treatment skid for CHP systems**

Digester gas storage can be used to smooth out gas production and usage peaks and valleys that occur in typical digester operation, and facilitate smoother CHP operation. During periods when production exceeds usage, excess gas fills the storage. Conversely, when usage exceeds production, digester gas is withdrawn from storage. However, most operating wastewater treatment plant CHP systems do not include digester gas storage; the volume of storage required to have a significant impact on operations can be substantial and the cost/savings impact of this is typically relatively minor.

Raw sludge storage prior to digestion is often used to promote constant and continuous feed to digesters, helping with digester stability and leveling gas production. A small digested sludge storage tank (roughly 4- to 8-hour capacity) has been shown to provide operational flexibility to the solids treatment process while also leveling out peak daily gas production—promoting more efficient operation of gas use equipment as well.

### 5.3.2 Fuel Cells

Fuel cells utilize the hydrogen present in the methane-rich digester gas as a fuel source in an electrochemical process. The methane is reformed to produce hydrogen and carbon dioxide prior to the fuel cell. The hydrogen is then combined with oxygen in the fuel cell to produce water and release electrons, which are captured as direct current (DC) electricity. For use in fuel cells digester gas must be processed to remove all the $H_2S$ and siloxane compounds present in the gas.

The fuel cells evaluated typically convert, as a percentage of fuel input power, 40 to 45 percent to electrical output and approximately 25 percent to recoverable exhaust heat for a total overall efficiency of approximately 65 to 70 percent. The manufacture and use of fuel cells at wastewater treatment plants for digester gas applications is currently limited, and they have not exhibited satisfactory long-term operation yet. Figure 5-5 is an image of the fuel cell demonstration facility at the King County South Treatment Plant in Renton, Washington, which is no longer in operation.

Fuel cells are also extremely expensive and have high yearly operations and maintenance (O&M) costs. Based on previous analyses of fuel cells in many other similar applications, the economics for fuel cells would likely result in negative returns not warranting further study.

As an electrochemical process, fuel cells produce significantly less pollutant by-products than reciprocating internal combustion engines, producing approximately 1 percent of the emissions. As a result, fuel cells may be exempt from air permit requirements; this requires confirmation with NWCAA should this technology be implemented.


**Figure 5-5. 1 MW fuel cell demonstration facility at South Treatment Plant**

### 5.3.3 Turbines

Turbines combust fuel and use expansion of the combustion products to rotate a turbine connected to an electrical generator. Heat can be recovered from the exhaust gases to meet plant heating needs. Gas turbines are typically much larger than would be appropriate for a facility the size of Post Point (see Figure 5-6 for an image of a gas turbine at the South Treatment Plant). An alternative for smaller gas flows is microturbines, which are essentially small gas turbines operating at high speeds to produce power and heat. Typically, they convert 30 to 35 percent of the fuel input to electrical output and 30 percent to recoverable exhaust heat for a total overall efficiency of approximately 60 to 65 percent.

There are currently several commercial manufacturers offering microturbine power generating units. Only two—FlexEnergy (formally Ingersoll Rand) and Capstone—have experience utilizing digester gas as a fuel source (see Figure 5-7 for an image of the Capstone microturbine package). For use in microturbines, digester gas must be processed to remove all the $H_2S$ and siloxane compounds present in the gas, typically to a level an order of magnitude lower than what is required for reciprocating engines.

Compared to reciprocating internal combustion engines, microturbines have low efficiencies, have not exhibited satisfactory long-term operation, and have relatively high capital costs. Based on previous analyses for other similarly sized applications, the economics are expected to result in negative returns, not warranting further study.

Microturbines would require an air permit from NWCAA, but the emissions from microturbines are typically much lower compared to engines.

**Figure 5-6. 3.5 MW gas turbine at South Treatment Plant**


**Figure 5-7. 4 x 200 kW microturbine package from Capstone**

## 5.4 Biogas Upgrading

The treatment of digester gas to biomethane suitable for pipeline injection and vehicle fuel use has gained increasing interest during the past decade because of the economic benefit of acquiring and selling the renewable identification numbers (RINs) associated with the biomethane. The Renewable Fuel Standard (RFS) adopted as part of the EPA Energy Policy Act of 2005 requires that motor-vehicle fuel in the lower 48 states contain specific volumes of renewable fuel for each calendar year. Under the compliance program, any party—including refiners, blenders, and importers—that produces or imports gasoline for U.S. consumption, will be subject to a “renewable volume obligation,” the purpose of which is to measure the amount of renewable fuel making its way into motor-vehicle fuel sold or introduced into U.S. commerce, and to ensure that it meets the RFS.

Under the EPA's RFS program, every gallon (gal) of renewable fuel produced or imported into the United States will be assigned a RIN. These RINs are a proxy that confirms the renewable obligations are being met; they can also be traded or sold to a party that finds it more economical to purchase RINs than to blend a renewable fuel with a non-renewable fuel. Under current regulations, any company can trade RINs if it is registered with EPA to participate in the program.

The result of this market has been that biomethane produced at municipal wastewater treatment facilities and sold as a vehicle fuel commands a premium value in the vehicle fuel marketplace, which is significantly higher than the value of the energy in the biomethane alone. Thus, more agencies are considering upgrading their digester gas to biomethane to take advantage of the environmental and economic benefits of offsetting non-renewable vehicle fuel use.

Digester gas upgrading can be accomplished through several technologies, including:

- Water solvent: marketed by Greenlane
- Pressure swing adsorption: marketed by Guild, ARC, and Carbotech
- Membrane separation: marketed by Air Liquide and DMT Carborex
- Chemical solvent: marketed by Purac

Figure 5-8 is an image of the high-pressure water solvent system used by King County at the South Treatment Plant since 1986 to upgrade the plant's biogas to biomethane.

These systems remove hydrogen sulfide, siloxanes, VOCs, and carbon dioxide, with the remaining product gas comprising 95 percent or greater methane. The waste gas from the process, known as "tail gas" (roughly 2 to 15 percent of the initial $CH_4$ content, along with the stripped carbon dioxide) can be flared, either with natural gas blending or by itself. (This tail gas has a heating value lower than normal digester gas so additional fuel may be necessary, depending on the methane content.) Depending on how the tail gas is managed, an air permit from NWCAA may be necessary.

The resulting biomethane can be distributed in several ways. One means of transmitting the biomethane is to inject the gas into a local natural gas transmission main and wheel it to the final end user. Pipeline injection requires that the gas be compressed to a pressure greater than the natural gas utility's transmission pressure (typically ranging between 100 and 800 pounds per square inch gauge [psig]) and will also require significant gas quality monitoring to ensure the biomethane does not adversely impact the integrity of the transmission main. The main advantage of this approach is that the biomethane can be injected and sold as the gas is produced—no storage or buffering is needed.

An alternative approach is to use the biomethane directly at a compressed natural gas (CNG) fueling station. These stations typically receive natural gas from a pipeline and use compressors to pressurize the gas to supply either fast- or slow-fill fueling stations. Fast-fill fueling stations compress CNG to roughly 4,200 psig and can take roughly the same amount of time to fill a CNG vehicle as a traditional gasoline- or diesel powered vehicle. Slow-fill fueling stations are often used for fleet vehicles, busses, or refuse haulers that are not in operation for a significant portion of the day. For these stations, the gas is fed to the vehicles overnight so that they are ready for use the next day. Figure 5-9 shows a typical CNG fueling station.


**Figure 5-8. Water solvent biogas upgrading system at King County's South Treatment Plant**


**Figure 5-9. Fast-fill fueling station from GreenField**

Storage for CNG systems is often required due to the constant production of digester gas and intermittent fueling periods. For a fast-fill station, high-pressure storage is required to have CNG on demand. A larger amount of storage results in higher utilization because overnight production can be stored for daytime dispensation (or vice-versa for slow-fill stations); gas must otherwise be flared when the storage is full. Figure 5-10 shows an example bank of high-pressure storage tubes. While storage is not required for normal slow-fill stations operating on pipeline natural gas, it would be recommended to increase the utilization of biogas when vehicles are not parked and filling at the slow-fill station. At night, the vehicles would be filled from both the production of biomethane and storage.


**Figure 5-10. High-pressure storage tubes for CNG**

Storage can become very expensive depending on the volume required, and consideration of the revenue from the additional biogas beneficially used needs to be compared to the high costs.

## 5.5 Pass/Fail Screening Criteria

The biogas end-use alternatives were evaluated against the pass/fail criteria identified in Section 2.1.2. Table 5-1 summarizes the evaluation of the key objections:

The only alternative that failed any of the pass/fail criteria was flaring as the primary end use for biogas, due to a lack of resource recovery and improvement in the carbon emissions. As discussed earlier, flares will still be included in all the alternatives as a backup system in case the main biogas end-use system is unavailable (similar to the use of a landfill as a backup end use for biosolids).

**Table 5-1. Initial Pass/Fail Screening of Biogas End Use Alternatives**

| Objective | Criteria | Boilers | Flares | CHP | Biogas Upgrading |
|---|---|---|---|---|---|
| Meets current regulatory requirement | Meets air quality permit and regulations | ✓ | ✓ | ✓ | ✓ |
| Uses a proven technology while allowing for innovation | Stabilization process technology meets established criteria. Non-critical components meet either established or innovative technology requirements | ✓ | ✓ | ✓ | ✓ |
| Maintains reliable end-use options | Maintains minimum of 1 end use or readily available backup alternative capable of handling the full biosolids flow under control of the City | ✓ | ✓ | ✓ | ✓ |
| Maintains safe working environment | Does not require specialized licensing to operate system beyond current wastewater operator license | ✓ | ✓ | ✓ | ✓ |
| | Does not require hazardous chemicals or steam as an integral part of the stabilization treatment or energy recovery process. | ✓ | ✓ | ✓ | ✓ |
| Meets the goals of the climate action plan | Compared to current practice, reduces GHG emissions. Beneficially uses inherent biosolids nutrient and energy resources. Substantially reduces use of non-renewable resources compared to current practice. | ✓ | X | ✓ | ✓ |
| Minimizes social impacts | Compared to current practice, technology does not increase untreatable odors at the fence line | ✓ | ✓ | ✓ | ✓ |

# Section 6: Development of Conceptual Alternatives

Based on the screening processes described in the previous sections, four conceptual alternatives were developed that are representative of the different approaches to applying the screened stabilization technologies and biosolids end uses. These conceptual alternatives are not intended to encompass every alternative available from the screened technologies but instead are intended to be representative of the basic options and provide a basis for further refinement in Phase 2 (including consideration for phasing project elements).

The four conceptual alternatives are summarized in Figure 6-1 and each is described in detail in the following sections.  The four alternatives all include anaerobic digestion (either Class A or Class B) and, for this initial phase of the project, only one biogas end-use alternative was carried forward as a representative end use (CHP using engines with boilers providing backup heat and flares providing emergency biogas disposal). In the next phase of the project, the different biogas utilization alternatives will be considered further.  The alternatives encompass three different end uses for the biosolids: Class B land application, a dried fertilizer product, and a top soil blend suitable for public use.  In addition, an offsite alternative was considered to consider the relative advantages and disadvantages of locating some or all of the solids processing facilities remote from the Post Point site.

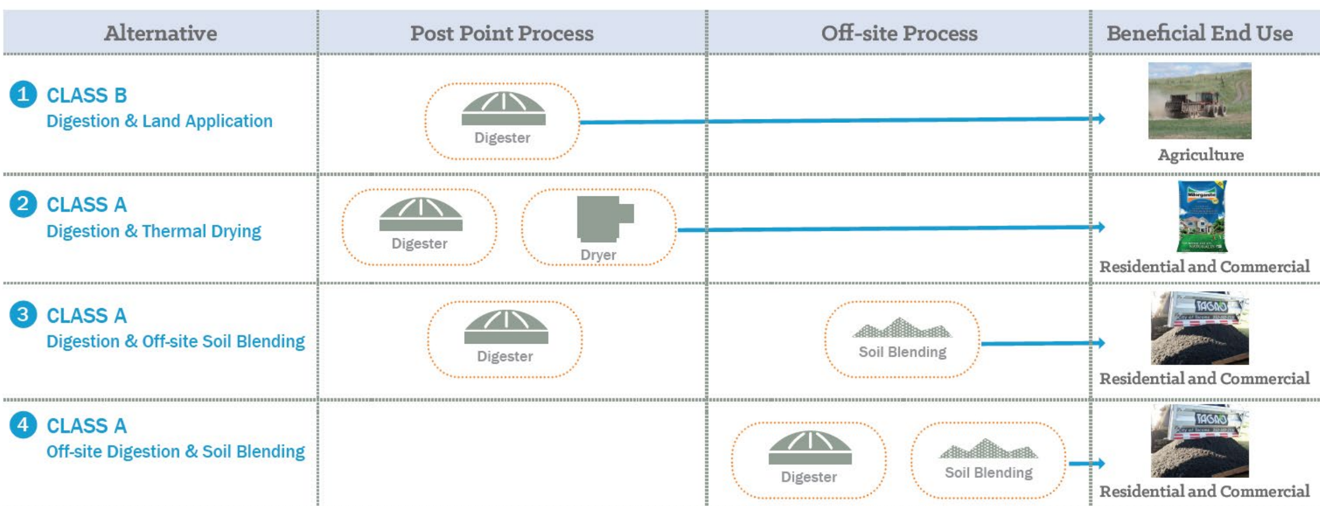


**Figure 6-1. Summary of conceptual alternatives**

A description of the design basis for developing the size and number of units for each alternative is included in Appendix A:. The results of the evaluation of each alternative is presented in the Section 7: and Section 8:.

## 6.1 Alternative 1: Class B Digestion and Land Application

The first alternative developed focused on production of a Class B biosolids product to be used for agricultural land application in eastern Washington. Figure 6-2 is a simplified process flow diagram of the process. The City could continue use of the existing gravity belt thickeners (GBTs) and centrifuges, but the existing GBTs will be approximately 50 years old in 2045 (as will the backup Sharples centrifuge) meaning replacement of the GBTs may be necessary as part of the project. The City's two centrifuges were installed more recently and could continue to be used in the new process; however, a third unit may be necessary to provide sufficient redundancy during peak loads.

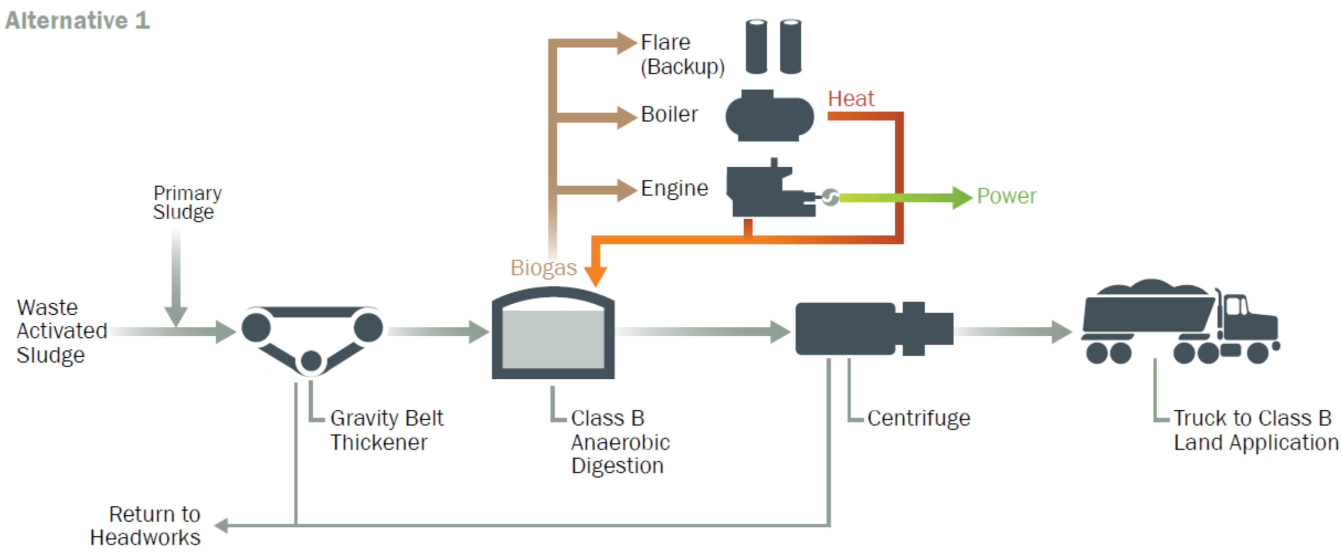


**Figure 6-2. Simplified process flow for Alternative 1**

Co-thickened sludge would be fed to mesophilic anaerobic digestion for solids stabilization. Heat for the process (as well as electricity) would primarily come from reciprocating internal combustion engines fueled with the biogas produced during digestion. Boilers would be used as a backup source of heat or to meet peak heating demands if they exceed the heat output of the engines, while flares would be required as a backup means to dispose of any excess biogas. The Class B biosolids produced from this process would be loaded onto trucks and hauled to eastern Washington for application to agricultural lands.

Figure 6-3 shows a conceptual site layout for the facilities envisioned as part of this alternative. The layout for the selected alternative will be refined further during subsequent phases of the project. The site layout was developed with the intent to demonstrate approximate site area requirements, and to demonstrate a potential approach for routing trucks through the loadout facilities (roadways are shown in purple).

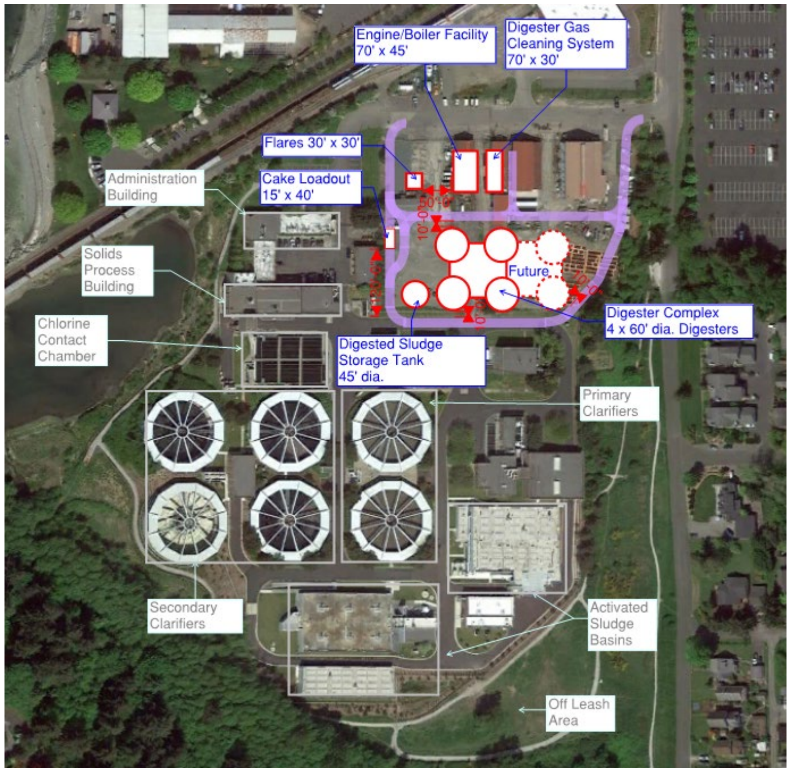


Figure 6-3. Conceptual site layout for Alternative 1

## 6.2 Alternative 2: Class B Digestion, Thermal Drying, and Dried Fertilizer Product

In Alternative 2, a dried fertilizer product would be produced for sale either as a bagged product for individuals or as a bulk sale to fertilizer distributors. To produce a dried product, a Class B digestion system identical to the one described for Alternative 1 would be implemented. After the dewatering process, a thermal dryer using biogas as the main fuel source would remove almost all the remaining moisture in the biosolids (see Figure 6-4). To complete the analysis of this alternative, belt drying technology was assumed as it requires the greatest amount of site space to implement. If this alternative is selected for implementation, a more detailed evaluation of drying technology options should be completed.

Unlike the other alternatives developed, Alternative 2 does not include a CHP system. The biogas-fired dryer would consume most of the biogas produced by the digesters, and there would not be enough biogas remaining for significant beneficial use in an engine. Instead, the digesters would be heated using boilers.

Figure 6-5 is a conceptual layout for the facilities included in this alternative. Like Alternative 1, truck routing has been considered for loading both dewatered cake (as a backup) and the final dried product. Most of the site is dedicated to the dryer facility and storage.

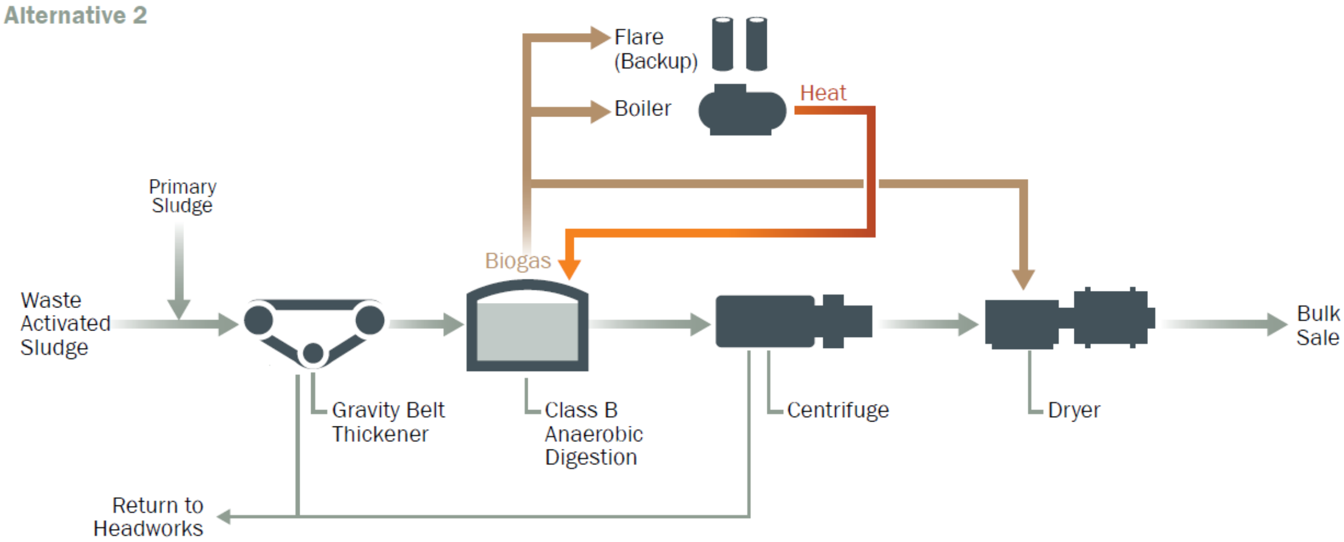


**Figure 6-4. Simplified process flow for Alternative 2**

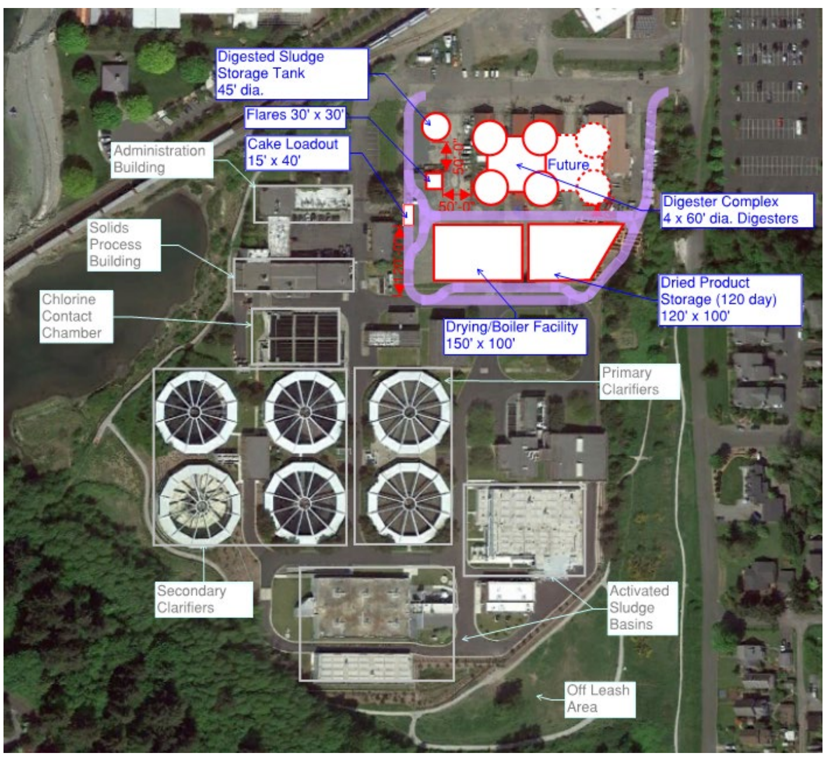


**Figure 6-5. Conceptual site layout for Alternative 2**

## 6.3 Offsite Location Viability and Benefits

The next two alternatives developed include utilizing the biosolids to produce a topsoil amendment product that could be distributed and sold locally. As described in Section 4.2, implementing this type of biosolids end use at any significant scale is not possible at Post Point due to the area required for soil blending (i.e., composting) operation. As such, a site remote from Post Point would be required to facilitate some or all of the new solids management facilities.

An offsite facility would also have other potential benefits to the City beyond allowing the City to produce a locally available biosolids product. Table 6-1 summarizes the pros and cons of including an offsite component to a solids processing facility for the City.

**Table 6-1. Pros and Cons of an Offsite Solids Processing Facility**

| Pros | Cons |
|---|---|
| Sufficient space for composting/soil blending operation | Land purchase required |
| Easier implementation of co-digestion of food waste and/or FOG | Additional site permitting |
| Could reduce trucking and neighborhood impacts to neighborhoods surrounding Post Point | Increased cost and complexity due to conveyance from Post Point |
| Could facilitate a regional processing facility for other municipalities in the region (achieving economies of scale for all the participating agencies) | City staff required at 2 sites |
| Preserves future capacity for Post Point liquid stream treatment | Could introduce trucking and neighborhood impacts to a new area of the city |
| Could open door to potential privatized operation options | |

The net overall benefit of an offsite alternative was determined using the TBL+ evaluation process (described in Section 8:). Before evaluating an alternative that includes an offsite component, the viability of offsite locations in the greater Bellingham area needed to be determined. High-level considerations for determining the viability of potential offsite locations at this planning phase include:

- Located within Whatcom County
- Zoned for industrial or public utility use
- Distance from Post Point accommodates either delivery of solids by pipeline (10 miles or less), or by truck and trailer (up to 30 miles one way)
- Sized to accommodate potential use (e.g., at least 5 to 10 acres)

From these considerations, a number of sites within Whatcom County were assessed using a variety of maps, comprehensive plan designations, and Google Earth. The sites were narrowed down during a field visit to confirm existing and adjacent land uses, suitability of access, and proximity to sensitive receptors (e.g., schools).

Based on this high-level analysis, it was generally confirmed that if an offsite alternative is chosen for implementation, there appear to be viable locations that could potentially serve as an offsite facility. Although further evaluation will be done in Phase 2 should an offsite alternative be selected, the identification of potential sites helped inform the development of representative alternatives by establishing approximate distances of travel and land costs.

## 6.4 Alternative 3: Class A Digestion at Post Point, Soil Blend Production Offsite

Alternative 3 represents a scenario in which a biosolids product is produced for sale and beneficial use locally. For the analysis performed here, a topsoil blend product was assumed rather than composting. If this representative alternative is selected for implementation, a more detailed consideration of producing a topsoil blend product versus compost should be completed. The major differences to consider would be the level of digestion required: a topsoil blend requires Class A biosolids to be produced through digestion, while a compost product may be produced with Class B biosolids as feedstock.

In this representative alternative, Class A biosolids would be produced through a TPAD process and the use of batch tanks. This process utilizes thermophilic digestion operated at 131°F instead of the mesophilic digestion process (98°F) described in the previous two alternatives (see Figure 6-6 for a high-level process schematic). Like Alternative 1, heat for the process would primarily come from a CHP system with boilers as a backup, and flares as a backup disposal method for excess biogas.

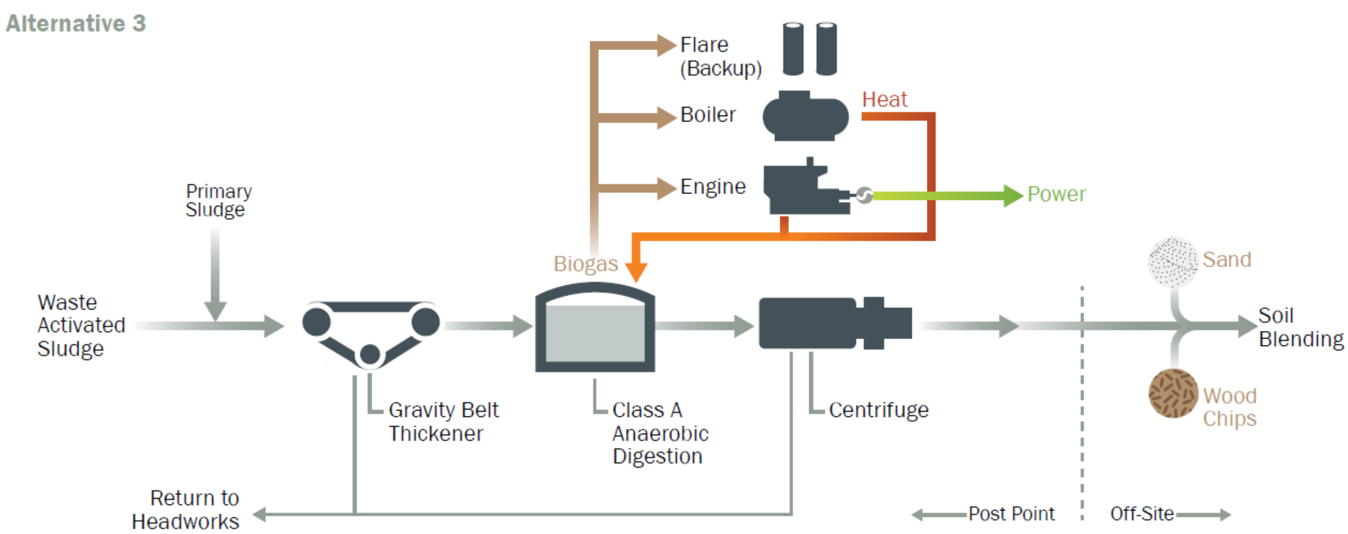


**Figure 6-6. Simplified process flow for Alternative 3**

As described in the previous section, development of topsoil amendment would require an offsite facility. Figure 6-7 and Figure 6-8 show the site layouts for this alternative both at Post Point and at a potential offsite location. The layout at Post Point is similar to that for Alternative 1, with the only difference being the inclusion of a TPAD system and batch tanks in place of a mesophilic digestion system. After digestion, the dewatered cake from Post Point would be hauled to the offsite facility for topsoil production. The topsoil blend is produced by mixing Class A dewatered cake with sand and sawdust at a volumetric ratio of 2 to 1 to 1. Thus, the offsite layout includes a mixing area, product packing (if a bagged product is produced), and an area for product storage. The site would also require space for administration and maintenance facilities. The total offsite area required is estimated at approximately 5 acres.

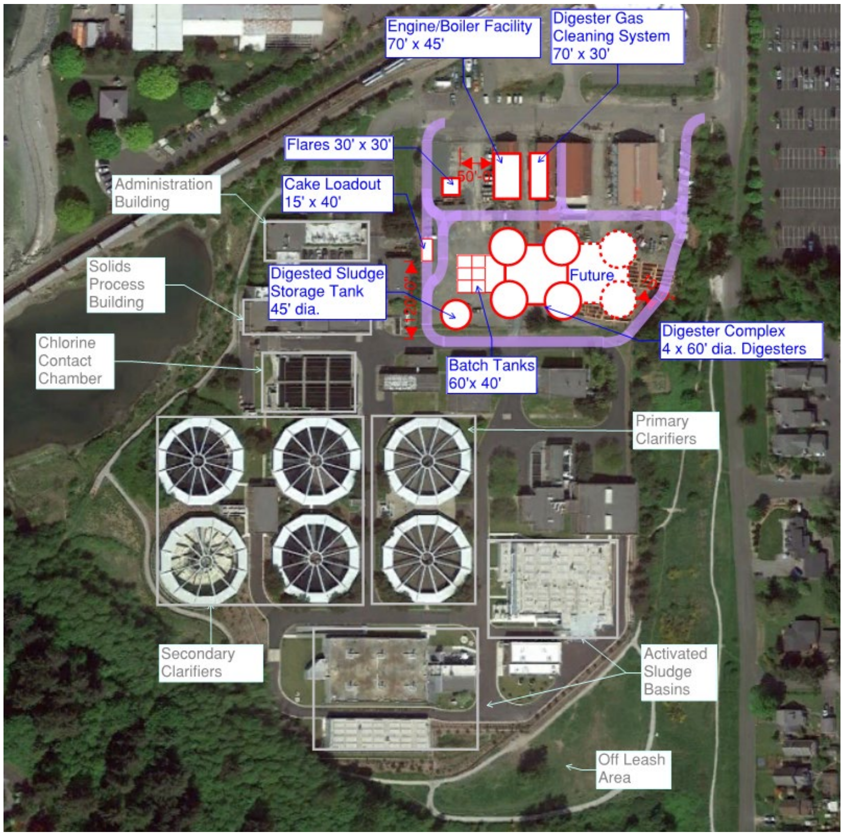


Figure 6-7. Conceptual site layout at Post Point for Alternative 3

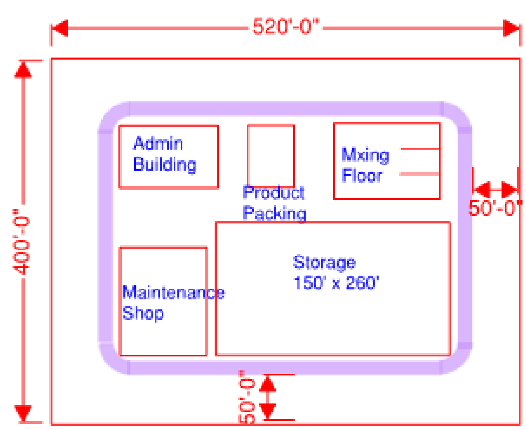


Figure 6-8. Conceptual site layout of offsite area for Alternative 3

## 6.5 Alternative 4: Offsite Class A Digestion and Soil Blend Production

Alternative 4 is a variant of Alternative 3 in which all the solids processing facilities are located offsite. This would preserve available space at Post Point to be used for future liquid stream capacity or treatment process upgrades. This would also eliminate the need to truck solids from Post Point either to the biosolids end use (in Alternatives 1 and 2) or for final processing (Alternative 3).

Figure 6-9 is a simplified process schematic for Alternative 4. This process is identical to the process described in Alternative 3; the only difference between the two is how solids are transported from the Post Point liquid stream treatment process to the solids processing facilities. In Alternative 4, primary sludge and WAS would be pumped together to an offsite location. The practical limits to the distance sludge can be pumped is on the order of 10 miles. Beyond this distance, the cost for pumping would become significantly higher (due to higher pressure losses, and the possibility of needing multiple sludge pump stations). Return streams from the thickening and dewatering process would need to be returned to Post Point. This could be done using a return stream pipeline in parallel with the sludge pipeline, or by routing the return streams into part of the existing sewer system.

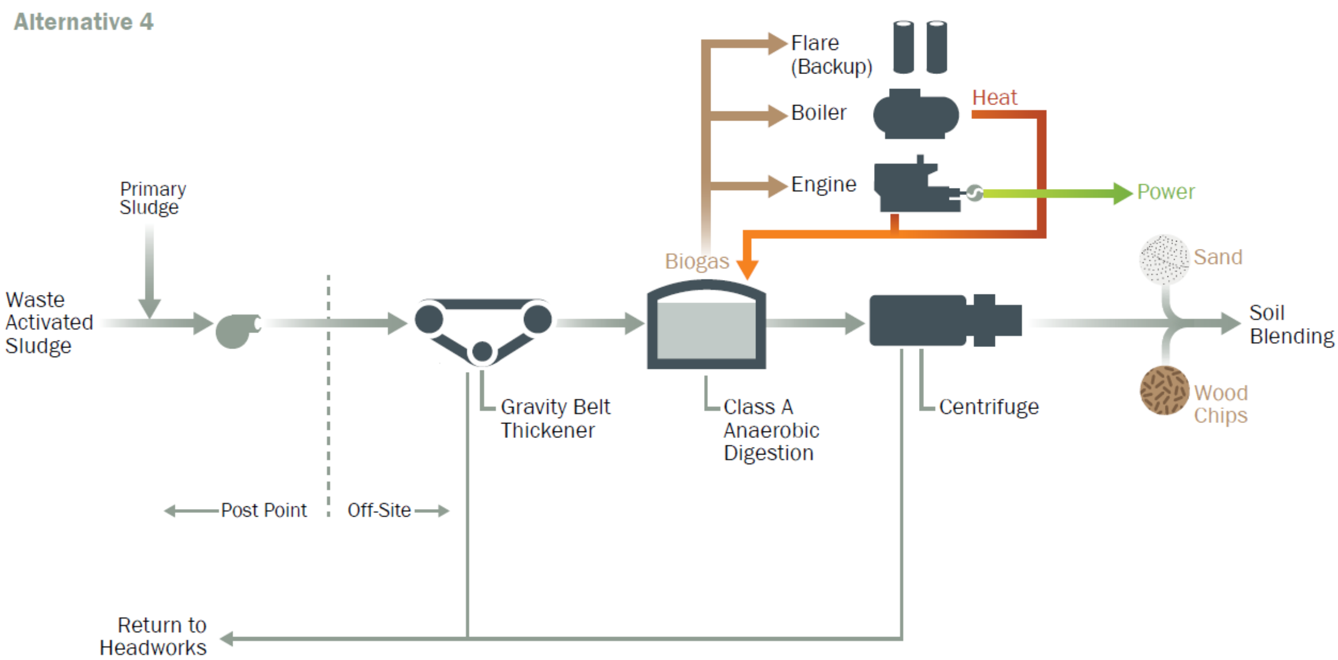


**Figure 6-9. Simplified process flow for Alternative 4**

Figure 6-10 shows a conceptual layout for the offsite facility. This alternative consists of all the same facilities as Alternative 3, but places them all on one site. The area required for this alternative is estimated at 10 acres.

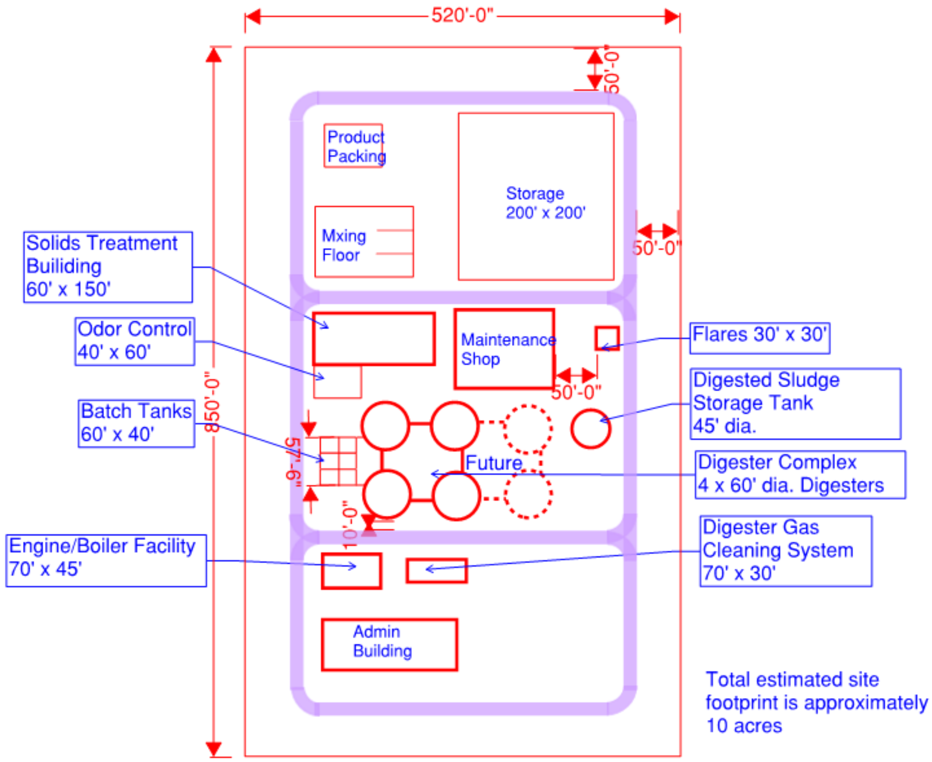


**Figure 6-10. Conceptual site layout for Alternative 4**

# Section 7: Solids, Energy, and Greenhouse Gas Evaluation

With the four alternatives defined, a technical evaluation of the relative solids, energy, and GHG emissions for each alternative was completed. To complete the analysis, Brown and Caldwell's Solids-Water-Energy-Evaluation Tool (SWEET) was used to evaluate the mass and energy balance and the performance of proposed alternatives at a high level. SWEET tracks volatile solids, inert solids, and water through potential process alternatives, and considers the energy required to power and heat those processes. This allows for energy production and material recovery to be estimated based on the expected flows and loads to the facility (identified in Section 2.2.3). It also allows for estimation of the carbon footprint of each alternative based on the mass and end use of recovered materials and the energy profile of each process.

The following sections describe the results of the evaluations using SWEET. The results of these evaluations provide the input into the TBL+ evaluation described in Section 8:.

## 7.1 Mass and Energy Results

Mass and energy outputs for each alternative were developed based on 2035 solids flows and loads at average annual conditions (see Section 2.2.3). This represents the average operating condition at the mid-point of the 20-year planning period. The solids treatment process performances are based on the design criteria presented in Appendix A:, while power, chemical, and vehicle fuel consumptions were based on historical data and the design team's engineering experience.

Several assumptions were made to complete the mass and energy balances. These are summarized in Appendix B:, but four assumptions of note are listed below. The following assumptions were used in the SWEET model:

- Alternative 1: Distance for hauling dewatered cake to land application sites was assumed to be 450 miles round trip. This assumes final disposition of the biosolids would be in eastern Washington.
- Alternative 2: Distance for hauling dried biosolids to a soil blending facility assumed to be 200 miles round trip. This assumes trucking to the greater Seattle area for final disposition. The final disposition of a dried fertilizer product could be a blend of local distribution within the Bellingham area and bulk end use at a location farther away than Seattle.
- Alternative 3: Distance for hauling dewatered cake to the offsite blending facility was assumed to be 40 miles round trip, based on representative offsite locations (discussed in Section 6.3). Distance for hauling the blended soil product to local distribution facilities (e.g., hardware stores, customer homes) was assumed to be 20 miles round trip.
- Alternative 4: No trucking of solids was assumed; sludge is assumed to be pumped 10 miles from Post Point to an offsite solids treatment facility (distance based on representative site locations discussed in Section 6.3). The distance for hauling blended soil product to local distribution facilities was assumed to be 20 miles round trip.

The mass and energy outputs from the SWEET model are summarized in Table 7-1. Detailed mass and energy emission calculations for each alternative are included in Appendix B:.

| Table 7-1. Summary of Mass and Energy Outputs from the SWEET (2035 Flows and Loads) | | | | |
|---|---|---|---|---|
| Parameter | Alternative 1: Class B Land Application | Alternative 2: Dried Fertilizer Product | Alternative 3: Onsite Digestion, Offsite Topsoil Production | Alternative 4: Offsite Digestion and Topsoil Production |
| Final product, wet (WT/d) | 51 | 12 | 105 | 105 |
| Truckloads required (trucks/d) | 1.7 | 0.6 | 5.0 | 3.5 |
| Vehicle fuel consumed (gal/d) | 154 | 24 | 31 | 26 |
| Electricity required (kWh/day) | 9,947 | 14,721 | 10,146 | 12,433 |
| Power generation (kWh/d) | 21,019 | 0 | 23,194 | 23,194 |
| Net power (kWh/d) [a] | -11,073 | 14,721 | -13,048 | -10,760 |
| Digester gas produced (scfd) | 364,970 | 364,970 | 402,725 | 402,725 |
| Methane produced (scfd) | 218,982 | 218,982 | 241,635 | 241,635 |
| Polymer use (kg/d) | 215 | 215 | 202 | 202 |

a. *Negative net power represents power exported; positive net power represents power imported.*

Table 7-1 facilitates some initial observations about the relative difference between the alternatives:

- Alternative 2 (producing a dried fertilizer product) would produce the least amount of end product (due to the removal of almost all of the water content during the drying process), therefore requiring the least number of truckloads. Alternatives 3 and 4 (which produce a topsoil product) have the most final product (due to the addition of sand and sawdust), therefore requiring the most truckloads. Alternative 1 requires the greatest fuel consumption because of the long distance required for land-applying biosolids in eastern Washington.
- The electricity consumption is fairly consistent among the alternatives with Alternative 2 (which includes thermal drying) and Alternative 4 (which includes sludge pumping to an offsite facility) requiring more electricity than the other two alternatives. Alternative 2 does not include any power production, as almost all the digester gas produced is required to heat the digesters and dry the biosolids. The net power production is significantly worse for Alternative 2 compared to the other alternatives.
- Alternatives 3 and 4 (which include Class A digestion) are assumed to achieve higher volatile solids reduction than Alternatives 1 and 2 (which include Class B digestion) because of the use of high temperature thermophilic digestion. The digester gas production from Alternatives 3 and 4 is higher than Alternatives 1 and 2, and the polymer consumption for dewatering is lower (due to the greater reduction in solids in the digestion process).

The values from this analysis formed the input to complete the TBL+ evaluation in Section 8:.

## 7.2 Greenhouse Gas Emission Results

In addition to the mass and energy balance, GHG emissions for each alternative were developed based on 2035 solids flows and loads at average annual conditions. GHG inventories for the proposed alternatives are developed based on GHGs emitted during operation of the biosolids treatment facilities, and transportation and final use of biosolids.

Emission scopes and factors are based on the guidelines published by The Client Registry (TCR) and Intergovernmental Panel on Climate Change (IPCC), and updated with recent publications. Emissions are divided into three categories representing the relative control that the owner has over them:

- Scope 1 emissions are direct emissions from sources owned by the agency (e.g., emissions from fuel consumed by the City, fugitive emissions from the City's facilities)

- Scope 2 emissions are indirect emissions from sources owned by the agency (e.g., emissions from the production of electricity consumed by the City)
- Scope 3 emissions are emissions from the manufacturing of materials used by the City (e.g., polymer used for dewatering)

Not all Scope 3 emissions have been accounted for in the comparison of alternatives at this time (e.g., emissions from the production of concrete and steel to construct new solids processing facilities have not been accounted for) but the significant Scope 3 emissions that are relatively different between the alternatives have been included.

The GHG emissions from each alternative are listed in Table 7-2. Detailed GHG emission calculations for each alternative are shown in Appendix B:. The electricity produced by a CHP system, carbon sequestration, and fertilizer substitution from land application of biosolids products is presented as a negative GHG emission, or carbon credits.

**Table 7-2. Summary of GHG Emissions (2035 Flows and Loads), Metric Tons of Equivalent $CO_2$ per Year**

| Scope | Parameter | Alternative 1: Class B Land Application | Alternative 2: Dried Fertilizer Product | Alternative 3: Onsite Digestion, Offsite Topsoil Production | Alternative 4: Offsite Digestion and Topsoil Production |
|---|---|---|---|---|---|
| Scope 1 | Consumption of natural gas | 0 | 0 | 0 | 0 |
| | Consumption of vehicle fuel | 658 | 91 | 115 | 97 |
| | Fugitive emissions | 233 | 122 | 329 | 329 |
| | **Scope 1 total** | **891** | **214** | **444** | **426** |
| Scope 2 | Electricity required | 1,699 | 2,515 | 1,733 | 2,124 |
| | Power generated | (3,591) | 0 | (3,962) | (3,962) |
| | **Scope 2 total** | **(1,891)** | **2,515** | **(2,229)** | **(1,838)** |
| Scope 3 | Production of polymer | 707 | 707 | 663 | 663 |
| | Production of vehicle fuel | 107 | 15 | 19 | 16 |
| | **Scope 3 total** | **814** | **722** | **681** | **678** |
| Credits | Fertilizer offset | (781) | (781) | (698) | (698) |
| | Carbon sequestration | (1,027) | (1,027) | (918) | (918) |
| | **Credits total** | **(1,808)** | **(1,808)** | **(1,616)** | **(1,616)** |
| **Total (metric tons/year)** | | **(1,995)** | **1,642** | **(2,720)** | **(2,350)** |

*Note: Values in parentheses denote overall reduction in GHG values (carbon offsets).*

From this analysis, it can be concluded that Alternative 2 (producing a dried fertilizer product) would have the highest overall GHG emission among the alternatives evaluated. Alternative 2 lacks the ability to generate renewable electricity, and thus has significantly higher Scope 2 emissions than the other alternatives. Alternative 2 is also the only alternative with a net positive carbon emissions profile.

Alternative 1 would have the highest Scope 1 and 3 emissions due to the long hauling distance required for biosolids land application in eastern Washington. Alternatives 3 and 4 have the best GHG emissions profile because of the increased digester gas production from utilizing a Class A digestion process (resulting in increased renewable power production) and the limited hauling distances required when distributing the final biosolids product locally. Of these two alternatives, Alternative 3 has a better profile because the emissions from trucking dewatered cake from Post Point to an offsite topsoil production facility is less than the emissions from pumping sludge from Post Point to an offsite facility for treatment and topsoil production.

# Section 8: Phase 1 TBL+ Evaluation Results

With the conceptual alternatives identified (Section 6:) and the evaluation of solids, energy, and GHG balance for each alternative completed (Section 7:), the TBL+ evaluation described in Section 2.1.3 was completed for each alternative to identify a preferred conceptual alternative.

For this first phase of planning, each parameter was evaluated to identify the alternatives that are most compatible with the criteria goal. The identified alternatives then serve as the optimal benchmark for the parameter against which each of the other alternatives is then ranked. The resulting evaluation provides the quantitative/qualitative basis for assessing each alternative. This scoring was completed collaboratively with the City's "core team" to ensure the views of all of the City's departments were incorporated. Preliminary results were presented to the community as part of the project's public involvement plan (described in Section 2:) and the feedback was incorporated in the final results presented below (see Section 9: for details).

The following sections describe the results of this evaluation for each category of the TBL+, including the total score for each alternative by category. As described in Section 2.1.3, all the categories are equally weighted, resulting in a maximum score of 25 points for each category of criteria.

## 8.1 Environmental Criteria

Each alternative was compared based on the environmental criteria defined in Section 2.1.3.1 using the results from the solids, energy, and GHG evaluations described in Section 7:. The results of the relative comparison of each alternative is presented in Table 8-1.

Table 8-1. Environmental Criteria

| Criterion | Alternative 1: Class B Land Application | Alternative 2: Dried Fertilizer Product | Alternative 3: Onsite Digestion, Offsite Topsoil Production | Alternative 4: Offsite Digestion and Topsoil Production |
|---|---|---|---|---|
| E1. Minimizes carbon footprint (GHG emissions) | 73% | 0% | 100% | 86% |
| E2. Protects air quality | 100% | 100% | 100% | 100% |
| E3. Maximizes opportunities for resource recovery | 25% | 25% | 100% | 100% |
| E4. Minimizes net energy usage | 88% | 0% | 100% | 76% |
| E5. Protects and improve local habitat | 60% | 60% | 100% | 80% |
| **Total score (out of 25 point possible)** | **17** | **9** | **25** | **22** |

This scoring results in a repeat of many of the conclusions described in Section 7::

- Alternative 2 (producing a dried fertilizer product) has a poor net energy use and GHG emissions profile compared to the other alternatives,
- Alternative 3 (offsite topsoil blend production) had the best GHG emissions and energy use profile.

In addition to these conclusions, it was also identified that:

- all the alternatives have a similar air quality profile,
- In terms of resource recovery, all the alternatives recover resources (including energy and the nutrient value of the biosolids) but the lack of a net positive energy balance for Alternative 2 and the lack of a local use for the recovered nutrient value of the biosolids for Alternative 1 results in a lower score for those Alternatives,
- In terms of local habitat protection, Alternatives 3 and 4 allow for local improvements in soil tilth by locally reusing the biosolids and thus these alternatives scored higher than Alternative 1 and 2. Alternative 4 scored lower than Alternative 3 because Alternative 3 would include the potential for stormwater management improvements as part of the upgrades at Post Point and an offsite facility.

The result is that Alternative 2 scores the worst in terms of environmental criteria, and Alternatives 3 and 4 score near each other (with Alternative 3 scoring the highest).

## 8.2 Social Criteria

Each alternative was compared based on the social criteria defined in Section 2.1.3.2. The social criteria are not as easy to measure in a quantitative sense (except for the number of truckloads required by each alternative), so the scoring is a qualitative assessment for each criterion. The results of the relative comparison of each alternative are presented in Table 8-2.

**Table 8-2. Social Criteria**

| Criterion | Alternative 1: Class B Land Application | Alternative 2: Dried Fertilizer Product | Alternative 3: Onsite Digestion, Offsite Topsoil Production | Alternative 4: Offsite Digestion and Topsoil Production |
|---|---|---|---|---|
| S1. Minimizes public exposure to noise (percent) | 100% | 100% | 80% | 60% |
| S2. Minimizes public exposure to odor (percent) | 100% | 100% | 100% | 100% |
| S3. Minimizes public exposure to truck traffic (percent) | 70% | 100% | 70% | 70% |
| S4. Minimizes local visual impacts (percent) | 67% | 33% | 67% | 100% |
| S5. Minimizes exposure to toxins (percent) | 100% | 100% | 100% | 100% |
| **Total score (out of 25 point possible)** | **22** | **22** | **21** | **22** |

The results of the analysis show there is no appreciable difference between the alternatives in terms of neighbor impacts.

- Alternative 3 and 4 scored lower in terms of noise because the offsite facilities were considered to be more likely to increase ambient noise levels wherever the offsite facilities are located.
- None of the alternatives is expected to noticeably increase public exposure to odors.
- The difference in truck traffic is scaled based on the number of trucks estimated to enter and leave the solids treatment facilities at Post Point.
- To compare the alternatives based on visual impacts, the relative amount of new facilities at Post Point was used. Alternative 2, which requires the most facilities (including a new dryer building) scores the

worst, while Alternative 4 scores the best as there would be no appreciable increase in the number of buildings at Post Point (because all treatment and topsoil production would be located at an offsite location).

- None of the alternatives is expected to increase the public's exposure to toxins

The result is that all of the alternatives score similarly, within 1 point of each other.

## 8.3 Financial Criteria

Each alternative was compared based on the financial criteria defined in Section 2.1.3.3. The financial criteria were scored based on comparative cost estimates that identify the difference in cost between the alternatives, and do not account for the entire cost of the proposed improvements. As such, the total project costs are not identified here, and will be developed during Phase 2 of the project. The results of the relative comparison of each alternative are presented in Table 8-3.

Table 8-3. Financial Criteria

| Criterion | Alternative 1: Class B Land Application | Alternative 2: Dried Fertilizer Product | Alternative 3: Onsite Digestion, Offsite Topsoil Production | Alternative 4: Offsite Digestion and Topsoil Production |
|---|---|---|---|---|
| F1. Optimizes system value | 100% | 85% | 91% | 39% |
| F2. Affordability | 100% | 85% | 91% | 39% |
| F3. Minimizes risk of end-use market sensitivity | 100% | 75% | 100% | 100% |
| **Total score (out of 25 point possible)** | **25** | **20** | **23** | **15** |

The results show that Alternative 1 is the lowest cost alternative while Alternative 4 is the highest cost (as a result of the need to purchase additional property, build infrastructure to convey solids from Post Point to the offsite location, and build administrative facilities at the offsite location similar to existing facilities already located at Post Point). Alternatives 2 and 3 are relatively close to Alternative 1 in terms of costs.

Alternative 2 scored lower in terms of sensitivity to commodity market prices because of it's higher reliance on outside commodities (namely, electricity).

## 8.4 Technical Criteria

Each alternative was compared based on the technical criteria defined in Section 2.1.3.4. Similar to the social criteria evaluation, the technical criteria do not lend themselves well to quantitative measurement so the scoring is a qualitative assessment of the relative benefits for each criterion. The results of the relative comparison of each alternative is presented in Table 8-4.

| Table 8-4. Technical Criteria | | | | |
|---|---|---|---|---|
| **Criterion** | **Alternative 1: Class B Land Application** | **Alternative 2: Dried Fertilizer Product** | **Alternative 3: Onsite Digestion, Offsite Topsoil Production** | **Alternative 4: Offsite Digestion and Topsoil Production** |
| T1. Incorporates reliability and proven performance | 83% | 87% | 93% | 93% |
| T2. Minimizes existing process impacts | 100% | 100% | 90% | 90% |
| T3. Provides flexibility for future | 50% | 30% | 50% | 100% |
| T4. Minimizes implementation complexity | 100% | 40% | 40% | 10% |
| **Total score (out of 25 point possible)** | **21** | **16** | **17** | **18** |

The results of this analysis are as follows:

- Reliability and proven performance: All the technologies considered are proven, but Class B digestion is more widely applied than thermal drying or Class A digestion. Thermal drying was also considered less reliable than other processes. In terms of end-use reliability, producing a Class B product was considered more susceptible to end-use market volatility than the Class A products.
- Impacts to existing treatment process: Class A digestion results in a stronger return stream (i.e., ammonia load) to the liquid treatment process than Class B digestion; therefore, alternatives using Class A digestion scored lower.
- Future flexibility: Similar to the visual impacts criterion (S4), alternatives were scored based on the amount of facilities required at Post Point under the assumption that more land use at Post Point limits the ability to modify or expand the plant in the future. Alternative 2 has the most number of new facilities so it scores the lowest, while Alternative 4 does not have any significant new facilities at Post Point and scores the highest.
- Implementation complexity: Alternatives that require the purchase and permitting of a new site were scored lower than alternatives that were confined to Post Point (and larger offsite areas were scored lower). In addition, the drying process was considered more complex and would require a greater level of operation and maintenance effort to implement successfully.

The result was that Alternative 1 had the lowest technical impacts of the alternatives considered and therefore scored the highest. Alternatives 2, 3, and 4 all scored within close proximity to each other.

## 8.5 Overall Score

Combining the scores from all four categories results in a total score for each alternative. Table 8-5 summarizes the score for each category, and the total score for each alternative.

| Table 8-5. TBL+ Scores | | | | |
|---|---|---|---|---|
| Category | Alternative 1: Class B Land Application | Alternative 2: Dried Fertilizer Product | Alternative 3: Onsite Digestion, Offsite Topsoil Production | Alternative 4: Offsite Digestion and Topsoil Production |
| Environmental | 17 | 9 | 25 | 22 |
| Social | 22 | 22 | 21 | 22 |
| Financial | 25 | 20 | 23 | 15 |
| Technical | 21 | 16 | 17 | 18 |
| **Total score (out of 100 possible points)** | **85** | **67** | **86** | **77** |

The result from this analysis is that Alternative 2 scores the lowest. Alternatives 1 and 3 score the highest, with Alternative 3 scoring slightly higher.

# Section 9: Public Outreach

The following sections describe the public outreach efforts associated with the biosolids program. This includes current outreach specific to informing the local community about the project and gathering feedback on the potential alternatives. Also discussed are recommendations on developing and maintaining a local education program to ensure long-term success of the City's biosolids program.

## 9.1 Local Public Involvement

As described in Section 2:, community input is a critically important factor to confirm that evaluation criteria and TBL+ evaluation results reflect the values of the City and the impacted stakeholders. The City held community workshops to inform the community and gather feedback to incorporate the community's values into the planning process (see Figure 9-1 for images from the May 23, 2017 workshop). The following workshops were held:

- May 23, 2017: The purpose of this workshop was to (1) introduce the project need and objectives and (2) gather public input about the criteria developed. The public's feedback supported resource recovery, and there was general support for moving away from incineration.
- July 31, 2017: The purpose of this workshop was to (1) update on project status, (2) introduce the alternatives following the pass/fail screening, and (3) provide an overview of the preliminary TBL+ results. The public's feedback was positive to selecting an alternative to maximize resource recovery.

**Figure 9-1. Images from May 23, 2017 community workshop**

During these workshops, the community provided feedback during one-on-one discussions with the project team, by asking questions during the City's presentation, and from follow-up questionnaires after the workshop was completed. From this input, a series of frequently asked questions and the corresponding responses were developed and posted to the City's biosolids website (see Appendix C). The most common feedback received was:

- support for an alternative that focused on resource recovery and environmental benefits
- preference for a biosolids product that would be available for local distribution and end use
- concern for local neighborhood impacts of a new facility, such as odors and truck traffic
- need for addressing safety issues associated with digestion facilities and biosolids end use

This feedback was incorporated into the TBL+ evaluation results described in the previous section. Specifically, the following criteria were impacted:

- E3: Maximize opportunities for resource recovery (greater emphasis was placed on locally recovering the inherent resource in the biosolids)
- E5: Protects and improves local habitat (greater emphasis was placed on the local improvements to habitat from beneficially using the biosolids in Bellingham).
- S3: Minimize public exposure to truck traffic (the number of trucks expected for each alternative was calculated and the alternatives were scored accordingly)
- T1: Incorporate reliability and proven performance (greater value was placed on the market flexibility of producing a Class A product and the use of reliable technologies)

The community's interest in minimizing odors and biosolids safety issues were noted but at this phase of the study, the alternatives considered were not appreciably different in terms of odor or safety concerns. All of the alternatives would include engineered odor control facilities to capture and treat odors from the facilities. In terms of biosolids safety, considerable academic research has been performed nationwide and in the Pacific Northwest on the suitability of biosolids recycling, establishing application (i.e., agronomic) rates, and the benefits of biosolids reuse. This research has overwhelmingly supported the benefits and safety of beneficial use of biosolids products when used appropriately within the US EPA regulatory framework. As a result, all of the alternatives were considered to safely use the biosolids resource.

In addition to these outcomes, updates and information on the study were provided on the City's biosolids website.

## 9.2 Public Education

An active organization of biosolids recyclers (Northwest Biosolids) leads research and public communications about biosolids recycling, and provides an effective forum for utilities and private companies to discuss biosolids issues and address public concerns. Collectively, Northwest Biosolids producers generate up-to-date information on producing and marketing products. Regulators are provided with required scientific information to guide creation, interpretation, and implementation of biosolids and compost protocols.

Utilities producing biosolids need active public education programs to inform their customers and broader communities. Most commercial biosolids recyclers and large utilities have well established education programs and materials. Biosolids recycling is generally well accepted in Washington, but there have been cases of public concern and demonstration during the last 40+ years of biosolids recycling. In other parts of the west (e.g., Southern California), municipalities are making efforts to move to at least some production of Class A biosolids, if not fully shifting their operations to the higher quality product.

To address these concerns, it is important for the City to develop a program to inform the local community of the benefits of a local biosolids program, and to address related public concerns. As part of these efforts, participation in the Northwest Biosolids organization is also recommended to provide the City with input and support from other local biosolids programs to maintain a successful, long-term program.

# Section 10: Findings and Recommendations

This section summarizes the findings from the Phase 1 TBL+ analysis and provides recommendations for next steps.

## 10.1 Findings

The initial screening of the world of solids stabilization processes, biosolids end uses, and biogas end uses resulted in the following processes being considered compatible with the values of the City:

- Stabilization processes: anaerobic digestion
- Biosolids end uses: land application, soil amendment, and dried fertilizer
- Biogas end uses: boilers, CHP, and biogas upgrading

From these viable processes, four conceptual alternatives were developed and analyzed. The key differentiators for the four alternatives considered are as follows:

- **Alternative 1, Onsite Class B digestion with offsite land application**: This is the least complex and least expensive alternative, but because a Class B product is produced, the final product requires long-distance hauling to eastern Washington and likely could not be used locally.
- **Alternative 2, Onsite Class B digestion with thermal drying to produce a dried fertilizer product**: This alternative has the advantage of producing a Class A product and the removal of almost all of the moisture in the solids, resulting in little trucking from Post Point. However, the significant amount of energy required to thermally dry biosolids results in a poor energy profile for this alternative compared to the others. In addition, the drying process is complex, expensive, and would take up a significant amount of space at Post Point, limiting the City's ability to expand the plant in the future.
- **Alternative 3, Onsite Class A digestion with offsite soil blending**: This alternative produces a Class A product that can be distributed locally. Because Class A digestion is used, this alternative has the lowest GHG emissions and lowest net energy use. The drawback to this alternative is the need to acquire and site the soil blending process at an offsite location due to space limitations at Post Point.
- **Alternative 4, Offsite Class A digestion with offsite soil blending**: Like Alternative 3, this alternative produces a Class A product that can be distributed locally, and has a relatively good GHG emissions and energy use profile. Siting all the facilities at a new offsite location also minimizes the impacts to neighbors surrounding Post Point, allows for a future regional biosolids plant and/or the co-digestion of other imported materials, and preserves the greatest amount of space on site at Post Point for future expansions. The offsite location also comes with new site acquisition and permitting risks, high costs associated with pumping solids from Post Point to the new offsite location, and increased costs for new administrative facilities and conveyance infrastructure.

The results from the TBL+ analysis are shown in Figure 10-1 and indicate that Alternative 1 and 3 have similar scores. Alternative 3 (onsite Class A digestion with offsite soil blending) has the highest overall score—receiving 86 out of a possible 100 points. Alternative 1 (onsite Class B digestion with land application) has the second highest overall score—receiving 85 out of a possible 100 points.

The methodology and results of this analysis have been presented to the community at a series of community workshops. The feedback received at these workshops has been in concurrence with the evaluation criteria used and the support for an alternative that recovers resources, allows for local end use of the biosolids resource, and improves the carbon footprint of the City's operations.

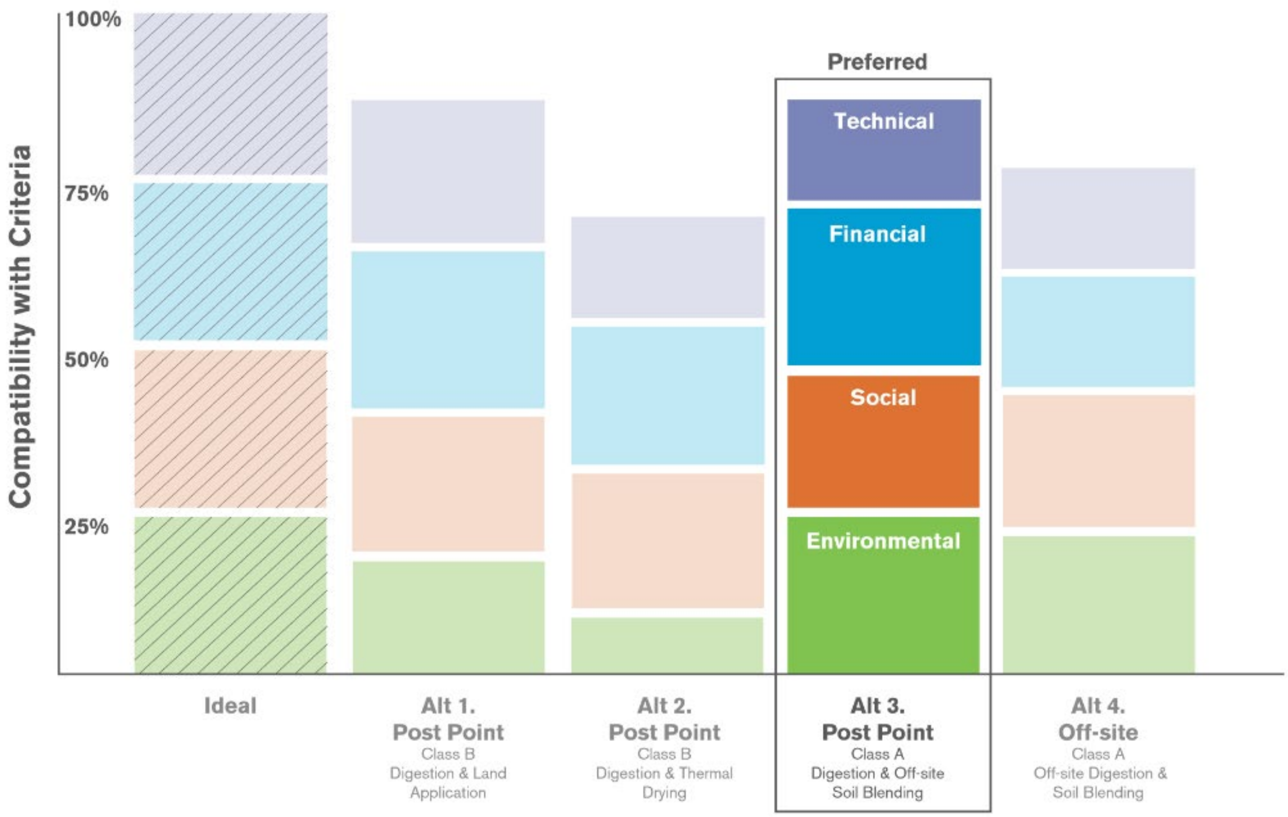


**Figure 10-1. TBL+ results**

## 10.2 Recommendations

Based on the results of the TBL+ analysis and public feedback with support for a local Class A product and maximized environmental benefit, Alternative 3 is recommended for further development and analysis. This alternative was identified as the alternative that best meets the City's Legacies and Strategic Commitments and provides the best blend of environmental, social, financial, and technical benefits.

Implementation does not preclude a phased approach that incorporates the second-highest scoring alternative (and the lowest cost alternative). Alternative 1 contains many of the same facilities at Post Point as Alternative 3, so if the City desired to save capital initially, Alternative 1 could be implemented and then at a future date the components of Alternative 3 could be phased in (including purchase of an offsite facility and potentially transitioning from Class B to Class A digestion, depending on the final soil amendment product selected: compost or a topsoil blend).

As such, the following next steps are recommended:

- Complete Phase 2 evaluations to identify the preferred alternative for implementation, including comparison of:
  - Implementing Class B digestion with offsite composting or Class A digestion with offsite topsoil blending
  - The specific anaerobic digestion process (e.g., mesophilic, thermophilic, temperature phased, etc.)
  - The preferred biogas utilization process
  - Phasing opportunities

- Identify City staffing recommendations.
- Develop complete project cost estimates and the associated rate impacts.
- Continue current public outreach efforts to inform community stakeholders, solicit input and feedback on evaluation methodology and results, and develop support for the preferred alternative.
- A market analysis of the final biosolids end product is required to confirm the local demand for the product to be produced and the potential sales price (to refine ongoing costs and rate impacts). The expected market demand could also impact phasing decisions as limited local demand could result in a portion of the City's biosolids being hauled to eastern Washington until the local market develops, such that the full volume of biosolids produced can be distributed locally.
- Participation in the Northwest Biosolids organization is strongly encouraged to develop internal City staff capability and knowledge of biosolids research. An ongoing City public education program will be important to the long-term sustainability of the City's biosolids program.

# Appendix A: Design Basis and Criteria

*Thickening*

| | | |
|---|---|---|
| Number of units | 2 | Both units are existing. One unit would be redundant except to process peak day flows and loads in 2045. |
| Hydraulic capacity, each (gpm) | 600 | As reported in Biosolids Business Case Evaluation (CDM, 2012) |
| Loading capacity, each (lb/hr) | 4,850 | As reported in Biosolids Business Case Evaluation (CDM, 2012) |
| Thickened sludge concentration (%-TS) | 5 | |

*Mesophilic Anaerobic Digestion*

| | | |
|---|---|---|
| Number of units | 4 | All units required for peak flows and loads, service condition is one unit out of service under average annual flows and loads |
| Hydraulic retention time (days) | 15 | Under peak two-week flows (peak condition) and average annual flows (service condition) |
| Organic loading rate (lb-VS/ft$^3$- d) | 0.18 | Under peak two-week loads (peak condition) and average annual loads (service condition) |
| Volatile solids reduction (%) | 58 | |

*Temperature Phased Anaerobic Digestion*

| | | |
|---|---|---|
| Number of units | 2 + 2 | Two thermophilic digesters plus two mesophilic digesters. All units required for peak flows and loads, service condition is one unit out of service under average annual flows and loads |
| Hydraulic retention time (days) | 15 | Under peak two-week flows (peak condition) and average annual flows (service condition). 7 days at thermophilic conditions, 8 days at mesophilic conditions. |
| Organic loading rate (lb-VS/ft$^3$- d) | 0.35 | Thermophilic phase only. Under peak two-week loads (peak condition) and average annual loads (service condition) |
| Volatile solids reduction (%) | 64 | |

*Digested Sludge Storage Tanks*

| | | |
|---|---|---|
| Number of units | 1 | |
| Hydraulic retention time (days) | 2 | At peak day flows |

*Centrifuges*

| | | |
|---|---|---|
| Number of units | 2 | Both units are existing and would be duty units. The existing, older third centrifuge could be used as a backup unit. |
| Hydraulic capacity, each (gpm) | 123 | Alfa Laval G2-95 data sheet |

| | | |
|---|---|---|
| Loading capacity, each (lb/hr) | 2,800 | Alfa Laval G2-95 data sheet |
| Dewatered cake concentration (%-TS) | 22 | |

*Thermal Drying*

| | | |
|---|---|---|
| Number of Units | 2 | Each unit sized for 60 percent of peak day load |
| Capacity, each (dry tons per day) | 18 | |
| Heat required (Btu/lb-$H_2O$ evaporated) | 1,500 | |
| Dried product concentration (%-TS) | 92 | |

*Product Storage*

| | | |
|---|---|---|
| Class B Cake (days) | 3 | Assumed one day of cake storage prior to thermal drying or top soil blend production |
| Dried Fertilizer (days) | 120 | |
| Top Soil Blend (days) | 120 | |

*Combined Heat and Power*

| | | |
|---|---|---|
| Number of units | 1 | One unit in service. |
| Electrical capacity, each (kW) | 1100 | Unit sized for max month gas production. |
| Heat capacity, each (MMBtuh) | 4.2 | Assumes 45 percent recovery |

*Hot Water Boilers*

| | | |
|---|---|---|
| Number of units | 2 | All units required for peak, service condition is one unit out of service under average annual |
| Heat capacity, each (MMBtuh) | 5 | Each unit sized for 50 percent of peak day |

*Flares*

| | | |
|---|---|---|
| Number of units | 2 | All units required for peak instantaneous flows and loads, service condition is one unit out of service under average annual flows and loads or operation of CHP |
| Capacity, scfm | 500 | Each unit sized for 60 percent of peak instantaneous |

# Appendix B: Solids-Water-Energy Evaluation Tool Assumptions and Results

## Summary of Bellingham Phase 1 Alternative Outputs

| Bellingham Phase 1 Alternatives | | | | | |
|---|---|---|---|---|---|
| **Alternative** | **Thickening** | **Stabilization** | **Dewatering** | **Post-Dewatering** | **End Use** |
| 1 | GBT | Meso | Centrifuge | - | Land Application |
| 2 | GBT | Meso | Centrifuge | Drying | Fertilizer |
| 3 | GBT | TPAD | Centrifuge | Blending (Off-Site) | Amendment |
| 4 (Off-Site) | GBT | TPAD | Centrifuge | Blending | Amendment |

| Alternative Average Daily Output Summary (Year 2035) | | | | |
|---|---|---|---|---|
| | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
| Final Product, Wet (WT/day) | 51 | 12 | 105 | 105 |
| NG Req. (cf/day) | 0 | 0 | 0 | 0 |
| Electricity Req. (kWh/day) | 9,947 | 14,721 | 10,146 | 12,433 |
| Power Generation (kWh/day)** | 21,019 | 0 | 23,194 | 23,194 |
| Net Power (kWh/day)* | -11,073 | 14,721 | -13,048 | -10,760 |
| No. of Trucks Required (trucks/day) | 1.71 | 0.61 | 5.03 | 3.51 |
| Vehicle Fuel Consumed (gal/day) | 154 | 24 | 31 | 26 |
| Digester Gas Produced (scf/day) | 364,970 | 364,970 | 402,725 | 402,725 |
| Methane Produced (scf/day) | 218,982 | 218,982 | 241,635 | 241,635 |
| Polymer Use (kg/day) | 215 | 215 | 202 | 202 |
| *Negative net power represents power consumed; positive new power represents power produced | | | | |
| **Alt 1,3,4, 90% biogas utilized in cogen. Alt 2, 70% biogas utilized in dryer. Remaining biogas is flared for all | | | | |

### Assumptions

**All Alternatives**

Flows and loads based on mid-point average, year 2035
PS dry mass flow is 60% of TS loading
WAS dry mass flow is 40% of TS loading
Average mileage for biosolids cake transport truck is 5 mpg
Biosolids cake transport truck hold 30 wet Tons of cake
Cogen beneficially utilizes 90% of digester gas produced, remaining gas is flared
GBT requires 8 lbs/ton of polymer
Centrifuge requires 25 lbs/ton of polymer
Methane is 60% of the digester gas produced
Based on experience with Annacis Island, heat recovered from co-gen is sufficient to heat digesters to thermophilic temperature and provide all building heat.

**Alt 1**

Biosolids cake deposited near Spokane, 450 miles round trip
Capacity of cake hauling truck is 30 wet ton per truck.

**Alt 2**

Thermal dryer utilizes 70% of biogas produced, remaining biogas is used for heating or flared. Calculations (Alt2 Tab) show energy required for drying is approximately 60% of energy of total digester gas production. Used 70% to be conservative.
Biosolids cake is deposited to hypothetical soil blending facility, 200 miles roundtrip
Capacity of hauling truck is 20 wet ton per truck.

**Alt 3**

Dewatered sludge is transported to offsite blending facility, 16 miles round trip (consistent with pumping distance of 8 miles one way in Alt 4)
Heat is not captured from TPAD heat exchanger
1 front loader operates 4 hrs/day, burns 3 gals of diesel/hr
Blended material is hauled to local distribution facilities, 20 miles round trip
Capacity of hauling truck is 30 wet ton per truck.

**Alt 4**

Heat is not captured from TPAD heat exchanger
1 front loader operates 4 hrs/day, burns 3 gals of diesel/hr
Combined sludge is pumped to off-site facility using 1-65 hp pump
End product consumer purchases soil amendment on-site
Blended material is hauled to local distribution facilities, 20 miles round trip
Capacity of hauling truck is 30 wet ton per truck.

## Bellingham Phase 1 Alternative Output Summary

### Greenhouse Gas Emissions, Tonne CO2e/year

| | | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
|---|---|---|---|---|---|
| Scope 1 | Consumption of Natural Gas | 0 | 0 | 0 | 0 |
| | Consumption of Vehicle Fuel | 658 | 91 | 115 | 97 |
| | Fugitive Emissions | 233 | 122 | 329 | 329 |
| | **Scope 1 Total** | 891 | 214 | 444 | 426 |
| Scope 2 | Electricity Required | 1,699 | 2,515 | 1,733 | 2,124 |
| | Power Generated | (3,591) | 0 | (3,962) | (3,962) |
| | **Scope 2 Total** | (1,891) | 2,515 | (2,229) | (1,838) |
| Scope 3 | Production of Polymer | 707 | 707 | 663 | 663 |
| | Production of Natural Gas | 0 | 0 | 0 | 0 |
| | Production of Vehicle Fuel | 107 | 15 | 19 | 16 |
| | **Scope 3 Total** | 814 | 722 | 681 | 678 |
| Credits | Fertilizer Offset | (781) | (781) | (698) | (698) |
| | Carbon Sequestration | (1,027) | (1,027) | (918) | (918) |
| | **Credits Total** | (1,808) | (1,808) | (1,616) | (1,616) |
| | **Total, Tonne CO2e/Year** | **(1,995)** | **1,642** | **(2,720)** | **(2,350)** |

## SUMMARY OF CO2 EMMISSION FACTORS FOR GHG CALCULATIONS

**Global Warming Potential**

| | |
|---|---|
| CO2 = | 1 |
| CH4 = | 23 |
| N2O = | 296 |

**Fertilizer Amounts**

| | |
|---|---|
| 4% | Nitrogen added |
| 1.5% | Phosphorus added |

**Conversions**

| | | |
|---|---|---|
| 1 Btu = | 0.0002928 | kWh |
| 1 MMBtu = | 293 | kWh |
| 1 kg = | 2.205 | lb |
| 1 cf = | 0.001 | MMBtu |
| 1 gal = | 3.785 | L |
| 1 tonne = | 1000 | kg |
| 1 cf CH4= | 0.020253165 | kg |
| 1 mol = | 0.79 | cf |

| Heating | CO2 E (as C equiv) | Source | Notes | | CH4 E | N2O E | |
|---|---|---|---|---|---|---|---|
| Coal | 121 kg/MMBtu | Biomass Energy Centre (UK) | Includes production emissions | | | | |
| Coal | 104 kg/MMBtu | 2015 Climate Registry Table 12 | Combustion only (no production) | | | | |
| Oil | 92 kg/MMBtu | Biomass Energy Centre (UK) | Includes production emissions | | | | |
| Oil No.2 | 74 kg/MMBtu | 2015 Climate Registry Table 12 | Combustion only (no production) | | | | |
| Nat Gas | 67 kg/MMBtu | Biomass Energy Centre (UK) | Includes production emissions | | | | |
| Nat Gas | 53 kg/MMBtu | 2015 Climate Registry Table 12 | Combustion only (no production) | | 1 g/MMBtu | 0.91 g/MMBtu | as g CH4 and N2O |
| Biogas | 0 | 2015 Climate Registry Table 12.9.1 | Excludes CO2 because biogas is biogenic | | 3.19 g/MMBtu | 0.62 g/MMBtu | as g CH4 and N2O |
| **Transport** | | | | | | | |
| Gasoline | 2.83 kg/L | Elsayed et al., 2003 | Includes production emissions | | | | |
| Gasoline | 2.8 kg/L | Biomass Energy Centre (UK) | Includes production emissions | | | | |
| Gasoline | 2.32 kg/L | 2015 Climate Registry Table 13 | Combustion only (no production) | | 0.24 g/L | 0.58 g/L | as g CH4 and N2O |
| Diesel | 3.14 kg/L | Biomass Energy Centre (UK) | Includes production emissions | | | | |
| Diesel | 2.7 kg/L | 2015 Climate Registry Table 13 | Combustion only (no production) | | 0.14 g/L | 0.082 g/L | as g CH4 and N2O |
| Fuel for biosolids land application | 4.55 kg/wet ton solids applied | BEAM default | | | | | |
| **Electricity** | | | | | | | |
| Puget Sound Energy | 0.468 kg/kWh | PSE 2015 GHG Inventory | Blend coal/hydro/gas/renewable | | Included in CO2 E | Included in CO2 E | |
| British Columbia | 0.013 kg/kWh | 2015 Climate Registry Table 14 | Mostly hydro | | 0.003 g/ kWh | 0.0004 g/kWh | as g CH4 and N2O |
| US Midwest | 0.821 kg/kWh | 2015 Climate Registry Table 14 | Mostly coal | | 0.0093 g/ kWh | 0.0134 g/kWh | as g CH4 and N2O |
| California | 0.278 kg/kWh | 2015 Climate Registry Table 14 | High renewable/gas | | 0.0129 g/kWh | 0.0027 g/kWh | as g CH4 and N2O |
| New York City | 0.999 kg/kWh | NY Hunts Pt GHG SWEET model | | | Included in CO2 E | Included in CO2 E | |
| **Chemicals** | | | | | | | |
| Polymer | 9 kg /kg polymer | BEAM default | Emission for use of polymer | | | | |
| Lime | 0.9 kg/kg lime | BEAM default | Emission for use of lime (stabilization) | | | | |
| Methanol | 3.71 kg/gal | NY Hunts Pt GHG SWEET model | Credit for methanol displaced | | | | |
| **Fertilizer Offset** | | | | | | | |
| N | 4 kg/kg N applied | BEAM default | Credit for N applied; Can assume 4% N by dry weight | | | | |
| P | 2 kg/kg P applied | BEAM default | Credit for P applied; Can assume1.5% P by dry weight | | | | |
| **Sequestration** | | | | | | | |
| Land Application | 0.25 kg CO2/ kg dry biosolids | BEAM default | | | | | |
| Mine Reclamation | 1.3 kg CO2/kg dry biosolids | BEAM Data Table for BC copper mine | | | | | |
| Compost | 0.25 kg CO2/ kg dry biosolids | BEAM default | | | | | |
| Soil Blend | 0.25 kg CO2/ kg dry biosolids | BEAM default | | | | | |

| **Fugitive Emissions** | **Multiply CH4 by 23 to obtain CO2 E** | | | | | | |
|---|---|---|---|---|---|---|---|
| Digester (fixed cover) | 0.01% of CH4 production | sjk estimate | Through pressure relief valve only; 10% gas loss for 10 hrs/yr | | See CO2 E column | | |
| Digester (floating cover) | 1.70% of CH4 production | sjk estimate | Based on 80-ft dia digester and 4-in annulus w/o water bath for skirt | | See CO2 E column | | |
| Sludge Dewatering (high s.g.) | 0.000022 kg CH4/L of sludge | sjk estimate | Assume 5% gas in sludge flow from well-mixed digester; no odor treatment | | See CO2 E column | | |
| Sludge Dewatering (low s.g.) | 0.086 g CH4/L sludge | sjk estimate | Assume 20% gas in sludge flow from poorly-mixed digester; no odor treatment | | See CO2 E column | | |
| Sludge Dewatering with biofilter | 0.013 g CH4/ L sludge | sjk estimate | Assume 40% removal in inorganic media biofilter (20% for organic media) Nikiema et al., 2005 | | | | |
| Sludge Drying | 0.01 g CH4/L sludge | sjk estimate | Without RTO emission control; from residual and soluble gas | | See CO2 E column | | |
| Sludge Drying | 0.0001 g CH4/L sludge | sjk est; E. Jacobson on RTO | With RTO emission control at 1% slip (Andritz drier) | | See CO2 E column | | |
| Cogen (recip engine; low eff) | 2.09% of CH4 to engine | Willis et al. 2013 | | | See CO2 E column | | |
| Cogen (recip engine; high eff) | 0.44% of CH4 to engine | Willis et al. 2013 | | | See CO2 E column | | |
| Cogen Turbine/Microturbine | 0.01% of CH4 to turbine | Willis et al. 2013 | | | See CO2 E column | | |
| Boiler (very efficient) | 0.01% of CH4 to boiler | Willis et al. 2013 | Also see "Heating (boiler)" above for alternative CH4 and N2O emissions | | See CO2 E column | | |
| Gas upgrading with thermal ox | 0.10% of CH4 to scrubber | Eron Jacobson | PA and membrane scrubbers 10% slip and 1% slip from thermal oxidizer | | See CO2 E column | | |
| Gas upgrading | 1.50% of CH4 to scrubber | Eron Jacobson | Water solvent w/o RTO 1.5% slip | | See CO2 E column | | |
| Fuel cell | 1.05% of CH4 to fuel cell | Willis et al. 2013 | Requires gas upgrade prior to fuel cell | | See CO2 E column | | |
| Flare (candle stick) | 5% of CH4 to flare | Willis et al. 2013 | | | See CO2 E column | | |
| Flare (modern enclosed) | 0.40% of CH4 to flare | sjk estimate | BC specs 1%; typically achieve 0.4% | | See CO2 E column | | |
| Flare (efficient) | 0.30% of CH4 to boiler | BEAM Data Tables | | | See CO2 E column | | |
| Flare (enclosed; low NOx) | 0.0030% of CH4 to flare | Willis et al. 2013 | | | See CO2 E column | | |
| Land Application (High) | 0.01 g CH4/L sludge | sjk estimate | From residual and soluble gas after dewatering; same as drying | | See CO2 E column | 0.50% of applied N as | BEAM Data Tables |
| Land Application (Low) | 0.01 g CH4/L sludge | sjk estimate | From residual and soluble gas after dewatering; same as drying | | See CO2 E column | 0.2% of applied N | BEAM Data Tables |
| Landfill (poor capture) | 20% CH4 capture and 10% oxidation | BEAM Data Tables | Assume 40% additional VSR (sjk estimate from Sacramento FSLs) | | See CO2 E column | TBD | |
| Landfill (good capture) | 75% CH4 capture and 40% oxidation | BEAM Data Tables | Assume 40% additional VSR (sjk estimate from Sacramento FSLs) | | See CO2 E column | TBD | |
| Sludge Lagoon | 0% CH4 capture and XX% oxidation | | Assume 40% additional VSR (sjk estimate from Sacramento FSLs) | | See CO2 E column | TBD | |
| Compost (uncovered) | 0.01 g CH4/g dry wt | BEAM Data Tables | | | See CO2 E column | 1.3% of initial N | BEAM Data Tables |
| Compost (covered with biofilter) | 0.006 g CH4/g dry wt | sjk estimate | Assume 40% removal in inorganic media biofilter (20% for organic media) Nikiema et al., 2005 | | | | |
| Compost (with C:N above 30) | | | | | | 0% of initial N | BEAM Data Tables |
| Soil Blend | 0.001 kg CH4/kg dry wt | sjk estimate | Assume same as uncovered compost | | See CO2 E column | 1.3% of initial N | Assumption |
| Incineration | 0.0000485 kg CH4/ kg dry solids | BEAM Data Tables | Assumes 20% TS cake | | See CO2 E column | 0.00049 g N20/g dry wt | BEAM Data Tables |

### Alt 1 Output Summary

| | |
|---|---|
| Final Product, Wet (WT/D) | 51 |
| NG Req. (cfh) | 0 |
| Electricity Req. (kW) | 414 |
| Power Generation (kW) | 876 |
| Net Power (kW)* | -461 |
| No. of Trucks Required (trucks/day) | 1.71 |
| Vehicle Fuel Consumed (gal/day) | 154 |
| Digester Gas Produced (scfm)** | 253 |
| Methane Produced (scfm)** | 152 |
| Polymer Use (kg/day) | 215 |

## Primary Sludge
Dry Mass Flow: 29203 PPD
TS: 3.2%
VS: 89%
Calorific Value: 10,000 Btu/lb VS
Feedstock Type: Primary Sludge
Energy Consumption: 0 hp; 90% Efficiency

## WAS
Dry Mass Flow: 20318 PPD
TS: 0.6%
VS: 85%
Calorific Value: 10,000 Btu/lb VS
Feedstock Type: WAS
Energy Consumption: 0 hp; 90% Efficiency

## Thickening
GBT
97% Capture
5.0% TS
Duty No. 2
Feedstock Type: Combined
Energy Consumption: 25 hp; 90% Efficiency
Polymer Use: 8 lbs/ton

## Stabilization
Digester (Meso)
VSR 58.0%
Duty No. 4
Sludge Inlet Temp: 65 F
Operation Temp: 95 F
560 Btu/cf
15 cf/lb VS
1.20 MMBtu/hr
Energy Consumption: 55 hp; 90% Efficiency
Shell Heat Loss: 7%

## Dewatering
Centrifuge
95% Capture
22% TS
Duty No. 2
Energy Consumption: 85 hp; 90% Efficiency
Polymer Use: 25 lbs/ton

## End Use
22519 PPD
22.0%
70%
End Use: Land Application
Energy Consumption: 0 hp; 90% Efficiency
Fuel Consumption: 450 miles/day; 5 mpg

## Biogas Utilization

CHP Engine
939 NG LHV
Duty No. 1
Therm Eff. 42%
Nat gas usage, cfh 0
Biogas Fuel use 90%
Engine Electrical Eff. 39%
Heat Recovery 3.22 MMBtu/hr
Energy Consumption: 60 hp; 90% Efficiency

Flare
Duty No. 1
Energy Consumption: 0 hp; 90% Efficiency
Digester Gas Flared: 10% scfm

| | Primary Sludge | | WAS | | Thickening | | Stabilization | | Dewatering | | End Use | | CHP Engine | | Flare | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wet Mass Flow | 38,021 | lb/hr | 191,154 | lb/hr | 40,029 | lb/hr | 39,016 | lb/hr | 4,265 | lb/hr | 4,265 | lb/hr | 4,265 | lb/hr | 4,265 | lb/hr |
| Dry Mass Flow | 1,217 | lb/hr | 2,063 | lb/hr | 2,001 | lb/hr | 988 | lb/hr | 938 | lb/hr | 938 | lb/hr | 938 | lb/hr | 938 | lb/hr |
| | 14.6 | DTPD | 24.8 | DTPD | 24.0 | DTPD | 11.9 | DTPD | 11.3 | DTPD | 11.3 | DTPD | 11.3 | DTPD | 11.3 | DTPD |
| VS | 1,083 | lb/hr | 1,802 | lb/hr | 1,748 | lb/hr | 734 | lb/hr | 697 | lb/hr | 657 | lb/hr | 657 | lb/hr | 657 | lb/hr |
| Water | 36,804 | lb/hr | 189,091 | lb/hr | 38,028 | lb/hr | 38,028 | lb/hr | 3,327 | lb/hr | 3,327 | lb/hr | 3,327 | lb/hr | 3,327 | lb/hr |
| TS | 3% | | 1.08% | | 5.00% | | 2.53% | | 22.00% | | 22% | | 22.00% | | 22.00% | |
| VS | 89% | | 87% | | 87% | | 74% | | 74% | | 70% | | 70% | | 70% | |
| Wet flow | 76.0 | gpm | 382.0 | gpm | 80.0 | gpm | 78.0 | gpm | 8.5 | gpm | 8.5 | gpm | 8.5 | gpm | 8.5 | gpm |
| Calorific Value | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 0 | Btu/lb VS | 0 | Btu/lb VS | 0 | Btu/lb VS |
| Electrical Demand | 0 | kW | 0.0 | kW | 41.4 | kW | 182.4 | kW | 140.9 | kW | 0.0 | kW | 49.7 | kW | 0.0 | kW |
| Unit Heat Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | -1.28 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 3.22 | MMBtu/hr | 0.00 | MMBtu/hr |
| Total Heat Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | -1.28 | MMBtu/hr | -1.28 | MMBtu/hr | -1.28 | MMBtu/hr | 1.93 | MMBtu/hr | 1.93 | MMBtu/hr |
| Unit Aux. Fuel Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr |
| Cum. Aux. Fuel Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr |
| Unit Process Fuel Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 8.52 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | -7.66 | MMBtu/hr | 0.00 | MMBtu/hr |
| Cum Unit Process Fuel Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 8.52 | MMBtu/hr | 8.52 | MMBtu/hr | 8.52 | MMBtu/hr | 0.85 | MMBtu/hr | 0.85 | MMBtu/hr |
| Generated Steam | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr |
| Power Generation | 0 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW | 0.88 | MW | 0.00 | MW |
| No. of Trucks Required | 0 | trucks/day | 0 | trucks/day | 0 | trucks/day | 0 | trucks/day | 0 | trucks/day | 1.706 | trucks/day | 0 | trucks/day | 0 | trucks/day |
| Vehicle Fuel Consumption | 0 | gal/day | 0 | gal/day | 0 | gal/day | 0 | gal/day | 0 | gal/day | 154 | gal/day | 0 | gal/day | 0 | gal/day |
| Digester Gas Produced | 0 | scfm | 0 | scfm | 0 | scfm | 253 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm |
| Methane Produced | 0 | scfm | 0 | scfm | 0 | scfm | 152 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm |
| Methane Utilized | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 137 | scfm | 15 | scfm |
| Polymer Use | 0 | kg/day | 0 | kg/day | 87 | kg/day | 0 | kg/day | 128 | kg/day | 0 | kg/day | 0 | kg/day | 0 | kg/day |

## Alt 2 Output Summary

| | |
|---|---|
| Final Product, Wet (WT/D) | 12 |
| NG Req. (cfh) | 0 |
| Electricity Req. (kW) | 613 |
| Power Generation (kW) | 0 |
| Net Power (kW)* | 613 |
| No. of Trucks Required (trucks/day) | 0.61 |
| Vehicle Fuel Consumed (gal/day) | 24 |
| Digester Gas Produced (scfm)** | 253 |
| Methane Produced (scfm)** | 152 |
| Polymer Use (kg/day) | 215 |

### Primary Sludge
- Dry Mass Flow: 29203 PPD
- TS: 3.2%
- VS: 89%
- Calorific Value: 10,000 Btu/lb VS
- Feedstock Type: Primary Sludge
- Energy Consumption: 0 hp; 90% Efficiency

### WAS
- 20318 PPD
- 0.6%
- 85%
- 10,000 Btu/lb VS
- Feedstock Type: WAS
- Energy Consumption: 0 hp; 90% Efficiency

### Thickening
- GBT
- 97% Capture
- 5.0% TS
- Duty No.: 2
- Feedstock Type: Combined
- Energy Consumption: 25 hp; 90% Efficiency
- Polymer Use: 8 lbs/ton

### Stabilization
- Digester (Meso)
- VSR: 58.0%
- Duty No.: 4
- Sludge Inlet Temp: 65 F
- Operation Temp: 95 F
- 560 Btu/cf
- 15 cf/lb VS
- 1.20 MMBtu/hr
- Energy Consumption: 55 hp; 90% Efficiency
- Shell Heat Loss: 7%

### Dewatering
- Centrifuge
- 95% Capture
- 22% TS
- Duty No.: 2
- Energy Consumption: 85 hp; 90% Efficiency
- Polymer Use: 25 lbs/ton

### Post-Dewatering
- Thermal Dryer
- 939 NG LHV
- 92.0% TS
- Duty No.: 1
- Nat gas usage, cfh: 0
- Biogas Fuel Use: 70%
- Inlet / Out Temp.: 95 F; 220 F
- 1,500 Btu/lb
- 4.87 MMBtu/hr
- Energy Consumption: 300 hp; 90% Efficiency
- Heat Loss: 5%

### End Use
- 0 PPD
- 92.0%
- 70%
- End Use: Fertilizer
- Energy Consumption: 0 hp; 90% Efficiency
- Transport Fuel Consumption: 200 miles; 5 mpg

### Biogas Utilization
CHP Engine
- 939 NG LHV
- Duty No.: 0
- Therm Eff.: 42%
- Nat gas usage, cfh: 0
- Biogas Fuel Use: 0%
- Engine Electrical Eff.: 39%
- Heat Recovery: 0.00 MMBtu/hr
- Energy Consumption: 60 hp; 90% Efficiency

Flare
- Duty No.: 1
- Biogas Flared: 30%
- Energy Consumption: 0 hp; 90% Efficiency

| | Primary Sludge | | WAS | | Thickening | | Stabilization | | Dewatering | | Post-Dewatering | | End Use | | CHP Engine | | Flare | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wet Mass Flow | 38,021 | lb/hr | 191,154 | lb/hr | 40,029 | lb/hr | 39,016 | lb/hr | 4,265 | lb/hr | 1,020 | lb/hr | 1,020 | lb/hr | 1,020 | lb/hr | 1,020 | lb/hr |
| Dry Mass Flow | 1,217 | lb/hr | 2,063 | lb/hr | 2,001 | lb/hr | 988 | lb/hr | 938 | lb/hr | 938 | lb/hr | 938 | lb/hr | 938 | lb/hr | 938 | lb/hr |
| | 14.6 | DTPD | 24.8 | DTPD | 24.0 | DTPD | 11.9 | DTPD | 11.3 | DTPD | 11.3 | DTPD | 11.3 | DTPD | 11.3 | DTPD | 11.3 | DTPD |
| VS | 1,083 | lb/hr | 1,802 | lb/hr | 1,748 | lb/hr | 734 | lb/hr | 697 | lb/hr | 697 | lb/hr | 697 | lb/hr | 697 | lb/hr | 697 | lb/hr |
| Water | 36,804 | lb/hr | 189,091 | lb/hr | 38,028 | lb/hr | 38,028 | lb/hr | 3,327 | lb/hr | 82 | lb/hr | 82 | lb/hr | 82 | lb/hr | 82 | lb/hr |
| TS | 3% | | 1.08% | | 5.00% | | 2.53% | | 22.00% | | 92.00% | | 92.00% | | 92.00% | | 92.00% | |
| VS | 89% | | 87% | | 87% | | 74% | | 74% | | 74% | | 74% | | 74% | | 74% | |
| Wet flow | 76.0 | gpm | 382.0 | gpm | 80.0 | gpm | 78.0 | gpm | 8.5 | gpm | 2.0 | gpm | 2.0 | gpm | 2.0 | gpm | 2.0 | gpm |
| Calorific Value | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS | 10,000 | Btu/lb VS |
| Electrical Demand | 0 | kW | 0.0 | kW | 41.4 | kW | 182.4 | kW | 140.9 | kW | 248.7 | kW | 0.0 | kW | 0.0 | kW | 0.0 | kW |
| Unit Heat Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | -1.28 | MMBtu/hr | 0.00 | MMBtu/hr | 0.85 | MMBtu/hr | 0.00 | MMBtu/hr | 0.17 | MMBtu/hr | 0.27 | MMBtu/hr |
| Total Heat Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | -1.28 | MMBtu/hr | -1.28 | MMBtu/hr | -0.43 | MMBtu/hr | -0.43 | MMBtu/hr | -0.27 | MMBtu/hr | 0.00 | MMBtu/hr |
| Unit Aux. Fuel Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr |
| Cum. Aux. Fuel Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr |
| Unit Process Fuel Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 8.52 | MMBtu/hr | 0.00 | MMBtu/hr | -5.96 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | -0.77 | MMBtu/hr |
| Cum Unit Process Fuel Bal. | 0 | MMBtu/hr | 0.00 | MMBtu/hr | 0.00 | MMBtu/hr | 8.52 | MMBtu/hr | 8.52 | MMBtu/hr | 2.55 | MMBtu/hr | 2.55 | MMBtu/hr | 2.55 | MMBtu/hr | 1.79 | MMBtu/hr |
| Generated Steam | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr | 0 | lb/hr |
| Power Generation | 0 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW | 0.00 | MW |
| No. of Trucks Required | 0.00 | trucks/day | 0.00 | trucks/day | 0.00 | trucks/day | 0.00 | trucks/day | 0.00 | trucks/day | 0.00 | trucks/day | 0.61 | trucks/day | 0.00 | trucks/day | 0.00 | trucks/day |
| Vehicle Fuel Consumption | 0 | gal/day | 0 | gal/day | 0 | gal/day | 0 | gal/day | 0 | gal/day | 0 | gal/day | 24 | gal/day | 0 | gal/day | 0 | gal/day |
| Digester Gas Produced | 0 | scfm | 0 | scfm | 0 | scfm | 253 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm |
| Methane Produced | 0 | scfm | 0 | scfm | 0 | scfm | 152 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm |
| Methane Utilized | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 0 | scfm | 106 | scfm | 0 | scfm | 0 | scfm | 46 | scfm |
| Polymer Use | 0 | kg/day | 0 | kg/day | 87 | kg/day | 0 | kg/day | 128 | kg/day | 0 | kg/day | 0 | kg/day | 0 | kg/day | 0 | kg/day |

## Alt 3 Output Summary

| | |
|---|---|
| Final Product, Wet (WT/D) | 105 |
| NG Req. (cfh) | 0 |
| Electricity Req. (kW) | 423 |
| Power Generation (kW) | 966 |
| Net Power (kW)* | -544 |
| No. of Trucks Required (trucks/day) | 5.03 |
| Vehicle Fuel Consumed (gal/day) | 31 |
| Digester Gas Produced (scfm)** | 280 |
| Methane Produced (scfm)** | 168 |
| Polymer Use (kg/day) | 202 |

### Primary Sludge
- Dry Mass Flow: 29203 PPD
- TS: 3.2%
- VS: 89%
- Calorific Value: 10,000 Btu/lb VS
- Feedstock Type: Primary Sludge
- Energy Consumption: 0 hp; 90% Efficiency

### WAS
- Dry Mass Flow: 20318 PPD
- TS: 0.6%
- VS: 85%
- Calorific Value: 10,000 Btu/lb VS
- Feedstock Type: WAS
- Energy Consumption: 0 hp; 90% Efficiency

### Thickening
GBT
- Capture: 97%
- TS: 5.0%
- Duty No.: 2
- Feedstock Type: Combined
- Energy Consumption: 25 hp; 90% Efficiency
- Polymer Use: 8 lbs/ton

### Stabilization
TPAD System

Digester (Thermo)
- VSR: 64.0%
- Duty No.: 2
- Sludge Inlet Temp: 65 F
- Operation Temp: 131 F
- 560 cf gas/VS
- 15 cf/lb VS
- 2.64 MMBtu/hr
- Energy Consumption: 60 hp; 90% Efficiency
- Shell Heat Loss: 7%

HEX
- Duty No.: 2
- Inlet Temperature: 135 F
- Outlet Temperature: 98 F
- HEX Efficiency: 70 %
- 1.01 MMBtu/hr
- Energy Consumption: 20 hp; 90% Efficiency

Digester (Meso)
- VSR: 0.0%
- Duty No.: 2
- Sludge Inlet Temp: 98 F
- Operation Temp: 98 F
- 560 Btu/cf
- 15 cf/lb VS
- 0.00 MMBtu/hr
- Energy Consumption: 30 hp; 90% Efficiency
- Shell Heat Loss: 4%

### Dewatering
Centrifuge
- Capture: 95%
- TS: 22%
- Duty No.: 2
- Energy Consumption: 85 hp; 90% Efficiency
- Polymer Use: 25 lbs/ton

### Post-Dewatering Soil Blending
Biosolids Cake — Soil Blending
- TS: 22%
- Duty No.: 1
- Energy Consumption: 10 hp; 90% Efficiency
- Transport Fuel Consumption: 16 miles; 5 mpg

Sawdust
- Dry Mass Flow: 18298 PPD
- TS: 50.0%
- VS: 95%
- Calorific Value: 10,000 Btu/lb VS
- Feedstock Type: Bulking Agent 1
- Energy Consumption: 0 hp; 90% Efficiency

Sand
- Dry Mass Flow: 78223 PPD
- TS: 95.0%
- VS: 0%
- Calorific Value: 10,000 Btu/lb VS
- Feedstock Type: Bulking Agent 2
- Energy Consumption: 0 hp; 90% Efficiency
- Transport Fuel Consumption: 20 miles; 5 mpg
- Front Loader Fuel Consumption: 4 hrs/day; 3 gal/hr

### Biogas Utilization
CHP Engine
- NG LHV: 939
- Duty No.: 1
- Therm Eff.: 42%
- Nat gas usage, cfh: 0
- Biogas Fuel use: 90%
- Engine Electrical Eff.: 39%
- Heat Recovery: 3.55 MMBtu/hr
- Energy Consumption: 60 hp; 90% Efficiency

Flare
- Duty No.: 1
- Energy Consumption: 0 hp; 90% Efficiency
- Digester Gas Flared: 10% scfm

| | Primary Sludge | WAS | Thickening (GBT) | Digester (Thermo) | HEX | Digester (Meso) | Centrifuge | Soil Blending | Sawdust | Sand | CHP Engine | Flare |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wet Mass Flow | 38,021 lb/hr | 191,154 lb/hr | 40,029 lb/hr | 38,911 lb/hr | 38,911 lb/hr | 38,911 lb/hr | 3,812 lb/hr | 3,812 lb/hr | 5,337 lb/hr | 8,768 lb/hr | 8,768 lb/hr | 8,768 lb/hr |
| Dry Mass Flow | 1,217 lb/hr | 2,063 lb/hr | 2,001 lb/hr | 883 lb/hr | 883 lb/hr | 883 lb/hr | 839 lb/hr | 839 lb/hr | 1,601 lb/hr | 4,860 lb/hr | 4,860 lb/hr | 4,860 lb/hr |
| | 14.6 DTPD | 24.8 DTPD | 24.0 DTPD | 10.6 DTPD | 10.6 DTPD | 10.6 DTPD | 10.1 DTPD | 10.1 DTPD | 19.2 DTPD | 58.3 DTPD | 58.3 DTPD | 58.3 DTPD |
| VS | 1,083 lb/hr | 1,802 lb/hr | 1,748 lb/hr | 629 lb/hr | 629 lb/hr | 629 lb/hr | 598 lb/hr | 598 lb/hr | 1,322 lb/hr | 1,322 lb/hr | 1,322 lb/hr | 1,322 lb/hr |
| Water | 36,804 lb/hr | 189,091 lb/hr | 38,028 lb/hr | 38,028 lb/hr | 38,028 lb/hr | 38,028 lb/hr | 2,973 lb/hr | 2,973 lb/hr | 3,736 lb/hr | 3,907 lb/hr | 3,907 lb/hr | 3,907 lb/hr |
| TS | 3% | 1.08% | 5.00% | 2.27% | 2.27% | 2.27% | 22.00% | 22.00% | 30.00% | 55.43% | 55.43% | 55.43% |
| VS | 89% | 87% | 87% | 71% | 71% | 71% | 71% | 71% | 83% | 27% | 27% | 27% |
| Wet flow | 76.0 gpm | 382.0 gpm | 80.0 gpm | 77.8 gpm | 77.8 gpm | 77.8 gpm | 7.6 gpm | 7.6 gpm | 10.7 gpm | 17.5 gpm | 17.5 gpm | 17.5 gpm |
| Calorific Value | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS |
| Electrical Demand | 0 kW | 0.0 kW | 41.4 kW | 99.5 kW | 33.2 kW | 49.7 kW | 140.9 kW | 8.3 kW | 0.0 kW | 0.0 kW | 49.7 kW | 0.0 kW |
| Unit Heat Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | -2.83 MMBtu/hr | 1.01 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 3.55 MMBtu/hr | 0.00 MMBtu/hr |
| Total Heat Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | -2.83 MMBtu/hr | -1.82 MMBtu/hr | -1.82 MMBtu/hr | -1.82 MMBtu/hr | -1.82 MMBtu/hr | -1.82 MMBtu/hr | -1.82 MMBtu/hr | 1.73 MMBtu/hr | 1.73 MMBtu/hr |
| Unit Aux. Fuel Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr |
| Cum. Aux. Fuel Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr |
| Unit Process Fuel Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 9.40 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | -8.46 MMBtu/hr | 0.00 MMBtu/hr |
| Cum Unit Process Fuel Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 9.40 MMBtu/hr | 0.00 MMBtu/hr | 9.40 MMBtu/hr | 9.40 MMBtu/hr | 9.40 MMBtu/hr | 9.40 MMBtu/hr | 9.40 MMBtu/hr | 0.94 MMBtu/hr | 0.94 MMBtu/hr |
| Generated Steam | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr |
| Power Generation | 0 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.97 MW | 0.00 MW |
| No. of Trucks Required | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 1.52 trucks/day | 0.00 trucks/day | 3.51 trucks/day | 0.00 trucks/day | 0.00 trucks/day |
| Vehicle Fuel Consumption | 0 gal/day | 0 gal/day | 0 gal/day | 0 gal/day | 0 gal/day | 0 gal/day | 0 gal/day | 5 gal/day | 0 gal/day | 26 gal/day | 0 gal/day | 0 gal/day |
| Digester Gas Produced | 0 scfm | 0 scfm | 0 scfm | 280 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm |
| Methane Produced | 0 scfm | 0 scfm | 0 scfm | 168 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm |
| Methane Utilized | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 151 scfm | 17 scfm |
| Polymer Use | 0 kg/day | 0 kg/day | 87 kg/day | 0 kg/day | 0 kg/day | 0 kg/day | 114 kg/day | 0 kg/day | 0 kg/day | 0 kg/day | 0 kg/day | 0 kg/day |

Alt 4 Output Summary

| | |
|---|---|
| Final Product, Wet (WT/D) | 105 |
| NG Req. (cfh) | 0 |
| Electricity Req. (kW) | 518 |
| Power Generation (kW) | 966 |
| Net Power (kW)* | -448 |
| No. of Trucks Required (trucks/day) | 3.51 |
| Vehicle Fuel Consumed (gal/day) | 26 |
| Digester Gas Produced (scfm)** | 280 |
| Methane Produced (scfm)** | 168 |
| Polymer Use (kg/day) | 202 |

## Primary Sludge

Dry Mass Flow 29203 PPD
TS 3.2%
VS 89%
Calorific Value 10,000 Btu/lb VS
Feedstock Type: Primary Sludge
Energy Consumption: 0 hp; 100% Efficiency

## WAS

20318 PPD
0.6%
85%
10,000 Btu/lb VS
Feedstock Type: WAS
Energy Consumption: 0 hp; 100% Efficiency

## Transport to Off-Site

Pump
100% Capture
0% TS
Duty No. 1
Feedstock Type: Combined
Energy Consumption: 65 hp; 90% Efficiency

## Thickening

GBT
97% Capture
5% TS
Duty No. 2
Feedstock Type: Combined
Energy Consumption: 25 hp; 90% Efficiency
Polymer Use 8 lbs/ton

## Stabilization

TPAD System

**Digester (Thermo)**
VSR 64.0%
Duty No. 2
Sludge Inlet Temp 65 F
Operation Temp 131 F
560 cf gas/VS
15 cf/lb VS
2.64 MMBtu/hr
Energy Consumption 60 hp; 90% Efficiency
Shell Heat Loss 7%

**HEX**
Duty No. 2
Inlet Temperature 135 F
Outlet Temperature 98 F
HEX Efficiency 70 %
1.01 MMBtu/hr
Energy Consumption 20 hp; 90% Efficiency

**Digester (Meso)**
VSR 0.0%
Duty No. 2
Sludge Inlet Temp 98 F
Operation Temp 98 F
560 Btu/cf
15 cf/lb VS
0.00 MMBtu/hr
Energy Consumption 30 hp; 90% Efficiency
Shell Heat Loss 4%

## Dewatering

Centrifuge
95% Capture
22% TS
Duty No. 2
Energy Consumption 110 hp; 90% Efficiency
Polymer Use 25 lbs/ton

## Post-Dewatering Soil Blending

**Biosolids Cake**
Soil Blending
22% TS
Duty No. 1
Energy Consumption 10 hp; 90% Efficiency

**Sawdust**
18298 PPD
50.0%
95%
10,000 Btu/lb VS
Feedstock Type: Buling Agent 1
Energy Consumption 0 hp; 100% Efficiency

**Sand**
78223 PPD
95.0%
0%
10,000 Btu/lb VS
Feedstock Type: Bulking Agent 2
Energy Consumption 0 hp; 90% Efficiency
Transport Fuel Consumption 20 miles; 5 mpg
Front Loader Fuel Consumption 4 hrs/day; 3 gal/hr

## Biogas Utilization

**CHP Engine**
939 NG LHV
Duty No. 1
Therm Eff. 42%
Nat gas usage, cfh 0
Biogas Fuel 90%
Engine Electrical Eff. 39%
Heat Recovery 3.55 MMBtu/hr
Energy Consumption 60 hp; 90% Efficiency

**Flare**
Duty No. 1
Energy Consumption 0 hp; 90% Efficiency
Digester Gas Flared 10% scfm

| | Primary Sludge | WAS | Pump | GBT | Digester (Thermo) | HEX | Digester (Meso) |
|---|---|---|---|---|---|---|---|
| Wet Mass Flow | 38,021 lb/hr | 191,154 lb/hr | 191,154 lb/hr | 40,029 lb/hr | 38,911 lb/hr | 38,911 lb/hr | 38,911 lb/hr |
| Dry Mass Flow | 1,217 lb/hr | 2,063 lb/hr | 2,063 lb/hr | 2,001 lb/hr | 883 lb/hr | 883 lb/hr | 883 lb/hr |
| | 14.6 DTPD | 24.8 DTPD | 24.8 DTPD | 24.0 DTPD | 10.6 DTPD | 10.6 DTPD | 10.6 DTPD |
| VS | 1,083 lb/hr | 1,802 lb/hr | 1,802 lb/hr | 1,748 lb/hr | 629 lb/hr | 629 lb/hr | 629 lb/hr |
| Water | 36,804 lb/hr | 189,091 lb/hr | 189,091 lb/hr | 38,028 lb/hr | 38,028 lb/hr | 38,028 lb/hr | 38,028 lb/hr |
| TS | 3% | 1.08% | 1.08% | 5.00% | 2.27% | 2.27% | 2.27% |
| VS | 89% | 87% | 87% | 87% | 71% | 71% | 71% |
| Wet flow | 76.0 gpm | 382.0 gpm | 382.0 gpm | 80.0 gpm | 77.8 gpm | 77.8 gpm | 77.8 gpm |
| Calorific Value | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS |
| Electrical Demand | 0 kW | 0.0 kW | 53.9 kW | 41.4 kW | 99.5 kW | 33.2 kW | 49.7 kW |
| Unit Heat Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | -2.83 MMBtu/hr | 1.01 MMBtu/hr | 0.00 MMBtu/hr |
| Total Heat Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | -2.83 MMBtu/hr | -1.82 MMBtu/hr | -1.82 MMBtu/hr |
| Unit Aux. Fuel Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr |
| Cum. Aux. Fuel Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr |
| Unit Process Fuel Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 9.40 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr |
| Cum Unit Process Fuel Bal. | 0 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 9.40 MMBtu/hr | 0.00 MMBtu/hr | 9.40 MMBtu/hr |
| Generated Steam | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr |
| Power Generation | 0 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW |
| No. of Trucks Required | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day |
| Vehicle Fuel Consumed | 0 gal/day | 0 gal/day | 0 gal/day | 0 gal/day | 0 gal/day | 0 gal/day | 0 gal/day |
| Digester Gas Produced | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 280 scfm | 0 scfm | 0 scfm |
| Methane Produced | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 168 scfm | 0 scfm | 0 scfm |
| Methane Utilized | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm |
| Polymer Use | 0 kg/day | 0 kg/day | 0 kg/day | 87 kg/day | 0 kg/day | 0 kg/day | 0 kg/day |

| | Centrifuge | Soil Blending | Sawdust | Sand | CHP Engine | Flare |
|---|---|---|---|---|---|---|
| Wet Mass Flow | 3,812 lb/hr | 3,812 lb/hr | 5,337 lb/hr | 8,768 lb/hr | 8,768 lb/hr | 8,768 lb/hr |
| Dry Mass Flow | 839 lb/hr | 839 lb/hr | 1,601 lb/hr | 4,860 lb/hr | 4,860 lb/hr | 4,860 lb/hr |
| | 10.1 DTPD | 10.1 DTPD | 19.2 DTPD | 58.3 DTPD | 58.3 DTPD | 58.3 DTPD |
| VS | 598 lb/hr | 598 lb/hr | 1,322 lb/hr | 1,322 lb/hr | 1,322 lb/hr | 1,322 lb/hr |
| Water | 2,973 lb/hr | 2,973 lb/hr | 3,736 lb/hr | 3,907 lb/hr | 3,907 lb/hr | 3,907 lb/hr |
| TS | 22.00% | 22.00% | 30.00% | 55.43% | 55.43% | 55.43% |
| VS | 71% | 71% | 83% | 27% | 27% | 27% |
| Wet flow | 7.6 gpm | 7.6 gpm | 10.7 gpm | 17.5 gpm | 17.5 gpm | 17.5 gpm |
| Calorific Value | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS | 10,000 Btu/lb VS |
| Electrical Demand | 182.4 kW | 8.3 kW | 0.0 kW | 0.0 kW | 49.7 kW | 0.0 kW |
| Unit Heat Bal. | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 3.55 MMBtu/hr | -1.73 MMBtu/hr |
| Total Heat Bal. | -1.82 MMBtu/hr | -1.82 MMBtu/hr | -1.82 MMBtu/hr | -1.82 MMBtu/hr | 1.73 MMBtu/hr | 0.00 MMBtu/hr |
| Unit Aux. Fuel Bal. | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr |
| Cum. Aux. Fuel Bal. | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr |
| Unit Process Fuel Bal. | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | 0.00 MMBtu/hr | -8.46 MMBtu/hr | 0.00 MMBtu/hr |
| Cum Unit Process Fuel Bal. | 9.40 MMBtu/hr | 9.40 MMBtu/hr | 9.40 MMBtu/hr | 9.40 MMBtu/hr | 0.94 MMBtu/hr | 0.94 MMBtu/hr |
| Generated Steam | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr | 0 lb/hr |
| Power Generation | 0.00 MW | 0.00 MW | 0.00 MW | 0.00 MW | 0.97 MW | 0.00 MW |
| No. of Trucks Required | 0.00 trucks/day | 0.00 trucks/day | 0.00 trucks/day | 3.51 trucks/day | 0.00 trucks/day | 0.00 trucks/day |
| Vehicle Fuel Consumed | 0 gal/day | 0 gal/day | 0 gal/day | 26 gal/day | 0 gal/day | 0 gal/day |
| Digester Gas Produced | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm |
| Methane Produced | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 0 scfm |
| Methane Utilized | 0 scfm | 0 scfm | 0 scfm | 0 scfm | 151 scfm | 17 scfm |
| Polymer Use | 114 kg/day | 0 kg/day | 0 kg/day | 0 kg/day | 0 kg/day | 0 kg/day |

# Appendix C: Frequently Asked Questions and Responses

# Resource Recovery at Post Point

*Turning our waste into valuable resources*

## Frequently Asked Questions

**Why is the City doing this project?**

The wastewater treatment plant at Post Point is designed to remove solids from our sewage so the water can be cleaned before discharging it into Bellingham Bay. Currently at Post Point, the City disposes these solids by burning them in large incinerators. The current incinerators are aging and need expensive on-going repairs. In addition, the incinerators are not consistent with our community's values because they:

- Destroy the valuable nutrients in the solids, rather than recycling them
- Don't recover the substantial energy content of the solids

Thus, the City is exploring other options to manage the wastewater solids and recover resources (nutrients and energy).

**How are the alternatives being evaluated?**

The alternatives for managing biosolids at Post Point are being evaluated using a two-step process. First, the range of all possible solids treatment and end-use alternatives were identified and screened based on pass/fail criteria. These criteria represented "must haves" for the community; any alternative that did not meet these basic criteria was considered unacceptable.

The second stage of the evaluation is a triple bottom line plus (TBL+) evaluation. The TBL+ evaluation uses financial, community/social, environmental, and technical considerations to compare alternatives based on community values.

The pass/fail and TBL+ criteria were developed based on the *Legacies and Strategic Commitments* adopted by the City Council on behalf of our community.

**What technologies have already been ruled out?**

Technologies were screened out that:

- Did not have a well-established track-record of treating wastewater solids
- Did not allow for recovery of biosolid nutrient and energy resources
- Required the City to bring outside materials into the plant to support the process
- Would adversely impact neighbors
- Were considered a safety risk

Based on the considerations above, the project team screened out:

- Some biological treatment methods (e.g., lagoons, aerobic digestion)
- Newer thermochemical processes (e.g., gasification, incineration)
- Continuing to burn or landfill the treated biosolids

As a result, the project team determined that anaerobic digestion is the best method for treating Post Point's biosolids (see "What is anaerobic digestion?"). The City continues to evaluate several processing and end-use options that work with anaerobic digesters to select the best overall system alternative.

### What is anaerobic digestion?

Anaerobic digestion occurs when microorganisms naturally decompose organic material in an air-free (anaerobic) environment. The digestion process is very similar to how the human digestion system breaks down food into the nutrients and energy we need to survive.

The digestion process in a wastewater treatment plant uses large tanks that are continually mixed and heated. Depending on the specific design of the digestion process, two potential classes of biosolids product can be produced – Class A and Class B (see "What is the difference between Class A and Class B biosolids?").

A tank producing Class B biosolids is kept at a temperature around 100 degrees Fahrenheit. A tank producing Class A biosolids is kept at a temperature around 135 degrees Fahrenheit. The flow-through process is very slow. Solids are generally in the tank for 15 to 30 days to allow for consistent breakdown of the material and to reduce pathogens.

Microorganisms that break down organic material in biosolids produce a biogas byproduct, a mixture of carbon dioxide and methane. This biogas can be recovered and:

- Used as a fuel to generate electricity and heat in an engine/generator at Post Point
- Purified and used as a natural gas replacement or in compressed natural gas (CNG) vehicles

Because the biogas is produced as part of the natural biological breakdown of our waste, it is considered a renewable fuel that can offset the greenhouse gas load of fossil fuels.

Solids are thickened and dewatered before and after digestion, respectively. These steps remove water from the solids, making the digestion process more efficient and reducing the weight and volume of biosolids that require transportation to their final end use.

### What is the difference between Class A and Class B biosolids? Why wouldn't we just produce Class A biosolids?

The only difference between Class A and Class B biosolids is the pathogen content. Class A biosolids have no detectable pathogens while Class B biosolids have reduced the pathogens by approximately 95%. This classification is based on the Environmental Protection Agency's (EPA) biosolids management regulations. The EPA has established that Class A biosolids are suitable for use by the general public whereas Class B biosolids must be used at sites with proper permits. As a result, Class A biosolids have a greater variety of potential end uses.

Most municipalities in the U.S. produce Class B biosolids instead of Class A. This is because, especially in Washington, there are many available permitted sites where Class B biosolids can be taken. The additional treatment required to produce Class A biosolids can be also expensive and energy-intensive. We will consider these benefits and costs when evaluating whether to produce Class A biosolids at Post Point.

The project team will consider benefits and costs when evaluating whether to produce Class A or Class B biosolids at Post Point. In either case, the benefits of nutrient and energy recovery will be realized.

### What biosolids end-use options are being considered?

Because of their organic content and nutrients, biosolids make an excellent fertilizer to support plant growth and rebuild damaged soils. The project team is considering a variety of land-based beneficial end uses for Post Point biosolids. These include:

- Sending the biosolids to dryland farms in central and eastern Washington for use as year-round fertilizer.
- Producing a compost or blended soil using the biosolids and wood waste. The compost or blended soil could be used locally by gardeners, landscapers, and farmers in Bellingham and the surrounding areas.
- Drying the biosolids to remove almost all water content, then bagging the dried product for sale as a fertilizer in local stores or across the Northwest.

Most biosolids programs have multiple end-use options to maximize opportunities for reuse; the project team intends to consider a diversified end-use program.

### What's in the biosolids? Are they harmful to the environment?

Biosolids are composed almost entirely of the rich organic matter recovered in the wastewater treatment process, but do contain some trace metals and chemicals from what people put in the sewers. Historically, metals in biosolids were a concern, but since the 1970s, the Environmental Protection Agency has extensively tested them to establish regulations that protect the environment and people from overapplication of metals to agricultural land.

There is a long history and widespread acceptance of biosolids reuse. Biosolids are proven to be safe for the environment and people when used in land-based applications.

### Is incineration still an option?

The pass/fail screening process considered incineration, but removed this option as a viable alternative because it did not sufficiently recover resources from the solids. If, after completing a detailed evaluation, we find that anaerobic digestion would not meet our community's values and goals, we may reconsider other options. For now, we are focusing on a resource recovery alternative.

### Will this process increase odors or noise?

The new system will have the same solids thickening and dewatering equipment as the current incineration process used at Post Point, so odors should not increase. The digesters are enclosed and airtight, and will only be exposed to air during infrequent cleanings. Odors could escape when biosolids are loaded onto trucks. The City wants to be a good neighbor to the surrounding community, and will assess odor control systems as part of the design to capture and treat any potential odors.

The new systems are not anticipated to be any noisier than the plant's current process. Any large mechanical equipment will be located indoors or within acoustic enclosures, and the digestion process only involves biological treatment of the solids in a closed tank. Like odor control systems, the project team will assess any noise mitigations measures that may be appropriate as part of the final system design.

### How would this project impact air quality in our area?

An anaerobic digestion process will have less impact on local air quality than the current incineration process. How much improvement will depend on how the biogas produced in the digesters is used. We are evaluating three possible biogas end uses:

1) Burning the gas in an engine-generator at Post Point to produce electricity and heat
2) Separating the methane from the biogas so it can be injected into the natural gas pipeline
3) Purifying the gas and compressing it so it can be used as a fuel in compressed natural gas (CNG) vehicles

Of these options, burning the gas onsite at Post Point would have the greatest impact on air quality.

### Will this project increase the number of trucks leaving the plant each week?

Currently, the City hauls roughly one truckload of ash per week from Post Point. Because a digestion system does not burn the organic material in the biosolids, the amount of solids and number of truckloads will increase, but the amount will depend on the final process selected. For example, if a biosolids drying alternative is selected, the number of trucks could increase to 4 to 5 per week. If an alternative without drying is selected, the number of trucks could increase to 1 to 2 trucks per day.

The impact of these additional trucks can be mitigated by choosing routes and travel times that impact as few people as possible.

### Will a greenhouse gas analysis be completed? How does anaerobic digestion compare to incineration?

Yes, the carbon footprint of each alternative is being evaluated and considered as part of the triple bottom line plus (TBL+) evaluation. The analysis will include:

- The energy consumed by the equipment
- The energy produced by the biogas system
- Fuel for trucking biosolids and any other feedstock (materials needed to support the process)
- Carbon sequestration from land applying the biosolids
- Nutrient offsets from using biosolids instead of chemical fertilizers
- Other relevant emissions

The project team's preliminary assessment is that nutrient and energy recovery from the anaerobic digestion system will significantly improve the treatment process carbon footprint compared to incineration.

### Can the new system produce more energy than the plant uses?

Generally, anaerobic digestion cannot produce more power than the entire treatment plant requires. The biogas produced is typically more than enough to power the digestion process and can provide additional power for about half of the treatment plant. We will evaluate this in more detail for each alternative. We will also consider whether to bring additional digester feedstock to Post Point (e.g., food waste, fats oils and grease) to generate more biogas. At other treatment plants, adding feedstock to digesters has resulted in more power being produced than the entire treatment plant needs. In this case, the treatment plant would sell power back to the power utility.

### How much will this project cost?

We are working through handling alternatives for solid waste to reflect the values of our community. One of the main evaluation triple bottom line plus (TBL+) criteria is the value of the biosolids project and associated costs. As we work though the community's priorities we will develop associated costs and anticipate producing financial numbers within the next year.

### What's the project schedule?

The project schedule will depend on which alternative is selected, but the new facilities could be completed as early as 2023.

### Where would the new system be located?

For most of the alternatives being evaluated, the new systems would be located in the northeast corner of the current treatment plant facilities. The City has identified this area for plant expansion through past Post Point facility planning efforts. The total area needed for new facilities would depend on which process is selected.

We are also looking at alternatives that use areas other than Post Point. Offsite locations would be required if the City creates a compost or Class A blended soil product, because these processes require more space than is available at Post Point. Offsite location options will not be identified unless the triple bottom line plus (TBL+) process indicates that an offsite alternative aligns best with our community's goals.

### How long will the new system last?

The City aims to create sustainable infrastructure, so reliability will be key. The digesters will be designed to have a long useful life.

- Structural components (e.g., concrete tanks and buildings) can last for up to 60 to 80 years
- Pipes generally need to be replaced after 40 to 60 years
- Mechanical equipment will last for 20 to 30 years

When we evaluate the financial implications of the different alternatives, costs will be included for equipment repair and replacement as it ages.