Consultant Engineering Services
Preliminary Assessment Report
Kingston Biosolids and Biogas Master Plan



PRESENTED TO

Utilities Kingston

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EXECUTIVE SUMMARY

Tetra Tech was retained by Utilities Kingston to provide an assessment of existing conditions and recommendations for enhancing renewable biogas generation and managing biosolids production at the Ravensview and Cataraqui Bay wastewater treatment plants (WWTPs) in Kingston, Ontario. Utilities Kingston is a multi-utility provider that is wholly owned by the City of Kingston. The purpose of the assignment is to develop a long-term, environmentally sustainable and cost effective biosolids management program that responds to current and future program challenges. The key elements of the project include evaluating opportunities to improve existing operations, as well as identification and description of available beneficial options for biosolids management and evaluation of potential feedstock sources to increase biogas generation. The outcome of the assignment is a report detailing evaluation of technology options, a business case analysis, and development of an overall biosolids master plan for Utilities Kingston.

This Preliminary Assessment report is intended to provide the framework for further development of the assignment. Scope to date has included an evaluation of potential technologies and pathways for Utilities Kingston to pursue. Tetra Tech has systematically investigated different facility operational categories and identified various processes within those categories. From there, a wide array of available technologies was identified and narrowed down to select and include those strategies which we believe offer the best technical and economic options for Utilities Kingston's consideration.

A detailed evaluation table is provided with this report demonstrating established screening criteria and results for various technologies. Upon discussion with Utilities Kingston, Tetra Tech has narrowed the field of technologies to be further investigated in the Detailed Assessment as follows:

Categories	Technologies
Sludge Pre-Treatment	1. Thickening 2. Biological Hydrolysis
Solids Stabilization	3. Anaerobic Digestion 4. Co-digestion at Ravensview (including SSO) 5. Co-digestion at Cataraqui Bay (including SSO)
Biogas Utilization	6. Microturbines 7. Reciprocating Engines 8. On-Site Boiler 9. Off-Site Vehicle Fueling
Dewatering	10. Centrifuge 11. Belt-Filter Press
Biosolids Management	12. Cake/Slurry Land Application

Based on the recommendations laid out in this report and recommendations derived from Workshop 1, Tetra Tech will proceed with the next phase of this study. The work will be comprised of a more detailed review of applicable technologies noted above and subsequent high level analysis of the respective impacts on capital and operating costs and new revenue sources.

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ACRONYMS & ABBREVIATIONS

Acronyms/Abbreviations	Definition
AD	Anaerobic Digestion
BHP	Biological Hydrolysis Process
BOD_5	5- Day Biochemical Oxygen Demand
CapEx	Capital Expense
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
EA	Environmental Assessment
FOG	Fats, Oil, and Grease
GHG	Greenhouse Gas
HSW	High Strength Waste
IFR	Issued for Review
IFU	Issued for Use
LCFS	Low Carbon Fuel Standard (California)
MOECC	Ministry of the Environment and Climate Change
OpEx	Operating Expense
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
RNG	Renewable Natural Gas
SSO	Source Separated Organics
THP	Thermal Hydrolysis Process
UK	Utilities Kingston
WAS	Waste Activated Sludge
WWTP	Wastewater Treatment Plant

LIMITATIONS OF REPORT

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1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) is providing a Preliminary Assessment of existing conditions and recommendations for enhancing biogas generation and managing biosolids production at the Ravensview and Cataraqui Bay wastewater treatment plants (WWTPs). Tetra Tech has followed up with our Background Review of Information made available through Utilities Kingston (UK), attended a stakeholder meeting with UK and the City of Kingston, visited operating facilities, and had several meetings and discussions regarding the options available to UK.

The key elements to be covered in this Preliminary Assessment include, but are not limited to:

- Provision of a general overview of the Ontario Municipal Class Environmental Assessment (EA) process and present general requirements moving forward;
- Provision of recommendations for engagement/involvement of various environmental approvals agencies navigating through the EA process;
- Presentation of a preliminary evaluation of existing wastewater treatment facilities and offer suggestions as to what additional investigation is required to meet the objectives of the evaluation;
- Presentation of a preliminary evaluation of digester performance and offer suggestions as to what additional investigation is required to meet the objectives of the evaluation;
- Identification and description of various biogas utilization options that are readily available on the market and should reasonably be considered for this application;
- Identification and description of available beneficial options for biosolids management/use that are readily available on the market and should be reasonably considered for this application;
- Identification and description of ancillary systems (e.g., odour control) and potential side stream production that may occur;
- Identification of any federal/provincial funding opportunities available for municipalities and discussions around what other private investment opportunities may be available;
- Presentation, in concept, around evaluating existing wastewater digestion systems and physical relocation of processes and building infrastructure to more effectively utilize available space and compound area(s);
- Presentation, in concept, around potentially consolidating biosolids processing at a single location as well as transportation of raw product from other facilities within the City of Kingston or adjacent communities for processing at a single location; and
- Presentation, in concept, around potentially accepting other easily digestible feedstock (such as source separated organics) to increase biogas generation, without significantly increasing the hydraulic load.

After working together with UK management and operations staff, and meeting with the UK stakeholders group, Tetra Tech has consolidated the above-noted items into five major project categories. These categories provide the framework for this report and will be further developed as part of the Detailed Assessment.

- Approvals Agency Positioning;
- Evaluation of Existing Operations;
- Technology Selection and Central Processing;

- Potential Business Case Scenarios; and
- Summary.

The IFU Preliminary Report will provide the basis for moving forward in the Detailed Assessment.

2.0 APPROVALS AGENCY POSITIONING

Utilities Kingston had initially focused on developing a comprehensive Master Plan for the management of biosolids produced at the Cataraqui Bay WWTP, but has since expanded this to consider all biosolids generated by UK's WWTPs. Biosolids are a nutrient-rich, organic by-product of the wastewater treatment process and are currently provided to the agricultural community for beneficial reuse in crop production.

The purpose of this study is to develop a long-term, environmentally sustainable, reliable, and cost-effective biosolids management program that responds to current and future program challenges. Specifically, the purpose is to evaluate biosolids management alternatives and methods and to recommend a strategy that ensures the program's long-term sustainability to the year 2037.

There are typically many challenges to be considered in the development of these strategies. While Tetra Tech recognizes that many of these challenges are currently addressed by UK's biosolids management strategy it is deemed valuable to reiterate their importance at this time. Typical considerations when undertaking a project of this nature include, but are not limited to:

- Projecting sludge and biosolids production rates over the proposed service life of new or upgraded biosolids facilities. Often using population projections and other indicators of increases in wastewater and biosolids production rates, as well as source separated organic (SSO) waste generation and diversion rates for options that involve co-digestion of SSO;
- Opportunities for generation of renewable energy in the form of biogas;
- Opportunities for co-digestion with organic waste to further enhance biogas generation and increase waste diversion rates;
- Reduced availability of agricultural land for land application of biosolids;
- Finite off-season storage capacity;
- Regulatory constraints; and
- Public sensitivities.

2.1 Ontario Environmental Assessment Act Approval

Municipalities may plan municipal works on a project by project basis, but it is recognized that in many cases it is beneficial to begin the planning process by considering a group of related projects or an overall system prior to dealing with project specific issues. By planning in this way, the need and justification for individual projects and the associated broader context are better defined. This is the basic rationale for completing a Master Plan, and it is understood that Utilities Kingston wishes to implement this approach prior to identifying a specific project. Ontario *Environmental Assessment Act* (EAA) requirements for approval of the individual project.

Master Plans are long-range plans which integrate infrastructure requirements for existing and future land use with environmental assessment planning principles. These plans examine an infrastructure system(s) or group of related projects to outline a framework for planning for subsequent projects and/or developments. Master Plans typically differ from project-specific studies in several key respects. Long-range infrastructure planning enables the proponent to comprehensively identify need and establish broader infrastructure options. The combined impact of alternatives is also better understood which may lead to other and better solutions.

Master Plans provide the context for the implementation of the specific projects, which make up the plan and satisfy, as a minimum, Phases 1 and 2 of the Class EA process. Notwithstanding that these works may be implemented as separate projects, collectively these works are part of a larger management system. Master Plan studies in essence conclude with a set of preferred alternatives and, therefore, by their nature, Master Plans will focus the scope of alternatives, which can be considered at the implementationstage.

Master Planning is a framework whereby the Class EA recognizes the place of such Master Planning studies in guiding sound environmental planning at the project-specific level. This approach recognizes that there are real benefits in terms of better planning when long-range comprehensive studies are undertaken and that proponents who undertake such studies can build on the recommendations and conclusions contained in them.

Master Plans typically differ from project-specific studies in several key respects. Long-range infrastructure planning enables the proponent to comprehensively identify need and establish broader infrastructure options. The combined impact of alternatives is also better understood which may lead to other and better solutions. In addition, the opportunity to integrate with land use planning enables the proponent to look at the full impact of decisions from a variety of perspectives.

The following are distinguishing features of Master Plans:

a. The scope of Master Plans is broad and usually includes an analysis of the system to outline a framework for future works and developments. Master Plans are not typically undertaken to address a site-specific problem.

b. Master Plans typically recommend a set of works which are distributed geographically throughout the study area and which are to be implemented over an extended period. Master Plans provide the context for the implementation of the specific projects that make up the plan and satisfy, as a minimum, Phases 1 and 2 of the Class EA process.

The municipal works being contemplated may be implemented as separate projects but collectively these works are part of a larger management system. Master Plan studies in essence conclude with a set of preferred alternatives and, therefore, by their nature, Master Plans will limit the scope of alternatives, which can be considered at the implementation stage.

2.1.1 The Master Planning Process

The work undertaken in the preparation of Master Plans recognizes the planning and design process of the Class EA process, and incorporate the key principles of successful environmental assessment planning. It is important that adequate consultation take place during each phase of the study process, including at the initiation of the Master Plan study so that the scope and purpose of the study are understood, and again when the process of selecting the preferred set of alternatives is initiated. At a minimum, the Master Planning process should address the first two phases in the Planning and Design Process of the Class EA.

When projects are undertaken which implement specific elements recommended in the Master Plan, it will be necessary for the applicable schedule to be determined for those projects subject to the Municipal Class EA. Depending on the scope and level of analysis of the Master Plan, the requirements of Phases 1 and 2 may have been satisfied at the project-specific level. Alternatively, Phases 1 and 2 may have to be revisited as they relate to the specific project. In addition, for Schedule B projects, it would be necessary to fulfil the consultation and documentation requirements.

The scope of Phase 1 is problem and/or opportunity identification. Phase 2 involves identifying alternative solutions to address the problem or opportunity by considering the existing environment and establishing the preferred solution taking into account public and review agency input. At this point, the appropriate schedule for the undertaking (in this case Schedule C). Schedule A and B projects do not need to proceed beyond Phase 2, whereas Schedule C projects must proceed through the remaining three phases.

For Schedule C projects, it would be necessary to fulfil the additional requirements of Phases 3 and 4 and consider the site-specific issues that were beyond the scope of the Master Planning process. Thus, the Master Plan would be used in support of further work carried out for specific Schedule B projects and further work in Phases 3 and 4 for specific Schedule C projects. Requests for an order to comply with Part II of the EAA, however, would be possible only for the specific projects identified in the Master Plan and not the Master Planitself.

The previous Class EA work for the Ravensview and Cataraqui Bay plants fell under Schedule C, but because the older of these was completed more than 10 years ago, it is no longer valid. Based on the options being considered to date, the current project would also be expected to fall under Schedule C, since it would involve the construction of new facilities and major expansion to existing facilities. Schedule C projects must proceed through the environmental planning process.

Ministry of the Environment and Climate Change (MOECC) specifically urges project proponents to discuss their Master Plan approach with the EAA Branch prior to proceeding. Given the broad scope of Master Plans, there are infinite variations on the basic approaches. Regardless of the approach, the onus is on the proponent to ensure that the requirements of the Municipal Class EA are met. To monitor the effectiveness and benefits of the approach, proponents are required to briefly summarize how the Master Plan followed Class EA requirements and copy this to the MOECC Environmental Approvals Branch, including copies of mandatory notices.

2.1.2 Renewable Energy Act Approvals

Specific to power generation in conjunction with the Province's purchase of power generated by renewable energy projects, which includes anaerobic digestion of waste. However, the Province has discontinued its feed-in tariff program for the purchase of renewable energy at premium pricing from all but smaller scale (i.e., 500 kilowatt generating capacity or less) projects. The exemptions from consultation and EAA approvals that the *Renewable Energy Act* processes afforded renewable energy project proponents would generally not apply to a renewable natural gas (RNG) project or to co-digestion of source-separated organic waste and sewage biosolids unless power is generated. The cancellation of the feed-in tariff program for projects larger than 500 kW effectively makes such projects uneconomical compared to the alternatives.

2.2 Regulatory Approvals Engagement

A proactive approach to communication and liaison with the MOECC has been initiated and will accelerate once a short list and preferred alternatives for the project are identified. While there may be certain advantages to options that involve centralized processing of biosolids from more than one of the three existing plants generating sludge, this option is expected to generate concerns and MOECC requests to consider additional potential impacts associated with a centralized facility. This is particularly true for alternatives that involve development of an additional site for which an Ontario *Water Resources Act* and EAA approval has not been previously obtained. This would be the case for any options that involve developing the Knox Farms site into a centralized biosolids processing facility, and the benefits of having the project identified as a renewable energy project and subject to certain approvals exemptions.

The proactive approach to engaging the MOECC and identified stakeholders is an integral part of successfully navigating the approvals requirements for implementing a program and associated infrastructure for enhanced biosolids management. An initial pre-consultation meeting was held with MOECC in which both local staff from the District and Regional operations offices and staff from the Environmental Assessment and Approvals Branch participated. MOECC representatives indicated that the general approach would be to streamline the approvals process for renewable energy and greenhouse gas reduction projects, consistent with the overall policy direction of the Ministry and the Provincial cabinet.

Tetra Tech would like to note that there was a change in the leadership of MOECC, but no significant change to the approvals processes is expected. A strong emphasis on promoting projects that are consistent with the Province's Climate Change Plan are expected to continue under the new Minister. The MOECC has stated in stakeholder meetings that it is contemplating consultative exemptions for anaerobic digestion projects that generate methane but no firm legislation has yet materialized.

Pre-consultation with MOECC is necessary to determine the specific approvals required and the conditions under which composting of biosolids would be approved. Consultation with other Provincial Ministries may also be relevant to the options being considered by UK, including the Ministry of Aboriginal Affairs, Ministry of Culture, Ministry of Municipal Affairs and Housing, Infrastructure Ontario, and the Ministry of Agriculture, Food and Rural Affairs (if land application of biosolids is to be carried forward as an option for biosolids management).

The MOECC general policy approach is to encourage and provide a streamlined and accelerated approvals process for projects that promote the objectives of its renewable energy and climate change plan for the Province.

The approvals process for this type of project is expected to be managed as a priority application due to its associated greenhouse gas emission reduction benefits. Applicable exemptions from the Class EA process would be expected to apply to the approval. However, because of the lack of precedent projects that have incorporated RNG and/or anaerobic co-digestion with respect to biogas energy projects that do not involve electrical power generation and are not small scale (i.e., less than 500 kW generating capacity – typically on-farm anaerobic digestion projects for managing agricultural wastes), this may create a level of uncertainty that may result in some delays in the processing of the application by Environmental Approvals Branch. The various stakeholders within MOECC identified to participate in a proactive communication approach include but are not limited to:

- MOECC Environmental Approvals Branch;
- MOECC Kingston District Office;
- MOECC Southeast Region Office;
- MOECC Renewable Energy Facilitation Office;

  MOECC Climate Change and Environmental Policy Division – Environmental Intergovernmental Affairs Branch;
- MOECC Environmental Approvals Access and Service Integration Branch; and
- MOECC Environmental Programs Division – Environmental Innovations Branch.

Additional consultation with MOECC both at the District and Regional operations level and with the Environmental Assessment and Approvals Branch is critical to ensuring that the approvals process remains a single accelerated process rather than separate processes with a cumulative approval time that could exceed the time required for a review and approval of a more conventional Class EA for a biosolids digester upgrade or expansion project.

3.0 EVALUATION OF EXISTING OPERATIONS

This section of the Preliminary Assessment report provides a summary of key findings related to the existing operations at the Ravensview and Cataraqui Bay facilities and presents potential options to enhance biogas generation, minimize biosolids production, and subsequently reduce biosolids handling and disposal.

Figure 3.1 identifies wastewater sludge as a source product and illustrates the potential management pathway(s) considered under this Preliminary Assessment. The figure is indicative of the current biosolids processing opportunities and the potential inclusion of SSO into the current operations.

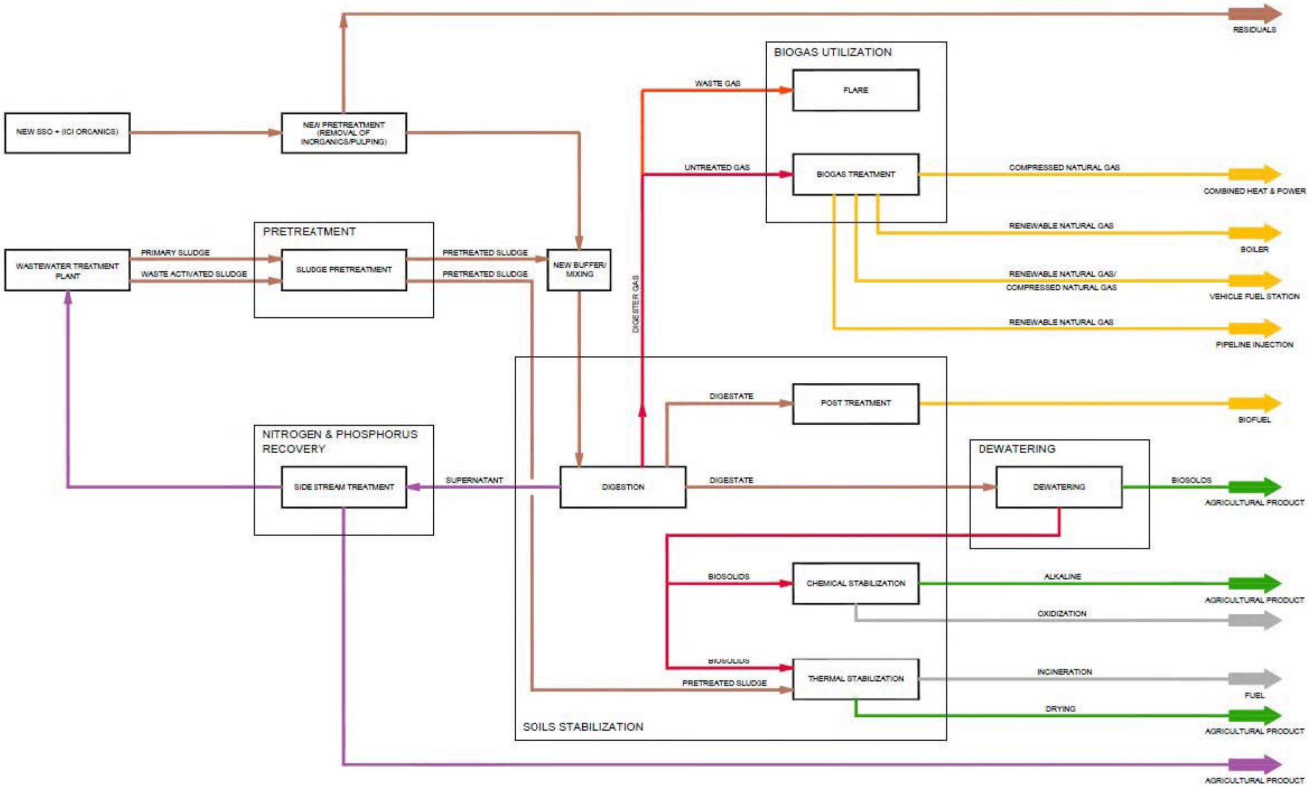

Figure 3-1. Potential Management Pathways Considered under this Preliminary Assessment

A full-size copy of the illustration is provided attached as Drawing 3.0.

We have identified six (6) general categories, currently in place at the Ravensview and Cataraqui Bay facilities, or considered in our evaluation as potential existing and/or new technological options for biogas generation and biosolids management. These include:

- Pre-treatment;
- Solids Stabilization;
- Biogas Utilization;
- Dewatering;
- Nitrogen and Phosphorus Recovery; and
- Biosolids Management.

For each category noted above a separate and independent flow diagram has been prepared to visually represent the individual processes considered and evaluated under this assignment.

Our assessment of which existing waste sludge management strategies to proceed with as part of our Detailed Assessment is based on certain criteria, including but not limited to, the following:

- General Cost Implications;
- Space Availability;
- Operations Compatibility;

- Environmental Impacts;
- Class EA Impacts; and
- Business Case.

Table 3.0 attached with this report presents the breakdown of our preliminary assessment and recommendation based on the above-noted screening criteria.

The following subsections identify each of the existing operations technology evaluations and provides a closer analysis of the advantages and disadvantages for each process evaluated in the screening process. It also provides additional information on which of these processes should be eliminated from the Detailed Assessment.

We recognize that there may be some questions expressed as to why some of the options have been eliminated and, as such, we are providing additional explanation of why they were dropped and what steps can potentially be taken by the UK and their stakeholders to make those options more beneficial.

3.1 Sludge Pre-Treatment

The following section covers options related to pre-treatment, specifically waste sludge pre-treatment. Waste sludge pre-treatment involves processing (treating) the sludge or wastewater before it undergoes further stabilization. For the case of UK, these options would be placed prior the anaerobic digestion unit operations at Ravensview and Cataraqui Bay.

The BIOSTYR® process employed at Cataraqui Bay and Ravensview facilities is an upflow submerged media biologically active filter (BAF). As an attached growth process, BIOSTYR is carried out in a series of individual cells containing submerged buoyant media, which provides surface area for microorganisms to attach and grow. Extra activated sludge falls off the media and is filtered and removed as waste activated sludge (WAS).

Municipal wastewater sludge, particularly WAS, is more difficult to digest than primary solids due to a rate-limiting cell lysis step. The cell wall and the membrane of prokaryotes are composed of complex organic materials such as peptidoglycan, teichoic acids, and complex polysaccharides, which are not readily biodegradable.

Sludge pre-treatment options discussed in this subsection include the following:

- Thickening;
- Hydrolysis; and
- Conditioning.

The following is a detailed discussion and evaluation to the aforementioned options. The attached Drawing 3.1 provides a flow diagram representation differentiating the options evaluated, and it will be used as a visual aid for the Workshop 1 presentation to describe the process identified and evaluated under this Preliminary Assessment.

3.1.1 Thickening

Thickening is a process used to increase the solids contents of the wastewater sludge by removing the liquid fraction (i.e., the fraction of solids within the sludge increases by decreasing the moisture content). Commonly, thickening processes use physical means where large solid particles would settle either naturally by gravity or more rapidly by application of chemicals and energy in a higher-rate system. A higher solids content sludge (i.e., less water content) would enhance biogas generation as less water would interfere during microbial activity (e.g., methanogenesis phase). Typically, thickening process increase solids content from 1-3% to 5-10% depending on the type of sludge and technology used. A polymer compound may also be added with a stirring mechanism to further increase settling activities thereby increasing the solids content. Table 3-1 summarizes key advantages and disadvantages with thickening technology.

There are numerous thickening options as a sludge pre-treatment option as briefly discussed:

- **Gravity Belt Thickeners** uses gravity (settling) and a porous drainage belt where water is pressed out and drained out of the sludge.
- **Gravity Thickening Tank** currently planned as an upgrade design at the Cataraqui Bay site for the BIOSTYR backwash system, consists of a top-fed large tank which is designed to have sufficient retention time and promotes densification and settling. Thickened sludge is withdrawn as it moves to the bottom of the tank.
- **Rotary Drum Thickener** uses rotating drums covered with media to thickensludge.
- **Centrifuge** uses centrifugal forces (outward forces from rotation) to "separate" the solids fraction to thicken sludge.
- **Dissolved Air Flotation** introduces dissolved air into the bottom of a flotation tank whereby the suspended solids would adhere to the tiny air bubbles and float to the top.
- **Co-Thickening** is an old sludge thickening process which introduces waste sludge into primary clarifiers to absorb organics on its surface and co-settling in the tank. Applying this process to waste sludge from the BIOSTYR process is not a typical approach.

Table 3-1. Advantages and Disadvantages of Thickening Technologies

Advantages	Disadvantages
▪ Increase dry solids concentration by removing water	▪ Limited to certain percentage of dry solid content
▪ Increase solids retention time in digesters	▪ Unable to destruct microbial cells
▪ Reduce digester capital and operational costs	▪ Requires chemical/polymer addition
▪ Relatively simple equipment/system	▪ Co-thickening reduces primary clarifier capacity and increases biochemical oxygen demand and total Kjehldahl nitrogen loading to secondary treatment process
▪ Relatively lower capital expense (CapEx) and operating expense (OpEx)	

Preliminary Assessment

Based on a preliminary review of the thickening process and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in our Detailed Assessment. It has been our experience that the thickening process can enhance biogas generation at a relatively low cost. There would be minimal environmental impact as there is already a process in place. There would need to be an amendment to the existing Environmental Compliance Approval but we do not believe that there would be any significant Ministry of Environment approvals issues.

3.1.2 Hydrolysis

Depending specific technologies, hydrolysis involves a series of thermal, chemical or biochemical reactions, which break down complex compounds into simpler forms, such as long chain polysaccharides into simple disaccharides and monosaccharides. The smaller compounds would then be more readily available and easily digested in an anaerobic digestion system. As a pre-treatment option, the hydrolysis process could increase digestion rates, improve process stability, and enhance biogas generation. Table 3-2 summarizes key advantages and disadvantages with the hydrolysis process.

There are two main types of hydrolysis process: 1) thermal hydrolysis process (THP), and 2) biological hydrolysis process (BHP) as briefly discussed:

1. **Thermal Hydrolysis Process (THP)** is commonly a two-step process, where sludge is subjected to high pressure and temperature conditions then followed by rapid decompression. This process uses steam to create the temperatures and pressures required for operation and significantly changes the sludge composition and characteristics, such as reduced volatile solids and total solids, reduced viscosity, as well as reduced pathogens.

2. **Biological Hydrolysis Process (BHP)** consists of a set of serial flow reactors up front of a mesophilic anaerobic digester. Sludge is heated in the first reactor to a moderate temperature (40~50^{o}C) to promote biological sludge hydrolysis. This process also enables shorter digester retention time with increased volatile solids reduction thus increases digestion efficiency and biogas generation in the following anaerobic digestion process.

Table 3-2. Advantages and Disadvantages of Hydrolysis Technologies

Advantages	Disadvantages
▪ Destruction of microbial cells - increased volatile solids reduction and volatile solids loading rates in subsequent anaerobic digestion	▪ Corrosion of mechanical equipment (THP)
▪ Increased digestion rates & process stability	▪ Complex and highly reactive processes: high temperature and pressure, use of steam (THP)
▪ Increased biogas generation	▪ Needs specialized training/license on operation (THP)
▪ Reduced solids volume for dewatering & disposal	▪ High capital expense and operating expense.
▪ Reduced filamentous foaming	▪ Less proven/installation in North America (BHP)
▪ Reduced viscosity of solids in digestion	▪ Biosolids unpasteurized, Class A certification not received yet (BHP)
▪ Reduced product odours following anaerobic digestion and obtain pasteurized Class A biosolids (THP)	

Preliminary Assessment

Based on a preliminary review of the Thermal Hydraulic Process (THP) and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in the Detailed Assessment. The technology is relatively expensive as a treatment enhancer and therefore it is typically justified in much larger scale plants, where economy of scale is a way to improve its competitiveness. Additionally, the complexity of THP poses technical and operational challenges such as a stationary engineer is required to operate the system using steam under the *Technical Standards and Safety Act*, 2000. Stationary engineers are in high demand in Ontario and may be difficult to recruit.

Biological Hydrolysis Process (BHP) provides similar process benefits as THP but operates under milder conditions, which eliminates the staff qualification requirement for stationary engineers. By reducing the digester retention time, the existing digester capacity as well as biogas yield can be increased. Due to the increased biogas yield, the overall quantity of biosolids is reduced. However, during the preliminary review, it is noted that BHP currently lacks full-scale references in North America. Data collected from full-scale installations in Europe and from the pilot unit in Guelph, Ontario are still undergoing approval process to obtain the Class A equivalent certification in Canada. To weigh advantages and disadvantages of BHP in more details, our recommendation is to **proceed** with further investigation as a potential option for UK in the Detailed Assessment.

3.1.3 Conditioning

Sludge conditioning is a pre-treatment process where sludge is treated with chemicals and/or energy (e.g., sonic, electromagnetic). The main purpose of conditioning the sludge is to change the sludge characteristics for easier treatment/processing, such as less energy needed for dewatering or to disrupt the cells increasing downstream digestion. For example, the heat could breakdown cell structure resulting in sterilization (Metcalf and Eddy 2003). Table 3-3 summarizes key advantages and disadvantages with thickening technology.

- **Chemical Conditioning** prepares the sludge for more economical treatment with vacuum filters or centrifuges by adding chemicals, such as alum, sulfuric acid, ferric chloride, and polymer.
- **Heat Conditioning**
- **Sonic Energy** involves the exposure of the microbial cells to ultrasound energy, ruptures the cell wall and membrane and releases the intracellular organics in the bulk solution, which enhances the overall digestibility
- **Electromagnetic Energy** uses electromagnetic radiation with a wavelength from 1 m to 0.1 mm (microwave spectrum ranges) to disintegrate sewage sludge and release the intercellular organics.
- **Mechanical Energy** is applied in disintegration of sludge in various form, e.g., high shear forces, high pressure and freeze-thaw cycles.

Table 3-3. Advantages and Disadvantages of Conditioning Technologies

Advantages	Disadvantages
▪ Different disintegration objectives can be achieved	▪ High capital and operating expense - consumption of energy and chemicals
▪ Increased cell disruption	▪ Relatively sophisticated operating conditions
▪ Improved anaerobic digestion efficiency and volatile solids destruction	▪ Lack of full-scale installation
▪ Reduces sludge quantity and raise biogas generation	

Preliminary Assessment

Based on a preliminary review of the conditioning process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in the Detailed Assessment. The conditioning process may not be easily integrated into UK’s WWTPs because most conditioning processes require a sophisticated operating condition. Also, some of the technology lack of full-scale operations (i.e., high throughput) which poses operational risks to the UK's WWTP.

3.2 Solids Stabilization

Stabilization is a process where the volatile solids within the sludge are further degraded resulting in a more stable/mature product and the volume of material to be handled is reduced. The main benefits to stabilization are reduced volatile organic compounds and pathogen concentration, and vector attraction, as well as, in some cases improved sludge handling and odours. There are many types of stabilization processes. Generally, they are classified as biological, physical, chemical, or thermal processes.

Digestion, either aerobic or anaerobic is a biological process that oxidizes carbon to carbon dioxide and water, converts nitrogen compounds to different chemical states (nitrogen gas in anaerobic digestion or nitrate in aerobic processes. Co-digestion is simply the addition of other substrates to the digester to improve gas production and overall performance. Chemical stabilization uses either an acid or a base to alter the chemical nature of the sludge.

Physical processes change the nature of the solids so they are more usable and can serve as a pre- or post-treatment process when combined with other processes. Finally, thermal processes can reduce the volume and fully oxidize the carbon in the sludge, by applying heat at several levels, from drying to combustion.

Solids stabilization processes discussed in this subsection include the following:

- Digestion;
- Co-Digestion;
- Post-Treatment/Composting;
- Chemical Stabilization; and
- Thermal Stabilization.

The following is a detailed discussion and evaluation to the aforementioned options. The attached Drawing 3.2 provides a flow diagram representation differentiating the options evaluated, and it will be used as a visual aid for the Workshop 1 presentation to describe the process identified and evaluated under this Preliminary Assessment.

3.2.1 Digestion

Digestion is a biochemical process where a consortium of bacteria would degrade/decompose the organic matter within the sludge. The type of bacteria depends on the type of process and the presence (or lack of) oxygen. Typically, digestion involves an in-vessel closed reactor.

Digestion processes discussed in this subsection include the following:

- Anaerobic;
- Aerobic; and
- Combined Aerobic/Anaerobic.

3.2.1.1 Anaerobic Digestion

Anaerobic digestion (AD) involves the degradation of organic material with no gaseous oxygen. In an anaerobic digester, gaseous oxygen is prevented from entering the system through physical containment in sealed tanks. Anaerobic microbes access oxygen from sources other than the surrounding air. The oxygen source for these microorganisms can be the organic material itself or alternatively may be supplied by inorganic oxides from within the input material.

Anaerobic digestion facilities vary on the number of stages (e.g., 1-stage or 2-stage reactors) and the operating temperature (e.g., mesophilic or thermophilic). One main benefit to anaerobic digestion is the generation of biogas, which consists mainly of methane gas. Once refined and processed, the biogas can be used in a variety of usable products, such as fuel (compressed natural gas [CNG]) and energy (through combined heat and power [CHP]). Table 3-4 summarizes key advantages and disadvantages with anaerobic digestion technologies.

Table 3-4. Advantages and Disadvantages of Anaerobic Digestion Technologies

Advantages	Disadvantages
▪ Well known process with large number of facilities currently in operation	▪ Digestate not considered as Class A product (Mesophilic)
▪ Energy generation from waste	▪ Longer retention time low vs. destruction Rate (Mesophilic)
▪ Stabilized biosolids that can be used as a soil conditioner	▪ Relatively higher energy input (Thermophilic, Temp Phased)
▪ Moderate CapEx	▪ High nitrogen and phosphorus content in the supernatant
▪ Reduced GHG Emissions	▪ Higher CapEx than aerobic

Preliminary Assessment

Based on a preliminary review of the anaerobic digestion process and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in our Detailed Assessment. Anaerobic digestion has many benefits that aligns with UK's main objective of this project of enhancing biogas generation.

3.2.1.2 Aerobic Digestion

Aerobic digestion is a biological process that occurs with the presence of gaseous oxygen. As aerobic digestion takes place, organic carbon in the aerobic digester is converted to carbon dioxide and heat. Unlike anaerobic process, aerobic digestion does not generate biogas but typically creates a stable biosolids that could be used as a soil amendment.

Compared to an anaerobic process, the reaction speed of aerobic digestion is much faster. Thus, it can be expected that an aerobic digester requires less solids retention volume and causes less odour issues since most volatile organic carbon is oxidized before emitting to the surrounding environment.

Aeration units are typically used to deliver air to digestion vessels to meet oxygen demand. As such, large amounts of energy are consumed to supply air to the system. Table 3-5 summarizes key advantages and disadvantages with aerobic digestion.

Table 3-5. Advantages and Disadvantages of Aerobic Digestion Technologies

Advantages	Disadvantages
▪ Lower CapEx than anaerobic digestion	▪ Higher power cost resulting from aeration requirements
▪ Simpler operation	▪ Open tanks can result in odour production
▪ Safer operation as there is no potential for gas explosion	▪ Relatively large footprint required
▪ Supernatant contains lower BOD_5 concentrations	▪ Aerobic biosolids difficult to mechanically dewatered
▪ Less odour concern	▪ Reduced process efficient in cold temperatures
	▪ Not able to generate biogas for energy production

Preliminary Assessment

Based on a preliminary review of the aerobic digestion process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. Aerobic digestion has many benefits but it does not align with UK's main objective of this project to enhance biogas generation. Energy cost is significantly higher than anaerobic digestion. In certain variation, e.g., Autothermal Thermophilic Aerobic Digestion, the process is a difficult change for plant staff who is used to conventional anaerobic digestion processes.

3.2.1.3 Combined Aerobic/Anaerobic Digestion

Combined aerobic/anaerobic digestion uses both aerobic and anaerobic mechanisms. The system has many variations but typically consists of two or more stages of sequential anaerobic and aerobic digestion processes.

Taking advantages of both aerobic and anaerobic microbial activities, the combined digestion system enables sludge stabilization and breakdown of organics relatively fast with less odour concerns. A significant portion of the organic carbon is consumed in the aerobic process instead of generating biogas in the anaerobic processes, the overall carbon utilization for biogas generation is not enhanced. Table 3-6 summarizes key advantages and disadvantages with combined aerobic/anaerobic digestion technologies.

Table 3-6. Advantages and Disadvantages of Combined Aerobic/Anaerobic Digestion Technologies

Advantages	Disadvantages
▪ Increased pathogen reduction	▪ More complex operation
▪ Solids stabilization with less odour issue	▪ Less energy efficiency (Aerobic Thermophilic Process)
▪ Improved sludge dewatering & disposal	▪ Organic carbon consumed in aerobic process

Preliminary Assessment

Based on a preliminary review of the combined aerobic/anaerobic digestion process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. The combined aerobic/anaerobic digestion process is considered not suitable for this project because it is only partially aligned with UK's main objectives. The combined aerobic/anaerobic digestion may reduce overall biosolids production but will not enhance biogas generation. Therefore, the process benefit cannot be offset by the increased capital cost and complexity to the overall plant operation, which requires additional staffing needs and technical support.

3.2.2 Co-Digestion

Many WWTPs have found that they can increase the amount of biogas generated by accepting high strength waste (HSW) from outside sources that may not currently discharge to the treatment facility. Materials such as source separated organics (SSO), fats, oil, and grease (FOG) from restaurants and food processors; waste and expired beverages from large producers such as soft drink and beer suppliers; and digestible wastes from some manufacturing processes, including dairies and agricultural operations, have been added into the solids stabilization systems at municipal wastewater treatment facilities, thus increasing the amount of biogas generated. To implement this approach, it is necessary to identify means of handling the HSW that do not increase the load to the liquid stream, which can increase operating cost and use capacity intended to serve other needs, including population growth. Also, depending on the source of the HSW, some form of pre-treatment may be required. This may range from a relatively simple equalization/holding tank for liquid wastes, such as expired beverages and soft drink manufacturing waste, to macerators and liquefaction systems for materials sourced from SSO or FOG to solids handling and processing equipment for SSO.

Another important factor is identifying the source of the HSW. The key factors include availability, i.e., is the material regularly produced and are the quantities relatively consistent. This includes consistency in quality as well as quantity. Then, the facilities where the material is to be processed must be adequately sized to handle the increased loadings and volumes, including having ability to process any side streams that are produced. Thus, for UK, the challenge is twofold. First, a source of material must be identified and means to obtain them secured. This includes how the materials are delivered to the facilities where they are to be processed, e.g., via truck, pumped/piped or some combination of means. Second, the processes needed to handle the material must be in place. This includes receiving facilities that can accept the material in a broad range of forms, from liquid to solids. For example, if the material is liquid, then equalization is likely needed. However, if the material is a semi-solid, such as FOG, the material may need to be heated to allow for better handling. Lastly, if the material is a solid, the processes to macerate, grind and liquefy the material will be needed.

Determining if co-digestion is a possibility, there must be a source of supply evaluation that should be done. Without knowing the quantity and carbon content of the feedstocks, it is difficult to assess the capacity that co-digestion could consume. Also important to note, SSO will have to be pre-treated before it can be mixed with the biosolid sludge. This will involve the removal of non-organic compounds (grit, stones, plastics, metal, etc.) that are typically thrown into green bins with the organic waste. Furthermore, the remaining organics should be pulped to ensure easy blending with the biosolids sludge prior to injection into the digestors. The level of pulping will be determined by the requirements established for the digestors. A review of the feasibility of co-digestion in each respective facility is discussed below.

3.2.2.1 Ravensview

This facility is site constrained and thus significant changes to address receiving HSW, may not be feasible. If a small, regular number of alternative feedstocks could be found, there may be a possibility that this approach could be used. Because it is likely that trucking of this material may be needed to this site, further consideration of the neighboring properties should be done. The area is largely residential and commercial trucking operations may not be feasible. Table 3-7 summarizes keyadvantages and disadvantages with co-digestion at Ravensview.

Table 3-7. Advantages and Disadvantages of Co-digestion at Ravensview

Advantages	Disadvantages
▪ Digesters in place	▪ Capacity needs be assessed
▪ CHP system could likely use additional biogas	▪ Site is constrained and additional tanks may not be possible
▪ HSW typically has high energy content per unit volume, so hydraulic capacity may be acceptable	▪ Transportation of HSW to the site could be problematic, given the neighbourhood
▪ Of the two existing sites, Ravensview has the most room for pre-treatment	▪ System to account for HSW is needed, separate from wastewater accounting
	▪ Additional odour from either pre-treatment or from the digestion plant may impact neighbouring community

Preliminary Assessment

Based on a preliminary review of co-digestion at Ravensview and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in our Detailed Assessment. While we believe that there will be challenges at Ravensview to provide for the additional technology given the space constraints, overall size of the facility, and site location we are recommending further investigating this option under the detailed assessment.

3.2.2.2 Cataraqui Bay

The facility at Cataraqui Bay is in a better location, relative to access via roadway than the Ravensview facility. The necessary improvements at the Cataraqui Bay site to accept material for co-digestion are the same as for Ravensview. However, the digestion process at Cataraqui Bay needs to be improved, based on its current size and condition, if co-digestion is to be used. Table 3-8 summarizes key advantages and disadvantages with co-digestion at Cataraqui Bay.

Table 3-8. Advantages and Disadvantages of Co-digestion at Cataraqui Bay

Advantages	Disadvantages
▪ Digesters in place, but need work	▪ Digester capacity upgrades needed
▪ Additional biogas may be used on site or at nearby industrial operation	▪ Transportation of HSW to the site requires use of relatively busy public roads
	▪ Significant digester modifications required

Advantages	Disadvantages
	▪ No CHP system is in use, so an all new process to use the gas is needed
	▪ There is little space on site for pre-treatment

Preliminary Assessment

Based on a preliminary review of co-digestion at Cataraqui Bay and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in our Detailed Assessment. There are currently design technologies being considered at the Cataraqui Bay facility that we believe warrant additional and more detailed assessment of the existing facility taking into consideration the option of co-digestion. This would include a more detailed analysis of the newly commissioned liquid process and the various impacts to the liquid stream processes by side streams generated by digestion of high strength waste.

3.2.3 Post-Treatment/Composting

Composting is an aerobic biological process in which organic material undergoes biological degradation to a stable end-product with minimum odour, when operated properly.

Composting is an exothermic process which attains temperatures in the pasteurization range of 50 to 70°C. There are three separate stages of microbial activity occur during the composting process:

- Initial mesophilic stage, during which temperatures within the pile increases from ambient to about 40°C.
- Thermophilic stage (40 to 70°C), caused by the heat generated through conversion of organic matter to carbon dioxide.
- Cooling stage associated with reduced microbial activity as composting approaches completion (i.e., curing).

This results in the inactivation of pathogens and high quality biosolids that can be used beneficially as a soil conditioner or organic fertilizer supplement. Compost produces a product that is typically well-accepted in the marketplace.

Methods for composting include: 1) windrow, 2) aerated static pile, and 3) combined in-vessel composting.

3.2.3.1 Windrow Composting

Windrow composting consists of long narrow parallel piles of the mixture through which aeration is achieved by natural convection and diffusion and when the piles are mixed. The windrow is remixed periodically by a turning mechanism to facilitate air movement and moisture release. Windrow operations are either uncovered or enclosed systems. The active composting period is 21 to 28 days. Table 3-9 summarizes key advantages and disadvantages with Windrow composting.

Table 3-9. Advantages and Disadvantages of Windrow Composting

Advantages	Disadvantages
▪ Simple centralized process	▪ Requires large footprint of land
▪ Suited for large volume of diverse wastes	▪ Requires heavy equipment for mixing
▪ High quality, marketable product	▪ Labour intensive, higher OpEx
	▪ May release leachate
	▪ Need vector (bird and animal) and odour controls

Preliminary Assessment

Based on a preliminary review of the windrow composting process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. Windrow composting requires large plots of land that may not be available to UK.

3.2.3.2 Extended Aerated Static Pile Composting

Extended aerated static pile composting is a similar process as windrow composting, but each pile uses an aeration system instead of passive aeration and mixing. A blower would force air into each pile through pipes within the pile. The increased air flow would cause additional and faster microbial degradation in the piles compared to windrows. The pile is typically covered or fully enclosed for reduced odour and for improved process control. Table 3-10 summarizes key advantages and disadvantages with extended aerated static pile composting.

Table 3-10. Advantages and Disadvantages of Extended Aerated Static Pile Composting

Advantages	Disadvantages
• Simple centralized process	• Requires heavy equipment for material handling
• Suited for large volume of diverse wastes	• Labour intensive, higher OpEx
• Faster process than windrow composting	• May release leachate
• High quality, marketable product	• Need vector (bird and animal) and odour controls
	• Higher power cost resulting from aeration requirements

Preliminary Assessment

Based on a preliminary review of the extended aerated static pile composting process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. Extended aerated static piles are currently being utilized as a post-treatment process to stabilize the sludge/biosolids at a relatively low cost with minimal environmental impacts however may not be suitable in this application due to space restrictions.

3.2.3.3 In-Vessel Composting

In-vessel systems for active composting are enclosed and mechanized processes, comprising a reactor(s) and conveyors that offer an increased degree of process and odour control. The systems are compact and can be highly automated. The control of environmental conditions such as air flow, temperature, moisture, and oxygen concentration can permit shorter composting times.

The mixture of dewatered sludge and recycled compost is fed into one end of a tunnel, silo, or channel of the in-vessel process and moves continuously towards the discharge end. Air supplied by blowers is forced through this mixture which may be periodically agitated. Table 3-11 summarizes key advantages and disadvantages with in-vessel composting.

Table 3-11. Advantages and Disadvantages of In-Vessel Composting

Advantages	Disadvantages
• Modular container, easy to scale	• Most facilities have a building for unloading
• Odorous air can be contained for odour control	• More labour intensive
• May combine mechanical mixing/forced aeration or aeration during unloading	• Product may not fully stabilized (varies on specific technology) - may still require a curing stage
	• Site size is still large and reactors can be costly to construct

Preliminary Assessment

Based on a preliminary review of the combined composting process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. Applications of this in-vessel composting has become rare due to relatively high CapEx and OpEx. In-vessel composting may not be of interest to UK due to the increased space/land needed for curing that may not be available on-site.

3.2.3.4 Agitated Bed

The agitated bed composting system is designed to have the shortest composting time. The agitated bed system has a continuous air to flow to allow maximum biological degradation and has the least amount of odour and leachate produced. The composting bed is agitated continuously with a large, specially-designed mixing unit. Typically, agitated bed systems produce the highest quality of compost. However, it requires large amount of financial support due to the continuous aeration. The capital costs can also be high, due to the specialized design of the agitator system. Table 3-12 summarizes the key advantages and disadvantages with agitated bed.

Table 3-12. Advantages and Disadvantages of Agitated Bed Composting

Advantages	Disadvantages
▪ Continuous flow process - large capacity	▪ Requires environment control
▪ Good adaptability - able to accommodate different type organic waste and design in different size and capacity	▪ Higher CapEx and OpEx
▪ Very little odour or leachate is produced	▪ Require technical expertise to operate it properly
▪ Less land and manual labour than windrow	

Preliminary Assessment

Based on a preliminary review of the agitated bed process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. Agitated beds require large amounts of financial support (capital and operating) and other options may be just as effective at a lower cost.

3.2.3.5 Soil Blending

Soil blending involves mixing biosolids with other compounds to produce an inorganic fertilizer. The inorganic fertilizer could then be applied on land as a soil amendment. Table 3-13 summarizes the key advantages and disadvantages with soil blending.

Table 3-13. Advantages and Disadvantages of Soil Blending

Advantages	Disadvantages
▪ Simple process	▪ Management of material storage and transportation
▪ Lower capital and operating expense	▪ Biosolids must process before be adequately treated they are blended with from another other materials

Preliminary Assessment

Based on a preliminary review of the soil blending process and an evaluation of advantages and disadvantages, and discussions with UK on this process our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. Soil blending is a relatively simple process and has a relatively low cost (both capital and operating) but is not suitable in this application to space constraints.

3.2.4 Chemical Stabilization

Chemical stabilization involves using chemical compounds, such as lime, to further stabilize the wastewater sludge via degradation/oxidization of volatile solids.

Two types of chemical stabilization processes were considered: 1) alkaline stabilization and 2) oxidation stabilization.

3.2.4.1 Alkaline Stabilization

Alkaline stabilization involves the addition of an alkaline material to raise the pH level to create conditions unfavorable for the growth of organisms, including pathogens. Relatively inexpensive alkaline material, e.g., hydrated lime ($Ca(OH)_2$), quicklime or cement kiln dust are commonly used, which makes it often the most cost-effective process for wastewater solids stabilization. This is particularly true where dependable markets for the alkaline product can be developed, such as in areas where alkaline materials are routinely applied to agricultural soils to manage soil pH and maximize crop yields. Other proprietary alkaline stabilization systems using various alkaline reagents which include a pasteurization process are available to produce biosolids from sludge. Table 3-14 summarizes the key advantages and disadvantages with alkaline stabilization.

Table 3-14. Advantages and Disadvantages of Alkaline Stabilization

Advantages	Disadvantages
▪ Essentially a pathogen free product	▪ End-product not suitable for all soils
▪ Developed market in Ontario	▪ High lime dosage limits land application rates
▪ Stability of product in storage	▪ Require high number of acres; No volume reduction or even an increase in volume
▪ Simple process and equipment	▪ Lime dust
▪ Low capital cost	▪ Potential for odour release (ammonia gas)
▪ Easy to upgrade from Class B to A (note that at Ravensview the process in use already produces Class A material)	▪ High operating costs due to chemical usage

Preliminary Assessment

Based on a preliminary review of the alkaline stabilization process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. The alkaline stabilization process may add certain benefits to the project because the market is established in Ontario that would make the Class EA approval easier as well as its low capital cost and simple equipment and process operation. However, there is no direct reduction of organic matter or sludge solids with the high pH alkaline stabilization process. There is actually an increase in the mass of dry sludge solids. Without supplemental dewatering, additional volumes of biosolids will be produced. This process is therefore considered not aligned with the project objectives as it neither enhances biogas generation nor reduces biosolids production. Ammonia gas release at high pH poses health and safety concerns to the operational staff.

3.2.4.2 Oxidation

The oxidation process (also known as advanced oxidation process) involves oxidizing compounds, such as ozone, hydrogen peroxide, hydroxyl radicals, to promote oxidation where the organic materials would undergo a complete stoichiometric reaction (i.e., the organic material could convert into carbon dioxide and water). Oxidation would degrade more complex organic compounds that may not occur biologically. Table 3-15 summarizes the key advantages and disadvantages withoxidation.

Table 3-15. Advantages and Disadvantages of Oxidation

Advantages	Disadvantages
▪ Handle wide range of sludge;	▪ Incomplete oxidation may occur
▪ Simple process;	▪ No volume reduction
▪ Low capital cost	▪ End-product not suitable for all soils
	▪ High OpEx
	▪ End-product has little or no market value

Preliminary Assessment

Based on a preliminary review of the oxidation process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. While running at high operating cost, the oxidation process does not produce a usable end-product that carries marketable value. The economy renders it less favourable in addition to the operational challenges posed by chemical storage and handling issues.

3.2.5 Thermal Stabilization

Thermal stabilization uses heat (or energy) to stabilize the sludge. Two types of thermal stabilization were identified: 1) incineration (combustion), and 2) drying.

3.2.5.1 Incineration

Sludge incineration involves the combustion of organic material at relatively high temperatures. The combustion could be used to generate power/energy and potentially be a viable technology for offset credits. However, there are environmental emission concerns, which may lead to a difficult Class EA process. Also, ash (non-combustible material) must be treated and disposed of afterwards. Table 3-16 summarizes key advantages and disadvantages with incineration technologies.

Table 3-16. Advantages and Disadvantages of Incineration Technologies

Advantages	Disadvantages
▪ Minimized volume of solids residual	▪ High capital cost
▪ No further post-treatment needed	▪ Large capacity required to make system viable
▪ Reuse of energy from the process for internal system operations or external marketable product	▪ No recycling of nutrients
	▪ Emission concerns
	▪ Supplemental fuel may be required
	▪ Very complex and require special training/license to operate

Preliminary Assessment

Based on a preliminary review of the incineration process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. The technology is extremely expensive as an ultimate solid stabilization process and therefore it is only justifiable in much larger scale plants, i.e., approximately 100 dry tonne solids per day, where economies of scale plays a key role in evaluation. The complexity of incineration process poses technical and operational challenges such as a stationary engineer is required to operate the steam system under the *Technical Standards and Safety Act*, 2000. Long Class EA approval process is also going to limit the feasibility of implementing this alternative.

3.2.5.2 Drying

Thermal drying is the process of evaporating water from sludge or biosolids by the addition of heat. Complete drying typically results in a product with 5 to 10 percent moisture content with significant volume reduction. During drying, sludge or biosolids undergo several structural changes as the moisture content decreases.

There are various drying processes which are classified based on the predominant method of transferring heat to the solids: convection, conduction, radiation or a combination of these. Dewatering is usually a prerequisite intermediate step in the drying process to reduce energy costs for evaporation of moisture. Table 3-17 summarizes key advantages and disadvantages with drying technologies.

Table 3-17. Advantages and Disadvantages of Drying Technologies

Advantages	Disadvantages
▪ Produces an essentially pathogen free product	▪ Large surface area with high ceilings required to accommodate dryer and dust control systems
▪ Considerable reduction in volume of product	▪ High energy requirement for dryer
▪ Easier to handle and reduced transportation costs	▪ Due to high carbon content and dryness of product, safety precautions are required to prevent auto-combustion
▪ Increase the number of final disposal or utilization options	▪ Product may not be stable when dried material is re-wetted
	▪ Dust can be problematic and cause operational concerns, even resulting in explosive atmospheres

Preliminary Assessment

Based on a preliminary review of various drying processes and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. The biosolids drying process is considered not suitable for this project because it is only partially aligned with UK's main objectives. The drying process reduces overall biosolids volume by removing moisture content but will neither reduce biosolids production nor enhance biogas generation. High energy consumption also contradicts the project objectives.

3.3 Biogas Utilization

Utilization of biogas is highly dependent on the quantity and quality of the available biogas. Tetra Tech has reviewed historic gas collection and gas chemistry at both Ravensview and Cataraqui Bay WWTPs. This section of the report summarizes this information and then summarizes four short-listed options for utilization of the biogas.

Cataraqui Bay's total biogas flow (flare and boiler) varies from about 1,000 to 3,000 m^3 per day (or 25 to 75 cfm) and is highly variable with consistently more biogas collected in the spring of the year. Figure 3-2 summarizes historic biogas flow in 2013 to 2016 from Cataraqui Bay WWTP.

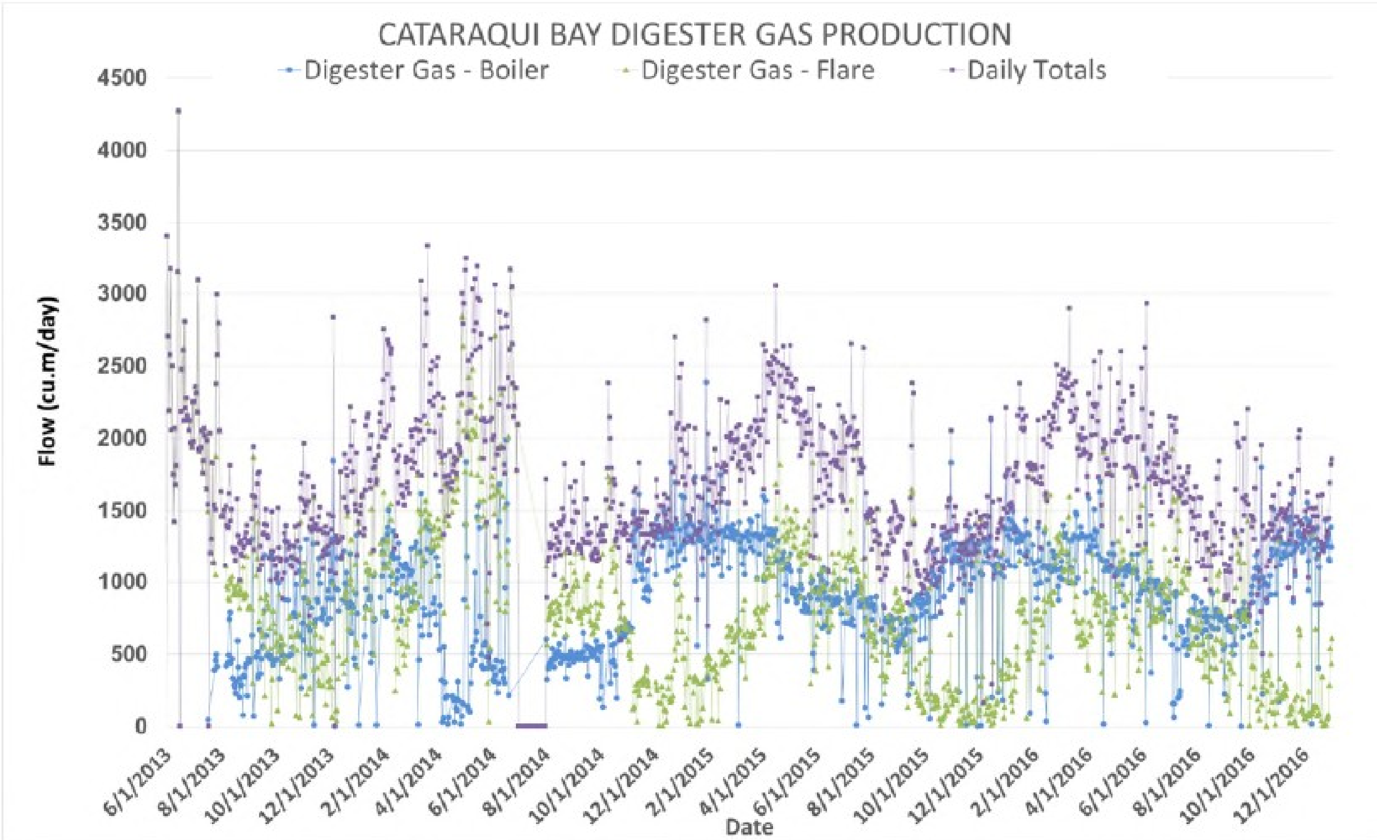

Figure 3-2. Cataraqui Bay Digester Gas Production (Boiler and Flare) in 2013-2016

The biogas chemistry data showed that Cataraqui Bay's biogas has excellent concentration of methane, with no oxygen or nitrogen levels. The data provided is three years old. Siloxane levels were found to be very low so Tetra Tech recommends re-testing to confirm the siloxane levels.

Ravensview total biogas flow (generator, flare, and boiler) varies from about 1,000 to 4,000 m^3 per day (or 25 to 100 cfm) is also highly variable with consistently more biogas collected in the spring of the year. Figure 3-3 summarizes historic biogas flow in 2013 to 2016 from Ravensview WWTP.

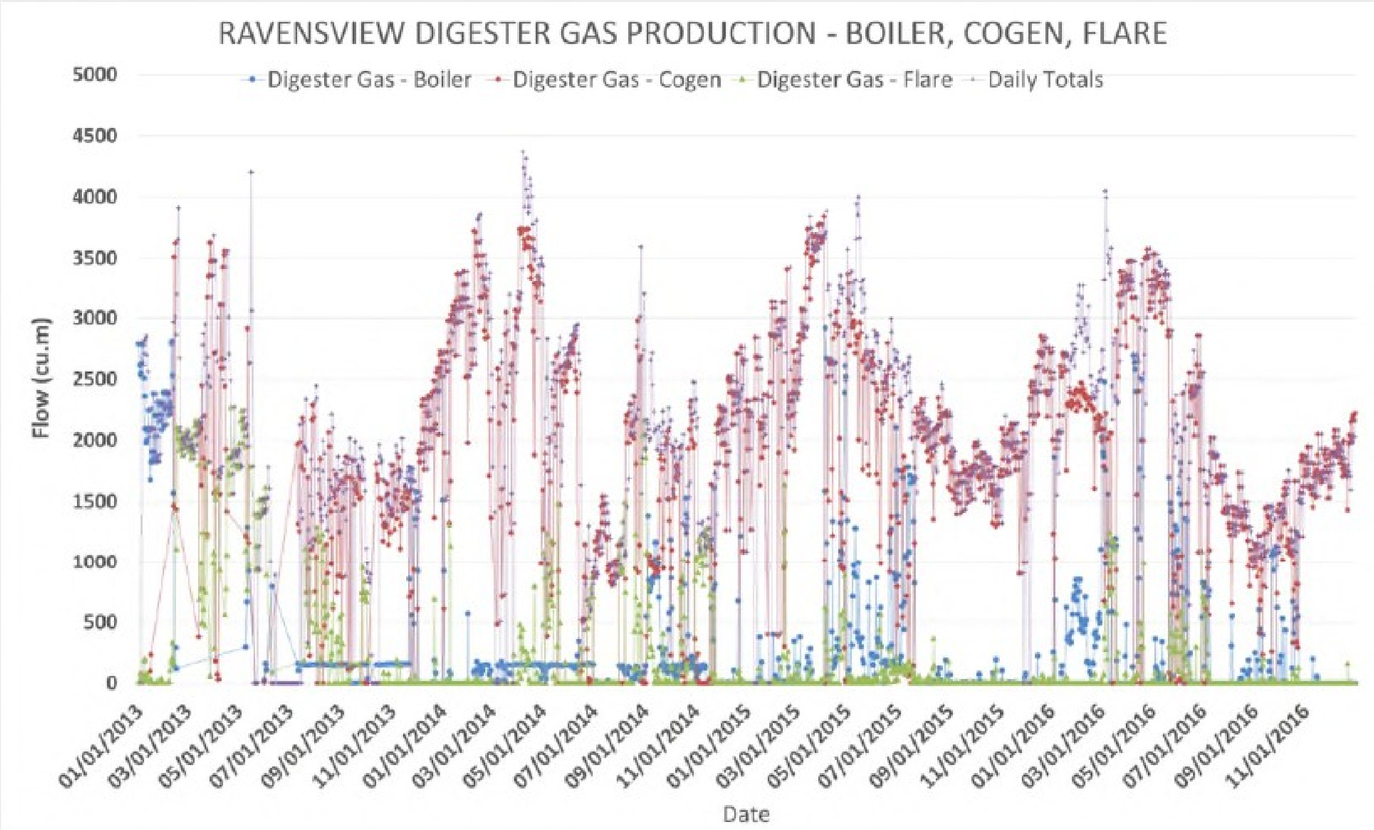

Figure 3-3. Ravensview Digester Gas Production (Boiler, Cogen, and Flare) in 2013-2016

The biogas chemistry data showed that Ravensview biogas has excellent concentration of methane, with no oxygen or nitrogen levels. The data provided is eight to ten years old. Siloxane levels were found to be very high and considering the age of these results Tetra Tech recommends re-testing all gas chemistry.

Additional sampling to retrieve more recent biogas chemistry and flow is recommended moving forward. Other issues to resolve with the biogas flow are:

- Where are the flow rates recorded?
- What could cause the seasonal variability?
- Is there calibration information available for flow meters?

Issues to resolve with the biogas chemistry are:

- Where were samples taken from each plant?
- Were samples taken from the same location, consistently?
- For Ravensview, were the samples raw or from post-treatment?

Biogas utilization options discussed in this subsection include the following:

- On-site CHP;

- Boilers;
- Vehicle Fuel Station;
- Pipeline Injection; and
- Fuel Cell Technology.

The following is a detailed discussion and evaluation related to the aforementioned options. The attached Drawing 3.3 provides a flow diagram representation differentiating the options evaluated, and it will be used as a visual aid for the Workshop 1 presentation to describe the process identified and evaluated under this Preliminary Assessment.

3.3.1 On-Site Combined Heat and Power

Cogeneration of electricity and heat is currently employed at Ravensview WWTP but not at Cataraqui Bay WWTP. This technique to convert biogas to energy is very common at WWTPs throughout Canada and the USA because it reduces the amount of electricity that must be purchased from the grid to operate the WWTP. This self-generation of electricity reduces costs because the cost of self-generated electricity is less compared to purchasing electricity from the grid. In addition, the heat from the generation equipment can be harnessed and employed to keep the WWTP digesters operating at peak temperature, especially in the winter months. Additional heat may also be recovered for use in building heating and meeting other on-site needs.

3.3.1.1 Microturbines

Microturbines have been employed as the prime mover for numerous biogas to energy projects. In addition to generating electricity a 300 kW microturbine can recover 1 million BTUs of heat per hour, or about 73,000 therms per year. A conceptual schematic for microturbines is shown in Figure 3-4. Manufacturers of microturbines include, but are not limited to: Ingersoll Rand and Capstone. Table 3-18 summarizes key advantages and disadvantages with microturbine technologies.

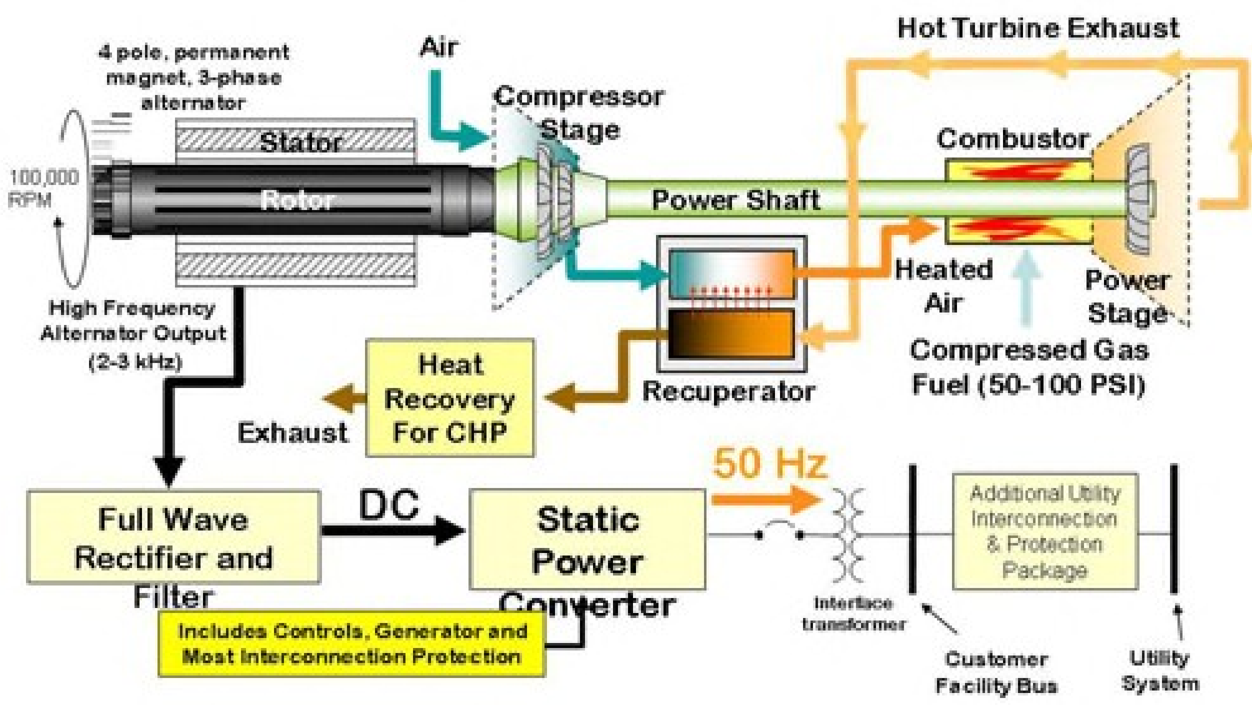

Figure 3-4. Conceptual Schematic for Microturbines

Table 3-18. Advantages and Disadvantages of Microturbines Technologies

Advantages	Disadvantages
▪ Depending on biogas volume can be very efficient	▪ Significant biogas conditioning and compression is necessary before injecting it into a microturbine
▪ Can utilize biogas with very low methane concentrations	▪ Typically higher capital cost per kilowatt generated than reciprocating engines
▪ One moving part so minimal maintenance	
▪ Low emissions	
▪ Stand Alone or Grid Connect	
▪ Can process very low biogas flow	

Preliminary Assessment

Based on a preliminary review of the microturbines and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in our Detailed Assessment. It has been our experience that using microturbines would require removal of all siloxanes in the raw biogas prior to injection into a microturbine.

3.3.1.2 Reciprocating Engines

Reciprocating engines have been employed as the prime mover for numerous biogas to energy projects. In addition to generating electricity, they can recover heat. A conceptual schematic for microturbines is shown in Figure 3-5. Manufacturers of reciprocating engines include, but are not limited to: Caterpillar and Jenbacher. Table 3-19 summarizes key advantages and disadvantages with reciprocating engines.

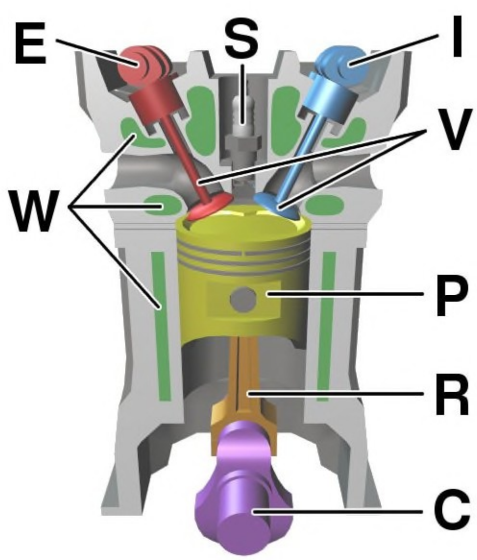

Figure 3-5. Conceptual Schematic of a Reciprocating Engine

Table 3-19. Advantages and Disadvantages of Reciprocating Engines

Advantages	Disadvantages
▪ Currently employed by UK so familiarity is high	▪ Air emissions
▪ Mechanics are familiar with them	▪ Higher Maintenance
▪ Very limited biogas cleanup is needed prior to injection into a reciprocating engine	▪ Methane of the biogas must be maintained above 45%
▪ Low capital cost	▪ Slightly lower efficiency than other energy recovery systems.
▪ Stand Alone or Grid Connect	

Preliminary Assessment

Based on a preliminary review of reciprocating engines and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in our Detailed Assessment. It has been our experience that using reciprocating engines would be the least capital cost.

3.3.2 Boilers

Whether on-site to keep the digesters warm in winter months or off-site at a manufacturing plant, boilers can be an opportunistic way to beneficially utilize biogas.

3.3.2.1 On-Site Boiler

Both Ravensview and Cataraqui Bay WWTPs currently utilize a boiler and biogas to maintain digester temperature. Both systems only use a small part of the biogas and both systems operate intermittently. As such, Tetra Tech does not believe this option, alone, maximizes the biogas and therefore should only be used in conjunction with other biogas to energy options.

Table 3-20 summarizes key advantages and disadvantages with on-site boiler technologies.

Table 3-20. Advantages and Disadvantages of On-Site Boiler Technologies

Advantages	Disadvantages
▪ Currently employed by UK so familiarity is high	▪ May not be able to employ all the biogas that is available
▪ Relatively simple to operate	▪ Lower thermal efficiency due to need to combust gas and recover heat
▪ Potential for producing more heat that can be used off site, such as in a heat district near the WWTPs	▪ May require air emission controls

Preliminary Assessment

Based on a preliminary review of on-site boiler and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation but only in conjunction with other beneficial use options.

3.3.2.2 Off-Site Boiler

Existing off-site boilers may be a good use for the biogas if:

a) They are in close proximity to the WWTP;

b) They can use all the biogas that is generated 24 hours per day 365 days per year;

c) They are financially stable and willing to commit to a long-term contract; and

d) The route for a pipeline is simple (very few road crossings, utility crossings and other route issues).

Preliminary Assessment

One potential boiler user was identified near Cataraqui Bay WWTP but upon preliminary screening the route for a pipeline to connect the WWTP to the off-site boiler was complex. Considering the small amount of biogas that is available our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment.

3.3.3 Vehicle Fuel Station

Cleaning and compression of biogas into renewable natural gas (RNG) has become commonplace in the USA and Canada. Several vendors of gas cleaning equipment are based in Canada such as Greenlane (BC), DMT (Quebec), and others. In addition, several USA equipment suppliers deliver their equipment to Canada such as BioCNG. Technologies for cleaning biogas into RNG are shown in Figure 3-6.

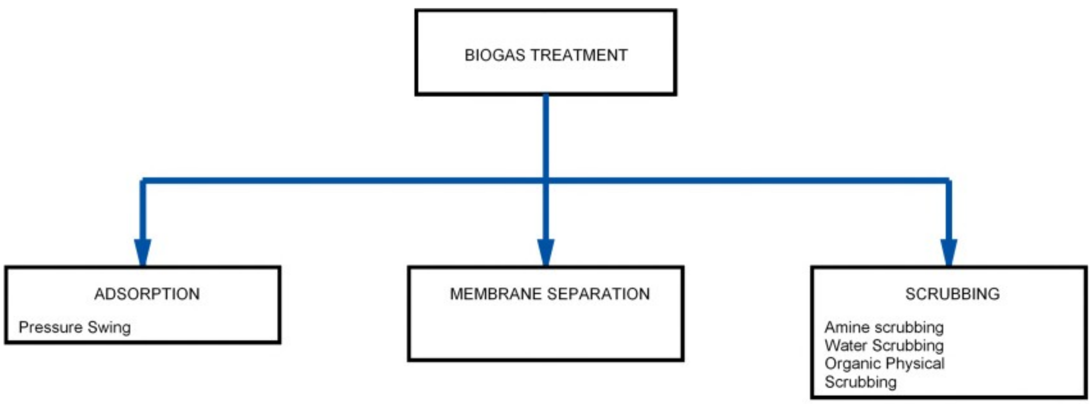

Figure 3-6. Biogas Treatment Flow Diagram

Once the RNG is created it is simply a matter of compressing it to 36,000 psig so that it may be dispensed into CNG vehicles. CNG Vehicles include police car fleets, school busses, trash trucks, snow plows, UPS delivery trucks and many others. There may be an opportunity to develop a long-term program to convert specific fleets to RNG over time, thus spreading the expenditure out to make financial management less of an impact.

3.3.3.1 On-Site Vehicle Fueling

For this option we consider fueling vehicles at the WWTPs. In this way a simplified delivery system can be employed that does not require connection to the natural gas grid nor transporting the RNG via tube trailers. Based on the amount of biogas historically collected it appears that each WWTP may produce 400 to 500 gasoline gallon equivalent per day. Table 3-21 summarizes key advantages and disadvantages with on-site vehicle fueling.

b) They can use all the biogas that is generated 24 hours per day 365 days per year;

c) They are financially stable and willing to commit to a long-term contract; and

d) The route for a pipeline is simple (very few road crossings, utility crossings and other route issues).

Preliminary Assessment

One potential boiler user was identified near Cataraqui Bay WWTP but upon preliminary screening the route for a pipeline to connect the WWTP to the off-site boiler was complex. Considering the small amount of biogas that is available our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment.

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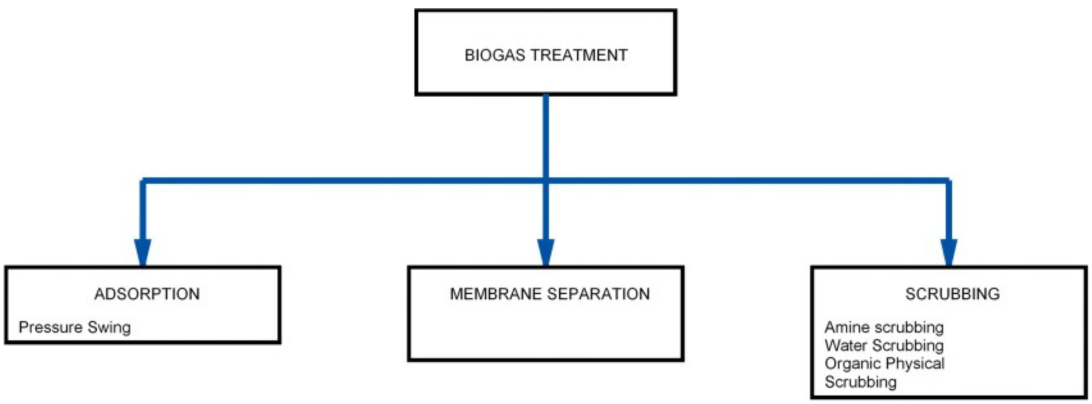

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Table 3-21. Advantages and Disadvantages of On-Site Vehicle Fueling

Advantages	Disadvantages
▪ Numerous technologies exist to clean the biogas to make RNG.	▪ A large enough CNG fleet must exist or will need to be established.
▪ Employing a local municipal CNG fleet can be simpler than multi contracts with private fleet owners	▪ CNG fleet must frequent the WWTP to refuel
	▪ Relies on space availability.

Preliminary Assessment

Based on a preliminary review of on-site vehicle fueling and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. We feel that there is not enough local CNG vehicles that would use UK's biogas so using on-site vehicle fueling would not be practical.

3.3.3.2 Off-Site Vehicle Fueling

For this option we consider producing the RNG at each WWTP then trucking or piping the RNG to an off-site vehicle fueling station located adjacent to Highway 401 where more CNG vehicles and fleets, including vehicles operated by the City of Kitchener and/or UK, may frequent the fueling station. Another contemplated option is to potentially ship CNG to the United States to take advantage of existing green fuel credits, Table 3-22 summarizes key advantages and disadvantages with off-site vehicle fueling.

In addition, there is the concept of capturing and storing gas for future use. As we move forward into detailed assessment, capturing and storing gas to even-out the gas flow into the energy production equipment will be evaluated. Tetra Tech notes that, typically a reasonably sized tank can even-out the flow over a few days to a week, but in the case of UK seasonal fluctuations in gas production exist that would likely require many big tanks. The cost-benefit may prove uneconomical but we believe it is worth pursuing further for additional analysis with the project.

Table 3-22. Advantages and Disadvantages of Off-Site Vehicle Fueling

Advantages	Disadvantages
▪ Numerous technologies exist to clean the biogas to make RNG.	▪ More costs for mother/daughter station and decanting.
▪ All the RNG we can make can be sold.	▪ Need to sign contracts with numerous CNG fleets that frequent Hwy 401 to confirm income revenue stream.
▪ Income from Ontario carbon credits and fuel sales	
▪ RNG can be sent to Hwy 401 via dedicated pipeline or tube trailers	

Preliminary Assessment

Based on a preliminary review of off-site vehicle fueling and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in our Detailed Assessment. It has been our experience that using an off-site vehicle fueling station would be feasible if there is enough interest from fleets to commit to a long-term purchase of the RNG.

3.3.4 Local or Regional Natural Gas Pipeline Injection

For this option we consider injecting RNG for each WWTP into a nearby natural gas pipeline and transporting the RNG via interstate pipeline to California where a contracted off-taker will purchase the fuel for their vehicles. Having an off-taker in California brings two additional revenue streams (i.e., low carbon fuel standard [LCFS] and renewable identification number [RIN]) to this option. Table 3-23 summarizes key advantages and disadvantages with local or regional natural gas pipeline injection.

Table 3-23. Advantages and Disadvantages of Local or Regional Natural Gas Pipeline Injection

Advantages	Disadvantages
▪ Highest potential revenue from CA LCFS, RINS, Ontario carbon credits, & fuel sales	▪ Impending rules for RNG in Ontario make for an unclear regulatory landscape and may mean that RINs and LCFS markets are temporary opportunities.
▪ All RNG created can be sold (many off-takers in the market)	▪ Currently, there is an insufficient amount of biogas to justify the $2 to $4 million NG utility interconnect costs and biogas cleanup costs.
▪ Canadian projects in Quebec have successfully undertaken projects that sell RNG to the US and capture the value of RINs and LCFS.	

Preliminary Assessment

Based on a preliminary review of local regional pipeline injection and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in the Detailed Assessment. Currently, there is an insufficient amount of biogas generated at either WWTP to justify the high capital cost for interconnecting to the natural gas pipeline.

3.3.5 Fuel Cell Technology

While Fuel Cell Technology was considered as an option the capital and operating costs associated with this type of technology are significantly higher than microturbines and reciprocating engines. Fuel cells are typically only applied in areas with large grants for alternative energy production. There are very few installations in North America. Therefore, it is Tetra Tech's suggestion to not pursue this technology as a viable option for Detailed Assessment.

3.4 Dewatering

Dewatering is a process of reducing the moisture content from wastewater sludge. Dewatering is typically a physical process whereby excess free water is removed from the biosolids/sludge. There are many benefits to dewatering biosolids/sludge including reducing the volume of material needed for hauling/trucking; reducing handling needs as the sludge becomes more of a slurry, semi-solid, or solid; where the material can be moved by buckets and conveyors; and allowing certain downstream process to be more effective and efficient such as incineration and composting.

There are centrifuges currently installed at both facilities. To provide background information on the dewatering discussion, provided below are examples of some typical process options:

- Centrifuge;
- Belt-Filter Press;
- Drying Beds;
- Rotary Vacuum Filters; and
- Enhanced Solar.

The following is a detailed discussion and evaluation to the aforementioned options. The attached Drawing 3.4 provides a flow diagram representation differentiating the options evaluated, and it was used as a visual aid for the Workshop 1 presentation to describe the process identified and evaluated under this Preliminary Assessment.

3.4.1 Centrifuge

Centrifuge uses centrifugal forces (outward forces from rotation) to “separate” the solids and liquids fractions to thicken sludge and remove the excess water by gravity. It is widely used in the industry, in particular, the “high solids” centrifuge which can produce a relatively dry sludge. Table 3-24 summarizes key advantages and disadvantages with centrifuge technologies.

Table 3-24. Advantages and Disadvantages of Centrifuge Technologies

Advantages	Disadvantages
▪ Small footprint, low staffing requirements	▪ High power consumption
▪ Contained odour source	▪ High CapEx and OpEx, expensive spare parts
▪ Major maintenance items easily removed/replaced	▪ Relatively complex equipment that operates at high rotational velocity
▪ Relatively higher solid capture rate	▪ Centrifuge dewatering may increase odour production and pathogen regrowth in dewatered biosolids

Preliminary Assessment

Based on a preliminary review of the centrifuge technology and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in the Detailed Assessment. Dewatering with a centrifuge has many advantages (e.g., small footprint, low staff and maintenance requirements, and able to produce a fairly dry product) that outweigh its disadvantages (e.g., high power consumption and cost).

3.4.2 Belt-Filter Press

Pressing, such as with the use of a belt-filter press, applies pressure to dewater sludge. The free water from the sludge is typically removed by gravity. However, some use a filter to further separate the solids and water, while others may use a vacuum to reduce odours. Table 3-25 summarizes key advantages and disadvantages with belt-filter press technologies. Systems using hydrolysis process typically use BFPs for dewatering, as they tend to be lower consumers of energy and produce dewatered cake with less odour than centrifuges.

Table 3-25. Advantages and Disadvantages of Belt-Filter Press Technologies

Advantages	Disadvantages
▪ Enclosed system provides good odour containment	▪ Low throughput and larger footprint
▪ Easy start up and shut down	▪ Cake solids to be lower than centrifuge
▪ Lower CapEx	▪ Polymer dosage expected to be slightly higher than centrifuge
▪ Low energy consumption	▪ Source of odour
▪ BFP dewatering has less impact on dewatered biosolids in terms of odour release and potential regrowth	▪ Relatively higher labour demand
	▪ Lower solid cake percent

Preliminary Assessment

Based on a preliminary review of the pressing dewatering technology and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in the Detailed Assessment. Pressing for dewatering purposes may be suitable because it has a relatively low cost and easy to implement operational (e.g., easy start up and shut down).

3.4.3 Drying Beds

Drying beds are commonly used in the United States for dewatering biosolids, typically for small to medium size communities. Sludge is placed on a bed of material designed to maximize evaporation and drainage. The drainage water is collected via piping system within the bed and is treated or disposed of, while the rate of evaporation depends on the environmental conditions. There are five types of drying beds commonly used: 1) conventional sand; 2) paved; 3) artificial media; 4) vacuum-assisted; and 5) solar. Table 3-26 summarizes key advantages and disadvantages with drying beds.

Table 3-26. Advantages and Disadvantages of Drying Beds

Advantages	Disadvantages
▪ Simple system - require minimum electrical energy input	▪ Drainage water must be captured
	▪ Requires mechanical devices to turn over the sludge in the initial stages of the drying process
	▪ Land intensive and construction costs
	▪ Labour intensive when applying and turning solids

Preliminary Assessment

Based on a preliminary review of the drying beds process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in the Detailed Assessment. Drying beds are not considered suitable for this assignment because a large footprint would be needed.

3.4.4 Rotary Vacuum Filters

A rotary vacuum filter consists of a large rotating drum covered by a cloth. The drum is suspended on an axle over a trough containing liquid/solids slurry with approximately 50-80% of the screen area immersed in the slurry. As the drum rotates into and out of the trough, the slurry is sucked on the surface of the cloth and rotated out of the liquid/solids suspension as a cake. When the cake is rotating out, it is dewatered in the drying zone. The cake is dry because the vacuum drum is continuously sucking the cake and taking the water out of it. At the final step of the separation, the cake is discharged as solid products and the drum rotates continuously through another separation cycle. Table 3-27 summarizes key advantages and disadvantages rotary vacuumfilters.

Table 3-27. Advantages and Disadvantages of Rotary Vacuum Filters

Advantages	Disadvantages
▪ Continuous and automatic operation, so operating cost is low	▪ Resistance to the passage of filtrate will increase as the sludge cake increase in thickness
▪ Produce relatively clean product	▪ High energy consumption by vacuum pump
	▪ Discharge cake contains residual moisture

Preliminary Assessment

Based on a preliminary review of rotary vacuum filters and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in the Detailed Assessment. Rotary vacuum filters are not the most effective option in biosolids dewatering. Residual moisture is relatively higher than centrifuges while the pressure difference is limited up to 1 bar due to the structure of the drum filter.

3.4.5 Enhanced Solar

Enhanced solar is similar to a drying bed but has a higher drying rate. This is because enhanced solar is typically housed in a “greenhouse” to increase the solar radiation. The greenhouse is typically a glass triangular structure. Table 3-28 summarizes key advantages and disadvantages enhance solar technologies.

Table 3-28. Advantages and Disadvantages of Enhanced Solar Technologies

Advantages	Disadvantages
▪ Low electrical consumption	▪ Odour concerns
▪ Enhance rate of drying	▪ Requires large footprint
▪ Reduced pathogens with an add-on UV system	▪ Needs regularly turning to create new drying surface
	▪ Requires chamber fans, circulation system and sludge turner to be controlled via PLC
	▪ Not used widely in North America

Preliminary Assessment

Based on a preliminary review of the enhanced solar technology and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in the Detailed Assessment. Enhanced solar dewatering requires a large footprint that may not be available to UK.

3.5 Side Stream Treatment

A significant nutrient load can be generated internally by wastewater treatment facilities. These nutrients can be found in the reject effluent, also known as side streams, which include the reject stream from membranes, supernatant liquid from sludge digesters, and the centrate/filtrate return stream from sludge dewatering processes, among others.

Activated sludge generated from wastewater treatment facility contains concentrated organic carbon, nitrogen and phosphorous. Organic carbon can be utilized in the anaerobic digestion process to generate biogas for energy recovery. However, nitrogen and phosphorous remain in the digesters either in the liquid phase or in biosolids. Organic nitrogen and phosphorous in the anaerobic digester effluents are conventionally returned to the headworks of the treatment facilities. As a result of the additional nutrient loading, associated energy cost and potential process upsets sometimes become a concern.

Side Stream Recovery processes discussed in this subsection include the following:

- Struvite Recovery; and
- Anammox.

The following is a detailed discussion and evaluation to the aforementioned options. The attached Drawing 3.5 provides a flow diagram representation differentiating the options evaluated, and it was used as a visual aid for the Workshop 1 presentation to describe the process identified and evaluated under this Preliminary Assessment.

3.5.1 Struvite Recovery

In WWTPs, magnesium ammonium phosphate (struvite) precipitation occurs spontaneously under conditions which are influenced by factors such as: concentration of magnesium (Mg^{2+}), pH, temperature, and competitive ions. These parameters are often difficult to control and, spontaneous precipitation of struvite creates operational problems in digestion systems.

Struvite recovery is the practice of recovering nutrients such as nitrogen and phosphorus from used water streams and converting them into a potentially marketable product as a fertilizer. Proprietary struvite recovery process allows phosphorus and nitrogen to be recovered while simultaneously avoiding operational and maintenance costs associated with uncontrolled struvite precipitation. Table 3-29 summarizes key advantages and disadvantages with Struvite Recovery processes.

Table 3-29. Advantages and Disadvantages of Struvite Recovery Processes

Advantages	Disadvantages
▪ Recover N and P simultaneously	▪ High capital and operating cost, which may not be offset by-product sales (limited by total phosphorus loading to the plant)
▪ Market ready fertilizer - High purity end-product	▪ Require careful operating control
▪ Reduced N and P loading back to the liquid train - reduced energy cost	▪ Proprietary system - requires special training to operate
	▪ Require addition of Magnesium
	▪ Lack of full-scale installation in Ontario

Preliminary Assessment

Based on a preliminary review of the struvite recovery process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in our Detailed Assessment. The technology is relatively expensive as a treatment enhancer and therefore it is typically justified in much larger scale plants, where economy of scale is a way to improve its competitiveness. Additionally, the complexity of proprietary struvite recovery process poses technical and operational challenges such as additional training and support staffing needs.

3.5.2 Anammox

ANAMMOX is another relatively new side stream biological treatment process that removes ammonium from effluents in a relatively cost-effective and sustainable way. Compared to conventional nitrification/denitrification process, Anammox bacteria converts ammonium (NH_4^+) and nitrite (NO_2^-) into nitrogen gas directly which results in a significant energy savings on operational costs while CO_2 emissions are reduced. Table 3-30 summarizes key advantages and disadvantages with Anammox processes.

Table 3-30. Advantages and Disadvantages of Anammox Processes

Advantages	Disadvantages
▪ Reduced Nitrogen loading - reduced oxygen demand	▪ Long start up time
▪ Less sludge production	▪ Sensitive to temperature, DO and nitrite, etc.
▪ Allows reliable operation of compact systems	▪ Proprietary system - requires special training to operate
	▪ Parameters need to be monitored frequently
	▪ Not used widely in North America
	▪ Does not generate product such as fertilizer

Preliminary Assessment

Based on a preliminary review of the Anammox process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in the Detailed Assessment. Being a relatively new technology, full-scale installation of Anammox in municipal applications, particularly in systems the size of those owned by UK, has not been widely accepted, which poses technical and operational challenges to UK such as additional training and support staffing needs. In the cases of implementing a proprietary Anammox process, a royalty fee may also apply.

3.6 Biosolids Management

Biosolids can be disposed of or processed/treated into beneficial end-use resources, such as for nutrient-recovery, for energy-recovery, and for other usable products.

Biosolids management options discussed in this subsection include the following:

- Land Application;
- Landfill; and
- Construction Material.

The following is a detailed discussion and evaluation to the aforementioned options. The attached Drawing 3.6 provides a flow diagram representation which differentiates the options evaluated, and it was used as a visual aid for the Workshop 1 presentation to describe the process identified and evaluated under this Preliminary Assessment.

3.6.1 Land Application

Land application involves spreading biosolids over land to condition the soil (e.g., increase nutrients) to promote plant/crop growth. The amount of biosolids land applied is determined based on the biosolids classification, the existing soil conditions (e.g., trace metal concentration level), and the nutrient requirements of the specific crops and fields. Typically, the biosolids are transported (via truck) to the area where they will be spread.

3.6.1.1 Liquid

The sludge/biosolids being land applied is typically less than 5% solids. This option is relatively simple as less processing equipment is needed, but can be expensive due to the hauling (trucking) of sludge to the land applied area. Table 3-31 summarizes key advantages and disadvantages with liquid land application.

Table 3-31. Advantages and Disadvantages of Liquid Land Application

Advantages	Disadvantages
• Simplest method requiring least amount of equipment	• High OpEx, due to hauling costs
• Good if end-users are concerned with dust	• Higher potential for spills
	• Higher odour generation potential
	• Weather dependent
	• Large storage volume required

Preliminary Assessment

Based on a preliminary review of the liquid land application process and an evaluation of advantages and disadvantages, our recommendation is to **not proceed** with further investigation as a potential option for UK in the Detailed Assessment. Liquid land application does not have a favourable business case due to its high operating cost from hauling between sites.

3.6.1.2 Cake/Slurry

Cake/slurry land application is similar to liquid land application where biosolids are spread onto lands to condition the soil. However, in cake/slurry land application, the biosolids are dewatered (or thickened) to a higher solids content (about 25% solids content or more) prior to land application. Table 3-32 summarizes key advantages and disadvantages with cake/slurry land application.

Table 3-32. Advantages and Disadvantages of Cake/Slurry Land Application

Advantages	Disadvantages
• Simple approach requiring minimal equipment	• Potential loss of control of final product
• Lower hauling volumes	• Weather dependent
• Application may be done by farmer or other end-user	• Potentially more reporting and management control required
• Provides outlet for nutrient recovery	

Preliminary Assessment

Based on a preliminary review of the cake/slurry land application process and an evaluation of advantages and disadvantages, our recommendation is to **proceed** with further investigation as a potential option for UK in the Detailed Assessment. Similar practice has been well accepted by many municipalities in Ontario. Typically, centralized biosolids management facilities are required to accommodate the off-season storage requirement.

3.6.2 Landfill

Landfill involves covering the wastewater sludge with soil and dirt. A sanitary landfill is designed to minimize adverse environmental impacts such as groundwater contamination and leachate run-offs. A third party would own and operate the landfill site and therefore the cost for UK would be relatively low. The cost associated would only be the transportation and tipping fee. Table 3-33 summarizes key advantages and disadvantages with local or regional natural gas pipeline injection.

4.0 TECHNOLOGY SELECTION AND CENTRALIZED PROCESSING

Centralized processing would involve combining the solids processing from both WWTPs at one location, either at one of the existing plants or at a new facility. Centralized processing could also be implemented to accommodate co-digestion, if alternate feedstocks are identified. Under this section, Tetra Tech considers "Centralized Processing" to allow for one of two scenarios as follows:

- **Scenario 1:** Expanding either the Ravensview or Cataraqui Bay sites to accommodate a processing technology upgrade and/or new facilities to provide capacity for both plants. Under this scenario, the option of accepting raw sludge (e.g., primary or waste activated sludge) from the other facility, or alternative feedstocks (e.g., food waste, yard waste, commercial or industrial waste) so that the product can be further treated and/or combined with another product (e.g., SSO) is considered. Using this approach, it would be possible to generate more biogas at one location, thus reducing the need for transporting the gas to another distribution point. Also, if a more effective biosolids processing system is implemented, it may be possible to minimize biosolids production.

- **Scenario 2:** Consideration of a third and independent facility to be established at a newly designed and constructed centralized location that could potentially accept raw feedstocks (e.g., wastewater sludge, food waste, and yard waste), from both the Ravensview or Cataraqui Bay WWTPs (as well as other potential generators) such that the materials can be digested to effectively generate more biogas and potentially improve volatile solids reduction.

Subject to input from Utilities Kingston and any project stakeholders through review of this Preliminary Assessment report, and input from Workshop 1, the Tetra Tech team has narrowed the field of technologies to be further investigated in the Detailed Assessment as summarized in Table 4-1.

Table 4-1. List of Short-Listed Technologies

Categories	
Sludge Pre-Treatment	Thickening Biological Hydrolysis
Solids Stabilization	Anaerobic Digestion Co-digestion at Ravensview (including SSO) Co-digestion at Cataraqui Bay (including SSO)
Biogas Utilization	Microturbines Reciprocating Engines On-Site Boiler Off-Site Vehicle Fueling
Dewatering	Centrifuge Belt-Filter Press
Biosolids Management	Cake/Slurry Land Application

The following subsections consider each of the above-noted processes and the technologies considered and offer opinion and recommendation under each scenario.

4.1 Sludge Pre-treatment

Two technologies were identified as having high potential for implementation and should be further assessed in the Detailed Assessment of the project as follows:

- Thickening; and
- Hydrolysis.

4.1.1 Thickening

The assessment of thickening technologies at either facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option moving forward. There would, however, be no consideration under Scenario 1 noted above, for moving a raw product to one facility or the other to accommodate this technology upgrade.

Should there be consideration for an independent and new facility the option of providing a centralized thickening process would be considered.

4.1.2 Hydrolysis

The assessment of hydrolysis technology at either facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option moving forward. There would, however, be no consideration under Scenario 1 noted above, for moving a raw product to one facility or the other to accommodate this technology upgrade.

Should there be consideration for an independent and new facility the option of providing an independent hydrolysis process would be considered.

4.2 Solids Stabilization

Certain solids stabilization technologies were identified as being relevant for further assessment in the Detailed Assessment phase of the project. These are discussed in further detail below.

4.2.1 Anaerobic Digestion

The assessment of anaerobic technologies at either facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option moving forward. There could, given a more detailed review of available space, be consideration under Scenario 1 noted above for moving a raw product to one facility or the other to accommodate this technology upgrade. The inclusion of additional organics under Scenario 1, makes this technology more attractive.

Should there be consideration under Scenario 2 for an independent and new facility the option of providing an independent anaerobic process would be considered. In this scenario, there could also be an additional consideration of inclusion of SSO and/or other organic products, should UK consider this as a separate initiative moving forward.

4.2.2 Co-Digestion (General)

UK has directed Tetra Tech to review the potential impact of adding 4000 tonnes per year of SSO that is currently generated by the City of Kingston. The City currently directs this waste to a private contractor that aerobically composts the material and uses the finished compost. As part of the Detailed Assessment, Tetra Tech will review the impact of adding the 4000 tonnes of material on each of the respective enhancement technologies that have been proposed to assess the operational impact, as well as the OPEX, CAPEX and revenue implications (including carbon credits). At this time, it is believed that methane generation could increase by 30 to 60% due solely to the addition of SSO.

In all instances, it is believed that the SSO stream will be pre-processed to remove non-organic elements and that the cleaned SSO stream will be blended with bio-solids prior to entering the digestors. Tetra Tech would also like to iterate that carbon credits derived from SSO may have a different value than those derived from the bio-solids.

4.2.3 Co-Digestion at Ravensview

The assessment of co-digestion at the Ravensview facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option.

Should there be consideration for an independent and new facility under Scenario 1 and/or Scenario 2, the option of providing an independent co-digestion process would be considered moving forward.

4.2.4 Co-Digestion at Cataraqui Bay

The assessment of co-digestion at the Cataraqui Bay facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option.

Should there be consideration for an independent and new facility under Scenario 1 and/or Scenario 2, the option of providing an independent co-digestion process would be considered moving forward

4.3 Biogas Utilization

Four technologies were identified to be further assessed in the Detailed Assessment of the project as follows:

- Microturbines;
- Reciprocating Engines;
- On-Site Boiler; and
- Off-Site Vehicle Fueling.

4.3.1 Microturbines

The assessment of microturbines to provide combined heat and power at either facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option moving forward.

Should there be consideration for an independent and new facility, it may still be possible to utilize microturbines to provide combined heat and power at the existing WWTPs and also microturbines would be considered under Scenario 2.

4.3.2 Reciprocating Engines

The assessment of reciprocating engines to provide for combined heat and power at either facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option moving forward.

Should there be consideration for an independent and new facility, it may still be possible to utilize reciprocating engine(s) to provide combined heat and power at the existing WWTP's and also reciprocating engine(s) would be considered under Scenario 2.

4.3.3 On-Site Boiler

The assessment of on-site boiler technology to provide for heat exchange technology at either facility is a process upgrade that will be undertaken for both sites independently regardless of whether centralized processing is considered as a viable option moving forward.

Should there be consideration for an independent and new facility, it may still be possible to utilize a boiler for partial load to provide digester heat at the existing WWTP's and also a boiler would be considered under Scenario 2.

4.3.4 Off-Site Vehicle Fueling

The assessment of on-site vehicle fueling would not consider utilizing either the Cataraqui Bay or Ravensview WWTPs for the reasoning provided under Section 3.0.

Should there be consideration for an independent and new facility located near Highway 401, the option of providing on-site vehicle fueling may be considered attractive. Under Scenario 2 there would be opportunity to plan for and make additional space available for this technology at the independent/new facility. In addition, depending on the quantity of biogas production at this independent/new facility and the distance to an existing natural gas pipeline, it might also be possible to inject the RNG into the natural gas pipeline for transport to an off-site vehicle fueling station in Canada or in the USA (California being the most economically beneficial).

4.4 Dewatering

Two dewatering technologies were identified as being further assessed as we move forward onto the Detailed Assessment of the project as follows:

- Centrifuge; and
- Belt-Filter Press.

4.4.1 Centrifuge

The assessment of centrifuge technologies at either facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option moving forward.

Should there be consideration for an independent and new facility the option of providing an independent centrifuge process could be considered

4.4.2 Belt-Filter Press

The assessment of belt-filter press technologies at either facility is a process upgrade that can, in theory, be undertaken independently regardless of whether centralized processing is considered as a viable option moving forward.

Should there be consideration for an independent and new facility the option of providing an independent belt-filter press process could be considered.

4.5 Biosolids Management

One biosolids management process was identified to be further assessed in the Detailed Assessment of the project as follows:

- Cake/Slurry Land Application

4.5.1 Cake/Slurry Land Application

A more thorough investigation of available area at both sites will need to be undertaken to more effectively assess the option of utilizing cake/slurry technologies. However, at this stage of the project, it is unlikely that under Scenario 1 noted above there would be any consideration given to moving product from Cataraqui Bay to Ravensview to accommodate this technology upgrade. We note that there is currently considerable area available at the Ravensview facility for the storage of biosolids. As part of the Detailed Assessment, modifications to the area to allow for the inclusion of this technology would be considered.

Should there be consideration for an independent and new facility, the option of providing cake/slurry land application would be considered a highly viable option. In this scenario, there would be an excellent opportunity to plan for and make additional space available for this technology upgrade.

5.0 POTENTIAL BUSINESS CASE SCENARIOS

Evaluation of business case scenarios will include a proforma review of preferred options derived from the technical evaluations denoted in Section 3.0. This will be done in two phases: (1) a high level review with approximate capital expenses (CapEx) and operational expenses (OpEx) with anticipated revenues, and (2) a more detailed review of up to three preferred options. The proforma review will be aligned to UK and/or City of Kingston proforma methodologies and span a budget cycle of 15 to 20 years. At this time, it is assumed that net present value will be the comparative number to evaluate the options. Specifically, the evaluation will include:

- **Capital Costs** – Civil, mechanical and building work (new or modifications of existing facilities), equipment purchases, upgrades to existing equipment and any other one-time costs such as design, engineering and permit costs associated with the implementation of options. Input from both the consultant and client teams will be used.
- **Operational Costs** – Changes (positive and negative) to costs associated with operations including staffing, ongoing maintenance, annual maintenance, consumables etc. Input from key personnel will be used in the evaluation.
- **Revenues** – Potential new revenues will be evaluated, such as biogas sales.

5.1 Biogas Generation

As noted in Section 3.3, biogas can be utilized in different ways. All uses will generate value from either the sale of energy or savings from displaced fuel consumption. In addition, many uses will generate value from environmental attributes that recognize greenhouse gas (GHG) reductions and other benefits to renewable energy. All forms of beneficial use of the biogas will generate GHG reductions from two separate streams:

i. The methane that would otherwise have vented to the atmosphere had the SSO been disposed of in landfill or during treatment of wastewater. The captured methane is converted to CO_2 when combusted, resulting in 20-times fewer GHG emissions because of the lower global warming potential of CO_2; and

ii. The methane from biogas will displace a fossil fuel when used for process heat, CHP or to generate a renewable fuel for transportation. Methane from biogas has an emissions factor of zero and the GHG reductions are from the volume of displaced fuels multiplied by their respective emissions factors.

There are two types of environmental attributes that recognize these sources of GHG reductions, as well as other benefits from renewable energy:

i. **Carbon Offsets** – The current Ontario Government is developing a protocol to recognize GHG reductions from anaerobic digestion of organic waste that will recognize the methane displaced from landfill or vented to the atmosphere in other processes. It will not recognize reductions from displaced fossil fuels. It is too early to tell whether activities from municipal WWTPs will be eligible under this protocol. However, if they are determined to be eligible activities, the existing digesters at Ravensview and Cataraqui Bay would have to have been commissioned after January 1, 2007 to be eligible. There is currently uncertainty if the election in June 2018 will change the direction of the Cap and Trade legislation. The two opposition parties have indicated that they are not in favour of continuing Cap and Trade.

   Offsets can be generated using voluntary protocols and sold to entities for the purpose of meeting voluntary targets. However, this is unlikely to be a viable option given the length of time both facilities have been recovering biogas for beneficial use.

ii. **Renewable Fuel Credits** – The Ontario and Federal Government has published a policy proposal for a renewable fuel standard that could involve a market instrument whereby biogas generators who displace fossil fuels for transportation can generate credits that fuel suppliers and refiners can use to comply with the standard. The regulatory framework and market mechanism, if adopted, is probably three to four years away. In the meantime, the existing US Renewable Fuel Standard (RFS) provides this opportunity for Canadian biogas generators who inject into a pipeline and contract the sale of the gas to a transportation end-user in the US. At least one Quebec landfill is doing so successfully and the very considerable value (~$30/GJ) is attracting many more to the market.

An additional attribute can be generated from the same activity when the gas is contracted for sale to a transportation end-user in California. The California LCFS enables a credit worth approximately $10/GJ or $90/tCO$_2$e to be generated in addition to the RFS credits.

Conclusion on Eligibility:

- Biogas recovery from the existing digesters will not qualify for compliance offsets and are unlikely to generate value through voluntary offsets. This would be the case if both AD plants were commissioned before 2007.
- Enhanced biogas recovery from expansion of facilities or co-digestion with SSO previously disposed of in landfill could potentially be eligible for compliance offsets. The new activity would have to capture methane vented to the atmosphere and the impending protocol would have to enable such activities.
- Methane recovered from both plants, as well as under a co-digestion scenario, could be eligible to generate renewable fuel credits under the US RFS and the California LCFS. The RNG option is the only one that opens this avenue as interconnection with a US-based end-user is required.
- The use of the biogas for a dedicated CNG application, on or off-site, would not generate US RFS or California LCFS credits. However, it would potentially generate credits or receive greater value than today should an Ontario renewable fuel standard be adopted.
- The ability to generate RFS and LCFS credits can be seen as a 'guarantee' that the RNG options holds significant value in environmental attributes while we await further policy development in Ontario. If chosen, UK could 'wheel' the RNG to an end-user in the US, capture the significant value for the period needed to recovery capital costs (likely under five years) and revert to selling the RNG in Ontario should a provincial standard come into effect.

Value of Environmental Attributes:

- Should any activities related to expansion or increased efficiency of methane recovery be eligible under the compliance offset protocol, the value associated with offsets is likely to be worthwhile though marginal in the economics of the project. This is likely the case at the current price of ~$15/tCO2e but could become a greater factor should the price align with federal minimum carbon pricing standards of $50/tCO2e in 2022.
- The value of US RFS and LCFS renewable fuel credits amounts to an estimated $400,000/yr for Cataraqui Bay and $520,000 for Ravensview at current prices. These amounts, considered individually or in aggregate, will not be sufficient to recover capital costs of biomethane conditioning (~$10M per plant) within acceptable payback or investment returns. In any case, the projects would likely have to generate in the order of 100,000 GJ/yr to obtain a pipeline connection for RNG under acceptable terms.
- Although no framework exists today to value the environmental attributes from using the biogas for a dedicated CNG application, there is significant future potential for this option. Current incentives derived from the Ontario Climate Change Action Plan are likely to help reduce capital costs, the increasing demand for RNG (as a result of OEB mandates) is likely to result in strong prices, and a future Ontario renewable fuel standard provides the prospect of high-value environmental attributes.

- Other programs and grants – both the federal government through MCIP and the provincial government through Ontario Municipal GHG Challenge Fund can be applied to both studies and capital for the UK group. Funding timelines for relevant programs can be researched as part of the Detailed Assessment.

5.2 Sale of Digestate

Another area of potential revenue could be the production of a more valuable digestate. During a site visit to the Lystek Organic Materials Recovery Facility in Dundalk, it was explained that due to the nature of the product that farmers paid for digestate and it represented a small net positive revenue source for the company.

5.3 Central Stabilization

Other potential revenue sources would be for UK to operate as a central stabilization facility thereby collecting "tipping" fees from surrounding municipalities to process their wastewater sludge and/or un-matured biosolids. In addition to the tipping fees, the added material could produce more biogas (i.e., more methane) that could be sold as RNG or Renewable CNG.

5.4 Source Separated Organics Processing

Another potential advantage can be to process curbside organics or SSO at a UK site. This could either be done at one of the existing sites or at a new site (i.e., Knox Farms). SSO could be treated within the existing process via co-digestion or in a standalone AD unit. In either case the SSO would have to be pre-treated to remove non-organics (i.e., plastic bags etc.) to ensure that the final digestate has value. By treating the SSO, UK could offset the current price paid to a contractor to have the material made into compost and furthermore produce more methane. If co-digestion or using a standalone AD is contemplated, the UK could furthermore process organics from the Industrial Commercial and Institutional sector in the region and leaf and yard waste collected in the spring and fall. As with having a regional Stabilization concept, UK could equivalently be a regional SSO facility for surrounding municipalities.

5.5 Summary

In all cases, the business case for all options will involve the potential increase in revenue versus the CapEx and OpEx costs. As noted in Section 3.0, UK does not generate enough methane gas under current conditions to undertake many of the above-noted initiatives. Increased biogas generation would have to occur with increased efficiencies and potential new carbon sources. Tetra Tech will provide an initial review of these items in the Detailed Assessment:

- Prices for RNG and Renewable CNG under different generation rates;
- Potential revenues for processed digestate; and
- SSO costs

6.0 SUMMARY

We are providing a summary of Preliminary Assessment Report as follows.

- **Section 1.0** of the report makes connection between what was identified in the original project proposal with what is being provided under this submission. The original project understanding of what UK wanted to achieve in completing the preliminary assessment as summarized in bullet form is established as five independent sections of the report moving forward. As we work towards completion of the Detailed Assessment and Class EA, we will continue to build on these five sections.

- **Section 2.0** of the report assesses the various requirements for environmental assessments under the different options contemplated in Section 3.0. Where the projects are undertaken in existing facilities (Cataraqui Bay and Ravensview) the requirements may require less stringent procedures and where a new site is contemplated, the requirements are less rigid. In all cases, constant consultation and communication with the MOECC will expedite the overall timing of approval toward implementation.

- **Section 3.0** of the report is at this time the key section of the submission in that a wide array of possibilities are evaluated and presented as potential pathway(s) considered under the assignment. We have systematically investigated different facility operational categories and identified various processes within those categories. From here, we have identified a wide array of technologies that are available and narrowed down our scope to identify and include those strategies which we believe offer the best technical and economic options for the UK's consideration.

  A summary table which establishes screening criteria has been prepared to identify which technologies we will build upon. We note that some of the options eliminated from consideration could be much more attractive should UK and their stakeholders consider options for the inclusion of SSO and other organics in their current waste management strategy.

- **Section 4.0** of the report builds on the list of technologies put forward and systematically assesses those technologies in consideration of a centralized processing facility located at either Cataraqui Bay, Ravensview or another location to be further considered and evaluated.

- **Section 5.0** of the report lays out the methodology for understanding the business case for the respective options that pass the initial tests determined in Section 3.0. The business case analysis for the recommended cases is done at a high level to allow for further screening. The analysis at the next stage does not include the review of an independent site.

This submission has taken the points identified below into consideration.

- The evaluation matrix table (Table 3.0) evaluates existing WWTP technologies, various biogas generation technologies, and various biosolids management options only.

- The last column of the evaluation matrix table (Table 3.0) identifies how potentially adding SSO for the various biogas and biosolids technologies could influence the recommendations currently identified.

- The inclusion of a new site (i.e., Knox Farms) may change the technology selection recommendations.

Based on the recommendations laid out in this report and recommendations derived from Workshop 1, Tetra Tech will proceed with the next phase of this study. The work will be comprised of a more detailed review of applicable technologies and subsequent high level analysis of the respective impacts on capital and operating costs and new revenue sources.

7.0 CLOSURE

We trust this Issued for Use report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
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REFERENCES

Canadian Council of Ministers of the Environment (CCME). 2012. Guidance Document for the Beneficial Use of Municipal Biosolids, Municipal Sludge, and Treated Septage. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. Available from http://www.ccme.ca/files/Resources/waste/biosolids/pn_1473_biosolids_guidance_eng_1.0.pdf [accessed on 15 August 2017].

Metcalf and Eddy. 2003. Wastewater Engineering: Treatment and Reuse, 4th Edition. McGraw-Hill, Boston, Massachusetts.

Water Environment Federation (WEF), Water Environment Research Foundation (WERF), and U.S. Environmental Protection Agency (USEPA). 2012. Solids Process Design and Management. Water Environment Federation, Alexandria, Virginia.

TABLES

Categories	Process	Technology	Cost Implications (1)	Space Availability (2)	Operations Compatibility (3)	Environmental Impacts (4)	Class EA Impacts (5)	Business Case (6)	Recommendation	Comments
Pre-treatment	**Sludge Pre-treatment**	**Thickening**	Low	Investigate Further	Easy	Minimal	Minimal	Easy	**Proceed**	It has been our experience that the thickening process can enhance biogas generation at a relatively low cost. There would be minimal environmental impact as there is already a process in place. There would need to be an amendment to the existing Environmental Compliance Approval but we do not believe that there would be any significant Ministry of Environment approvals issues.
		Hydrolysis	High	Investigate Further	Difficult	Minimal	Moderate	Moderate	**Proceed (biological hydrolysis only)**	Biological Hydrolysis Process (BHP) provides similar process benefits as THP but operates under milder conditions, which eliminates the staff qualification requirement for stationary engineers. By reducing the digester retention time, the existing digester capacity as well as biogas yield can be increased. As a result of the increased biogas yield, the overall quantity of biosolids is reduced. However, during the preliminary review, it is noted that BHP is currently lack of full scale references in North America. Data collected from full scale installations in Europe and from the pilot unit in Guelph Ontario are still undergoing approval process to obtain the Class A equivalent certification in Canada.
		Conditioning	High	No Further Review	Difficult	Minimal	Moderate	Moderate	**Do Not Proceed**	The conditioning process may not be easily integrated into UK's WWTPs because most conditioning processes require a sophisticated operating condition. Also, some of the technology lack full-scale operations (i.e., high throughput) which poses operational risks to the UK's WWTP.
Solids Stabilization	**Digestion**	**Anaerobic**	High	Investigate Further	Easy	Significant	Moderate	Easy	**Proceed**	Anaerobic digestion has many benefits that aligns with UK's main objective of this project of enhancing biogas generation.
		Aerobic	Moderate	Not Available	Easy	Moderate	Minimal	Easy	**Do Not Proceed**	Aerobic digestion has many benefits but it does not align with UK's main objective of this project to enhance biogas generation. Energy cost is significantly higher than anaerobic digestion. In certain variation, e.g. Autothermal Thermophilic Aerobic Digestion, the process is a difficult change for plant staff who is used to conventional anaerobic digestion processes.
		Combined Aerobic / Anaerobic	High	Not Available	Difficult	Moderate	Moderate	Difficult	**Do Not Proceed**	The combined aerobic/anaerobic digestion process is considered not suitable for this project because it is partially aligned with UK's main objectives. The combined aerobic/anaerobic digestion may reduce overall biosolids production but will not enhance biogas generation. Therefore, the process benefit cannot be offset by the increased capital cost and complexity to the overall plant operation, which requires additional staffing needs and technical support.
	Co-digestion	**Ravensview**		Investigate Further					**Proceed**	Based on a preliminary review of co-digestion at Ravensview and an evaluation of advantages and disadvantages, our recommendation is to proceed with further investigation as a potential option for UK in our Detailed Assessment. It is our belief that co-digestion at Ravensview may be difficult to implement, given the space constraints, overall size of the facility, and site location but it is worth further assessment.
		Cataraqui Bay		Investigate Further					**Proceed**	Based on a preliminary review of co-digestion at Cataraqui Bay and an evaluation of advantages and disadvantages, our recommendation is to proceed with further investigation as a potential option for UK in our Detailed Assessment. There are currently design technologies being considered at the Cataraqui Bayfacility that we believe warrant additional and more detailed assessment of the existing facility taking into consideration the option of co-digestion. This would include a more detailed analysis of the newly commissioned liquid process and the various impacts to the liquid stream processes by side streams generated by digestion of high strength waste. It has been our experience that co-digestion at Cataraqui Bay could be a difficult to implement successfully given the size of the facility. Also, as the liquid process at the facility is very new, the impacts on the liquid stream processes by side streams generated by digestion of high strength waste are unknown at this time.
	Post Treatment /Composting	**Windrow**	Low	Not Available	Easy	Moderate	Moderate	Moderate	**Do Not Proceed**	Windrow composting requires large plots of land that are not currently available at the Cataraqui Bay and Ravensview facilities.
		Extended Aerated Static Pile	Low	No Further Review	Easy	Moderate	Minimal	Moderate	**Do Not Proceed**	Extended aerated static piles may be beneficial for UK as a post treatment process because the piles would further stabilize the sludge/biosolids at a relatively low cost with minimal environmental impacts. An off-site composting facility may be considered to implement this process alternative.
		In-Vessel	Moderate	Not Available	Moderate	Minimal	Moderate	Difficult	**Do Not Proceed**	Applications of this in-vessel composting has become rare due to relatively high capital and operating costs. In-vessel composting may not be of interest to UK due to the increased space/land needed for curing that may not be available on-site.
		Agitated Bed	High	No Further Review	Difficult	Minimal	Moderate	Difficult	**Do Not Proceed**	Agitated beds require large amounts of financial support (capital and operating) and other options may be just as effective at a lower cost.
		Soil Blending	Low	No Further Review	Easy	Minimal	Moderate	Easy	**Do Not Proceed**	

Notes: (1) High, Moderate, Low.; (2) Available, Not Available, Investigate Further; (3) Easy, Moderate, Difficult;
(4) Minimal, Moderate, Significant; (5) Minimal, Moderate, Significant; (6) Easy, Moderate, Difficult

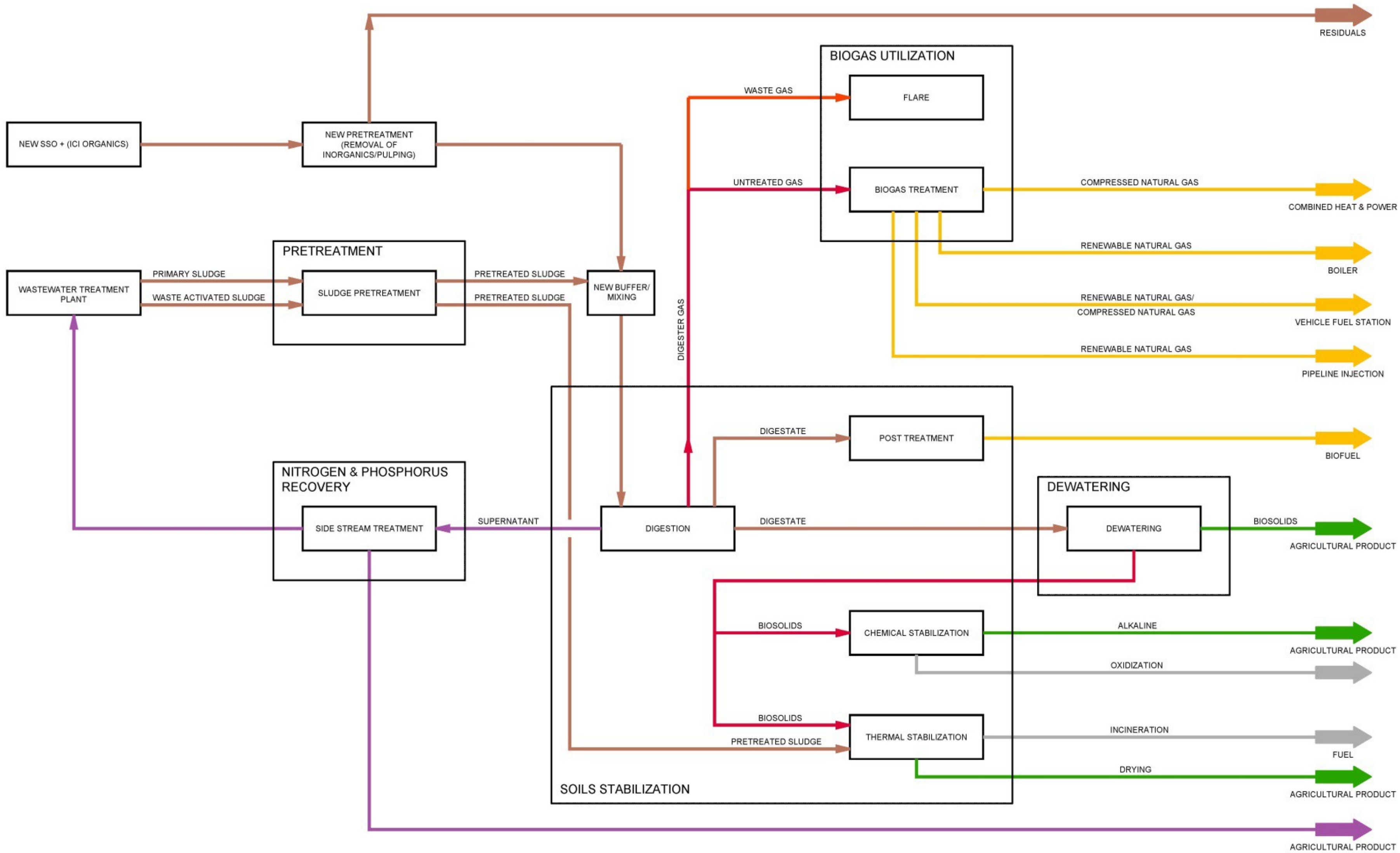
Categories	Process	Technology	Cost Implications (1)	Space Availability (2)	Operations Compatibility (3)	Environmental Impacts (4)	Class EA Impacts (5)	Business Case (6)	Recommendation	Comments
Solids Stabilization (cont'd)	**Chemical Stabilization**	**Alkaline Stabilization**	Low	No Further Review	Easy	Moderate	Minimal	Moderate	**Do Not Proceed**	The alkaline stabilization process may add certain benefits to the project because the market is established in Ontario that would make the Class EA approval easier as well as its low capital cost and simple equipment and process operation. However, there is no direct reduction of organic matter or sludge solids with the high pH alkaline stabilization process. There is actually an increase in the mass of dry sludge solids. Without supplemental dewatering, additional volumes of biosolids will be produced. This process is therefore considered not aligned with the project objectives as it neither enhances biogas generation nor reduces biosolids production. Ammonia gas release at high pH poses health and safety concerns to the operational staff.
		Oxidation	Moderate	No Further Review	Moderate	Moderate	Moderate	Moderate	**Do Not Proceed**	While running at high operating cost, the oxidation process does not produce a useable end-product that carries marketable value. The economy renders it less favourable in addition to the operational challenges posed by chemical storage and handling issues.
	Thermal Stabilization	**Incineration**	High	Investigate Further	Difficult	Significant	Significant	Difficult	**Do Not Proceed**	The technology is extremely expensive as an ultimate solid stabilization process and therefore it is only justifiable in much larger scale plants, i.e., approximately 100 dry tonne solids per day, where economies of scale plays a key role in evaluation. The complexity of incineration process poses technical and operational challenges such as a stationary engineer is required to operate the steam system under the Technical Standards and Safety Act, 2000. Long Class EA approval process is also going to limit the feasibility of implementing this alternative.
		Drying	High	Investigate Further	Moderate	Significant	Significant	Difficult	**Do Not Proceed**	The biosolids drying process is considered not suitable for this project because the drying process reduces overall biosolids volume by removing moisture content. It does not reduce biosolids production nor enhance biogas generation. High energy consumption is also contradicting to the key project objectives.
Biogas Utilization	**On-Site Combined Heat and Power**	**MicroTurbines**	Moderate	Investigate Further	Moderate	Minimal	Minimal	Moderate	**Proceed**	It has been our experience that using microturbines would require removal of all siloxanes in the raw biogas prior to injection into a microturbine.
		Reciprocating Engines	Moderate	Investigate Further	Easy	Moderate	Moderate	Moderate	**Proceed**	It has been our experience that using reciprocating engines would be the least capital cost.
	Boiler	**On-Site Boiler**	Low	Investigate Further	Difficult	Minimal	Minimal	Easy	**Proceed**	Proceed with further investigation but only in conjunction with other beneficial use options.
		Off-Site Boiler	High	No Further Review	Difficult	Significant	Significant	Difficult	**Do Not Proceed**	One potential boiler user has been identified near Cataraqui Bay WWTP but upon preliminary screening the route for a pipeline to connect the WWTP to the off-site boiler is complex and considering the small amount of biogas that is available and the potential risk of the customer not requiring heat under given timing scenarios our recommendation is to not proceed.
	Vehicle Fuel Station	**On-Site Vehicle Fueling**	Moderate	No Further Review	Easy	Minimal	Minimal	Moderate	**Do Not Proceed**	We feel that there is not enough local CNG vehicles that would use UK's biogas so using on-site vehicle fueling would not be practical at this time.
		Off-Site Vehicle Fueling	Moderate	Investigate Further	Easy	Minimal	Minimal	Difficult	**Proceed**	It has been our experience that using an off-site vehicle fueling station would be feasible if you can get enough fleets to agree to buy all your RNG.
	Pipeline Injection	**Local or Regional Pipeline Injection**	High	No Further Review	Moderate	Moderate	Moderate	Difficult	**Do Not Proceed**	Currently, there is an insufficient amount of biogas generated at either WWTP to justify the high capital cost for interconnecting to the natural gas pipeline. **The inclusion of SSO into the City's waste acceptance program could provide for increased Biogas generation and make this a more attractive option.**
Dewatering	**Dewatering**	**Centrifuge**	High	Investigate Further	Easy	Minimal	Minimal	Easy	**Proceed**	Dewatering with a centrifuge has many advantages (e.g. small footprint, low staff and maintenance requirements, and able to produce a fairly dry product) that outweigh its disadvantages (e.g. high power consumption and cost).
		Belt-Filter Press	Moderate	Investigate Further	Easy	Minimal	Minimal	Easy	**Proceed**	Pressing for dewatering purposes may be suitable because it has a relatively low cost and easy to implement operational (e.g. easy start up and shut down).
		Drying Beds	High	No Further Review	Moderate	Moderate	Moderate	Moderate	**Do Not Proceed**	Drying beds may not be suitable because a large footprint is needed that may not be available.
		Rotary Vacuum Filters	Moderate	Investigate Further	Moderate	Moderate	Moderate	Moderate	**Do Not Proceed**	Rotary vacuum filters are not the most effective option in biosolids dewatering. Residual moisture is relatively higher than centrifuges while the pressure difference is limited up to 1 bar due to the structure of the drum filter.
		Enhanced Solar	Moderate	Not Available	Moderate	Minimal	Minimal	Difficult	**Do Not Proceed**	Enhance solar dewatering require a large footprint that may not be available to UK.

Notes: (1) High, Moderate, Low.; (2) Available, Not Available, Investigate Further; (3) Easy, Moderate, Difficult;
(4) Minimal, Moderate, Significant; (5) Minimal, Moderate, Significant; (6) Easy, Moderate, Difficult

Categories	Process	Technology	Cost Implications (1)	Space Availability (2)	Operations Compatibility (3)	Environmental Impacts (4)	Class EA Impacts (5)	Business Case (6)	Recommendation	Comments
Nitrogen and Phosphorus Recovery	**Side Stream Treatment**	**Struvite Recovery**	High	Investigate Further	Difficult	Moderate	Moderate	Difficult	**Do Not Proceed**	The technology is relatively expensive as a treatment enhancer and therefore it is typically justified in much larger scale plants, where economies of scale is a way to improve its competitiveness. Additionally, the complexity of proprietary struvite recovery process poses technical and operational challenges such as additional training and support staffing needs.
		Anammox	High	Investigate Further	Difficult	Moderate	Moderate	Difficult	**Do Not Proceed**	Being a relatively new technology, full scale installation of Anammox in municipal applications, particularly in systems the size of those owned by UK, has not been widely accepted, which poses technical and operational challenges to UK such as additional training and support staffing needs. In the cases of implementing a proprietary Anammox process, a royalty fee may also apply.
Biosolids Management	**Land Application**	**Liquid**	Moderate	No Further Review	Easy	Moderate	Moderate	Difficult	**Do Not Proceed**	Liquid land application does not have a favorable business case due to its high operating cost from hauling between sites.
		Cake/Slurry	Moderate	Investigate Further	Easy	Moderate	Moderate	Moderate	**Proceed**	Similar practice has been well accepted by many municipalities in Ontario. Typically, centralized biosolids management facilities are required to accommodate the off-season storage requirement
	Landfill	**Cake or Liquid**	Moderate	No Further Review	Easy	Difficult	Significant	Difficult	**Do Not Proceed**	Based on our experience, using landfill as a disposal option would provide the least beneficial use as it does not utilize nutrient recovery and has a poor perceptive from the public.
	Construction Material	**Bricks**	High	No Further Review	Moderate	Moderate	Moderate	Difficult	**Do Not Proceed**	Using biosolids for construction material may have a difficult business case due to the minimal experience elsewhere and high cost associated.

Notes: (1) High, Moderate, Low.; (2) Available, Not Available, Investigate Further; (3) Easy, Moderate, Difficult;
(4) Minimal, Moderate, Significant; (5) Minimal, Moderate, Significant; (6) Easy, Moderate, Difficult

DRAWINGS



CLIENT

Utilities Kingston

TETRA TECH

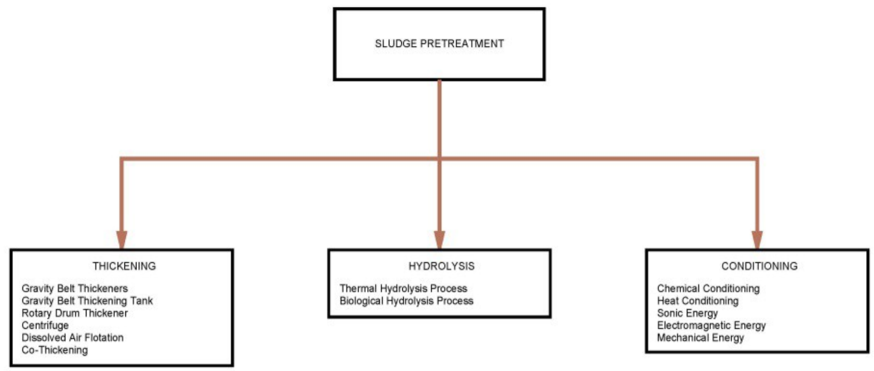
PRELIMINARY ASSESSMENT REPORT
KINGSTON BIOSOLIDS AND BIOGAS MASTER PLAN

MASTER FLOW DIAGRAM

PROJECT NO.	DWN	CKD	REV
704-SWM.SWOP03442-01	C.F.	G.T.	0

OFFICE	DATE
Mississauga, ON	August 29, 2017

Drawing 3.0



CLIENT: Utilities Kingston

TETRA TECH

PRELIMINARY ASSESSMENT REPORT
KINGSTON BIOSOLIDS AND BIOGAS MASTER PLAN

SLUDGE PRETREATMENT

PROJECT NO.	DWN	CKD	REV
704-SWM.SWOP03442-01	C.F.	G.T.	0

OFFICE	DATE
Mississauga, ON	August 29, 2017

Drawing 3.1

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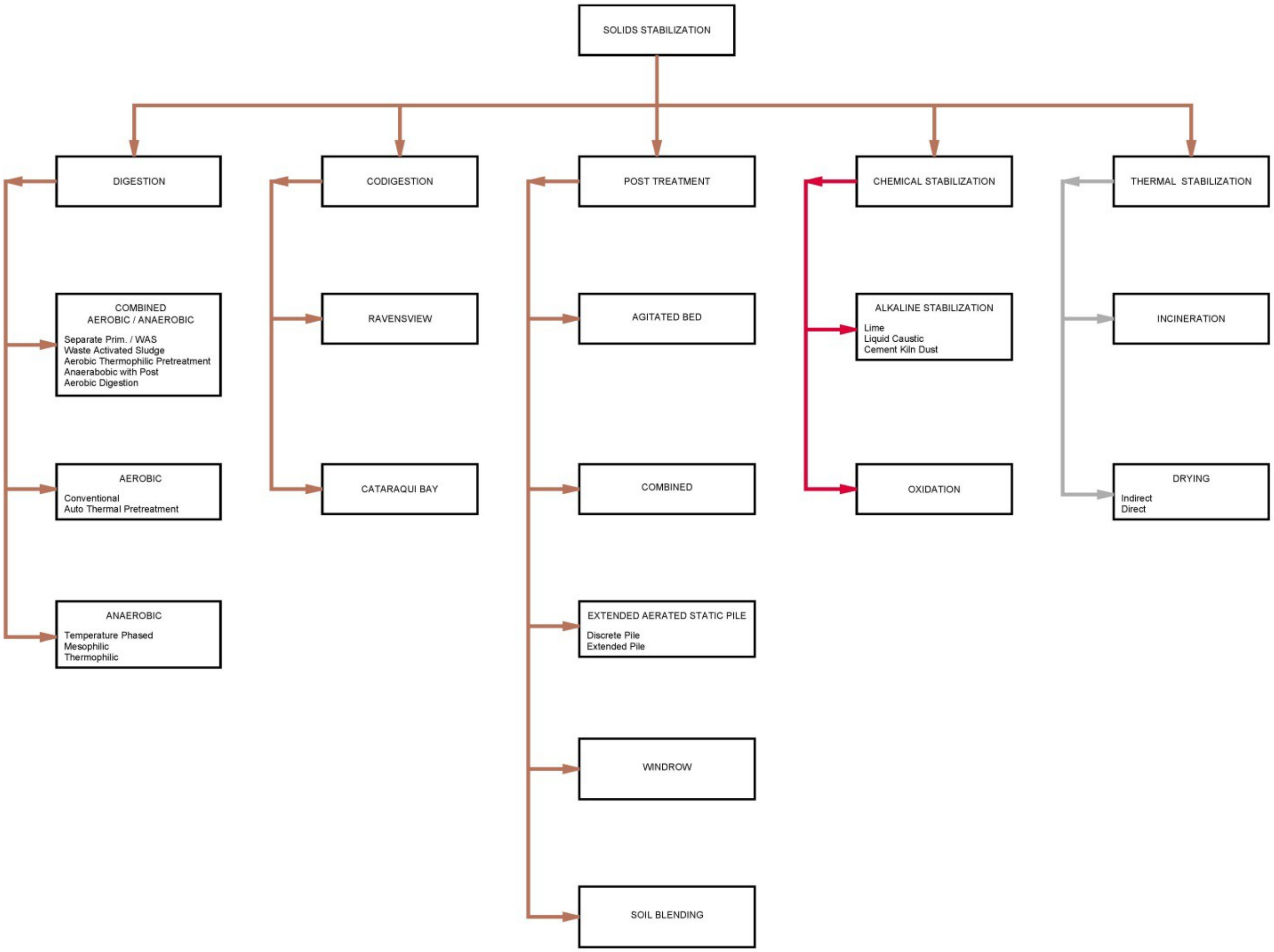


CLIENT

Utilities Kingston

TETRA TECH

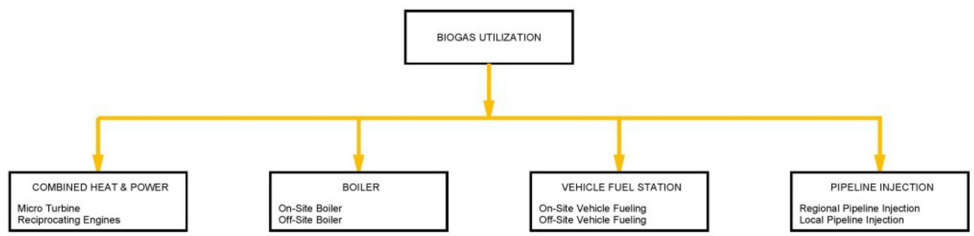
PRELIMINARY ASSESSMENT REPORT
KINGSTON BIOSOLIDS AND BIOGAS MASTER PLAN

SOLIDS STABILIZATION

PROJECT NO.	DWN	CKD	REV
704-SWM.SWOP03442-01	C.F.	G.T.	0

OFFICE	DATE
Mississauga, ON	August 29, 2017

Drawing 3.2



CLIENT

Utilities Kingston

TETRA TECH

PRELIMINARY ASSESSMENT REPORT
KINGSTON BIOSOLIDS AND BIOGAS MASTER PLAN

BIOGAS UTILIZATION

PROJECT NO.	DWN	CKD	REV
704-SWM.SWOP03442-01	C.F.	G.T.	0

OFFICE	DATE
Mississauga, ON	August 29, 2017

Drawing 3.3

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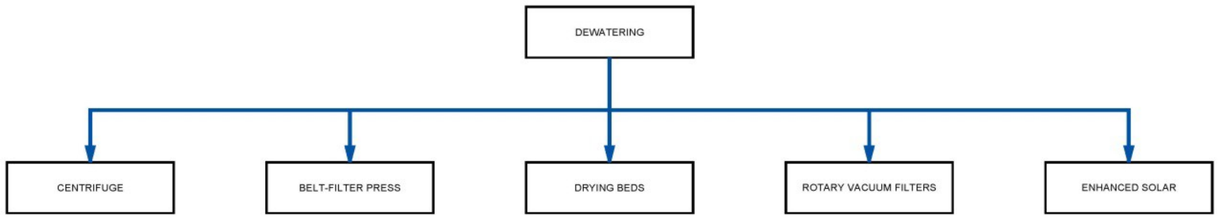
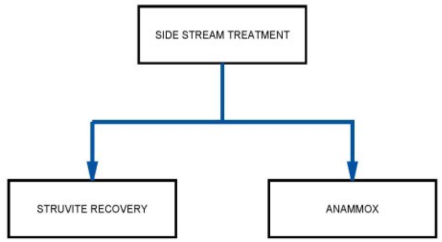


CLIENT

PRELIMINARY ASSESSMENT REPORT
KINGSTON BIOSOLIDS AND BIOGAS MASTER PLAN

DEWATERING

PROJECT NO.	DWN	CKD	REV	
704-SWM.SWOP03442-01	C.F.	G.T.	0	**Drawing 3.4**
OFFICE: Mississauga, ON	DATE: August 29, 2017			



CLIENT

Utilities Kingston

TETRA TECH

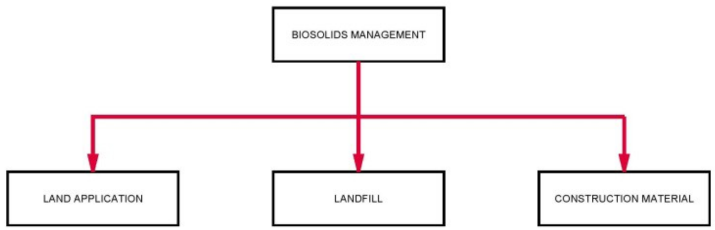
PRELIMINARY ASSESSMENT REPORT
KINGSTON BIOSOLIDS AND BIOGAS MASTER PLAN

SIDE STREAM TREATMENT

PROJECT NO.	DWN	CKD	REV
704-SWM.SWOP03442-01	C.F.	G.T.	0

OFFICE	DATE
Mississauga, ON	August 29, 2017

Drawing 3.5



CLIENT

Utilities Kingston

TETRA TECH

PRELIMINARY ASSESSMENT REPORT
KINGSTON BIOSOLIDS AND BIOGAS MASTER PLAN

BIOSOLIDS MANAGEMENT

PROJECT NO.	DWN	CKD	REV
704-SWM.SWOP03442-01	C.F.	G.T.	0

OFFICE	DATE
Mississauga, ON	August 29, 2017

Drawing 3.6

APPENDIX A

TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

GEOENVIRONMENTAL

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Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

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The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by third parties other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary exploration, investigation, and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 NOTIFICATION OF AUTHORITIES

In certain instances, the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by TETRA TECH in its reasonably exercised discretion.