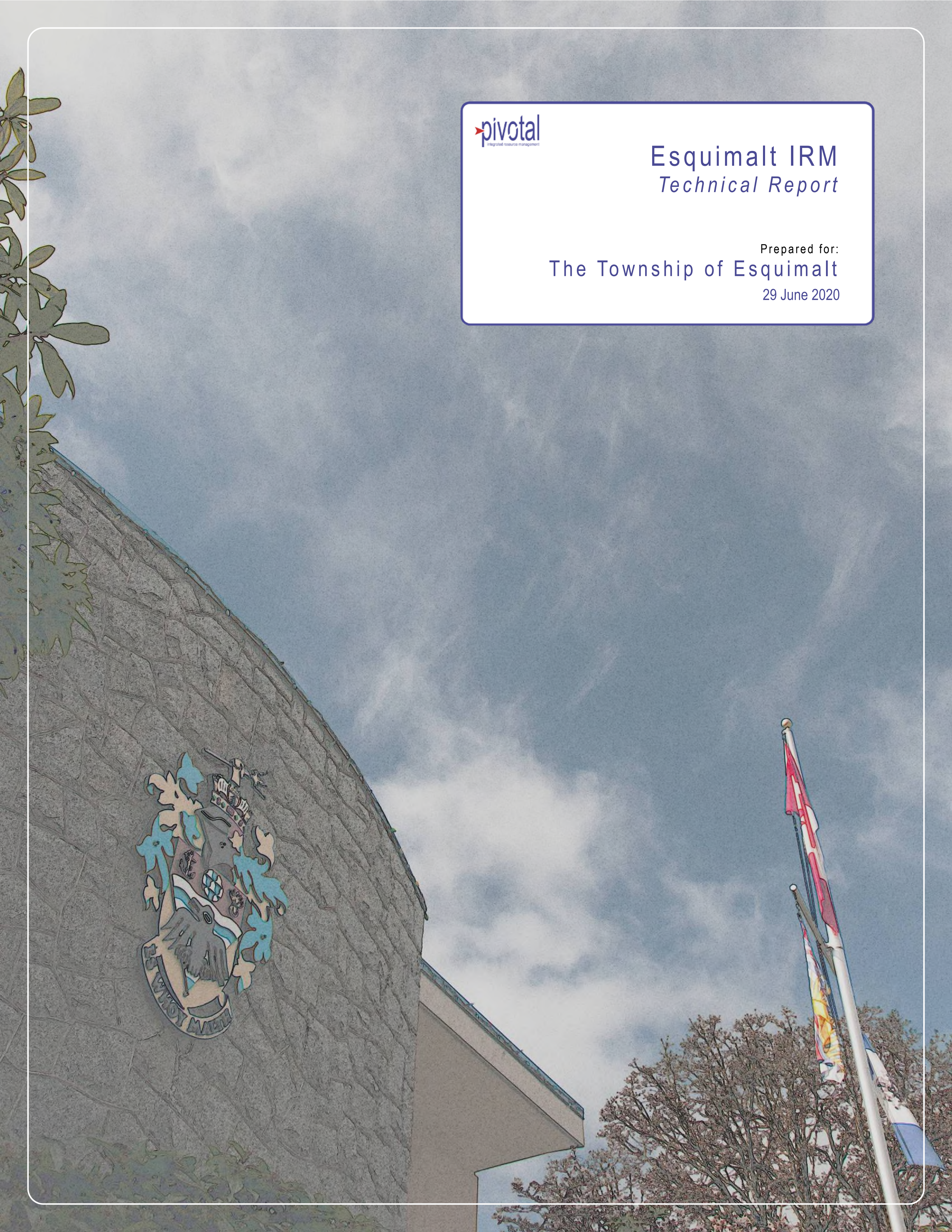


Esquimalt IRM
Technical Report

Prepared for:
The Township of Esquimalt
29 June 2020

pivotal
integrated resource management

Mr. Jeff Miller
Director, Engineering and Public Works
The Township of Esquimalt
1229 Esquimalt Road
Esquimalt, BC V9A 3P1

29 June 2020

Dear Mr. Miller

ESQUIMALT IRM - TECHNICAL REPORT

We are pleased to submit the IRM Technical Report for your review and consideration, which we understand will be presented to Council on 6th July, 2020. We trust this assists and as there is much to digest in this study, will be pleased to answer questions or expand on aspects as required.

Yours truly,

Graeme Bethell
President
Pivotal IRM Inc.

Chris Corps
CEO
Pivotal IRM Inc.

Pivotal IRM Inc.,
4464 Markham Street,
Victoria,
British Columbia
Canada
V8Z 7X8

t: (250) 478 8820
e: info@pivotalirm.com
www.pivotalirm.com

Table of Contents

Links are clickable in electronic versions of this document.

Figures & Tables

1 Executive Summary

During the planning process for CRD's McLaughlin Point sewage treatment plant planning, it became clear that Esquimalt's community supports Integrated Resource Management, which arose from a provincial study and initiative published in 2008. After CRD decided not to pursue IRM, Council commissioned the current study to assess whether and how it might implement IRM for Esquimalt's wastes, given community support.

Summary Metrics - Recommended Option	*Scenario 2b*
General	
Estimated total capital cost (upper range costing)	≈$21.3m
Estimated annual O&M cost	≈$1.7m
Tonnes/yr landfill diversion	≈9,000 t/yr
Public sector model	
Internal Rate of Return (before debt)	22%
Total net taxpayer profit (30yr life cycle)	≈$226m
Taxpayer dividend per yr, avg 1st 10 yrs	≈$360/home
Private sector model	
Leveraged IRR (30% equity, net of debt)	48%
Total net profit after debt, leveraged (30yr life cycle)	≈$235m
Environmental & resource recovery	
GHG tCO2e/yr reduction	4,500 tCO2e/yr
CO_2e reduction, life cycle vehicles equivalent	29,100 cars
Total biochar tonnes/yr	1,210 t/yr
Sequestered carbon (30yr life cycle)	≈107,000 tCO2e
Face yield, mw thermal	≈2.00 mw
Total recovered mw thermal (30 yr life cycle)	≈528,000 mWht

Figure 1: Key Metrics - Recommended Option

Our main conclusion is that IRM can be implemented in Esquimalt and that this can reduce taxpayer costs, lower Green House Gases and sequester carbon, recover resources and maximize landfill diversion, which if more broadly adopted regionally, could extend Hartland Landfill's existing capacity to 2186. IRM has the potential to generate a profit, net of both capital and operating costs, and become a new source of revenues for the Township. There would be small additional employment and more money would remain and be re-spent in the community.

The Township collects ≈52% of the identified waste streams and while a plant could be implemented solely addressing this waste, it may only achieve breakeven. However private haulers are willing to contribute their wastes, which improves economies of scale, raises viability and which we recommend pursuing. A plant can be phased, starting at ≈$15m, rising to ≈$21m as the community grows. Optionally the cost could be reduced or even eliminated, depending on: (a) procurement approach; and, (b) grants.

We recommend the Township's Canteen Road Public Works site as a plant location and that the Township can meet the Ministry of the Environment and Climate Change Strategy (MoE) 5Rs pollution prevention strategy. The analysis has assumed use of this site and would need updating if a different site is chosen. Reviews by CRD (and this study) concluded Advanced Gasification is a suitable technology, as required by the Ministry's regulations to proceed.

IRM was originally conceived to viably maximize carbon reduction and resource recovery. Esquimalt has set a target of being corporately carbon neutral with 38% reduction by 2030 and carbon neutral by 2050. At full operation the net projected GHG reductions would be ≈4½ times the Township's corporate GHG profile or ≈12% of the entire community's GHG profile, i.e. ≈4,500 tCO_2e annually (≈223,000 tCO_2e over its lifetime), while potentially yielding a dividend to taxpayers of ≈$360 per home, which equates to a net life cycle profit/dividend of ≈$227m. The recommended option can also sequester ≈107,000tCO_2e over the project's life cycle, which means IRM could be carbon negative – i.e. beyond carbon neutral – while reducing taxpayer cost, net of debt and all other costs. This is a considerable benefit and achievement, but we caution will only be achieved with diligence.

We assessed options using the wastes collected by the Township, or by adding privately collected wastes. This would address the community's overall wastes and produce a more complete plan, but the extra volume would also improve efficiency, maximizing landfill diversion, financials, GHG reduction and resource recovery. An optimized IRM plan can potentially achieve the highest landfill diversion rate we are currently aware of in BC.

We concluded that not pursuing IRM will increase Esquimalt taxpayers' costs, because the regional use of anaerobic digestion requires continual taxpayer funding, while only dealing with ≈11% of Esquimalt's wastes. By contrast IRM can address 100% of the wastes currently collected by the Township and the revenues from IRM can avoid taxpayer support. Not pursuing IRM with Advanced Gasification will also miss the opportunity to maximize resource recovery, cannot optimize GHG reduction, and may either sub-optimize or miss the opportunity to sequester carbon.

Should Council decide to proceed further, we recommend a number of steps before making a major financial commitment. Key to these is testing, which is needed to prove that the system will work with the actual proposed wastes and to secure a manufacturer's guarantee. Comment on next steps is expanded in the report.

Experience with Advanced Gasification in Europe is that it stimulates economic development, attracting like-minded businesses and boosting eco-education, training and eco-tourism. In a European example it provided the community with a tangible connection to climate action and in Esquimalt for instance, might be by using a sterile biochar that removes carbon from the atmosphere. These and related aspects will be explored during public consultation.

In closing it is important to note that engagement was undertaken to confirm key aspects such as the potential to contract with haulers, manufacturer pricing and procurement options with alternate service delivery. Implementation is thus considered feasible and if undertaken appropriately, is expected to be both financially and environmentally beneficial for the Township and Esquimalt taxpayers.

2 Assumptions & Limiting Conditions

The information in this document was compiled for the purpose of providing a preliminary assessment of the potential for implementing IRM of waste streams generated in the Township of Esquimalt using gasification. The authors have prepared this document at the request of the Township, solely for this purpose.

Information in this report from which conclusions have been derived has been provided by third parties. While reasonable skill, care and diligence have been exercised to assess the information acquired during the preparation of this report, no guarantees or warranties are made concerning the accuracy or completeness of this information, although the information provided by others is represented to be accurate by the suppliers. This document, the information it contains, the information and basis on which it relies and factors associated with implementation of resource recovery from gasification are subject to changes which are beyond the control of the authors.

IRM requires an inter-disciplinary approach. As a result, components of the document were prepared by professionals in one field who are not qualified in the other fields of study. While diligence has been applied to the assessment, the scope of this report did not allow for full inter-disciplinary cross-verification of all components.

This report includes screening-level estimates which should not be relied upon for design or other purposes without verification, for example through detailed feasibility studies and especially as recommended by the authors. The authors do not accept responsibility for the use of this report for any purpose other than that stated above and do not accept responsibility to any third party for the use, in whole or in part, of the contents of this document. This report is intended to provide a preliminary assessment to meet the purposes of this study and cannot be applied to other jurisdictions or applications without conversion, analysis and confirmation with the authors of this report of any use and limitations of application of any information in this report. Any use by any entity or client, consultants, sub-consultants or any third party, or any reliance on or decisions based on this document, are the responsibility of the user or third party.

Parties seeking to rely on this report should not do so without first satisfying themselves to the accuracy and extent of the contents, which have been prepared for the specific purposes of the client.

3 Background

3.1 Introduction

The purpose of this study is to evaluate and assess the potential for an Integrated Resource Management (IRM) approach to manage waste streams generated by the Township of Esquimalt, which comprise: (a) liquid waste and liquid waste energy; (b) solid wastes collected by the Township – comprising MSW, food scraps, yard and garden wastes; and, (c) solid wastes collected by private haulers – which are similar to Township-collected wastes but are collected from businesses and higher-density development. The Township wishes to assess the potential implementation of an IRM system to see whether it can create additional benefits for the community from these waste streams.

In summary the Report comprises:

- A background on IRM, including a brief explanation of what it is, as well as existing work and reviews, and other contributory information;
- A general review of pertinent technology, Esquimalt's demographics, current waste volumes and an analysis of whether IRM makes sense for Esquimalt, alternate technological approaches and aspects contributing to IRM;
- An IRM assessment, including a description of project scenarios, analysis of possible locations, costs, revenues, intangible aspects, risk, procurement and other pertinent aspects;
- The report findings, covering IRM results based on financial, environmental and recovered resources, scenario selection and phasing, conclusions and recommendations.

A number of supporting appendices are included, containing further information referenced in the report.

Note that we have attempted to use laymen's terms to allow a broader range of readers to understand this document but inevitably some aspects are technical.

3.2 What is IRM

Integrated Resource Management or "IRM" is an approach to managing water, energy and waste that aims to maximise their use and value as resources, in ways that reduce costs to taxpayers (or even create profit) and reduce greenhouse gas emissions (GHGs) and pollution. IRM was created in 2008 as a result of a BC provincial study on how to maximize resource recovery from waste, for the Ministry of Community Service and the BC Cabinet Committee on Climate Change.

IRM is defined as a fully integrated life cycle assessment and comparison of options by which resources can be recovered from waste, to maximize the benefits to the environment and the taxpayer. The life cycle options analysis allows the community to then determine the best options, thus bringing together the full financial and environmental impacts of options so that informed social decisions can be made (i.e. "Triple Bottom Line"). IRM thus makes the financial and environmental consequences transparent, so meaningful and informed public engagement can plan the best direction. Figure 2 summarizes Pivotal's IRM process.

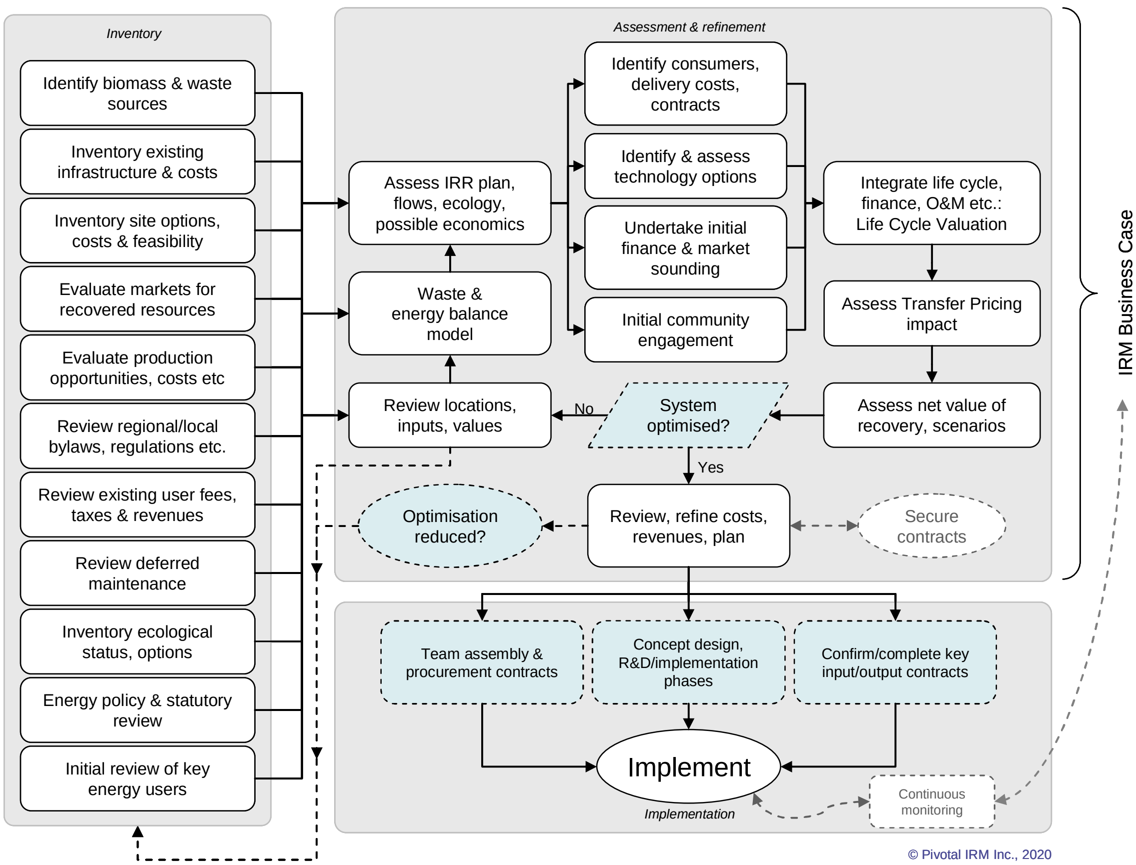


Figure 2: IRM Process Overview

IRM principles are primarily driven by the United Nation's Brundtland Commission on sustainable development,[1] whose main conclusion was that:

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

Pivotal's IRM model has been independently audited and uses international standards to assess life cycle both environmentally and financially, so the full impact to future taxpayers

---

[1] For a summary see Wikipedia.

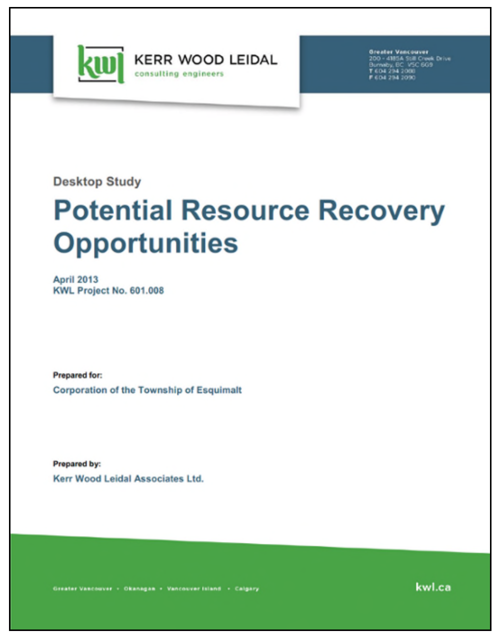
and the environment is clear. Our analysis and this report are aligned as closely as possible to internationally accepted valuation standards, to facilitate financing and transparency.

3.3 Prior IRM Studies

3.3.1 Resource Recovery Study

In April 2013 Kerr Wood Leidal (KWL) completed a study of potential resource recovery opportunities with a focus largely on wastewater. Resource recovery options included:

- Heat Recovery from raw sewage and effluent;
- Biogas from anaerobic digestion used to generate heat and/or electrical power, or upgraded to biomethane to replace natural gas;
- Reclaimed water from treated effluent;
- Biosolids from digestion combusted as fuel or applied to the land as fertilizer;
- Nutrient recovery from phosphorus (struvite).


KERR WOOD LEIDAL
consulting engineers

Desktop Study

Potential Resource Recovery Opportunities

April 2013
KWL Project No. 601.008

Prepared for:
Corporation of the Township of Esquimalt

Prepared by:
Kerr Wood Leidal Associates Ltd.

kwl.ca

Figure 3: KWL Resource Recovery Study, 2013

KWL concluded that the most readily available resources would be: heat from raw sewage or treated effluent; biogas combustion or upgrading to sell the biogas to the natural gas grid; and dried biosolids combusted in solid-fuel boilers. As it originated from a wastewater perspective, the study excluded consideration of solid waste and related IRM options.

The study recommended further assessment of a District Energy System (DES) to replace conventional heating and cooling, and assessment of a purple pipe system to distribute reclaimed water, including for use in irrigation systems. These have current application. It recommended assessing a Compressed Natural Gas (CNG) fuelling station fuelled by biomethane from the anticipated anaerobic digester.

KWL's report is now out of date for three main reasons: (1) the community rejected anaerobic digestion in Esquimalt so the associated resources and generation potential are located at Hartland, so their benefit is unavailable in Esquimalt; (2) other aspects such as land application of biosolids have been rejected – although CRD recently allowed temporary application; and, (3) KWL assumed sewage flows ≈50% higher than have since proven to be available, according to CRD's latest data on sewage flows, which means the study's main key assumption has proven to be an over-estimate. The study is thus largely not applicable without being re-commissioned, although aspects such as the DES continue to have relevance and are considered in this study. The energy advisors to our team, who specialize in Net Zero projects, recommend that KWL's DES and related linkages to the IRM plant need to be reviewed at an early stage, should this project proceed further.

3.3.2 Ministry of the Environment Study

We were also asked to comment on a report prepared for MoE by Stantec in 2011 which reviewed 'waste to energy alternatives,' mainly focused on incineration. The study appears to have mostly relied on a 2008 US DOE report and for example, did not consider any Advanced Gasifier systems from Europe or similar systems in Japan, which were in operation and included plants that had received international awards or were EU centres of excellence. While the report noted that gasification was a rapidly advancing technology, the study was limited in scope and omitted consideration of technologies recommended to CRD by their experts, so has limited application for Esquimalt's purposes.

3.3.3 IRM Task Force Study

Following provincial encouragement to consider IRM for CRD's liquid waste treatment project, CRD formed an IRM Task Force to assess how IRM might be implemented. The Task Force engaged technology providers and independent experts who recommended gasification, but CRD ultimately did not pursue this, which they explained was because provincial funding was linked to the production of Class A biosolids, which are produced by anaerobic digesters, not gasifiers.

Provincial legislation gives municipalities the primary responsibility and pre-eminence to decide how they want to deal with waste. Regional Districts have the responsibility for authoring a waste management plan for the region, which then has to reflect what communities want. Esquimalt is thus able to adopt an IRM approach if it chooses, which will in due course be reflected in the regional solid waste management plan. We contacted MoE for confirmation of this and they directed us to the documentation confirming it.[2]

The primary objective of the IRM Task Force was to determine whether IRM could provide financial and environmental benefits. The Task Force's overall conclusions were that IRM was feasible and would provide financial and environmental benefits.[3] The Task Force concluded that a structure was desirable to avoid jurisdictional conflicts – such as the municipal authority on waste but regional responsibility to plan – and supported a pilot project to treat biosolids, kitchen scraps and MSW. The concept was that a technology demonstration would address questions and risk, however the Task Force was disbanded before this could progress.

The Task Force and Technical Oversight Panel had nevertheless sought proposals from possible IRM providers, including gasification suppliers. It concluded that IRM could integrate solid and liquid wastes managed by CRD while also maximising resource recovery including generation of energy and even generate a possible revenue stream.

Further research was undertaken by HDR Consultants in August 2017 (RFEOI 16-1894) where proponents indicated that gasification could deal with MSW, kitchen scraps, biosolids and mixed wastes as single streams or in mixed recipes. Finally CRD confirmed that IRM has "*the*

---

[2] See BC MOE waste management web site.

[3] See Report From The CRD Integrated Resource Management Task Force.

potential to impact every aspect of solid waste management in the region."[4] CRD ultimately decided not to pursue IRM. Other work has been undertaken on IRM within CRD's liquid waste management project, with additional comments provided starting on page 15.

3.4 Climate Change

The Township has completed Climate Action Revenue Incentive Program (CARIP) Public Reports for 2017, 2018 and we are advised 2019 is in preparation. These summarize plans and action to be taken to reduce corporate and community energy and greenhouse gas (GHG) emissions and report on progress towards achieving carbon neutrality. We also reviewed Esquimalt's community emissions total, available from provincial data.

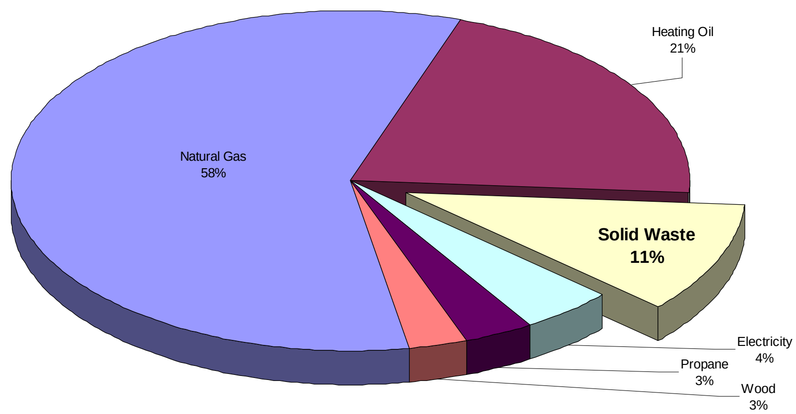


Figure 4: Esquimalt GHG Sources

As the Township's carbon reporting is available separately, we summarize that:

- Esquimalt's overall total GHGs published in the province's Community Energy & Emissions Inventory ("CEEI") 2012[5] as 37,644 tCO_2e. This is the total emissions from all documented activities in Esquimalt;

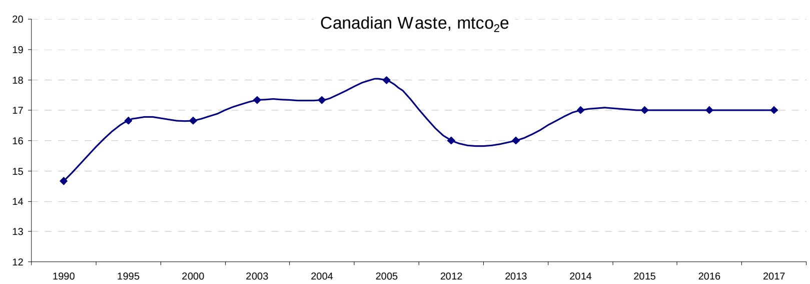


Figure 5: Canadian GHGs From waste, 1990-2017

- Esquimalt has established goal of reducing community GHG emissions by 38% by 2030 and to become carbon neutral by 2050;
- CEEI data shows 2017 Esquimalt waste as being 6,223 tonnes or 2,459 tCO_2e;
- Esquimalt has a municipal corporate annual balance of 1,005.25 tonnes per annum CO2e that it needs to eliminate to become carbon neutral.

---

4 CRD ERM 17-30 at page 2.

5 We note that although an accepted calculation of tCO_2e, we consider it incomplete as some components are omitted. Esquimalt's actual total GHGs are expected to be higher than the provincial totals. See CEEI web site and data.

In summary for IRM to eliminate the Township's corporate operations' GHG profile, reductions have to exceed 1,005 tCO_2e. To eliminate the total emissions for the entire community, GHG reductions have to exceed 37,644 tCO_2e.[6] In that context it is worth noting the commitments by the World Green Building Council and United Nations that all buildings need to be Net Zero Energy or carbon neutral by 2050, and that IRM contributes to these resolutions.[7]

While Figure 4 shows that Esquimalt's waste contributes ≈11% of the overall community GHG total, IRM has the potential to replace heating – which is often provided by natural gas and heating oil. Thus, using energy recovered from waste to displace fossil fuels has the potential to reduce the community's carbon profile to a greater degree than shown by Figure 4. All scenarios prepared by us indicate the potential to eliminate the Township's corporate GHG profile while the percentage GHG reduction for the whole community varies depending on plant size.

Consideration also has to be given to increasing heat impacts from climate change. CRD's projections[8] indicate rising temperatures year-round with reduced rainfall in summer months. Rising temperatures will tend to shift demand away from heating towards increased cooling – both of which can be provided from gasification of waste and are included in our models. CRD also projects greater storm events during winter, spring and fall, which is expected to worsen sewage influent and infiltration. During the June-September months from which the Average Dry Weather Flow ("ADWF") are calculated[9] volumes are projected to fall by ≈20%, but temperature dilution from I&I may reduce energy recovery potential.

Efforts to reduce emissions from waste have resulted in increased waste separation and sorting so organics – a major GHG contributor – can be managed differently to reduce their GHG impact. Unfortunately Figure 5 shows that emissions from waste have been fairly stable recently, despite waste separation and landfill diversion efforts. Local trends are similar, since CRD's data shows that organics diversion has been risen to ≈39% between 2009 and 2016 (Figure 21), at appreciable cost (in some instances exceeding $400/tonne as compared with landfilling at $110/tonne, unsorted). Although this will have improved since CRD's last study, this means ≈61% is still being landfilled. Multiple communities have experienced difficulties with converting food waste into compost[10] and a Vancouver biomass expert notes that demand and price for compost is low. This has resulted in companies becoming marginal or failing[11] – as shown for example in Richmond, Duncan, Saanich and at Duke Point. The main challenges are summarized as: (a) community pressure – both for and against; (b) odour – the largest challenge; (c) separated organics being contaminated, e.g. with plastics; and, (d) lack of profitable markets for the resulting compost.[12] This is discussed further as part of section 4.1 *Technology Review,* on page 15.

---

6 Source: BC Provincial CEEI reports.

7 See United Nations' Sustainable Development goals and the World Green Building Council's Net Zero site.

8 Climate Projections for the Capital Region, CRD, 2017

9 Per Stantec memo to CRD, 2017: "*...average dry weather flow (ADWF)... is the sum of the base sanitary flow plus the flows attributed to groundwater infiltration during the... period from June 1st to August 31st.*"

10 See for example online articles #1, #2, #3, #4, #5, #6, #7.

11 A Richmond facility attracted the most complaints and largest fines in BC history, was facing fines of up to $1m/day and had a cleanup cost was estimated at ≈$24m.

12 As examples of this: The operator of a (now closed) Saanich plant reported as much as 50% of the organics had to be rejected due to contamination. A composting operation at Duke Point, Nanaimo had to be refinanced and was resold twice and contracts were restructured. A Duncan site processing Saanich waste is under pressure from odour complaints. Smaller farm compost operations in Saanich also report contamination problems.

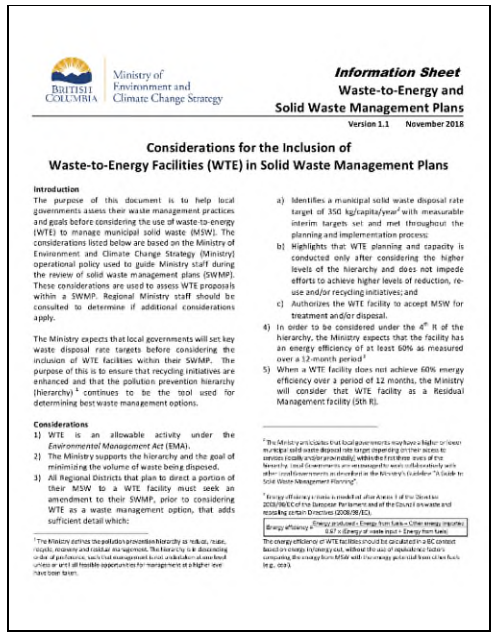
3.5 Regulatory

The key main regulatory processes that IRM will be required to meet are: (a) the Ministry of the Environment and Climate Change Strategies' (MoE) pollution prevention 5R's guideline, aimed to maximizing recycling, reuse etc.; (b) MoE's facilities and emissions regulations; (c) compliance with regional waste management plans; and, (d) Esquimalt's community support and approvals.

3.5.1 5R's Guidelines

MoE's guidelines for the management of wastes is based on a pollution prevention hierarchy to Reduce, Reuse, Recycle, Recover and Residuals Management. This prioritizes levels by which municipalities should approach waste management, i.e. options for any material should be considered at each level, before moving down the hierarchy. The purpose is to ensure waste management practices maximize recycling before considering a waste to energy recovery solution. The policy is also to encourage use of the hierarchy as a tool to determine best waste management practices.

Much of the waste in BC is collected by private haulers who either deposit it at a regional landfill or at a regulated facility typically other than a landfill, such as a Blue Box recycling centre which are available across BC. Under current waste management plans resource recovery has primarily been focused on composting programs for kitchen scraps and other organics with a few municipalities and regional districts using anaerobic digestion to recover biogas to heat the digesters and/or for electrical production.


BRITISH COLUMBIA | Ministry of Environment and Climate Change Strategy

Information Sheet
Waste-to-Energy and Solid Waste Management Plans
Version 1.1 November 2018

Considerations for the Inclusion of Waste-to-Energy Facilities (WTE) in Solid Waste Management Plans

Introduction
The purpose of this document is to help local governments assess their waste management practices and goals before considering the use of waste-to-energy (WTE) to manage municipal solid waste (MSW). The considerations listed below are based on the Ministry of Environment and Climate Change Strategy (Ministry) operational policy used to guide Ministry staff during the review of solid waste management plans (SWMP). These considerations are used to assess WTE proposals within a SWMP. Regional Ministry staff should be consulted to determine if additional considerations apply.

The Ministry expects that local governments will set key waste disposal rate targets before considering the inclusion of WTE facilities within their SWMP. The purpose of this is to ensure that recycling initiatives are enhanced and that the pollution prevention hierarchy (hierarchy)[1] continues to be the tool used for determining best waste management options.

Considerations
1) WTE is an allowable activity under the *Environmental Management Act* (EMA).
2) The Ministry supports the hierarchy and the goal of minimizing the volume of waste being disposed.
3) All Regional Districts that plan to direct a portion of their MSW to a WTE facility must seek an amendment to their SWMP, prior to considering WTE as a waste management option, that adds sufficient detail which:
   a) Identifies a municipal solid waste disposal rate target of 350 kg/capita/year[2] with measurable interim targets set and met throughout the planning and implementation process;
   b) Highlights that WTE planning and capacity is conducted only after considering the higher levels of the hierarchy and does not impede efforts to achieve higher levels of reduction, re-use and/or recycling initiatives; and
   c) Authorizes the WTE facility to accept MSW for treatment and/or disposal.
4) In order to be considered under the 4th R of the hierarchy, the Ministry expects that the facility has an energy efficiency of at least 60% as measured over a 12-month period[3]
5) When a WTE facility does not achieve 60% energy efficiency over a period of 12 months, the Ministry will consider that WTE facility as a Residual Management facility (5th R).

Figure 6: MoE W2E Guidelines[13]

There are no examples where thermal (gasification) treatment is being used to produce synthesis gas (syngas) for the recovery of electricity or heating/cooling. This is unfortunate because energy production is higher than Anaerobic Digestion but toxic chemicals and pathogens are destroyed, GHG emission reductions are significantly higher, the resulting biochar is more valuable than compost as a soil amendment or filtration medium and the process also generates revenue streams from the sale of energy, GHG credits and biochar.

The CRD has enacted Bylaws for managing biosolids using anaerobic digestion to produce biogas, which will be used to maintain optimum temperature of the digesters. We understand the current proposal is to barge residual biosolids to the Lower Mainland for burning with coal in a cement kiln as the final disposal measure, however it would be possible for this to be diverted to Esquimalt's gasifier if this was acceptable to the community. We understand final

[13] See MECC web site.

contracts have not yet been signed and barging is an appreciable cost for CRD and accepting these in Esquimalt could reduce costs. CRD's plan is not final at the time of writing and may be worthy of discussion, but only if accepting these wastes is acceptable to the community.

3.5.2 Facilities and Emissions Regulations

In order to consider energy recovery, MoE expects that local governments will follow the 5R's guidelines, which outline the primary elements for approval of a proposed waste to energy recovery facility (Figure 6):

- Municipal and Regional waste disposal rates must be at or below MoE's guideline rate of 350 kg/capita/yr before considering the inclusion of an IRM energy recovery from waste;
- Partner with their Regional District to amend their regional Solid Waste Management Plan (SWMP) to include the IRM energy recovery facility;
- The proposed IRM facility's energy recovery efficiency must be a least 60% for the selected technology;
- The proposed IRM facility's emissions must meet the Operational Certificate requirements of a waste to energy mass burn incinerator;
- There must be adequate public consultation of the proposed IRM energy recovery project before approval can be provided.

In summary the disposal rate and energy yield meets 5R's guidelines. IRM gasification is also expected to meet MoE's emission standards. Therefore, we conclude the Township and its proposed use of Advanced Gasification is able to meet and exceed Ministry guidelines.

3.5.3 Solid Waste Management Plan

The current CRD Solid Waste Management Plan (SWMP) has commenced the process to be updated and they expect a draft of the new SWMP will be presented to the CRD Environment Committee and the Board in the fall, which provides adequate time for the Township to submit their intention to have an IRM facility, to be included in the new SWMP. In preparation, the Township should confirm community support for an IRM approach.

The primary issues MoE requires assessed include:

- Best Available Technology - Several reviews of alternative energy recovery technology options have been undertaken by CRD and the IRM Task Force that demonstrate the Township has approached this project in a manner to ensure that the IRM facility will use best available technology. The independent review by CRD confirmed Advanced Gasification as a technology but per request, we have included a technology review and comparison starting on page 15;
- Financial Viability - Extensive TBL financial modelling has been undertaken to ensure that the selected IRM approach maximizes resource recovery and is the most cost effective option available;

- Air Emissions Compliance - From the manufacturer's records and from previous waste testing the selected IRM option shows compliance with all environmental air emission regulations for municipal waste incinerators. Calculation of actual air emissions from Esquimalt's waste is planned to be undertaken at the next stage of the project and there are no indications this will not comply;
- Site Specific Issues – MoE requires site-specific issues to be considered, which are explained in greater detail later. Note that several gasifiers have been approved in BC[14] and all meet site specific requirements set out in their permit authorizations. There are no issues currently known that suggest an IRM facility in Esquimalt would not be compliant and permitted;
- Public engagement – Engagement through the West Shore Innovation Days, the IRM Task Force public engagement, and the engagement to follow as part of this study contribute to meeting MoE's requirements for public engagement. Prior engagement has demonstrated support, hence this study;
- Biochar Value - Biochar production from the IRM facility will be tested prior to final selection to confirm its use as a soil amendment and its potential to be used as air or water filter medium where the market is much more valuable.

In summary, the Township's proposed IRM direction appears consistent with and able to meet or exceed current provincial government requirements, as the technology has been reviewed and what is being proposed is the best available. This study confirms IRM using gasification can provide optimum resource recovery and is the most cost-effective approach. The Township's per capita waste levels appears to comply with the 5R's guidelines enabling it to proceed to energy recovery. Combined, this confirms that Esquimalt has met the initial Provincial requirements to proceed with the detailed planning and assessment of an optimized IRM facility in Esquimalt to be part of the Regional SWMP.

3.5.4 Municipal Development Permits

Esquimalt's Development Permitting (DP) process arises from the development application procedures and fees outlined in Bylaw 2791 which sets out the process for the development of an IRM facility and addresses:

Timing – A development permit application must be submitted to the Director of Development to commence the permitting process. This application would include a selected site; description of the complete IRM facility with inputs/outputs; GHG profile; MoE approval process; public consultation outcomes and conceptual designs. We have allowed ample time for this to take place by providing a two year planning and preparation allowance in modelling.

Site zoning – zoning requirements are outlined in Appendix A of Bylaw 2791 and in this case the IRM facility will require Industrial Zoning. If the zoning has to be changed to allow gasifier operations, it will trigger a requirement for a site profile to be undertaken under the Contaminated Sites Regulations, which may increase costs slightly and extend the timeline for overall permitting requirements.

---

[14] For example in Victoria, at UBC in Vancouver and UNBC's northern campus in Prince George.

Application for Development – A detailed project description will have to include all features of the pre-development phase including concept design, site geology, lot size, zoning and MoE's Environmental Impact Assessment (EIA). The EIA would include a description of the technology chain from feedstock receiving and processing to the gasification system and thermal oxidation/heat exchanger with air emissions treatment. It will also include the impacts from onsite construction, commissioning followed by long term operations.

Public consultation – A public consultation process must be conducted with residents within 100 m of the proposed site as per Appendix B of Bylaw 2791. The consultation process must be carried out in accordance with the terms of the DP process adequately advising residents of the public consultation meetings via mail and flyers, provide details of where, when and at what location consultations are to occur as well as outline the opportunities to provide input.

Development application fees – The development permit fees are outlined in Appendix B of Bylaw 2791 and are likely to be in the order of $25,000.

3.6 Grants

All levels of government manage grant and funding programs to encourage research development and demonstration of clean energy technologies in Canada. Canada's investment in clean energy is an important part of building a clean economy and therefore, grants are available.

There are multiple grant sources and programmes change frequently, so while some may end, typically others replace them. Suitability, availability and application will need to be reviewed should the project proceed further. A list of identified current grants is included in *Appendix 4:Grants* on page 83. Other grants become available periodically without notice, for example at the time of writing, there is discussion that COVID-19 economic stimulus grants may be made available for green infrastructure, which an IRM plant should qualify for.

While grants are generally designed to be beneficial, they usually involve meeting goals and objectives from the grant programme's objectives that may not entirely align with a specific project's capabilities or even the community's purpose. They also usually require cost sharing and often involve third parties, for example with federal/provincial grants. Application and approval thus usually adds risk, cost and sometimes considerable delay. Some grants have criteria that are an aimed at other technologies or processes and may thus be an imperfect fit for gasification, while other grants can be smaller than the cost of applying for them. There is also usually extra reporting so the grantor can document that their objectives are being achieved and the money expended correctly. In short while grants are often attractive, they are not always as helpful as they might seem.

The main difficulties with grants are that they can raise costs, cause delays, increase uncertainty and risk. We have for current purposes assessed system viability without relying on grants, but included a general comment about the impact that grants may have on viability. We generally recommend clients do not rely on grants and even avoiding them if possible.

4 Analysis

This section reviews pertinent IRM technologies, proceeding to narrow this down to and compare anaerobic digestion with gasification and from this, identifies the best available technology option. We then analyse population statistics and growth projections in order to estimate future volumes of both liquid and solid waste streams, to assess possible resource recovery opportunities. While the scope of work for this study focused on gasification due to prior work by the community, during meetings with staff it became clear that the study needed to confirm and comply with MoE requirements, so technology options were reviewed and documented accordingly. The section concludes with a review of what is needed to understand feedstock characteristics from initial laboratory and physical testing, to the process train and possible output products.

4.1 Technology Review

4.1.1 Possible Options

In order to consider energy recovery from waste, the Province requires a review of suitable technologies and that the process to consider them has met it's 5R's process. As appreciable work has been undertaken by CRD on technologies, we have thus undertaken a brief review of how Esquimalt came to support IRM with a preference for gasification, including technology assessment, community exposure and feedback, with summary comments on technologies.

CRD assessed liquid and solid waste treatment technologies for the Core Area Wastewater Treatment Plant at McLaughlin Point, from 2006 to 2016. Since 2006 CRD has held at least six proposal calls including Requests for Information, Requests for Expressions of Interest and one Request for Technical Innovation, i.e. technologies have been exhaustively reviewed previously but none have proceeded. CRD's studies mainly focused on recovering resources from biosolids but proposals were able to service both liquid and solid waste streams.[15] During this time and because Esquimalt was the focus for plant location, the community provided comment on options, which led to local community support for IRM and gasification, consistent with provincial encouragement to adopt Integrated Resource Recovery – similar to IRM but omitting financial assessment. CRD's studies thus provide background on technologies, albeit with main focus on residuals management, and are summarized below.

CH2M Hill, Associated Engineering and Kerr Wood Leidel provided advice to CRD between 2006 and 2009, where a range of technology options were considered. With regard to biosolid residuals, these included low technology options such as willow coppice land

---

15 CAWTP Assessment of Biosolids Treatment Appendix L, page 16, Table 3.1, CRD 2016.

applications. Significant community resistance to land application was based on the potential for contamination,[16] and in 2011 CRD Board banned biosolids land application. Proposals calls and options for alternate technologies were constrained as a result and although the province stated that other options would be considered, and despite community resistance that included protests and marches to the Legislature, CRD retained focus on digestion without having resolved biosolids residuals.

From 2009 through 2015 Stantec considered 21 options and in 2016 MoE approved CRD's plan for thermophilic anaerobic digestion and drying the biosolids. Under this, the West Shore communities developed Westside Solutions' Innovation Days chaired by Esquimalt and Colwood Mayors, which held a proposal call and received a range of presentations on technologies, which covered wastewater treatment and biosolids management, i.e. solid residual organic wastes, for which the two main technologies advanced were incineration and Advanced Gasification. CRD did not ultimately follow on the recommendations, but Innovation Days included public participation over multiple days and resulted in community support for IRM and gasification.[17] These contributed to the Township's current direction.

In terms of solid waste studies locally, in 2011 CRD, the Regional District of Nanaimo and Cowichan Valley Regional District commissioned a study[18] assessing options for a large W2E system serving all three regions. It is unclear why a centralized system was stipulated given decentralized systems are feasible, as documented by CRD elsewhere. The stipulation for a centralized plant added both capital and ongoing costs, and increased GHGs. This would only have been needed for incineration-based options, which the study favoured. Other factors in the study also constrained the conclusions, e.g. generation of methanol. Cost was thus increased by these scope limitations and direction (e.g. forcing three regions' waste to be transported centrally, even to Gold River). The study's scope and assessment limitations resulted in unfavourable conclusions and the direction was not pursued.

Composting is an option for organics processing, and is consistent with "cradle-to-cradle" approaches providing the resulting compost is usable, but this has been challenging as previously noted.[11] For composting to be useful, the product must have utility or it fails to support cradle-to-cradle or reduce carbon emissions – the primary objectives. In that regard a local hauler reports that there is no demand for compost and that they have four years' unsold supply on hand. A community watchdog reports that Saanich peninsula farms will not take organics due to community concern about contamination and toxins, i.e. there is limited or no demand for the composted products even if they are free (Class A Biosolids are potentially problematic for similar reasons). These comments apply to food production lands however, as two farms using compost for non-food production report challenges and additional costs separating contaminants within the compost or using the compost viably. The impact on lands using compost if they are returned to food production is unknown.

Whether well founded or not, we conclude there are challenges using compost in this region. Given the foregoing and as composting has a nutrient approach similar to anaerobic digestion, but without the potential to yield other products, composting has not been considered further but anaerobic digestion is a suitable option for consideration.

---

16 CRD's experts noted that land application might have 22 years' life before contamination would be problematic (Brown & Caldwell 2009, ss3.2.1.2).

17 Other than Innovation Days, public support was also indicated during McLoughlin Point rezoning, in several publications and with presentations from groups including Esquimalt Residents' Association, RITE Plan and STAG.

18 See Tri-Regional Study, AECOM, 2011.

A number of other technologies are in the development stage and may become technologies suitable for consideration in waste management, such as Biofuels generation. For example demonstration-scale projects in Alberta and Nova Scotia are progressing, but have not proven themselves stable enough to date, or have the financial substance to guarantee both performance and yield, such they can prove and then underwrite, performance with Esquimalt's waste streams.

4.1.2 Selected Technologies

The nature, volume and composition of Esquimalt's waste, combined with the rejection of incineration and problems with composting, leave few acceptable technology options.

Analysing CRD's 2016 composition study we find that organic wastes are ≈11% of total dry wastes received at Hartland but ≈21% of the wet volume (Figure 7 and Figure 21). Because of the high moisture content, engineers often focus on technologies able to handle wet waste and do not always consider how the water can be inexpensively recycled and maximise the energy, which is in the dry portion of the waste. Doing so would halve the volume being managed, but also significantly reduce capital and operating costs, by concentrating on the solid fraction of the waste – the part that contains the energy and resources. The water itself is also a recoverable resource if treated.

	Digester			Gasifier		
CRD waste category	Y/N/R	Wet	Dry	Y/N/R	Wet	Dry
Organic Waste	Y	28,485 t	9,970 t	Y	28,485 t	9,970 t
Paper and Paperboard	R			Y	20,790 t	13,514 t
Plastics	N			Y	19,305 t	17,375 t
Wood and Wood Products	N			Y	22,950 t	18,360 t
Construction and Demolition	R			R		
Textiles	N			Y	7,965 t	5,576 t
Composite Products	N			Y		
Other	N			N		
Ferrous Metal	R			R		
Glass	R			R		
Electronics	R			R		
Hazardous Waste	N			N		
Rubber	N			Y	1,080 t	1,080 t
Non-Ferrous Metal	R			R		
Bulky Objects	N			N		
Household Hygiene	N			Y	9,315 t	3,726 t
Total suitable		**28,485 t**	**9,970 t**		**109,890 t**	**69,599 t**

	Digester Wet	Digester Dry	Gasifier Wet	Gasifier Dry
Yes, handles it	21%	11%	81%	75%
No, doesn't handle it	51%	58%	6%	8%
Recycle	28%	32%	13%	17%

Figure 7: Technology Comparison by Waste Category[19]

The focus on solid waste "as is" rather than drying it, often results in waste separation and selecting anaerobic digestion, which although rejected by the community for the Viewfield Road location, is still a valid technology and generally an improvement over composting. We should note however that because of the focus on 'wet' solutions such as digestion, analyses almost always: (a) does not assess or manage the water content of solid wastes separately; and, (b) omits consideration of other options such as gasification, which could halve plant size. Most studies do not mention or assess over 90 gasification systems operating in Europe and Asia processing MSW, scraps and biosolids with an equivalent total of more than 1,000 years' operation. One manufacturer for example, has 28 systems with 57 gasifiers operating since 1980. Omitting consideration of these plants affects decisions as it means only technologies advanced for consideration are chosen, in turn increasing taxpayer cost and reducing the potential for resource recovery.

The primary two options considered for Esquimalt's current purposes are thus anaerobic digestion and Advanced Gasification. Their ability to handle wastes is compared in Figure 7,

[19] Source: CRD 2016 Solid Waste Stream Composition Study, analysis by Pivotal.

which uses CRD's 2016 waste composition assessments, which will likely be similar to Esquimalt's waste composition.

Note that while Figure 7 shows gasification can handle a wide variety of wastes, this does not preclude them being handled by recycling, as this gradually improves. Some provinces have found that the economics of recycling are proving unviable with little demand for products, so Figure 7 shows that gasification provides the option to address waste streams if recycling is unworkable, or if new recycling methods become available, those wastes can be extracted and recycled as and when this becomes possible and desirable. Notably, gasification is less reliant on waste separation or dry wastes, which is critically important for anaerobic digestion or incineration for example. This may be attractive for some residents.

We comment on the technologies as follows:

- **Anaerobic digestion** uses bacteria to digest organic compounds in sewage to primarily produce biogas, usable to generate heating, cooling and power. Approximately 11% of CRD waste is suitable for anaerobic digestion (Figure 7), which have been extensively reviewed by CRD as part of the new liquid waste system. The biogas is typically burned to heat the digesters and operations building, and to provide hot water, but can be cleaned up to be saleable as a Renewable Natural Gas ("RNG") at as much as ten times the cost of natural gas. However this biogas will be used to maintain a suitable operating temperature in the digester, so the only potential GHG offset is likely to be from avoidance of landfill off-gassing. CRD's 2016 business case for the Hartland digester indicated no plan to sell methane yield Renewable Natural Gas and did not provide an assessment of the carbon footprint of the project.[20]

  Figure 8: Planned Anaerobic Digester, Hartland Landfill

  Figure 9: Digester, Annacis Island

  Biosolids are produced as a residual from digestion, which has historically been used for soil augmentation. However there is rising concern that this can contribute to soil toxicity, due to increasing volumes of chemical and pharmaceutical materials in waste, which digestion does not destroy. Pharmaceuticals also disrupt the biological processes in the digester,

[20] CRD more recently indicated they may sell digester methane by redirecting landfill gas to heat the digester (which was previously used to generate and sell green electricity). Landfill capture was also expanded recently, funded by CRD taxpayers, but no viability assessment was available. As both the digester and landfill capture are taxpayer-funded costs, the viability of RNG production is unclear but is accepted to be a cost not a profit.

resulting in sub-optimal performance. Residuals from digestion are typically ≈50% of the initial feedstock and may not be permissible for local land application, so need to be landfilled or incinerated, resulting in potential residual GHGs and costs. Currently CRD is planning to transporting these residuals to burn them as part of cement manufacturing in the Lower Mainland. Digestion is thus not in itself a complete solution for the wastes it process and requires additional technologies to be added.

The net energy yield from the biogas and residuals disposal has been calculated[21] to be 239GJ net per day (2.1 MW/tonne). Air emissions from biogas combustion are permitted in BC. Note that because digestion only addresses ≈11% of the waste stream, digestion and recycling combined leave ≈63.5% of the waste stream unaddressed, once residuals are taken into account.

Digesters typically require extensive land area (Figure 8) as they comprise multiple units typically containing up to ≈30 days' supply of gas. They are located in less populated areas due to risk of odour and explosion, which can be managed but adds risk.[22] Locating a plant in Esquimalt is complex due to site limitations and was firmly rejected by the community when CRD proposed this for the Viewfield Road site.

Figure 10: RotoGasifier, Louisiana

- **Gasification** is a chemical and physical process where the feedstock is heated in a controlled chamber with minimal oxygen to produce a synthesis gas ("syngas"), usable to generate heating, cooling and power. Feedstocks need to be carbonic in nature to produce energy making them suitable for a range of wastes. As opposed to incineration (which burns waste, requiring extensive air emissions control systems), gasification is a quasi-manufacturing process that minimizes the need for emissions control systems and is operated to avoid generating toxins.[23]

Figure 11: Dockside Green Energy Plant

Approximately 75% of CRD waste flow is suitable for gasification. Residuals are primarily biochar and fly ash, which are usable and saleable. Gasification and recycling combined,

[21] See CRD biosolids web pages.

[22] See for example: odour articles #1 #2 #3; explosion articles #1 #2 #3.

[23] By contrast half the cost of incineration plants are typically their emissions control systems to manage particulates and toxins.

should be able to treat the entire municipal waste load, when combined with Blue Box recycling and Extended Producer Responsibility programs for paints and other household hazardous materials.

In terms of energy recovery, gasifiers generate syngas (synthesis gas – a mixture of gasses) used for heating, cooling and other purposes. Output has been measured at ≈ 3.23 MW/tonne, with syngas emissions similar to natural gas boilers whose emissions are permitted in BC.

Gasifiers do not require large areas (e.g. Figure 10, where a unit roughly double in size to Esquimalt's needs occupies a site similar to Esquimalt's Public Works Yard). Gasifiers generate little noise, odour and emissions, which means they can be located in urban areas with little impact to adjacent uses. A gasifier is located in Dockside Green adjacent to residential development (Figure 11).

4.1.3 COMPARISON

In 2017 The Chair of CRD's IRM Task Force asked us to compare the life cycle cost of anaerobic digestion with gasification for biosolids management, using CRD budget projections provided to the Task Force. We have updated this with gasifier revenues, operating and maintenance costs described in sections 5.3 and 5.4 starting on page 43. Feedstock delivery is excluded and the summary is after debt in current dollars, i.e. excluding inflation.[24] The results are tabled in Figure 12 and show that whether on a cost basis ("Annual payments") or net cost basis ("Cost/revenue per tonne"), gasification is financially superior. Note that these costing were not developed by Pivotal but use actual bid costs and CRD's business case for the digester, with budget calculations from CRD's engineers for the gasifier, which are high, i.e. more accurate costing would further improve the gasifier's financial advantage.

	2016 Digester	2016 Gasifier
Capital plant	-$127.0m	-$50.0m
Pmts 25yrs @ 4%	-$7.8m/yr	-$3.1m/yr
O&M	-$3.0m/yr	-$1.6m/yr
Annual payments, yr 1	-$10.8m/yr	-$4.7m/yr
Revenues, yr 1		+$5.7m/yr
Net costs/revenues/yr, yr 1	-$10.8m/yr	+$1.0m/yr
Cost/revenue per tonne/yr	-$1,291/tonne	+$122/tonne

Figure 12: Technology Financial Comparison

A technology comparison summary is provided in Figure 13 with comments as follows.

- Gasification is a cheaper solution both in initial and ongoing costs, life cycle costs and costs per processed tonne. Gasifiers can potentially be profitable whereas digesters require ongoing taxpayer-funded financial support;
- Gasification is a more complete solution. Whereas digestion leaves 63% of the waste stream needing to be addressed gasification should be able to convert it all;
- Gasification has a higher energy recovery yield at ≈3.23MW/tonne of waste compared to digestion at ≈2.1MW/tonne;

[24] Discounted cash flows have not been used as these distort the financial results for projects of this type.

- Gasifiers are scalable and can be phased. Digesters are more difficult to phase or scale and more reliant on projections being accurate;

- Digesters are usually located in remote areas due to odour and explosion potential, and Esquimalt has limited location options of this type. The community rejected digestion in 2013 for biosolids processing, with public meetings mainly citing odour, traffic and explosion concerns for the proposed location in an industrial neighbourhood with adjacent residential. By comparison gasification is simpler to locate as it requires smaller sites, thus improving location options; avoids odour production (as it is not a biological process with long storage durations); and experts in Europe and the USA confirm no gasifier has exploded in recorded history. For both digestion and gasification traffic would not change as the trucks are already circulating the community;

- In terms of risk, digesters' main risks are odour, explosion, finance and technology. Gasification has less operational risks but increased technology risks, with lower finance risk as the systems are cheaper to both develop and run. Both systems' risks are manageable and both the technologies and the yields can be guaranteed by substantial, qualified companies, thus addressing risks (subject to procurement approach);

- Digestion requires greater taxpayer support than gasification.

Aspect	Anaerobic digestion	Advanced Gasification
01 Site size	Large, usually multiple acres	Small - ≈1 acre for small plant
02 Location	Remote desirable	Can be urban
03 Typical location	Rural or away from population	Industrial or light industrial
04 Risks (see text)	Odour, explosion, sensitive to inputs, underperformance, life cycle cost, taxpayer support, soils amendment containments	Underperformance, taxpayer support, life cycle profit, technology history
05 Viability	Requires continual taxpayer support	Can be viable, taxpayer support minimal/contingent, if underperforming
06 Feedstock suitability	≈11% of volume Organics only	≈75% of volume Most solid wastes
07 Wastes not addressed by technology	≈63%	≈8%
08 Proven with proposed feedstocks	Expected to be possible with organics; unsuitable for wider waste streams	Satisfactory initial tests with MSW, organics, biosolids; more tests desirable
09 Phasing & expansion	Difficult/no	Yes, 6-10 months fabrication lead
10 Performance guarantee	Potentially but adds cost	Potentially but adds cost
11 Residuals	Half of feedstock	None
12 Recovered, saleable resources	Biogas for heating/RNG	Heating, cooling, biochar
13 Energy yield per tonne	2.1 mw/tonne or 7.6 GJ/tonne	3.2 mw/tonne or 11.6 GJ/tonne
14 Soils amendment yield/tonne	None - being incinerated	250-300 kgs per tonne, sterile
15 Capital cost per tonne processed, life cycle	≈-$232 per tonne	≈-$91 per tonne
16 Operating cost per tonne processed,	-$3.0m/yr	-$1.6m/yr
17 Total net life cycle cost/revenue, undiscounted, current $$, after debt	≈-$1,291 per tonne	≈+$122 per tonne
18 Est. extra costs/revenues	Unknown cost to handle unaddressed waste; at minimum landfill tipping fees	Landfill tipping fees for any improperly sorted residuals
19 Annual tCO2e reduction	Not assessed by CRD	≈7,600 tCO2e
20 Life cycle CO2e reduction	Not assessed by CRD	≈380,000 tCO2e

Figure 13: Technology Comparison

In summary while digestion is a better known solution, on almost all indices Advanced Gasification is better suited to address Esquimalt's needs.

MoE requires technologies be reviewed as part of waste planning and decisions concerning implementing energy recovery, which has been undertaken by several engineering companies for CRD over the past decade. CRD has held at least six expressions of interest, requests for information and proposal calls on this matter. The IRM calls resulted in the IRM Task Force recommending the best option as Advanced Gasification. Figure 13 and the IRM Task Force's review both point toward Advanced Gasification as a suitable technology.

4.1.4 Gasification System

In selecting technologies for municipal systems, a common approach is to exclude from consideration any technology unless there are multiple existing operating examples identical to that proposed – essentially a "proxy approach." In Esquimalt's case however few or no examples are likely to be processing the exact wastes and volumes at the required size, scalability and flexibility, or with the current or future mix of feedstocks, feedstock fluctuation and phasing in Esquimalt. The "proxy approach" is a leap of faith that an example in one location means it will work elsewhere, and not a guarantee that it will work in Esquimalt.

Instead of a proxy approach, we focus on risk management and proving a system will work. This uses a sequenced protocol where: (1) Esquimalt's actual wastes are tested in an existing system to prove the system will work with Esquimalt's actual proposed wastes; and, (2) based on physical and laboratory tests, the manufacturer then guarantees the system will achieve the yields, which are then used in the business case. Because this tests actual wastes and physically proves operation before taxpayer commitment, and links payment to performance, it is a faster and cheaper way to confirm that systems will work, and is more directed while reducing taxpayer risk before proceeding. More information is included in section 4.4 *Feedstock Process* on page 35, and we note that not all systems manufacturers are willing to consider this risk management approach.

A wide variety of gasification systems exist but several factors are key in determining the optimum gasification solution:

- Increasing investment is being made to maximize yield from gasifiers such as plasma arc systems. While these claim high energy yields they are generally less proven with high consumables, low up-time and can be susceptible to feedstock fluctuations;
- Some gasification systems are ultimately less viable due to high consumables and related operating and maintenance costs;
- Some systems do not scale well for the sizes needed for Esquimalt;
- Some systems have low up-time operation, e.g. some plasma arc systems;
- Systems such as fluidized bed designs while high yielding and stable, are better suited to RNG production and not well proven with variable waste feedstocks of the type proposed in Esquimalt, so again are less suitable for the current purposes;
- Unmodified updraft/downdraft gasification systems while generally proven, are better suited to predictable feedstocks with little variation, as they can otherwise suffer from aspects such as bridging, ash volatilisation and other factors that trigger reduced efficiency with periodic possible system shutdown, reducing viability and reliability.

Working in conjunction with experts operating existing plants and academics at three universities in Europe and the US, we reviewed over 90 gasification systems to assess we identify as best suited to Esquimalt's needs, summarized in Figure 14.

#	Technology	Units	MSW	Capex/tonne	Opex/tonne	RNG	Biochar	Scalable	Feedstock flexibility	mwT/tonne	Uptime	Economic
1	RotoGasifier	<10	Yes	Low	Low	Low	Yes	Yes	V. high	V. good	80-90%	Good
2	Circle Draft	<10	Yes	Low	Low	Low	Yes	Limited	Moderate	Good	50-75%	Moderate
3	Plasma	10-50	Yes	V. high	High	High	No	No	V. high	Excellent	25-50%	Poor
4	Fluidized Bed	50+	Probable	High	High	High	No	Limited	Limited	Excellent	75-90%	Marginal
5	Up/downdraft	50+	Probable	Moderate	Moderate	Low	Yes	Yes	Moderate	Good	50-75%	Moderate
6	Pyrolysis	50+	Yes	Moderate	Moderate	Low	Yes	Yes	High	V. good	75-90%	Poor

Figure 14: Gasifier Technology Summary

Note that a basic explanation of the main different types of gasification is provided in the *Glossary* on page 73, with Figure 14 explained as follows:

- The number of operating units is summarized by technology and includes variants. This is an estimate because typically more systems are operating than are documented.
- As the Township is expressly interested in MSW capability, we have summarized each technology's ability to handle this. Typically all systems have tested or run with MSW, so "probable" refers to the long term operating potential.
- Capex/tonne provides an indication of the total capital cost in relation to the number of tonnes processed. This is relevant because technologies such as plasma arc gasification have high capital cost but many systems have as low as 25-50% uptime, which raises the cost per tonne.
- Opex/tonne, similarly to capex/tonne, provides an index of the overall operating costs for each tonne processed. Pyrolysis systems for example have a low opex, but as they often struggle with MSW, the operating costs rise in relationship to the tonnes processed.
- RNG is a comment on whether the systems can produce Renewable Natural Gas, i.e. methane (chemical symbol CH_4). Syngas from fluidized bed systems for example have a good carbon-to-hydrogen ratio, so the potential RNG yield is high, whereas pyrolysis systems and RotoGasifiers usually have poor carbon-to-hydrogen ratios, so the methane (RNG or CH_4) yield is low. Note that just because plants can produce RNG does not mean that it is viable to do so, which depends on feed-in-tariff and other factors.
- The ability to produce biochar is inherent in most systems but the yield varies widely, mostly being dependent on the feedstock. Some systems produce no biochar (dual internally circulating fluidized bed for example) as the biochar is recirculated internally to fuel operations, which improves the energy yield but at the expense of biochar production. Because biochar is a valuable product, internal reuse can thus lower the overall viability, net of increased energy yield.
- Scalability is a key consideration for Esquimalt due to community growth and phasing requirements. Some systems' lack of ability to be phased or plants to be increased (or if need be, reduced) in size makes them unsuitable candidates given Esquimalt's comparatively small waste volumes. Plasma arc and Dual fluidized bed systems likely fall under this category.

- Feedstock flexibility is important and will stress a system's robustness. Because Esquimalt's wastes can change and are not well defined, the flexibility to handle future changes in feedstock are extremely important. Fluidized bed and up/downdraft systems tend to be impacted by such variations. This would not necessarily rule them out, but means that spare units would be needed to handle issues when individual units fail when the feedstock changes. Where systems have both low scalability and difficulty with feedstock variations, they should be considered secondary options.

- The megawatt energy yield per tonne is a comparative indicator of the thermal output, which can be used for heating, cooling or electricity generation. This needs to be considered in tandem with the revenues from energy yield and other factors, e.g. while plasma arc systems are the highest yield, their lower uptime and higher capex and opex mean that the higher yield per tonne processed is more than offset by other factors. Note that energy costs in BC are in general fairly low, so the revenues from a high mw/tonne are at best an incomplete indicator of viability.

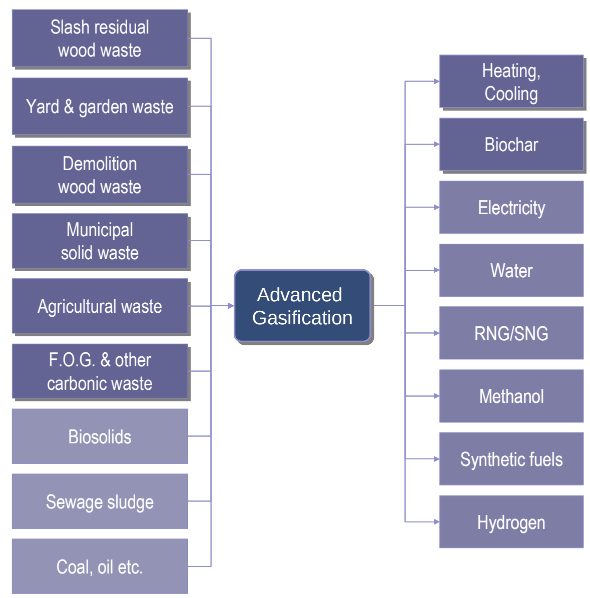


Figure 15: Feedstock & Resource Recovery Options

- Uptime is a critical factor. All systems will have maintenance downtime, but downtime due to difficulties processing MSW mean that, in combination with high consumables (i.e. high opex), some systems' economics are poor. Uptime can be solved however if the systems are highly scalable with low capex, by adding a comparatively inexpensive spare unit to offset unexpected downtime. Thus, plasma arc systems low uptime is difficult to offset as they are not highly scalable; which is offset by their relatively high flexibility and robustness in being able to handle MSW.

- The "Economic" column is a summary assessment of the linked factors of energy and biochar yield, the value of these products, capex, opex, uptime, robustness and scalability over a system's life cycle. Note that this is our assessment given the specific factors affecting the Township of Esquimalt and would likely differ elsewhere, if factors such as feedstock, growth, variability, flexibility, funding, markets etc. change. In reading this column for example: while pyrolysis systems have potential to be candidates for Esquimalt, they are less robust in handling MSW, leading to questionable uptime reliability, so their overall economic ranking is likely to be poor.

We have detail for each of these technologies but it is not the main function of this report to provide this detail. Also, it exceeds the scope and budget of this study to evaluate examples of each of the better options. We will be pleased to provide further detail on gasifiers reviewed if needed.

From our review, the RotoGasifier is the most suitable option for Esquimalt. The RotoGasifier's low number of plants is not a dissuading factor given that (a) it has been tested and proven to work with local wastes (Figure 27); and, (b) has had a long development cycle with proven plants and can be guaranteed. Up/downdraft and Circle Draft systems while potentially less expensive, have greater constraints with uptime and flexibility, so their overall economics and suitability for Esquimalt are lower. While there are a number of high-yielding plasma arc systems worldwide processing MSW, these are not scalable to Esquimalt's size and usually have high downtime, making them less viable despite a superior potential energy yield per tonne. The RotoGasifier's developmental track record since the 1990's, superior feedstock flexibility and robustness, scalability and overall net viability are notable and while its energy yield may not be the best, it is superior to almost all other systems and technologies, which helps maximize GHG reduction and carbon sequestration, which are key community commitments.

The RotoGasifier is an Advanced Gasification system, so our conclusion is similar to Advanced Gasification being recommended by CRD's IRM Task Force. Because of the variation in system outputs and given the conclusions summarised in Figure 14, we worked with TSI, the RotoGasifier system manufacturer, on budgets etc. As a final safeguard, we have then outlined a best practice implementation approach used by the World Bank and others to provide taxpayer assurance that the RotoGasifier is the best option.

The Advanced RotoGasification system developed from rotary dryers and pyrolysis units, modified to provide gasification while rotating the feedstock. This improves resilience with varying feedstocks and can be scaled to meet the sizes required for Esquimalt, handling wastes and generating products shown in Figure 15. There are a considerable number of plants in existence so the system has an extended development and performance history. While no plants are currently operating with Esquimalt's exact proposed waste mix, plants are operating with similar feedstocks and both laboratory and physical demonstration tests with local MSW and sewage sludge waste (shown in Figure 27) have shown suitability, supplemented with the manufacturer being potentially able to guarantee performance. More information on the system is included in *Appendix 2:Advanced Gasification* on page 76.

A key aspect of the RotoGasifier is that multiple revenue streams are possible from the system's outputs. Not all gasifiers have this multiple revenue streams or adaptability to vary them, with some plants having few revenue streams and little flexibility. Some are purely operated as cost centres. Figure 15 shows the possible feedstock inputs and resulting resource recovery options, with less-preferred options greyed out. While some technologies pursue notionally higher value outputs such as biofuels, this is less proven and less robust. Additional reasons to select the RotoGasifier is therefore that the yields are compatible with the wastes available and basic energy and other outputs, which support viability, making the RotoGasifier simpler to implement while managing risk.

4.2 Demographics

When community services requiring significant capital investment are planned, they have to consider how demand for services will change in the future, so the plant and services can be sized to meet future needs. We thus reviewed demographics and waste volumes under varying scenarios.

Firstly, a concern with major infrastructure is that sizing can be highly reliant on projections that don't happen. We thus analysed statistics from CRD, BC Stats and Stats Canada and while the year-on-year percentage population growth is somewhat erratic, illustrated in Figure 16, long term growth has been reasonably stable (if low) since 2000.

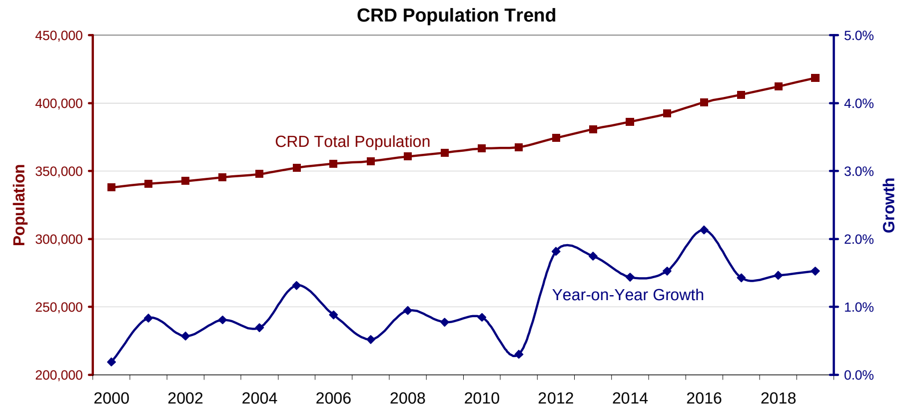


Figure 16: Overall CRD Population Trend

There are appreciable regional population growth disparities, shown in Figure 17 and Figure 18, with come communities exhibiting low growth while others have grown rapidly. This appears to be partly a function of having land suitable for development, and differing degrees to which communities embrace expansion. While Figure 17 shows the overall total growth by community within CRD, the issue becomes clearer when the annual percentage growth is viewed over time, shown in Figure 18.

	Population					
Community	1991	1996	2001	2006	2011	2016
Central Saanich	13,684	14,611	15,348	15,745	15,936	16,814
Colwood	13,468	13,848	13,745	14,687	16,093	16,859
CRD	299,550	317,989	325,754	345,164	359,991	383,360
CRD Core (CALWMP)	239,138	250,487	256,227	271,654	283,977	303,542
Esquimalt	16,192	16,151	16,127	16,840	16,209	17,655
Highlands	1,094	1,423	1,674	1,903	2,120	2,225
Indian reserves	3,214	3,806	4,667	4,670	5,282	5,244
Langford	15,642	17,484	18,840	22,459	29,228	35,342
Metchosin	4,232	4,709	4,857	4,795	4,803	4,708
North Saanich	9,645	10,411	10,436	10,823	11,089	11,249
Oak Bay	17,815	17,865	17,798	17,908	18,015	18,094
Saanich	95,583	101,388	103,654	108,265	109,752	114,148
Sidney	10,082	10,701	10,929	11,315	11,178	11,672
Sooke			8,735	9,704	11,435	13,001
Victoria	71,228	73,504	74,125	78,057	80,017	85,792
View Royal	5,996	6,441	7,271	8,768	9,381	10,408

Source: CRD &Statistics Canada

Figure 17: CRD Demographics, 1991-2016

Esquimalt's population[25] rose from 16,192 in 1991 to 17,655 in 2016, the latest year with available formal census data. Figure 18 shows this is an increase of 1,463 or 0.3% per annum over 25 years, i.e. the long term average growth rate. In the last five years however, Esquimalt's growth has risen to 1.7% per annum. This happened during a sustained peak in the economy, coinciding with increased activity in Esquimalt naval construction.

The 10 year growth rate (0.5% per annum between 2006 and 2016) is likely to be more representative as it spans most of a full economic cycle, however it includes a time when

25 Source: CRD and Stats Canada.

Esquimalt was less conducive to growth and omits expansion of maritime activity. As such, we feel 0.5% likely understates the stable moderate growth rate, which is more likely to be in the ±1% range, i.e. similar to the regional average.

	Fm: 1991			Fm: 2006			Fm: 2011		
	To: 2016	*25 yrs to 2016*		To: 2016	*10 yrs to 2016*		To: 2016	*5 yrs to 2016*	
Community	**Increase**		**%pa**	**Increase**		**%pa**	**Increase**		**%pa**
Central Saanich	+3,130	+23%	+0.8%	+1,069	+7%	+0.7%	+878	+6%	+1.1%
Colwood	+3,391	+25%	+0.9%	+2,172	+15%	+1.4%	+766	+5%	+0.9%
CRD	+83,810	+28%	+1.0%	+38,196	+11%	+1.1%	+23,369	+6%	+1.3%
CRD Core (CALWMP)	+64,404	+27%	+1.0%	+31,888	+12%	+1.1%	+19,565	+7%	+1.3%
Esquimalt	+1,463	+9%	+0.3%	+815	+5%	+0.5%	+1,446	+9%	+1.7%
Highlands	+1,131	+103%	+2.9%	+322	+17%	+1.6%	+105	+5%	+1.0%
Indian reserves	+2,030	+63%	+2.0%	+574	+12%	+1.2%	-38	-1%	-0.1%
Langford	+19,700	+126%	+3.3%	+12,883	+57%	+4.6%	+6,114	+21%	+3.9%
Metchosin	+476	+11%	+0.4%	-87	-2%	-0.2%	-95	-2%	-0.4%
North Saanich	+1,604	+17%	+0.6%	+426	+4%	+0.4%	+160	+1%	+0.3%
Oak Bay	+279	+2%	+0.1%	+186	+1%	+0.1%	+79	+0%	+0.1%
Saanich	+18,565	+19%	+0.7%	+5,883	+5%	+0.5%	+4,396	+4%	+0.8%
Sidney	+1,590	+16%	+0.6%	+357	+3%	+0.3%	+494	+4%	+0.9%
Sooke				+3,297	+34%	+3.0%	+1,566	+14%	+2.6%
Victoria	+14,564	+20%	+0.7%	+7,735	+10%	+0.9%	+5,775	+7%	+1.4%
View Royal	+4,412	+74%	+2.2%	+1,640	+19%	+1.7%	+1,027	+11%	+2.1%

Source: CRD &Statistics Canada. Analysis: Pivotal

Figure 18: CRD Community Growth Trends, 1991-2016

In summary Esquimalt's population growth has been somewhat erratic historically, but has recently consolidated at rates at or above the regional average, ranging from a minimum of ≈0.3% per annum to a high of ≈1.7% per annum. We conclude that in the longe term, a moderate sustainable rate is likely to be closer to ≈1% per annum.

Following discussion with Township staff we note their expectation that Esquimalt's population is likely to level off at a maximum ≈25,000 some time over the next twenty years. This is based on current planning, service capacities, growth and development assumptions, but is in great part a reflection of the community not now having appreciable spare developable density. We discuss this later as part of our analysis and projections.

Population projections in the region are notoriously difficult due to fluctuating local and international economics and especially, local political constraints or enablement of growth. Because growth has historically fluctuated, planning any plant size based on growth projections is inherently risky but avoidable by using alternate strategies.

We thus conclude that any IRM solution needs to be flexible and adaptable to demographics, i.e. able to adjust to population growth and resulting waste services as and when it occurs. Any plan should not be dependent on achieving a specific growth projection that might well never be achieved, or changes overnight due to unpredictable regulatory or policy changes that render prior projections inapplicable, stranding assets, viability and environmental results.

4.3 Waste Analysis

Two types of waste were flagged for resource recovery consideration: liquid and solid wastes. Within these, two main factors need to be considered: the volume and nature of the waste (usually termed "composition"); and how this will change over time. At the same time, consideration must also be given as to whether it's (a) possible and (b) worthwhile, to recover the resources.

4.3.1 Liquid Waste

We recommended deferring consideration of liquid waste resource recovery, which we were asked to explain.

There are three main types of resources that can potentially be recovered from sewage: (a) energy from solids; (b) heat; and (c) water.

In implementing its liquid waste plan, CRD will process the region's liquid wastes at a new plant at McLoughlin Point in Esquimalt. From there, extracted solids will be pumped in a slurry to an anaerobic digester located at Hartland Landfill in Saanich, ≈18km from McLoughlin. This means that extracting energy from sewage solids will be unavailable in Esquimalt, unless it is later reconsidered. For current purposes this recovery option has thus been discounted.

Turning to the potential to extract heat energy from sewage, KWL's 2013 study (section 3.3.1 on page 7) assumed rising sewage flows but data kindly supplied by CRD (Figure 19) shows, conversely, that flows have been falling, with opportunity to fall further as communities repair existing pipes. Reducing flows means the heat energy available for recovery is uncertain. Sewage flows appear to have stabilized at 70-72 ML/Day from a peak of 100ML/Day in 2006, a fall of ≈28%, whereas the model used for sewage flow projections[26] anticipated that sewage flows would increase by ≈12% over this period. Flow increases were assumed in KWL's resource recovery study for Esquimalt, which means the study's underlying assumptions have not been experienced in practice, making the study's conclusions risky to rely on without updating. While the McLaughlin plant capacity is sized at ≈50% above recent flows, which allows for aspects such as storm events, the divergence of projections from actual flows makes it uncertain whether resource recovery from sewage is worthwhile and whether the projection models can be relied on for energy planning of this type.

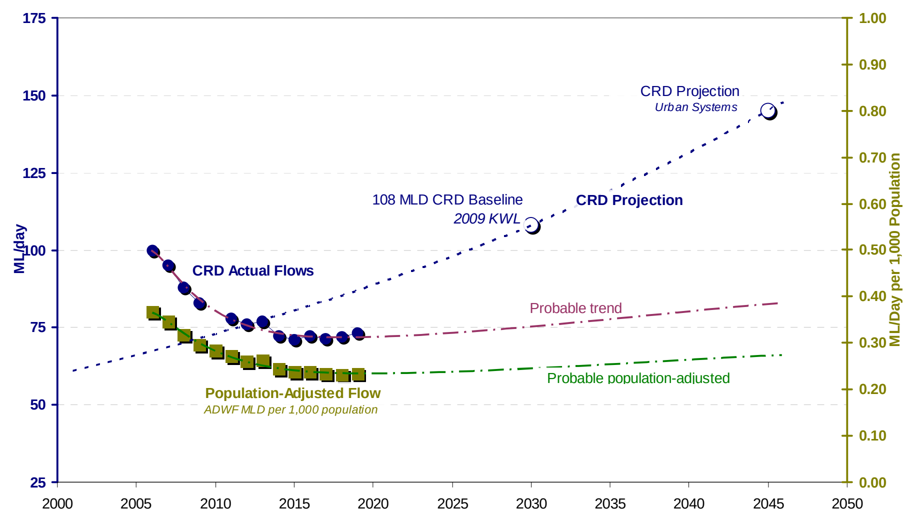


Figure 19: CRD Core Liquid Waste Volumes

[26] KWL originally developed the sewage flow projection model for CRD in 2000.

KWL's 2013 study concluded energy recovery from liquid waste flows was marginal. Given reduced flows shown in Figure 19, we expect viability would be lower and extraction of energy from sewage would probably be unviable. Given the difficulty experienced in predicting flow volumes, we recommended waiting until there is greater certainty, after McLoughlin opens and actual flows/temperatures are measurable, rather than relying on estimates based on projection models, with associated risks. We also recommended not considered water recovery from sewage because as discussed later, substantial volumes of water can be recovered from solid waste if desired, but the economics of doing so are currently unviable. The deferral of this aspect was thus agreed with staff, but can be revisited as desirable.

4.3.2 Solid Waste Composition

Municipal Solid Waste is typically a mixture of different material types that require technologies able to handle them. Esquimalt does not have an assessment of waste composition, but a summary of CRD's 2016 composition assessment for Hartland Landfill is summarized in Figure 20 with detail provided for both 2010 and 2016 composition studies shown in Figure 21.

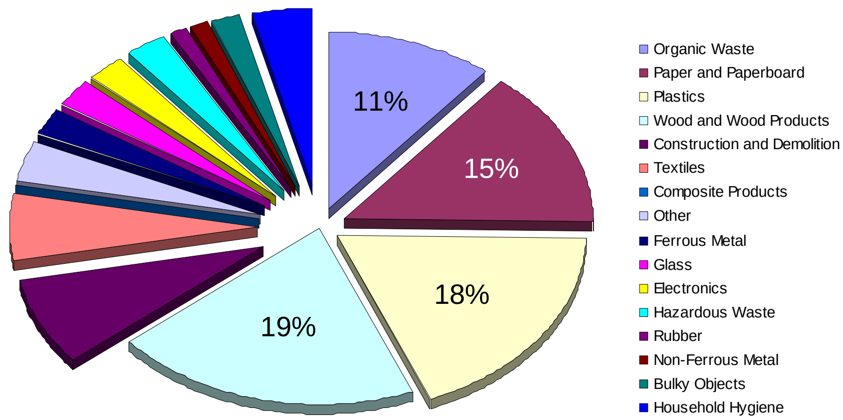


Figure 20: CRD 2016 Solid Wastes by Dry Weight

CRD periodically commission solid waste composition studies (most recently in 2009-2010 and 2016)[27] and we understand an update is being considered. Until Esquimalt's wastes are tested, CRD's analyses are the closest assistance available in assessing Esquimalt's waste composition.

- Organic waste has been a focus for diversion by CRD as this is a major source of GHGs. We calculate that organic waste received at the landfill fell between 2009/2010 and 2016 by ≈ 18,121 tonnes or ≈9.4% per annum, which is a ≈39% overall diversion rate over ≈6 years, i.e. assuming the review is correct, ≈61% of the organic volume was still reaching the landfill in 2016.
- Between 2009/10 and 2016 CRD's population rose from ≈360,000 to 383,000 and through increased organics diversion and other strategies, meant the waste per capita received at the landfill fell from 426kg/person on average to 352kg/person.
- CRD's composition studies track waste received at Hartland landfill but other wastes are known to exist, for example some are already being trucked and incinerated at a mid-

[27] See CRD Solid Waste document hub, 2010 and 2016 studies.

Island pulp mill and some communities (e.g. Saanich) have signed contracts to handle their organics independently of CRD.

- CRD's current approach with solid wastes varies, for example:

    a. Plastics and Styrofoam, amongst other recyclables, are now also being considered for alternate approaches as recycling has been called into question as China, the Philippines and Malaysia now reject Canadian materials;

    b. Biosolids will be trucked/barged and incinerated in Lower Mainland cement plants, although other options have not been ruled out;

    c. Kitchen scraps and yard and garden wastes are being considered for in vessel composting or anaerobic digestion at Hartland but are mostly currently being sent to the Lower Mainland.

Capital Regional District, Hartland Landfill Composition Studies											
	Study: 2009-2010				Study: 2016				Analysis		
Category	**Tonnes**	**Wet %**	**Dry %**	**kg/person**	**Tonnes**	**Wet %**	**Dry %**	**kg/person**	**↑/↓**	**%pa**	**Diversion**
Organic Waste	46,606 t	30%	16%	129	28,485 t	21%	11%	74	-18,121t	-9.4%	39%
Paper and Paperboard	25,362 t	17%	16%	70	20,790 t	15%	15%	54	-4,572t	-3.9%	18%
Plastics	20,059 t	13%	18%	56	19,305 t	14%	19%	50	-754t	-0.8%	4%
Wood and Wood Products	15,225 t	10%	12%	42	22,950 t	17%	20%	60	7,725t	+8.6%	-51%
Construction and Demolition	9,385 t	6%	8%	26	9,045 t	7%	8%	24	-340t	-0.7%	4%
Textiles	8,441 t	6%	6%	23	7,965 t	6%	6%	21	-476t	-1.2%	6%
Composite Products	7,931 t	5%	6%	22					-7,931t	N/A	
Other	7,468 t	5%	7%	21	3,645 t	3%	4%	10	-3,823t	-13.4%	51%
Ferrous Metal	3,638 t	2%	4%	10	2,430 t	2%	3%	6	-1,208t	-7.8%	33%
Glass	2,974 t	2%	3%	8	2,295 t	2%	2%	6	-679t	-5.1%	23%
Electronics	2,928 t	2%	3%	8	2,430 t	2%	3%	6	-498t	-3.7%	17%
Hazardous Waste	1,179 t	1%	1%	3	2,430 t	2%	3%	6	1,251t	+15.6%	-106%
Rubber	1,083 t	1%	1%	3	1,080 t	1%	1%	3	-3t	-0.1%	0%
Non-Ferrous Metal	982 t	1%	1%	3	945 t	1%	1%	2	-37t	-0.8%	4%
Bulky Objects					1,755 t	1%	2%	5	1,755t	N/A	
Household Hygiene					9,315 t	7%	4%	24	9,315t	N/A	
Total	**153,261 t**	100%	100%	426 kg	**135,000 t**	100%	100%	352 kg			
Population	359,991				383,360					+1.3%pa	
Kg per capita per annum	426 kg				352 kg				*Approx avg.*	-3.1%pa	

Figure 21: Hartland Waste Composition Analysis[28]

While some wastes included in the 2009-2010 composition study have been diverted, their volume didn't disappear, but have been diverted and are no longer being handled at Hartland Landfill.[29] This means that current landfill rates could rebound, which an IRM approach may help to address.

The waste industry usually assesses solid waste using "wet" weights and with their high GHG potential and percentage of the wet volume at landfills, organic wastes have been a focus. However moisture is the largest single component in municipal solid waste – but is rarely counted. Since *dry* material is a potential energy resource, Figure 21 applies our assessment of average moisture content (based on tests in CRD and elsewhere), showing that organics are ≈21% of the wet volume but only ≈11% of the dry volume. This fundamentally affects

[28] Figure 21's calculations are consistent with CRD's 2018/1019 Hartland Landfill Gas Monitoring Report, page 8, that "*A conservative estimate of 20,000 tonnes has been [diverted] … through 2018.*"

[29] For example, organic wastes did not drop from 46,606 to 28,485 tonnes per annum, the wastes were redirected to other locations such as composting operations on the Saanich Peninsula, the Cowichan Valley and Lower Mainland.

decisions and approaches, since moisture can be easily removed by waste heat from gasification while maximizing energy recovery. It shifts the primary focus from organics to having a more complete plan that maximizes reuse, recycling, resource recovery and landfill diversion, i.e. consistent with MoE's 5Rs policy.

4.3.3 Solid Waste Volume

Figure 22 shows that in 2019/2020 the Township collected 3,398 tonnes waste, largely from single-family residences, and provides the 2020 budget costs which include wages, new bin purchases, bin advertising stickers and vehicle depreciation (the "Tipping Fees" column, also shown as a $/tonne). For contrast we included CRD's Hartland tipping fees, to cover landfill costs. Note that the Township's costs are higher because they also cover haulage, systems and staffing. We are aware of costs in other communities, some of which exceed $400/tonne including haulage, i.e. the Townships costs appear to be within the range experienced elsewhere. The estimated moisture content of the wastes is shown with the resulting estimated dry annual tonnage. The latter is the most pertinent, as explained later.

Township of Esquimalt, 2019/2020	Tipping fee	Tonnage	$/tonne	Moisture	Dry	Hartland
Yard & Garden	$202,182	1,778 27%	$113.71	40%	1,067	$59.00
Food waste	$157,147	566 9%	$277.50	60%	227	$120.00
Subtotal	$359,329	2,344 36%			1,293	
			$153.28	45%		
MSW	$292,480	1,054 16%	$277.50	25%	790	$110.00
Total	$651,809	3,398 52%	$191.81	39%	2,084	
Plus: private hauled wastes		3,100 48%		25%	2,325	
Total current estimated volume		6,498 100%			4,409	
Total current estimated volume, dry tonnes per day, public only					5.7dtpd	
Total current estimated volume, dry tonnes per day, combined					12.1dtpd	
Unsorted MSW moisture content					37%	

Figure 22: Esquimalt Waste Summary

The Township collects wastes from only a portion of the community, mostly comprising single family homes and small apartments, whereas private haulers mostly collect waste from larger multifamily buildings and businesses. We thus canvassed private haulers known to be active in the community who state that in 2019 they collected ≈3,100 tonnes of MSW in Esquimalt, which is added into Figure 22's totals. The haulers believe this contains only a small amount of non-Esquimalt wastes. The total of ≈6,498 tonnes is close to the provincial estimate for

Esquimalt of 6,223 tonnes in 2017 and is thus considered credible, so private haulage comprises ≈48% of the waste volume with the Township collecting ≈52% of the volume.

Notably, the combined volume of public and private wastes calculates as ≈347 kg/person (including yard & garden waste, which is not in the provincial guideline). The provincial guideline is for communities to reduce waste through the first 3R's, down to 350kg/person/year, so the total known waste in Esquimalt is below this provincial threshold guideline. Under MoE guidelines Esquimalt can thus consider energy recovery from waste.

The Township's data on waste volumes fluctuate during the year as shown in Figure 24 for 2018, the most recent year for which a full range of data is available, with an appreciable variance between food and MSW, compared to yard and garden wastes. This is likely due to seasonal factors, which highlights the complexity of addressing waste volumes and sizing plant appropriately. Other years vary from these flows and while not all data is available for each waste stream by month from 2011-2019, we were able to interpolate and estimate volumes where the data appears anomalous or was not collected.

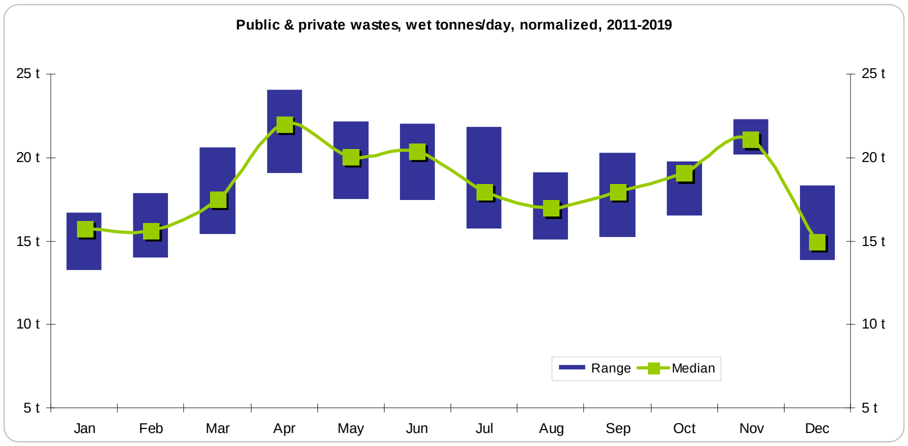


Figure 23: All Wastes, Wet Tonnes/Day

Figure 23 shows the total known Esquimalt wastes as (a) a range of volumes in wet tonnes per day, by month, between 2011 and 2019 (i.e. the way the wastes are received); and (b) the median volumes. This confirms an appreciable range of volumes over the year and thus, the need for any plant to be able to handle fluctuating waste volumes. Figure 25 shows the same data but adjusted to cover the underlying dry tonnage, which is key to determining energy yield and plant size.

Figure 23 is useful to scope receiving volumes and related aspects such as receiving bins, dryer capacity and tipping fees, whereas Figure 25 is more useful to estimate gasifier processing capacity, dried feedstock storage bin size, conveyor hoppers etc. Figure 25 suggests that *current* waste volumes are likely to be mostly addressed by three 5-tonne gasifiers, supplemented by either a balancing strategy to cover excess flows, or preferably a fourth unit to address extra volumes and plant rotation for emergency, downtime and maintenance purposes. As growth occurs or if sporadic volumes become more frequent, a fifth unit could be added; or the unit capacities adjusted if this proves to optimize operations (e.g. by purchasing 7-tonne units, not 5-tonne).

Figure 23 and Figure 25 assess the current total waste volume in Esquimalt but a smaller plant would be possible addressing purely the Township's own wastes. Other options have not been explored in detail pending a decision to pursue an IRM plan

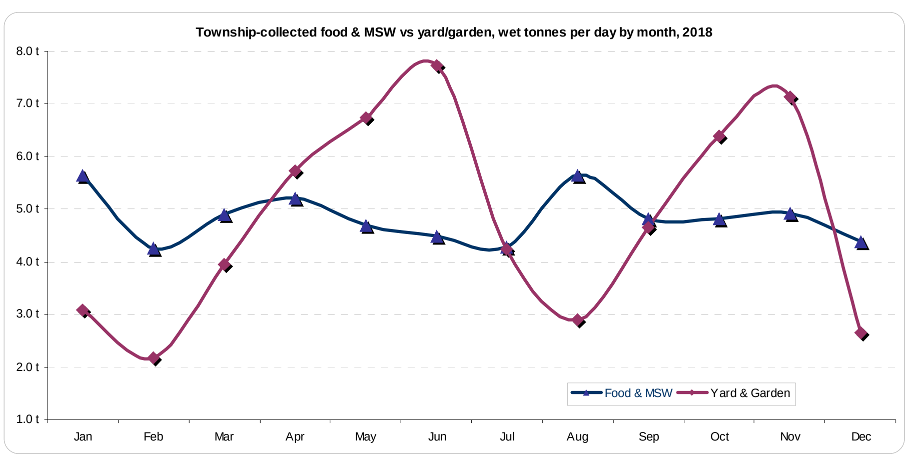


Figure 24: Esquimalt monthly waste flow comparison

further, but scenarios were developed comparing the Township's waste alone, compared to the entire waste stream. Should the decision be made to proceed further, additional review of underlying waste volumes will benefit, to improve accuracy and costing, and help address peak volumes while minimizing and phasing plant.

Addressing Esquimalt's private wastes would require the cooperation of haulers, so we contacted selected haulers[30] who expressed interest and support for supplying material to an IRM plant, once the concept was explained. The main concern was cost impact, which we anticipate would be minimal or an overall reduction and benefit to haulers, since it would reduce trucking and related costs.

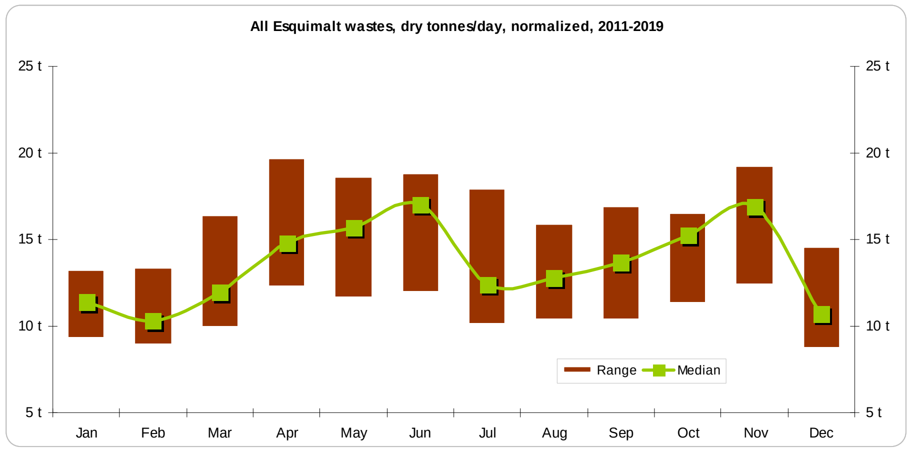


Figure 25: All Wastes, Dry Tonnes/Day

While haulers' interest is subject to further discussion once Council determines direction, their waste volume has been considered for scenario planning purposes and would be formally confirmed should Esquimalt proceed. We conclude that an IRM plant would benefit both haulers and taxpayers through reduced trucking, GHGs and cost-effectiveness, as well as improving resource recovery. Haulers are generally supportive and live in the communities they serve, so we do not feel that securing their waste will be a barrier.

4.3.4 Solid Waste Volume Projection

In planning major systems, a key consideration is how demand will grow over time. For current purposes we have adopted a 30 year projection "life cycle", although the equipment itself will have a 50 year design life with appropriate operating and maintenance costs (which has been included in life cycle projections). Since this is an extended duration and financing would likely be over a shorter duration, we chose to assess the first 30 years of the life cycle for projection purposes. The main question is how the volume of waste might grow over this term, which is primarily affected by:

- Increasing efforts to minimize waste and improve diversion, offset by increasing population. Other external factors such as senior government regulation and packaging changes will also change the nature of the waste, not just the volume;
- Waste volumes per person have fluctuated over time with CRD data likely embedding a higher portion of urban densification. CRD reports indicate 2018 Hartland waste volume

[30] Personal conversation between G Bethell and haulers, March and April, 2020.

at ≈388kg/person[31] up from 2016's 352kg/person but down from 426 kg/person in 2009 (Figure 21);

- Figure 18 shows that population growth has varied appreciably in Esquimalt, with higher rates of growth more recently. This wide range illustrates that projecting potential growth factors creates challenges (and impacts allowances needed for plant size).

We understand that the community is currently expected to reach a buildout at some point over the next ten to fifteen years, with an initial estimate of ≈25,000. While this will tend to limit potential growth in waste volume, aspects such as densification and/or increased home occupancy ratios might also cause maximum buildout projections to be exceeded. Conversely, recessionary factors or slow-down in naval base operations would extend the duration to achieve buildout or reduce growth. We thus ran scenarios independently of the buildout threshold, so the impact on plant sizing can be assessed.

Figure 18 shows a range of growth scenarios based on recent trends (0.3% to 1.7% per annum), estimated to 2053.[32] As it cannot be assumed that the waste per capita will remain fixed, several scenarios have been considered: (a) The Township's current collection volume excluding other sources; (b) the Township's waste plus collaborating known private sources; (c) CRD's 2009-2010 waste per capita and (c) CRD's 2016 waste per capita. A range of possible flows has to be taken into account in projecting plant size, shown in Figure 26.

Waste volume projections						30+3 yr projection
			Wet tonnes per annum		Dry tonnes per day	
			182kg/head	347kg/head		
Scenario	Growth	Popn	a) Township	b) Combined	a) Township	b) Combined
Current	0.0%/yr	18,716	3,398 t	6,498 t	5.7 t	12.1 t
1: Minimum	0.3%/yr	20,600	3,700 t	7,200 t	6.3 t	13.3 t
2: Moderate	1.0%/yr	25,700	4,700 t	8,800 t	7.8 t	16.6 t
3: High	1.7%/yr	32,100	5,800 t	11,100 t	9.8 t	20.7 t

Figure 26: Wet/Dry Volume Estimates[33]

Figure 26 estimates waste volumes with varying population growth scenarios[34] based on either (a) the Township's current waste collections; or (b) combined Township and privately hauled Esquimalt wastes. It indicates a minimum plant size using Esquimalt's *current* municipally-collected waste (estimated at ≈52% of the waste volume) at ≈3,400 wet tonnes per annum. Once private wastes are included and a minimum growth scenario calculated, scenarios range from a low of ≈7,200 tonnes/year to a high of ≈11,100 tonnes, albeit the more likely scenario is ≈8,800 tonnes per annum at the end of 30 years. Inclusion of private wastes while voluntary can be handled by contract and is a more complete solution, addressing the community's wastes, i.e. the most consistent in waste planning, climate change GHG reduction and landfill diversion.

31 159,942 tonnes waste per Hartland 2018 landfill gas report (page 7); 412,220 population per CRD statistics.

32 Allows for two year's preparation, one year's construction, 30 year life cycle.

33 Projections are rounded. Detailed calculations were used by waste stream and may vary from the rounded totals.

34 Figure 26 uses straight line compound growth projections, which in practice is unlikely to occur, but assists in developing a range of scenarios to understand the impact of varting growth rates.

An important aspect of Figure 26 is that growth happens slowly, so the initial plant size is likely to be manageable for some years before the plant's capacity has to be expanded. This affects budgeting and phasing as well as initial costs and risk, considered below.

Given the variability of waste volumes shown in Figure 24 through Figure 25, Figure 26 still represents an appreciable range, which increases risk because of uncertainties about population growth and waste reduction. However this risk can be almost entirely addressed using a risk-managed "just in time" approach:

- Gasifiers are scalable and units can be added relatively quickly (within 6-8 months, plus commissioning). This means that if, as and when the volume of waste grows, and/or as waste characteristics change, suitably configured gasifiers can be added and the plant adjusted or expanded.
- This "just in time" approach: (a) allows for technology adaptation and improvement; (b) avoids the need to pay a higher cost today, which would increase cost to current residents for a future need that is uncertain; (c) limits initial taxpayer investment and risk; (d) reduces resulting debt and operating costs until the need to spend more is proven; and, (e) allows system design to match waste characteristics available in the future, not the ones guessed today to potentially occur in the future.

Figure 27: Demonstration Test of Local Waste

In short a just-in-time approach allows for the plant to be sized as initially needed, then expanded as/when the need is proven and avoids building a plant for a volume that may not materialize. We have thus considered a phased just-in-time approach with allowance for future expansion and adaptability, discussed in section 5.

4.4 Feedstock Process

It is important to understand the gasification process as it impacts location, site use etc.

Waste streams available within the Township include: MSW; food scraps and source separated organics; yard and garden waste; and wood waste, including Construction & Demolition [C&D] materials. Recyclable materials, including metals, glass, plastics, paper/card board and related materials are separated into the Blue Box program and reused/recycled accordingly. Electronic wastes are also separately recycled along with white goods and appliances. Figure 15 illustrates gasifier potential feedstock and resource recovery options, but note that while some aspects are possible, they are not recommended. Advanced Gasification is able to handle a range of carbonic materials and Figure 15 shows the range of acceptable wastes and principal resource recovery options in bold. Figure 28 shows the general process for handling these waste feedstocks.

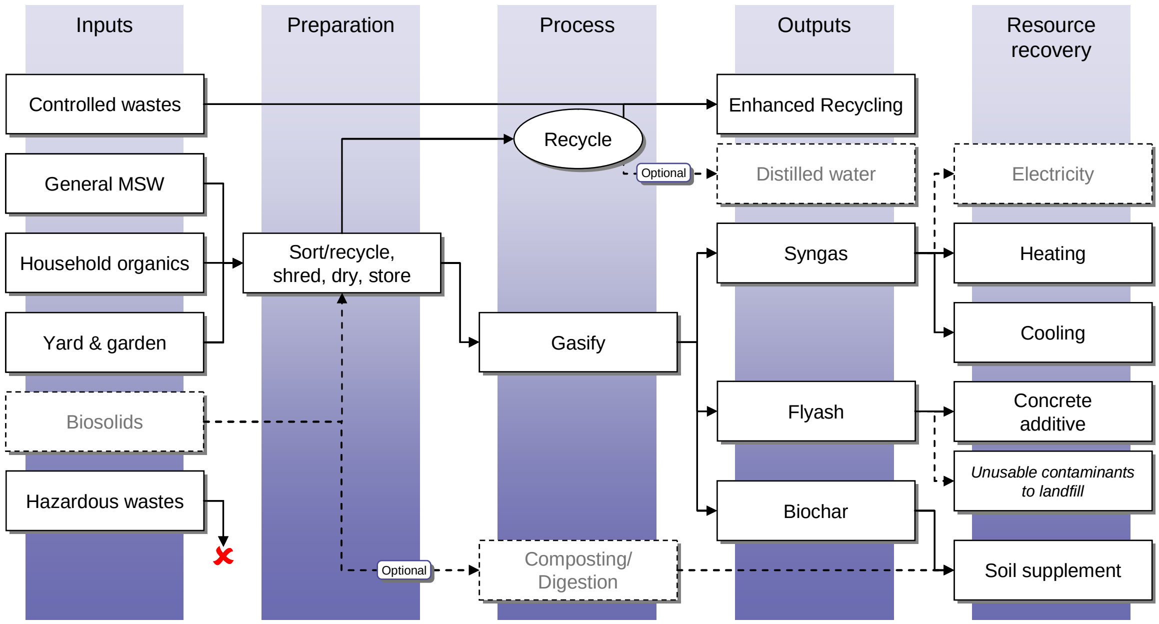


Figure 28: Gasification General Process

Laboratory testing has been previously undertaken of selected waste samples from Langford and Sooke, which is believed to be close to but not the same mixture as Esquimalt. An initial physical demonstration test has also been undertaken and independently observed as being satisfactory (Figure 27), i.e. the gasifier successfully processed the local MSW and biosolids. We recommend undertaking formal structured laboratory and physical tests however, as the fastest and least expensive way to confirm Esquimalt's proposed wastes will work. Formal tests are a minimum pre-requisite for a potential manufacturer's system guarantee and would be needed to confirm aspects such as biochar quality and potential – which would help resolve risk relating to one of the larger revenue sources.

It is helpful to explain how a guarantee would likely work. Firstly the manufacturer would contract with Esquimalt to deliver an agreed system design and energy yield, on which the business case is predicated. This would be determined by testing actual samples of the proposed wastes, both in a laboratory and in an existing gasifier. Funds would be bonded and held in trust and only released when the expected performance is achieved. In this way, Esquimalt taxpayers would be buffered from the risk of non-performance or under-performance. Certain advance funds – testing, design etc. would have to be expended but these are small relative to the cost of the system, covered by the guarantee. While the manufacturer would charge for this guarantee, the cost would likely be comparatively acceptable. Because testing includes samples of the actual proposed feedstocks, this sequenced approach provides physical recorded proof that the system works, before proceeding. This will quickly and very visually help address taxpayer and risk concerns.

The test shown in Figure 27 used locally-obtained MSW. It shows the gasifier can handle waste and modelling shows it can be viable and feasible. We note that on reviewing data provided for this study, we have not found issues that would cause a system not to operate successfully. Testing is thus a desirable and recommended next step. Base tests are likely to cost ≈$20-30,000, which secures proof of operation with actual waste, within weeks, at a fraction of the cost of a full system. Note that the cost and tests have to be confirmed depending on components required to reduce risk.

Recent international media coverage[35] of recyclables in the Philippines and Malaysia revealed that recycling was not happening as expected. For example as a result of this and given concerns over ocean plastics, CRD revisited the potential for plastics and Styrofoam to be handled locally. The RotoGasifier can handle these products, including compound materials where separation and recycling is not possible (either technically, practically or economically). The remaining household garbage consists primarily of dirty paper/cardboard, hard and film plastic, food and other organic material, leather, fabrics, shoes and other textiles, and related discarded materials. This general municipal refuse may contain small residual amounts of metal, glass and other inert materials which should ideally be removed for added recycling before the material is shredded, dried and placed into storage for processing through the gasifier.

Inert wastes that are missed during sorting and recycling will not affect the gasifier, as the materials will be expelled with the biochar. It is however better to sort and extract these items where feasible, to improve energy yield and increase recycling. Notably, this approach and the technology itself are resilient to improperly sorted wastes.

The Advanced Gasifier's rotating design helps eliminate the potential for ash fusion, which was a contributory reason to select the RotoGasifier as the best available technology. Ash fusion can lead to downtime while maintenance is undertaken. No other issues were found in the samples that would impact maximizing uptime through ongoing management and operating procedures will monitor feedstock in the event unexpected materials are included in the waste or other issues arise.[36]

Waste Type	Moisture content	Mineral ash content	Fusion Issues	Contaminants
MSW	25% - 35%	20% - 30%	No	Possible
Food scraps	60% - 80%	20% - 30%	No	No
Yard/Garden	50%	5% - 30%	No	No
Wood (C&D)	5% - 20%	5% - 7%	No	No

Figure 29: Composition Summary

Figure 29 summarizes the typical main composition of MSW, which can include chlorine and sulphur, which can form acid and sulphur dioxide (and ammonia if biosolids are gasified). This is managed with off-the-shelf standard in-line cleaning equipment, the need for which will be confirmed once testing and analysis has been completed. Besides the use of scrubbers, selective catalytic reduction systems and standard air emissions control equipment will be installed to remove particulates using an electrostatic precipitator (ESP) or coated bag filter system. Both have proven satisfactory on plants in Victoria and Europe for example.

Food scraps typically also contain napkins and other paper, cloth towels, plastic bags etc., and have a high water content and will likely require shredding and drying prior to gasification. Alternatively, there may be situations where they may only need to be mixed to be at or near the desired level of moisture content, or dried using heat from the oxidation heater. These adjustments are part of normal operating procedures.

---

35 See for example an overview video, a ≈20 minute CBC documentary video exposing this issue, or videos #1 or #2, showing repatriation of recyclables for incineration in Burnaby. Atlantic province clients report similar issues.

36 In the event wastes exceed standards, yield would be reduced and not result in system failure.

Yard and garden waste primarily consists of pruned branches under 3 inch, shrubs, weeds, leaves and grass clippings (woody branches, weeds and shrubs will need to be chipped/shredded for gasification). Optionally this could be expanded to accept all woody material including tree trunks and large branches, which are suitable for the gasifier. The shredder/chipper can handle C&D waste wood which would be selectively sorted and processed in the IRM facility, i.e. the design can be adapted to allow for increased range and volume of wastes with little effort or cost, thus aiding increased diversion.

A key aspect of Yard & Garden waste is the highly cyclical nature of the wastes and volumes received in Spring and Fall, shown in Figure 24. Initial data did not show this but later data revealed fundamental differences in flow rates, causing the entire plant size, unit sizes, pricing and phasing to be recalculated. This item needs more review should IRM progress, but adequate assumptions have been possible for the current analysis to proceed.

A concern in terms of energy yield is moisture content. Typical moisture content of green wood is 40% - 45%, C&D wood 5% - 15% and the mineral ash content 5% - 7% and possible syngas contaminants from this are typically low. Pivotal staff managed the Dockside Green gasifier where particulate emissions were consistently below MoE permit requirements and we would expect a plant in Esquimalt to be similar. The plant will use energy recirculation and compatible dryers (used in drying sewage sludge and food scraps), specifically designed for energy recirculation and passing dryer air to the oxidation systems where volatile organics are mixed with syngas to improve energy yield and address odour.

In summary although more detailed assessment will be needed should IRM proceed further, we have not identified anything in the possible feedstock that is likely to cause significant issues for an Advanced Gasifier, or jeopardise achieving compliance with applicable regulations, or failing to meet the goals and expectations of the community financially or environmentally. Testing of the actual proposed wastes will be needed to confirm this but existing tests (Figure 27) have demonstrated successful operation.

5 IRM Assessment

This section outlines the IRM Options; assesses potential plant locations; proximity to possible consumers of recovered resources; the capital and operating costs including the viability of options; procurement models; and a possible implementation schedule. These factors were entered into a life cycle business case model that calculates the life cycle for 30 years [plus preparation and construction] for financial aspects and 150 years for GHGs. Inflation is also considered since this can have an appreciable impact. The general process used as a guide to assess IRM for Esquimalt is illustrated in Figure 2 on page 6.

Pivotal's IRM model is a "highest and best use and value" cash flow investment model, consistent with financial standards but adapted to use the same standards and approaches to address environmental and resource aspects.[37] The models allow for interactive assessment of options so financial, resource recovery and environmental impacts and cost/benefit can be compared and the best options chosen to maximize value over their life cycle. The assessment of resource recovery is thus dynamic and adjusted to address varying waste volumes, thus allowing the impact on Esquimalt residents to be assessed as assumptions are adjusted. Scenarios were then run to assess phasing and cost, and reduce risk. The following describes the inputs, assumptions, process and conclusions.

5.1 Main Scenarios

Based on the evaluation of population demographics and waste stream volumes and after discussion with staff, we assessed the following scenarios:

Scenario	Growth	a) Township	b) Combined
Current		3,398 t	6,498 t
1: Minimum	0.3%/yr	3,700 t	7,200 t
2: Moderate	1.0%/yr	4,700 t	8,800 t
3: High	1.7%/yr	5,800 t	11,100 t

Figure 30: Scenario Summary

Figure 30 summarizes a range of growth scenarios (1-3) in combination with either Township-only wastes (a) or combined Township and privately-hauled wastes (b). Further detail is provided on flow variations and scenarios in 6 *Findings*, starting on page 59. Given these potential flows, plant size was estimated, initial needs and expansion potential taken into account, with the following consideration of sites, phasing potential and budgets.

[37] The IRM model and approach is proprietary to Pivotal but has been independently reviewed and approved by multiple climate change, financial and accounting experts, including academics.

5.2 Location Options

Over the past few years, the primary site owned by the Township and suggested for consideration is the Public Works Yard at the northeast intersection of Canteen and Esquimalt Roads. An alternate site was also suggested in the lands adjacent to Archie Browning Sports Centre. Although other site options exist, these are the main current options, considered as follows:

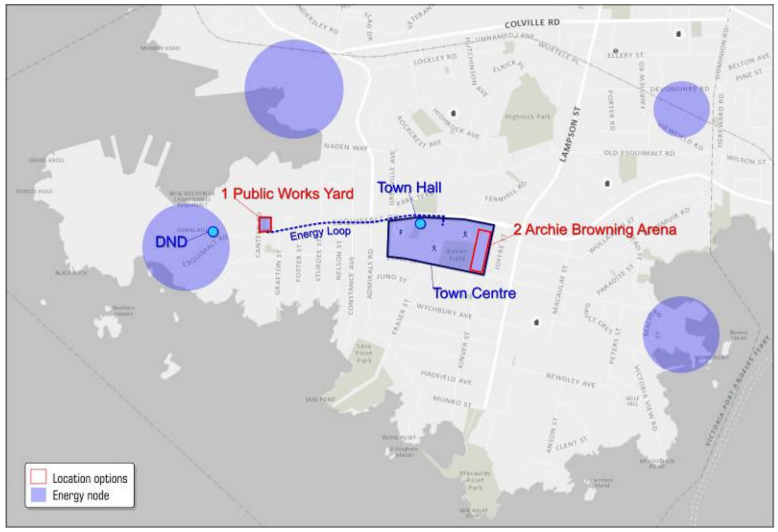


Figure 31: Possible Locations & DES

1. **Public Works Yard** – this small site on Canteen Road is already well used, but there should be sufficient space to accommodate a plant, with expansion potential and without requiring existing activities to be relocated, if planned carefully. Staff expressed concern about phasing on this site so an initial discussion of options is provided in section 5.2.1 *Phasing on page 41*. Subject to decisions over plant size, we are satisfied a plant can be suitably phased using the western portion of this site, with minimal impact to the main (upper) part of the site.

   The site is already zoned for similar use, but would need to be approved for a variation in zoning to permit energy generation. The location has reasonable proximity to users able to take advantage of the plant's recovered energy (for example Figure 31 illustrates a District Energy System alignment to serve the municipal centre). Given the gradual densification of the corridor between Canteen Road and the town centre, this is a suitable location with a loop commencing at the Public Works Yard, extending initially to the municipal centre and Archie Browning, then expanding as demand permits.

   The Township owns and controls the site and it already has a somewhat similar industrial use, so it is considered a potentially suitable option. The Public Works Yard activities do not need the energy an IRM plant would produce, so the energy will have to be delivered to nearby consumers using an energy loop.

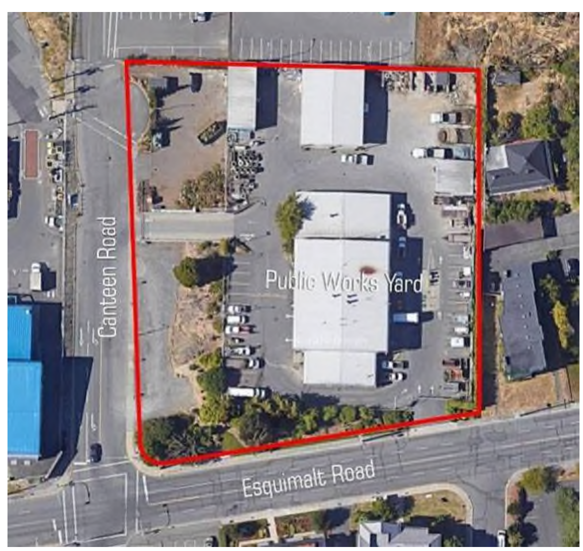


Figure 32: Public Works Yard[38]

2. **Archie Browning Sports Centre** – this is a potential energy consumer due to the

[38] Courtesy Google Maps.

Centre's high energy needs. It has potential land if much of the plant can be located underground, thus avoiding any reduction in the land use. The location could also serve the nearby municipal building, Esquimalt Recreation and Village Centres. The location marked "A" on Figure 33 is one alternative, as this could be completely shrouded from adjacent buildings, but some other locations and orientations are possible on this site too.

Some challenges exist however. Archie Browning Sports Centre is nearing the end of its life cycle and it is assumed will be redeveloped at some point, which due to phasing may see it relocated on the site. Since this has not commenced it cannot yet be determined how the gasifier could work with the Sport Centre or integration as part of the Recreation Centre. Access thus cannot yet be determined but would logically be from either Esquimalt, Fraser or Lyall Streets, however locating the plant and access, would likely be delayed until the broader planning is completed. This would make an IRM plant on this site dependent on planning for this centre, thus delaying implementation. Locating an IRM plant at this site would also likely be part-underground and/or with parking above, both raising costs and increasing servicing complexities and costs.

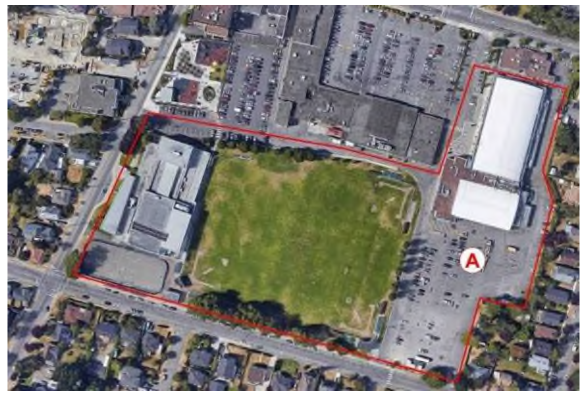


Figure 33: Archie Browning Site

5.2.1 PHASING, ACCESS & TRAFFIC

As the Public Works Yard might initially appear to be too small a site, it helps to show an existing plant located in White Castle, Georgia (Figure 48 on page 77), which has more than double the capacity estimated to be needed for Esquimalt, but on a similar footprint to that at the Public Works site, which should thus be suitable provided if it can be integrated with the Yard operations to accommodate truck unloading and turning manoeuvres.

Figure 34 illustrates some options using the Public Works Yard Canteen Road frontage to develop the IRM plant. Having the site on two levels creates both a difficulty and a possible advantage: the ramp needed to service the upper part of the site can be relocated or if required, retained. While design will be needed to confirm necessary detail, one option is to receive feedstocks from the upper level, which might mean allowing 2-3 trucks per day into this area. Alternatively it may be possible to receive trucks from Canteen Road, but this would likely increase costs. As illustrated in Figure 34, the "B" part of the site for example might contain the gasifier(s) and related energy systems, with the gasifiers on sleds, thus being removable directly onto Canteen Road for off-site maintenance or replacement.

As an alternative, Figure 35 shows moving buildings 1-3 to site 4, to create a single area for an IRM plant at the rear of the site which while not as large, is usable. Relocation of existing buildings would add cost – but may be desirable if this also improves the Public Works Yard's utility. In both options the systems would likely be at sub-grade level to mitigate appearance and access, allowing for decking overhead and two levels of operation. Existing staff parking can be located on parking structures built over the IRM plant – which would increase cost but may be expedient.

In summary there are several options for how the Canteen Road site might be utilised, subject to more detailed review and discussion. We note that the site has a significant rock outcrop, which will increase site preparation costs, but will be offset by reducing foundation costs to carry the main plant. An estimated allowance for this has been included in budgets.

Figure 25 is helpful in showing that current Township waste volumes could be addressed by two five tonne per day units, with a third for high waste volumes and as a backup or maintenance unit. Within a few years and as/when waste volumes grow, other units would be added. Figure 34 illustrates the approximate size estimated for multiple gasifiers on site "B" with associated service access. The 'sled' or container size that would likely be used similar to the gasifier shown in Figure 38 (or the central unit in Figure 47). This provides some sense of the comparatively small size of the units, their suitability and that it would be reasonably simple to add further units as and when needed.

Figure 34: Public Works Yard Layout 1

In the long term future should waste volumes become excessive, site modifications prove impossible or excessively expensive, the Public Works site may become unsuitable. In that event it may be necessary to open a second site, or intensify use of the Public Works site, or relocate. Using gasifiers on removable sleds supports this flexibility and importantly, is consistent with a just-in-time service adaptation strategy, which lowers risk and initial cost.

In short, options exist to accommodate growth if and as required without the need to plan, build or budget for this from inception, in contrast to solutions such as anaerobic digestion, which requires major investment and reliance on projections that may never happen.

Figure 35: Public Works Yard Layout 2

Traffic is a concern for all projects in Esquimalt and warrants consideration. In that regard and assuming the plant takes both Township and private wastes, the volume at the start of the project is estimated at ≈18 tonnes per day, which is currently collected by trucks already operating in the community (estimated at ≈2-3 truck visits to the IRM facility per day). This is anticipated to rise to a maximum of ≈25 tonnes which will likely be supplied by the same ≈2-3 trucks per day at peak (they will have slightly bigger loads). *It is important to note that we do not currently expect this to increase truck traffic in Esquimalt.* These trucks are already collecting waste in the community but instead of going to Hartland Landfill, will make a much shorter trip to Canteen Road, thus reducing overall disturbance and GHGs by unloading at Canteen Road. At any given point near the site we anticipate that at maximum, residents might see trucks going to the plant for perhaps three 30 second intervals in total each way (arriving and departing), but spread over the entire day. Additional employee traffic is anticipated to be a maximum of perhaps 3-5 additional cars or bicycles over the span of the entire day, as existing Township employees would likely transfer to the IRM plant. While the final traffic impact will need review once plant capacity, private waste suppliers and staffing are confirmed, we currently expect no significant noticeable impact to surrounding buildings.

5.2.2 Site Conclusions

In conclusion, Archie Browning and Esquimalt Recreation Centre can be serviced from the Public Works site and while this would require a District Energy Loop, the Canteen Road site is simpler to service, more appropriately zoned and allows for phasing in other DES users, as and when opportunity permits. It is also simpler to expand and phase appropriately. We thus conclude Archie Browning is a secondary option but the preferred site and assumed herein for modelling purposes, is the Public Works Site. Other options exist if their consideration proves necessary however, and were discussed with staff, but these are not as controllable, are less accessible, have higher costs to make workable (and with greater difficulty) but importantly, would increase cost to deploy recovered resources. This does not necessarily rule them out as being viable or usable, but they are not as good as the above two options.

The Public Works Yard site on Canteen Road is owned and controlled by the community and is in a location with compatible uses, but it is also likely to be the most acceptable from a traffic and servicing perspective. Although there is residential property adjacent to the east, these are unlikely to see, hear or smell the plant as they will be buffered by the existing buildings (and the gasifier would not create odour, noise or emissions).

The Canteen Road site suitability will require confirmation following preliminary plant layout and design stage and as planning progresses through detailed assessment, public engagement, regulatory approvals, financing and Council's decision. As the site is owned by the Township, we have excluded land cost. Should either of these sites not be acceptable, we conclude that other sites are likely to be possible, but would need additional work to confirm. Non-owned sites will increase plant costs.

5.3 Costs

Capital costs

Capital costs have been assessed for plant development with budgets obtained from suppliers for major plant and equipment components. This includes costs for items such as shipping, staffing, supplies, insurance etc. Basic allowances were included for enclosures, which should be reviewed once the plant size and location have been determined, but we anticipate savings may be possible through co-location at the Public Works Site. These will be offset to some extent by additional site preparation costs (rock removal and stabilisation, parking accommodation etc.).

Most of the main plant can be fabricated locally to address possible issues with exchange and import duty, which are currently somewhat in flux. We have previously met with qualified BC fabricators for the gasifier – whose bids have been competitive for other plant fabrication – to confirm quality and timeliness of delivery, as this is the largest single component. Other fabricators exist experienced making TSI's plants in Alberta and Quebec. Budgets were developed for this project based on the main plant scenarios.

Because feedstock laboratory and physical testing has not yet been undertaken, some uncertainty exists about the equipment needed to prepare the feedstock, storage, emissions control, chemicals management etc. Standard assumptions have been included in the capital and operating budgets. We do not currently expect any extraordinary costs but the budget should be reviewed once plant size is confirmed, testing has been completed and the system design confirmed, as this would alter overall system pricing.

Soft costs and fees

The initial capital cost mainly relates to preparation, impact assessments, permits, design and implementation planning, regulatory and other aspects. Regulatory agencies were approached to confirm process which for the most part relates to emissions monitoring. Costs and timing for these aspects were included in the model, for municipal processes, licensing and associated fees.

Contingency & inflation

Contingencies were set at 20% for the planning and preparation period as this is where extra time and cost typically occurs. Following discussion with major suppliers, a 15% contingency has been used for construction and associated soft costs. We assumed the highest additional margin indicated to us (cost plus 15% on all capital costs) rather than quoting costs as "cost ±15%" which is a common practice. This is conservative and means that (in Scenario 2b for example) the budget total is under $19m ±15%, but $21.3m has been used to test viability.

BC's long term inflation rate was used for inflation-adjusted models and run in parallel to current cost models so the impact of inflation could be assessed. Inflation can have an appreciable impact on life cycle value. Values quoted are thus the amounts that would be expected to be received, adjusted for inflation.

Finance

The interest rate applicable to debt depends greatly on the procurement approach. The lowest rate can be obtained by the Township owning and operating the plant, but this can add risk if not carefully managed. The highest cost of debt is likely to be for a private provider absorbing the risk with minimal taxpayer-backed guarantees. We assessed the cost of finance under varying scenarios and included this in the model. The implications are considered in the *Risk & Procurement* section.

We model IRM using both cash flow and DCF models to allow comparison. As the debt finance rate is a reflection of the risk of a project, and the cash flows include it, risk is included in the finance rate. DCF calculations exclude debt, so the discount rate reflects risk in DCFs. An alternative cost of money approach was used in selecting the discount rate, assuming that the community has taken reasonable steps to reduce risk whether the project is community-owned or implemented with alternate procurement.

Operating & maintenance costs

Experience with staffing for gasifiers in Victoria, the USA and Europe were used to develop basic staffing models. Private haulers have been canvassed and provided comment on staffing and waste processing requirements. Operating and maintenance costs were projected based on industry standards for a project of this type and projected for the life cycle. Note that existing staff may choose to transfer and potentially upgrade skills, which in combination with other possible savings (such as GHG reduction costs, GHG taxes, etc.), we estimate should reduce Township budgets by ≈$4-500,000 annually but has not been taken assumed in the models, i.e. we expect there will be further savings. O&M budgets vary depending on the scenario used and are included as line 02 in Figure 30.

5.4 Revenues

IRM systems have multiple potential outputs which are saleable and the revenues are used to partially or fully offset system costs. The main revenues include:

- **Electricity**. Currently, BC Hydro is not actively pursuing new sustainable energy contracts because the province is a net exporter of electricity, but electricity generation can be added later, should circumstances change and BC Hydro express interest in supporting sustainable local power generation. Note that we have modelled electricity viability and conclude it is a marginal financial and environmental benefit, largely due to high costs of compliance with BC Hydro requirements, extended process and contract, increased risk and a low feed-in tariff. This may change if local generation rises in priority, for example to avoid expenses in funding additional transmission lines.

  Since BC's electrical generation is dominantly hydro-electric, the potential CO_2e reduction from sustainable electrical energy is not high, except in displacing air conditioning, which can also be achieved with a DEL. We have thus excluded electricity from the planned model at this point.

	Heat	Power
Thermal	3.23mw/tonne	—-
Thermal & electrical	2.26mw/tonne	0.73mw/tonne

Figure 36: Yield Per Dry Tonne of Waste

- **Heating and cooling**. Gasification generates substantial amounts of heat and by using absorption chiller systems can produce cooling, which means that gasification can displace both natural gas and electricity. On average, Canada uses fossil fuels for an appreciable portion of its thermal needs and the lifecycle GHG intensity of natural gas is 0.252tCO_2e /MWht whereas electricity's lifecycle GHG intensity is 0.071tCO_2e /MWht.[39]

  Natural gas typically costs in the range of $2-2.50/GJ (adjusted for efficiency to $3/GJ), but government is pressing suppliers to achieve increasing percentages of "Renewable

[39] GHGenius model v4.03 and Government of Canada 2018 National GHG Inventory.

Natural Gas" (RNG) to displace fossil-based methane. The syngas produced by RotoGasification is not directly usable as natural gas and so has historically not qualified as being renewable, however this appears to now be changing where syngas displaces natural gas. In the case of the proposed Esquimalt plant, syngas would displace natural gas for heating.

While confirmation will be required from the BC Utilities Commission (BCUC), we have discussed with Fortis and other utilities the potential for output to in effect, qualify as RNG, which is achieving prices of $20-30/GJ, so we have thus adopted a value of $20/GJ in modelling and assessed the implications in initial sensitivity models. Cooling is priced equivalent to the cost of electricity so for modelling purposes we have adopted $0.11/kwh. The ≈1km DES cost has been estimated and included as part of the system capex and the IRM model includes adjustment for conversion losses etc.

- **Water**. The largest single element of solid waste is in fact water but this is almost never reported. Kitchen scraps, yard and garden waste can contain as much as 70% moisture, i.e. only 30% is the dry component that creates energy. This is why incineration of waste is expensive, since combustion of waste requires it to be as dry as possible. By contrast Advanced Gasifiers work best with a moisture content of 20-25%, but can tolerate up to 50% moisture content, making them ideal for managing both liquid waste residuals and solid waste. In addition water (H_2O) when gasified, separates into hydrogen and oxygen, which the gasifier turns into hydrogen and carbon monoxide, the main components of syngas. Recycled heat is used to dry waste to the requisite level, with the water condensed as a bi-product, which has the potential to be filtered and reused as distilled water. In the IRM models we ran, we calculate up to 3.2 million litres of water may be generated and potentially reused annually as distilled water.

  Capital Regional District has an efficient potable water system with ample clean water supply at extremely low cost. Filtering water recovered from gasification for possible use and sale would thus add cost and not be competitive, net of revenues from sales. Therefore while the option exists to add filtration and bottle the water as distilled water, it would currently increase taxpayer cost to recover and sell water. We have thus assumed this will not currently be pursued, but can be explored and added in subsequent years if circumstances change and there is viable demand. The distilled water from gasification will be cleaned and discharged to storm sewers, or possibly to the main sewer. This decision can only be made once the volume is determined and wastes tested.

- **Carbon Credits**. Gasification of municipal waste has the potential to significantly reduce carbon emissions and is a verifiable offset able to be sold on carbon markets. Federal government has been pushing for a move towards carbon tax of $50/t$CO_2$e, by 2022 but this is not the level of revenues that might be achieved from sale of credits. The question thus arises as to the level that credits might achieve in the long term. If sale of heating is confirmed under BCUC regulations, the CO_2e benefit would not be available, which has been assessed as part of modelling.

  In emerging markets, long term values are difficult to predict and because carbon credits sell essentially to brokers, an allowance has to be made for profit margin. For modelling purposes we estimated half the expected value of carbon tax, then canvassed opinions from carbon sector professionals. They confirmed this as being reasonable. A rate of $25/t$CO_2$e has thus been applied which in reality, is likely to prove conservative as climate action strengthens.

- **Tipping fees**. Esquimalt collects waste from dominantly single family homes and charges based on cost recovery for this service. We calculate (Figure 22) the Township's total costs including haulage and disposal total on average approximately $191.81/tonne, although components are up to $277.50/tonne. As noted in s.4.3.2 (page 29), staff confirm that the Township does not collect all waste in Esquimalt and our research identified an additional 3,100 tonnes, which implies the total waste generated in Esquimalt may be in the order of 6,498 wet tonnes in 2019.

  There are thus two main initial plant options: a first that addresses solely the volume collected by the Township; and a larger volume that includes other Esquimalt waste volumes. Both would need Council and community support but the larger plant would be consistent with the need to plan for all the community's wastes. Both smaller and larger plant capacity options have been assessed.

  Regarding collection costs and to provide context, tipping fees at Hartland are currently $120/tonne for food waste, $59/tonne for yard waste, and $110/tonne for mixed MSW, which excludes the cost of collection and haulage. We used $75/tonne as a volume-adjusted average for food, yard and garden waste and $110/tonne for sorted MSW in modelling. This excludes haulage costs since these are needed to support collection and delivery of wastes to the plant, but which should be able to drop slightly, given that a local IRM plant should reduce or avoid trips to Hartland.

  While total revenues vary depending on plant size, it helps to provide context to this item. Tipping fees have historically risen roughly in line with inflation so this revenue is considered to have low risk. Tipping fee revenues are important in that where the plant is sized to cope with the full community waste, the tipping fees approach the cost of financing the plant. Since ≈52% of the tipping fees is controlled by the Township and ≈48% can be pre-contracted, this risk can be reduced before the project is committed.

- **Biochar**. Biochar represents an appreciable portion of the potential revenues from gasification and as it may be unfamiliar, greater detail is provided on this aspect.

  Most people will be familiar with biochar as charcoal for barbecues, which is usually wood, heated so the volatile organic compounds turn into gas and the residual is a crystalline carbon char, usually black and in lumps or powdery and containing minerals. Biochar is where the source is biogenic in nature and since waste is

Figure 37: Biochar Output & Testing

mostly biogenic (typically >88%), gasification of waste can create a biochar. It can be used as a sterile soil amendment for rehabilitation or stabilisation, or as a soil supplement. At the higher end, biochar may also be familiar as "activated charcoal filters", used for air filtration in the medical, laboratory and other sectors. Lower quality filters also use it, for example in pool and aquarium installations. Figure 50 provides a list of biochar uses, which are increasing because the carbon lattice structure retains organics, fertilizer, water and minerals, which are beneficial for restoring soils, improved plant growth etc.

Because it is sterile and retains minerals, biochar can essentially act as a fertilizer and subject to testing, should be able to exceed requirements for local land application, if this is desired. Figure 37 shows biochar output with weather testing. It can also be fabricated as a briquette (Figure 52), but an important benefit is its ability to maintain its structure and retain water, microbes and fertilizers.

Values for biochar have generally risen, linked to the biochar market and quality. Pivotal's research of retail biochar prices from late 2019 shows a range of retail prices, with the highest quality activated carbon filtration as high as US$48,000 per tonne.

Without testing and certification, values of biochar from waste are difficult to predict and likely to achieve lower levels of value. West Biofuels currently sell untested bulk biochar from RotoGasifier tests in California to a local municipal parks department, for use as a soil amendment, at US$750/tonne. Biochar used as a soil supplement is typically in the range of US$4,000 and higher retail. Following consultation with industry advisers in the US, we used US$2,000/tonne in modelling to test the sensitivity of the financial model.

Biochar has an element that commentators believe is increasingly likely to raise biochar's profile and value in the future. Independent studies have concluded that biochar sequesters carbon when used as a soil additive and the tCO_2e of biochar is 2.9336 times the weight. This means that with for food scraps for example, 100 "wet" tonnes would generate about 12 dry tonnes of biochar, which has a carbon sequestration potential of ≈35 tonnes CO_2e. While the amount sequestered varies depending on the nature of the waste, sequestration is gaining attention as a way to reduce atmospheric carbon but is not fully reflected in carbon credits or other revenues, which is currently the only financial value attached to sequestration. The intangible value of sequestration is increasingly substantial.

Because biochar is one of the more important contributors to the business case, and the exact amount of biochar can only be determined by testing and certification, we have recommended early testing so the value and sequestration potential are confirmed and pre-contracted before proceeding much further. Assessment of test results from biochar experts has been engaged but more will be required and as testing opens the potential for a system and yield guarantee, it is a recommended, fast and simple risk mitigation step.

5.5 Intangible Benefits

Over and above the tangible benefits of developing an IRM gasification system in Esquimalt there are numerous potential intangible benefits that will stimulate economic development and prove to have benefits over and above the economics. The following list outlines some of the potential benefits likely to be achieved by the Township:

- The evidence of similar examples in Europe is that projects of this nature produce attention nationally and internationally, due to the linkage of financial and environmental leadership. An EU example resulted in demand for education and training, tourism, and partnerships from like minded business leaders, new commercial locations and hotels. We thus expect a multiplier effect where other business is generated because of the commitment to sustainability an IRM plant demonstrates. An example in Austria generated a 35% boost to a small rural community over a 5-10 year period after years of the community declining in commerce and size.

- We expect there to a local re-spending effect, where investment in local infrastructure and employment reduces payments to outside communities, and is replaced by retaining expenditures within the community. Examples of these include cessation of landfill spending, cessation of energy payments (heating, cooling) to external companies, and improved revenues from sale of biochar reducing taxpayer costs, allowing taxpayers to spend the financial benefit locally.

- External direct full-time jobs will likely be created in addition to the employees currently with the Township. Some employment will be technical but others will be more unskilled, thus providing broader employment opportunities. We also anticipate indirect service and support employment, the extent of which is difficult to quantify but unlikely to be large.

- There is an advantage for other BC and Canadian communities to understand how Esquimalt achieved and exceeded carbon neutrality on operations at negligible difference in cost, including sequestering carbon. In Europe this has generated eco-tourism and eco-training opportunities, increasing media coverage of the community. This creates media and recognition benefits without media expenditures and a positive association of the community with sustainable direction. As sequestration is a key international goal, this aspect is likely to gain the Township considerable and broad media coverage, with positive connotations.

- As noted previously, emissions from gasification are expected to be equivalent to a natural gas flue and are ≈88% atmospheric, i.e. not from fossil sources.

- A final relevant benefit for the region relates to Hartland Landfill. Assuming the recommended option is implemented in Esquimalt and then adopted across the region, there would be appreciable landfill diversion, which is projected to hit capacity by 2045. An Esquimalt IRM plant would only extend this life by approximately two years but if IRM is broadly adopted, the landfill's utility would be extended until at least 2186. We have not priced this benefit in financial or environmental terms, but it would be very considerable indeed.

5.5.1 Broader Carbon & Energy Reduction

IRM was in part conceived to reduce GHGs, which is a community objective. Should the decision be made to implement IRM, the plant will use an energy loop to distribute recovered energy to consumers, most likely in the vicinity of the municipal core and recreation centre – originally assessed by KWL. In that event, planning should include a review of facilities to assess how to reduce their energy needs, which would permit the recovered sustainable energy to supply more buildings, thereby further reducing those buildings' carbon footprint and their energy costs. This is how IRM has been implemented in Sweden for example.

Our energy engineering advisor's review of the potential concluded that Esquimalt will benefit from a strategic Net Zero assessment to understand how to both reduce energy costs and carbon costs and also, how to phase in a District Energy Loop as part of a DES. This will benefit even if IRM is not pursued, because it is expected to support carbon reduction and reduce energy costs. Without this assessment, the DES will be planned based on existing energy demand, which will miss the potential to maximize both carbon and cost reduction. Most of this benefit will accrue to the Township, but we expect would also benefit other buildings and owners, and is thus recommended.

5.6 Risk & Procurement

Simple changes to how IRM might be procured could almost eliminate the cost, and/or near-eliminate the risk. Risk and Procurement are thus extremely important issues.

Many communities have common approaches to service delivery and use basic ways to obtain services. While self-supply and taxpayer funding of services may often be preferred, it has implications that should be carefully compared with other options. An introductory discussion of risk and procurement follows but a follow-up workshop is highly recommended.

5.6.1 Risk

We were asked to provide a preliminary comment on the main risks. While not a full risk assessment, it is intended to provide a preliminary grasp of the main aspects, their probability, impact potential and resolution options. There are a number of risks specific to projects of this nature worthy of note.

Item	Comment
Technology & operating risk	Almost all systems used in the waste sector have some form of technology risk, some being more widely known than others. The question is whether the risk/benefit ratio of pursuing an IRM direction makes the systems worthwhile; what alternatives exist; and whether the risks of the technologies are reasonable and can be managed. IRM uses more advanced technologies with fewer existing precedents in the way that Esquimalt intends to operate. This represents potential risk. However as shown by the technology review, other options to address waste have proven either incomplete, expensive, or fail to achieve environmental or resource recovery objectives and many have their own significant risks. While IRM has technology risk, the waste sector has few simple solutions, which is why innovation is needed with direct effort required to manage them. The issue for Esquimalt is therefore whether the risk represented by gasification is acceptable, given the alternatives and options for managing the risk.

Item	Comment

Firstly some studies suggest there are no gasifiers operating with MSW, which is incorrect. Internationally there are a significant number of gasifiers handling municipal wastes, with considerable operating track record. We have reviewed information on over 90 gasification plants operating in Europe and Asia processing MSW, scraps and biosolids with an equivalent total of more than 1,000 years' operation and more certainly exist operating successfully, processing MSW or MSW components. This is because gasifiers work with any carbonic material and do not treat MSW's carbonic feedstock differently.

Secondly, the risk can be managed either through running physical samples of the waste through a test unit in California, or by purchasing a small mobile unit (similar to that shown in Figure 38) for extended on-site tests.

Thirdly, the risk can be managed through guarantees. These would ensure handover and payment only occurs when the systems are achieving stable yields equal to those in the business case. Long term operating risk is partly a function of technology, but mostly down to the operator. This risk can also be offset through offsite monitoring. Combined, these insulate taxpayers from technical risk.

Lastly initial demonstration tests have been successful using local wastes and prove the systems work (Figure 27). The tests were independently observed and separate laboratory tests also confirmed suitability.

Figure 38: Mobile RotoGasifier Unit

The main technology selected is Advanced Rotary Gasification (RotoGasifier) manufactured by TSI Inc. of Washington State. The company was established in the 1990's with a long track record of successful operations and plants at multiple scales, including the world's largest gasifier pellet plant (Figure 47). Construction companies and operators with balance sheets exceeding C$20bn are prepared to underwrite the system and provide a full wrap (i.e. a guarantee). The fact that large companies with substantial funds are prepared to underwrite the gasifier provides assurance that the system works.

Should there be any concern about the technology after formal laboratory and physical tests, it may be possible to test the recommended system with an initial 5 tonne removable sled unit (similar to Figure 38). This should provide comfort with the system's capability and resolve any remaining questions about technology risk.

Item	Comment
	In summary while the probability of technology risk is high with all systems – not just Advanced Gasification - the impact is considered low/minimal (i.e. underperformance until corrected) and the ability to mitigate is high. Technology risk should not be a reason to reject the approach.
Feedstock risk	Esquimalt's feedstock characteristics have varied over the past ten years and can be expected to continue to vary. Any approach to managing waste must thus be adaptable to changes and resilient to feedstock fluctuations. Even though the plant is a multi-fuel system, this can be a challenge because waste quality will be managed by operators, not system manufacturers, making it difficult for them to guarantee systems. The community will want to dispose of waste but often lacks the diligence to separate wastes correctly, which places higher emphasis on ongoing management. Feedstock risk thus needs careful consideration. Historically landfills have been used and easily handle waste fluctuations, but these result in leachate, odour and rising GHGs, and fail to capture energy except at high additional cost and have significant residual post-closure costs and environmental challenges, which are rarely included in the cost during their operating life cycle. New technologies based on biological systems do a better job of capturing energy and avoiding environmental risk, but are susceptible to fluctuation (e.g. anaerobic digestion is sensitive) and have a high life cycle cost and thus, risk. Biological systems also have a limited band of wastes they can manage and are a less complete solution than gasification (noted in Figure 7). Feedstock variation is a less important risk for the Advanced RotoGasifier, which is a thermochemical and physical process. This provides a greater degree of control and certainty and the systems can be adjusted to manage changes in feedstock within broad operating limits. While the above should be sufficient to address technology risk, all technologies are susceptible to changes in feedstock, which is outside the technology supplier's control. A sample of waste from Langford, similar to Esquimalt's waste, has been tested by TSI and confirmed suitable for gasification. A demonstration test was also run (Figure 27), but has not yet been run for an extended duration, i.e. the system is expected to work, and has physically worked with similar wastes, but further testing is desirable. The system will be designed to handle a specific type of waste, with pre-specified tolerance. Ongoing effort will be needed to ensure the waste falls within the specifications, so this is considered a manageable risk but not without cost and process. Much of this can be addressed prior to substantial investment and commitment through testing.
Contract risk	There are multiple types of contract risk, the following considers some of the more distinctive risks only. Construction risks are common for capital projects with known mitigation strategies (insurance, bonding etc.) and

Item	Comment
	should be considered separately. The Township has some control of current waste collection services but this is not mandated by law and cessation is a potential risk. While the Environmental Management Act provides for the Minister to direct waste in a jurisdiction to be processed in a specific way, this has been declined for other communities such as Metro Vancouver, the issue being that doing so essentially expropriates a personal chattel. Private haulers expressed interest entering into long term contracts to deliver the waste. These contracts may also be at risk. This is managed by the system being sufficiently competitive to ensure that it can retain contracted haulers or if these fail, their replacements. This will be more challenging initially so care has been taken to assess the initial financial performance. While the taxpayer may be the 'underwriter of last resort' to the risk, most scenarios show that revenues should generate sufficient margin to avoid requiring subsidy. Other unique contract risks likely relate to long term systems maintenance, which has been raised with suppliers and can be managed through intellectual rights/permits, plans and licences in the event of supplier failure. Standard contract risks (such as construction) are typical for projects of this type and can be managed through appointing a General Contractor. Three qualified contractors are interested in taking this risk as a full wrap with this specific technology, two locally and one nationally, although more are likely to exist. This is positive as one in particular is familiar with the systems and suppliers and will guarantee them, with >C$10bn book value, i.e. substantial capability.
Cost/revenue risk	Revenue risks exist and are potentially significant, but most are considered low probability and manageable as they can be largely pre-contracted. Tipping fee risk can be contracted with haulers or is controlled by the Township. Biochar risk is the single largest risk so extra information on this component has been provided. Discussions with sector experts and gasifier experience is that this risk can be mitigated by testing samples and pre-contracting (see *Revenues* on page 45 and *Appendix 3:Biochar* on page 78 for more information). In terms of pricing, we re-checked with sector advisors to confirm potential and selected a sale price in the mid- to upper-end of the range for low grade soil supplements, knowing it should be feasible to exceed this price with good management, i.e. this risk is moderate as the price chosen is conservative. The volume output is also comparatively small, making it less risky to address. Biochar is an emerging market and currently prices are rising, but the long term growth risk of this revenue is not known. We tested the sensitivity of the IRM model to changes in biochar

Item	Comment
	revenues and mitigated this risk by ignoring growth potential for this item, beyond normal inflation. Revenues from heating and cooling can be contracted with community assets but recently, Fortis has indicated that it considers syngas to be equivalent to Renewable Natural Gas, making it eligible for RNG tariffs. We have a general LOI with Fortis for RNG production and have confirmed pricing potential with a major utility that has committed above the rates used. This price will require BC Utilities Commission ratification, but is logically being treated as RNG given that it replaces the need for natural gas and is from sustainable sources considered to be atmospheric carbon, and already complies with the sustainable electrical generation requirements. The value used in models represents a one third reduction from the maximum RNG rate indicated to us, i.e. is considered conservative, to manage risk. The risk of tipping fees and energy price reducing over time is considered low. This is as distinct from feedstock risk, discussed above. Cost risk was managed by obtaining budgets from providers and added appropriate contingencies however, until testing is undertaken and the feedstock and plant size confirmed, budgets should be regarded as preliminary but reasonable for current purposes. Enquiries were made to confirm debt and refinance rates under a range of possible procurement scenarios but the probability and impact of these is low. In summary revenue risk probability is initially high but addressed through pre-contracting, i.e., making it manageable. In the long term, contracts will require management and renewal, so this risk is considered low/moderate but manageable. Impact of both is likely to be limited to short term financial underperformance that is manageable. Initial cost risk is considered low in probability and impact given allowances in the model and will be addressed through underwritten performance-oriented fixed contracts. Long term cost risk exists and has been allowed for in modelling; impact is likely reduced financial performance.
Regulatory risk	While enquiries with the Ministry of the Environment indicate the Township should have authority to implement a system and the process to comply with environmental regulations is considered feasible, this requires confirming. As it should be feasible to mitigate this risk at low cost, but the risk is a pass/fail impediment, we recommend resolution of the ability to proceed first. Compliance is then a stringent but normal and manageable process. Environmental and other regulations could change, which is a concern for any private sector company or investor contemplating a project of this type. This affects emissions, aspects such as mandated recycling processes, and more. Typically existing permitted systems are either grandfathered or additional equipment added to provide compliance. RotoGasifier air emissions are

Item	Comment
	similar to that of high efficiency natural gas boilers, and particulates are handled through the Best Available Control Technology (BACT), so these risks can be pre-managed prior to commitment and managed continually. The risk is considered to have low long term impact and to be manageable. Community permitting is known to the Township and in its control. Planning and zoning risk require community participation but prior efforts (West Shore Innovation Days etc.) all indicate support. This risk is considered manageable. Over time community support could change, in which case the plant could be dismantled and moved, but this risk is considered low and manageable with reasonable cost to mitigate if it occurs. Regulatory risk may exist with BCUC approval for RNG, but would also occur if the plant moved into electrical generation. As this is a normal and understood process and associated risk, it exists but is considered low. While the probability of regulatory risk is considered low/moderate, it is manageable through grandfathering so the overall impact is considered low.

In summary, risks exist and in projects of this type are to be expected. The largest risk – technology performance matching the business case – can be offset using suitable procurement management. Most other risks can be mitigated before making final commitment to proceed. We do not consider any risks identified to date to be insuperable.

5.6.2 PROCUREMENT THROUGH DELEGATED MANAGEMENT

One option for Esquimalt is that waste management is delegated to CRD. The advantage to this is that it would reduce complexity for Esquimalt, albeit with the associated risks and costs. Esquimalt would be reliant on CRD's planning and management and their solution, which Esquimalt taxpayers would pay for, but have less control of. Staff thus asked us to comment on this aspect.

The first consideration is how CRD plan to proceed with managing waste. In 2018 CRD issued an expression of interest for respondents to provide proposals to handle organics and residuals, but to date this call has not proceeded. As it was an expression of interest the responses were not firm proposals, so the cost is unknown and timescale uncertain. We have been advised that CRD are now considering using anaerobic digestion, which would cope with Esquimalt's organics but not other wastes. As noted earlier, digestion would leave ≈63.5% of Esquimalt's solid waste stream unaddressed whereas gasification should cope with all solid wastes. To fully compare the cost to Esquimalt taxpayers of using CRD's digestion approach with gasification, we would need to add CRD's cost of addressing the remaining ≈63.5% of Esquimalt's waste stream (per Figure 7), which raises the question of the planned other solutions to waste management.

CRD commenced public engagement to prepare a new solid waste management plan in 2019, which can typically take several years to complete and approve, so it does not currently have a plan or budget for the remaining 63.5% of solid wastes. This prevents us estimating the cost, timescale or environmental benefit of CRD's direction with an IRM plan for Esquimalt, however digestion requires lifetime taxpayer financial support, which gasification avoids, so on this item alone, CRD's direction is expected to be more expensive.

This report concludes that appreciable GHG reductions are possible from gasification and an IRM approach – significantly exceeding the Township's corporate emissions and making an appreciable contribution to overall community GHG reduction. For the aspects of CRD's direction confirmed to date, we could not find an assessment of the GHG potential of anaerobic digestion (from when the CRD Liquid Waste Management project's business case was approved). While we cannot calculate this impact, the reduced energy capture of digestion compared to gasification means there is reduced ability to offset fossil fuels, and Hartland's location makes it difficult to deploy these benefits, so we expect at least on this aspect, that the environmental benefits of the known direction will be less than an IRM approach with a gasifier in Esquimalt. Should CRD maximize GHG reduction, this would be shared with other communities and the proportion shared with Esquimalt is not known.

It will be operationally simpler for Esquimalt to assign responsibility to CRD and it would reduce direct risk, but not avoid it. This risk would be handled by CRD and proportionately charged to Esquimalt taxpayers. Since this study concludes that implementing an IRM solution in Esquimalt could yield a financial and environmental dividend, devolving responsibility to CRD would probably reduce these potential dividends and benefits accruing solely to Esquimalt taxpayers – assuming CRD adopted them, which as noted above with CRD declining to pursue IRM (or the provincial direction, IRR), currently appears unlikely.

CRD's current known direction thus suggests it may be more expensive and less environmentally positive to delegate waste management to CRD than to have an IRM plant in Esquimalt. CRD could nevertheless revert to an IRM approach, in which case this aspect can be reviewed once CRD's plans and costs are firmer.

The main issue the Township will wish to consider is whether in overall terms, the potential financial and environmental benefits of an IRM approach are outweighed by the cost, risk and responsibility of setting up an IRM plant, and whether IRM is within Esquimalt's capacity and capability. While CRD is one way of addressing these issues, another is whether the costs and risks could be addressed by outsource contracting to companies with the technical and financial capacity to handle them. Initial enquiries (and the financial analysis) confirmed the potential for outsourcing with qualified companies, discussed below.

5.6.3 Alternate Procurement

In 1998 the NDP government at that time committed to using Public-Private Partnerships (P3's) with the objective of reducing capital debt, risk and costs, shifting procurement to a governance position where the direction, quality and performance criteria under which a service is delivered, whether by contract (with government ownership – the traditional mechanism) or some form of outsourcing. There are many variants to how such contracts can be structured and services delivered.

Two specific factors cause problems with standard procurement for IRM: (a) a lack of expertise in the consulting sector knowledgeable, experienced, qualified and competent with gasification; and, (b) very few technologies qualified and able to meet Esquimalt's needs, with typically few or no prior evidence of the exact wastes Esquimalt needs to process. This means quality advisory support for Advanced Gasification and IRM is low, making proposal calls difficult to draft, review, rate and rank; and the technologies wanted are difficult to attract. Private sector providers are in consequence hesitant to bid – they lose confidence in the process – and rarely take risks they cannot control (e.g. emissions, regulatory etc.). These combine to make traditional procurement and contracting ineffective.

It is not the primary function of this report to provide recommendations on procurement but it would be remiss to omit it, because it can completely change the costs for taxpayers. For example one approach could eliminate the entire cost and substantially reduce or eliminate risk. Procurement is thus a critical aspect to consider.

Should Council decide to consider IRM further, we strongly recommend holding a procurement workshop because traditional procurement of IRM has repeatedly proven not to work and using it yet again will in our view be guaranteed to fail. This does not mean that IRM cannot be implemented however, as there are internationally adopted approaches[40] using benchmarks to protect taxpayer value, which are better suited and will in our view be necessary.

5.7 Implementation

In the event the Township considers proceeding further, it helps to have some basic understanding of what the next steps might be, because this illustrates how risk is managed. Foremost, we recommend taking a measured approach to mitigate risks as this will safeguard both project and taxpayer value. Aspects include, in no special order:

- Confirm IRM can meet MoE requirements and that CRD will amend the Solid Waste Management Plan accordingly. Confirm regulatory and development process;
- Undertake Detailed Development and Implementation Feasibility Assessment and develop an Implementation Plan;
- Undertake laboratory and physical tests for physical, chemical and energy suitability; model potential air emissions for the preferred option;
- Hold a workshop to more fully understand some of the key implications and options such as procurement, risk management, contracting etc;
- Confirm design and layout, costs and schedule; revise potential expansion and associated implementation plan, phasing and pricing;
- Undertake energy demand assessment for Esquimalt's core, map against plant outputs; prepare detailed DES plan including contract assessment; obtain pre-contractual commitments;
- Secure agreements with private haulers to confirm availability of waste supplies for an IRM facility through Letters of Intent with conditional contracts;

[40] See Wikipedia article and international legal expert summary.

- Prepare scope and cost for project management of IRM Plan implementation including bid process and selection of Prime Contractor, construction, testing, commissioning and certificate of performance and formal hand-over.

- Secure a suitable performance guarantee with gasifier manufacturer, and subsequently confirm a full engineering wrap from a qualified company/consortium with fixed cost contract and energy guarantee;

- Update capital and operating cost projections; update business case; and,

- Consider establishing an advisory committee with experienced appointees from disciplines able to provide advice and an element of oversight.

These steps and more should be structured following consultation with staff. Figure 39 illustrates phasing for an initial plant.

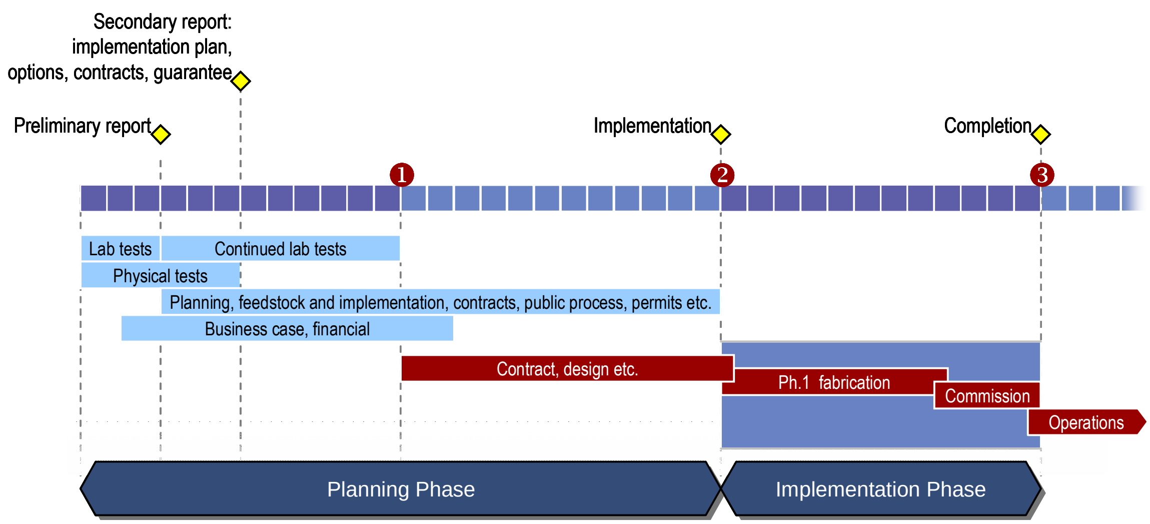


Figure 39: Implementation Outline

MoE and community confirmation, procurement approach and funding availability, testing and business case refinement are initially the most important. Testing is required to confirm a guarantee. Should any step raise concerns, the project would be suspended to allow for correction or the project cancellation, up to decision point 2. Up to that point costs will rise but will be comparatively low. We have not included phasing in Figure 39 (beyond a first phase) as this will depend on Council decisions. Most scenarios have the potential for a viable initial plant to be initially smaller but expand as demand and waste volumes rise.

6 Findings

6.1 Introduction

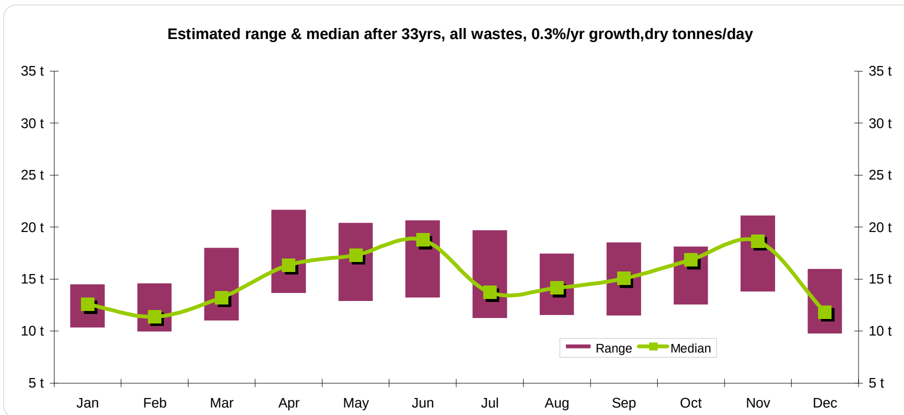


Figure 40: Scenario 2a – Minimum Growth

This section reviews modelling and findings from six scenarios developed with varying waste volumes and community growth potentials. The model combines financial and non-financial aspects, as described previously. Each scenario is a result of iterative assessment to attempt to optimize each scenario, to reduce costs, improve revenues and maximize resources and environmental results. This means additional research was undertaken to clarify wastes and obtain improved costs, but as the scope of the study is limited, further refinement of the preferred scenario is recommended, assuming the decision is taken to proceed further. The iterative optimization process is illustrated in Figure 2, *IRM Process Overview* on page 6.

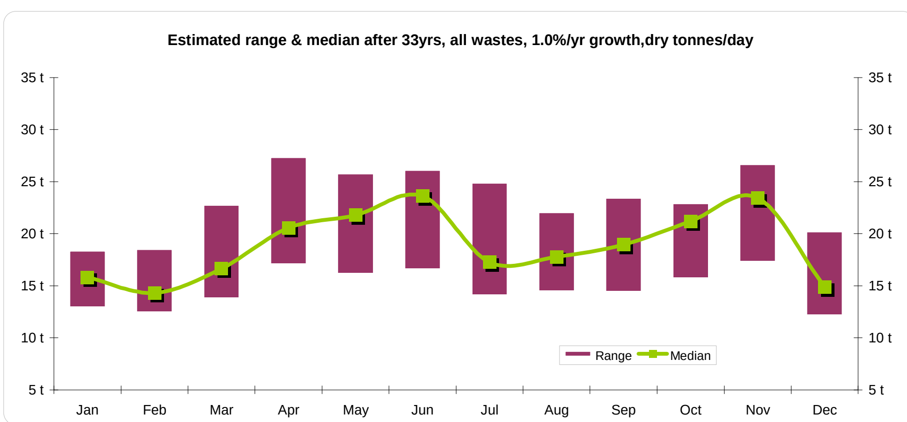


Figure 41: Scenario 2b - Moderate Growth

Reporting is summarized by major heading, since detailed modelling comprises full life cycle projections for 30 years plus residuals/reversion, adjusted for tiered equity and debt financing. Environmental models include full life cycle projection for GHG emissions (up to 150 years), since emissions have long life cycle. The environmental model was developed for Pivotal by Michael Wolinetz of Navius Research Inc., using international standards (government of Canada, EPA etc.) and includes life cycle projection by GHG emission gas and type so GHG reduction can be optimized. Should the project proceed, Navius should be contracted to undertake a more detailed assessment of the GHG and sequestration values.

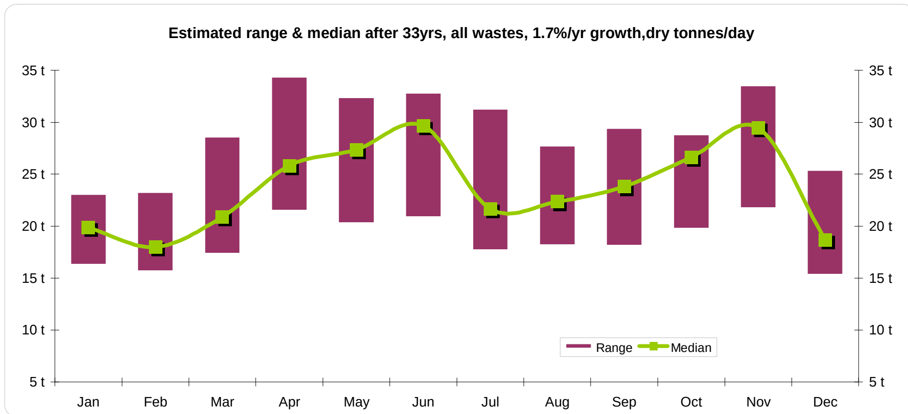


Figure 42: Scenario 2c - High Growth

Figure 30 summarized six main scenarios for assessment, however significant feedstock fluctuations mean that plant scale, unit sizes and the ability to adjust systems to meet changing volumes will be essential. Within the six scenarios, we thus looked at the implications of feedstock fluctuation, assessing both the median and range of possible flows, based on evidence of monthly data from 2011-2019. This was then applied individually to the Township's collections of MSW, yard and garden waste and food scraps, and interpolated to apply to private haulage volumes. While Figure 40, Figure 41 and Figure 42 look at combined wastes under low, moderate and high growth scenarios respectively, we assessed the implications for Township-only wastes and concluded that Figure 41 provides an understanding for plant and equipment sizing and planning.

6.2 IRM Results

Value is internationally defined as a financial sum that something can be sold, between a willing buyer and seller, acting at arm's length and without undue influence. This relies on something having a 'market' value, but government infrastructure often has little in the way of market equivalent or value, so the more applicable main metrics relate to the "worth" of a project. This allows for a broader assessment of environmental and resource benefits than purely their 'value in exchange', as in this case. An example of worth is that the community might think it is 'worth' undertaking something for the environmental and other benefits it creates, even if the cost exceeded revenues. In other words it is 'worth' implementing even though it couldn't be sold since it had negative 'value' on the open market. Worth can thus include the more intangible aspects of a project.

IRM models use financial metrics but also include non-financial metrics such as resource recovery and measurable environmental results. This moves towards a "Triple Bottom Line" assessment of worth. In this report the social dimension is not assessed, since this will be determined by Council and the community, who will have their own opinions of the project's overall "worth." The metrics in this assessment thus provide a range of indicators, so the community can reach its own conclusions of the project's "worth."

6.2.1 METRICS

The following explains the main indicators used in Figure 43 *Scenario Summary* on page 65. These metrics are intended to be used in combination, for example GHG reduction or landfill diversion indicators can be used with financial indicators, so the GHG results can be compared with the costs/revenues it took to produce them. Inflation is applied throughout the cash flow projection at BC's long term inflation rate of ≈2%.

One aspect we recommend strongly against is relying on discounted cash flow (DCF) metrics such as NPV and IRR. While useful in a market context, they fundamentally distort long term government project performance. While relevant should Esquimalt decide to partner with a private sector provider, they can be misleading and result in poor decisions if incorrectly interpreted. We will be pleased to explain this further if desirable.

A) Main indicators

The main project components for basic comparison of different options & scenarios		
01	Total capex	The total estimated cost of the plant in 2020 dollars, undiscounted.
02	Annual O&M	The annual operating and maintenance costs in 2020 dollars as at the plant's opening.
03	Waste volume	The total waste volume capacity of the plant, in original "wet" tonnes, as received. Plant operations (receiving, holding, metering, gasifier, dryer etc.) are adjusted to handle volumes and moisture content, by scenario.
04	Est. unit size/capacity	Volume processed by the gasifier in dry tonnes per day. This refers to gasifier capacity, which is adapted for each scenario to attempt to optimize overall net financial yields.

B1) Public Financial

Provides financial indicators for public delivery assuming 100% debt.		
05, 06	IRR, NPV	Internal Rate of Return and Net Present Value are discounted cash flow indicators used by the private sector to estimate the value of a project and are market indicators with limitations for public projects. The IRR is the percentage return over the project's life cycle from investing the project cost today, intended to be comparable with other investments where the project cost are invested initially. Few government infrastructure projects are undertaken in the way an IRR calculates. A common private sector threshold for an IRR in a 100% debt model might be 15%, but lower if there is a government covenant (say ≈11%). A lower yield may be perfectly acceptable for government undertaking a public project, especially if there are few alternatives.

		Governments often accept the IRR without appreciable challenge if it exceeds the cost of borrowing. The NPV is the "present value" of the project today, net of all future costs and revenues, over the project's life cycle, using a discount rate based (here) on the "cost of money." The discount rate emphasizes early costs and reduces longer term revenues, leading to distortion. For example $100 from sale of heating, in 30 years, becomes an NPV of $22.59. Since in practice costs of heating go up not down, discounting distorts long term project revenues. A positive NPV means the cost is exceeded by revenues and a higher value indicates lower likelihood of taxpayer support. A negative NPV may also be acceptable for a public project provided debt is included, which it is in our models.
07	ROI	The ROI is the ratio between the value of the project (i.e. its expected returns) as a ratio of the initial capital investment. The higher the ROI the better. Some analysts use different ways of calculating ROI but in this instance the ROI uses the net returns expected over the project's life (revenues minus costs, including the costs of capital). Generally, a positive ROI is good but a negative ROI may also be acceptable in a government context. The more the ROI exceeds the cost of capital the better it is viewed.
08	Life cycle profit/loss	The total net profit or loss from the project over its life cycle, undiscounted, inflation-adjusted. Similar to ROI, but provides an indication of the net profitability of the project over the projection period (here, 30 years). In a public context a positive net life cycle value indicates a dividend or profit and the higher the better, but a loss may also be acceptable (but suggests taxpayer support may be required). Note that this can disguise periodic negative cash flows where subsidy is required. #08 is not discounted and thus is not adjusted for time or risk, as compared with #06, which is discounted for time and risk. Metric #08 is distorted less by risk and time adjustments, since the cost of capital is included as a project cost, so it is closer to the net amount the taxpayer can expect over the life of the project.
09	EBITDA	Earnings before interest, taxes and depreciation. A standard financial indicator but has limitations for long term sustainable projects where debt etc. can be leveraged to improve viability. Largely an indicator used by the accounting professions, it helps to understand the overall revenue potential, undistorted by other factors.
10	Simple payback	Approximate number of years before the initial capital investment is repaid, net of costs. Less used by the public sector as it relates mostly to the point at which breakeven is achieved, which is of lesser concern in the public sector.

11 & 18	Taxpayer dividend/subsidy/yr, avg	The average dividend or subsidy required from taxpayers over the first ten years of operations. Adjusted and net of all costs and revenues, but assuming current tipping fees. Divided by the number of homes from Stats Canada 2016 totals, i.e. providing an estimate of the approximate dividend or subsidy for each home.

B2) Private Financial

Estimates the probable position of a private sector partner, financier and/or operator, for the project. Assumes 30% equity 70% debt, with refinancing.		
12, 13	IRR, NPV	See B1)05, B1)06. Private sector hurdle rates will vary depending on whether guarantees are available for aspects such as feedstock, but will typically be a minimum 15% at 100% debt and seeking 25-30% leveraged IRR on equity. NPV is typically compared to equity invested and usually required to at least exceed equity investment for the project to be of interest. The discount rate is usually set at the cost of capital or higher if the project is risky.
14	ROI	See B1)07. Private sector ROI is a less important metric for projects of this type but typically exceeding 15% ROI on 100% debt is a minimum requirement, with ROI >25% leveraged desirable.
15	Life cycle profit/loss	See B1)08. Private partners will require an appreciable return and will be interested to confirm a healthy long term cash flow, since #15 can tend disguise periodic dips in viability.
16	EBITDA	See B1)09. Private investors require a healthy EBITDA to sustain projects in the event viability changes over the project's life cycle. Threshold target requirements vary.
17	Simple payback	See B1)17. This is a basic indicator usually used in the private sector to estimate breakeven. Private sector interest is best with payback of ≈3-5 years or less. Beyond ≈7-10 years private interest in projects can be limited without underwriting or similar support.
18	Equity invested	Estimated total assuming 70/30 debt/equity on the initial capital investment. Depending on procurement structure and potential for public guarantees, lenders may require a higher equity ratio, reducing the potential leverage. 70/30 split is based on discussions with funds and an assumption of limited recourse but that Esquimalt will provide a long term contract for waste and associated fees.

C) Resource recovery

Physical resources recovered from waste, or resulting from conversion of waste, capable of beneficial utilisation.		
19	Face yield, mwt	Hourly gross thermal yield in megawatts. Measured gross at the point of generation, which will be greater than actually delivered.

20, 21	Total mwt/yr & life cycle	Total gross thermal yield in megawatt hours annually and over the project's life cycle. Measured gross at the point of generation, which will be greater than actually delivered.
22, 23	Total GJ/yr & life cycle	Total gross thermal yield in gigajoules annually and over the project's life cycle. Measured gross at the point of generation, which will be greater than actually delivered.
24, 25	Total biochar tonnes/yr & life cycle	Total projected maximum tonnage of biochar annually and over the project's life cycle, gross FOB plant. Note that this is not the same as the tonnes of CO_2e in #32 and #33, since the sequestered potential value is ≈3 times the weight of the biochar.
26, 27	Water potential, litres/yr & life cycle	Potential maximum water recoverable annually and over the project's life cycle. Note that this is initially expected to be filtered and discharged, as it is unviable to reuse at current CRD water rates.

D) Environmental

28, 29	tCO2e/yr && life cycle, redn/increase	Metric tonnes of carbon dioxide equivalent either reduced (in black) or red (a net increase) from the proposed project compared to the current management of waste (mostly landfilling). This is the projected GHG reduction/increase either annually (#28) or over the project's life cycle (#29). Note that this initial estimate compares between current waste processing and planned IRM system, net of emissions from each operation and assuming aspects such as unsold composting. The GHG reduction may increase once a detailed assessment is undertaken. Note also that the life cycle reduction is many times the annual tCO_2e reduction because emissions benefits have up to 150 years' life cycle.
30, 31	Vehicle equiv/yr & life cycle, less/more	The number of vehicles' emissions that the GHG reduction or increase is equal to, using standard government comparative indicators, either annually or over the project's life cycle.
32, 33	Sequestered carbon, tCO2e/yr & life cycle	The number of metric tonnes (GHG carbon dioxide equivalent) that biochar is potentially able to sequester. Note that tCO_2e is different to the total tonnage of biochar (#24 and #25 above) as biochar sequesters ≈2.9x the weight as tCO_2e. Further explanation including on sequestration is provided in *Appendix 3: Biochar* on page 78 and in section 5.4 starting on page 45.
34	Life cycle $/tCO2e profit/cost	The total project profit or cost, net, divided by the total life cycle tonnes carbon dioxide equivalent. This is useful for comparing GHG reduction options as it allows for net cost or profit comparison as a standalone GHG reduction strategy. Note that this includes any carbon taxes or credits, assuming these are paid/received. An amount greater than zero (i.e. a profit) indicates a net positive

		contributor financially, given the GHG increase or reduction noted by indicators 28 and 29.
35, 36	Tonnes/yr & life cycle landfill diversion	Total metric tonnes annually and over the project's life cycle, diverted by the proposed project. Useful for comparison of different potential waste diversion initiatives, in combination with other indicators (e.g. #'s 8 & 15), to determine whether diversion is achieved through increased taxpayer cost or conversely, profit.

6.2.2 Main Findings

		Township waste collections only			Combined Township/Private Waste Collections		
	Scenario	1a	2a	3a	1b	2b	3b
	Population growth %	0.3%	1.0%	1.7%	0.3%	1.0%	1.7%
A) Main indicators							
01	Total capex	$16.4m	$17.3m	$17.8m	$21.3m	$21.3m	$25.3m
02	Annual O&M	-$1.5m	-$1.5m	-$1.6m	-$1.7m	-$1.7m	-$1.9m
03	Waste volume	3,740 t/yr	4,670 t/yr	5,830 t/yr	7,150 t/yr	8,930 t/yr	11,150 t/yr
04	Est. unit size/capacity	6 dtpd	8 dtpd	10 dtpd	13 dtpd	17 dtpd	21 dtpd
B1) Financial : Public delivery : Inflation-adjusted, 100% debt							
05	IRR	5%	9%	13%	16%	22%	24%
06	NPV	≈$1m	≈$11m	≈$24m	≈$46m	≈$71m	≈$93m
07	ROI (life cycle)	510%	660%	890%	1,040%	1,370%	1,470%
08	Life cycle profit/loss	$16m	$47m	$86m	$152m	$226m	$297m
09	EBITDA	$0.8m	$1.4m	$2.1m	$3.4m	$4.7m	$6.2m
10	Simple payback	≈21yrs	≈14yrs	≈10yrs	≈8yrs	≈6yrs	≈6yrs
11	Taxpayer dividend/subsidy/yr, 1st 10 yr avg	≈-$60/home	≈$0/home	≈$90/home	≈$200/home	≈$360/home	≈$480/home
C) Resource recovery							
19	Face yield, mwt	≈0.80 mw	≈0.90 mw	≈1.20 mw	≈1.60 mw	≈2.00 mw	≈2.50 mw
20	Total mwt/yr	6,700 mWht	8,300 mWht	10,400 mWht	14,100 mWht	17,600 mWht	22,000 mWht
21	Total mwt, life cycle	201,000 mWht	249,000 mWht	312,000 mWht	423,000 mWht	528,000 mWht	660,000 mWht
22	Total GJ/yr	23,960 GJ	29,930 GJ	37,340 GJ	50,740 GJ	63,390 GJ	79,070 GJ
23	Total GJ, life cycle	718,800 GJ	897,900 GJ	1,120,200 GJ	1,522,200 GJ	1,901,700 GJ	2,372,100 GJ
24	Total biochar tonnes/yr	460 t/yr	570 t/yr	710 t/yr	970 t/yr	1,210 t/yr	1,510 t/yr
25	Life cycle biochar, tonnes	13,800 t	17,100 t	21,300 t	29,100 t	36,300 t	45,300 t
26	Water potential, litres/yr	0.9 ml/yr	1.1 ml/yr	1.4 ml/yr	1.1 ml/yr	1.4 ml/yr	1.7 ml/yr
27	Life cycle water potential, litres	26.4 ml	32.9 ml	41.1 ml	32.8 ml	40.9 ml	51.1 ml
D) Environmental							
28	tCO2e/yr redn/increase	1,600 tCO2e/yr	2,000 tCO2e/yr	2,500 tCO2e/yr	3,600 tCO2e/yr	4,500 tCO2e/yr	5,600 tCO2e/yr
29	Life cycle tCO2e redn/increase	81,001 tCO2e	101,185 tCO2e	126,245 tCO2e	178,632 tCO2e	223,139 tCO2e	278,358 tCO2e
30	Vehicle equiv/yr less/more	350 cars/yr	440 cars/yr	550 cars/yr	780 cars/yr	970 cars/yr	1,210 cars/yr
31	Life cycle vehicles less/more	10,600 cars	13,200 cars	16,500 cars	23,300 cars	29,100 cars	36,300 cars
32	Sequestered carbon, tCO2e/yr	1,343 tCO2e/yr	1,678 tCO2e/yr	2,093 tCO2e/yr	2,844 tCO2e/yr	3,553 tCO2e/yr	4,432 tCO2e/yr
33	Life cycle sequestered carbon, tCO2e	40,290 tCO2e	50,330 tCO2e	62,795 tCO2e	85,333 tCO2e	106,594 tCO2e	132,972 tCO2e
34	Life cycle $/tCO2e profit/cost	$190/tCO2e	$470/tCO2e	$680/tCO2e	$850/tCO2e	$1,010/tCO2e	$1,070/tCO2e
35	Tonnes/yr landfill diversion	3,740 t/yr	4,670 t/yr	5,830 t/yr	7,150 t/yr	8,930 t/yr	11,150 t/yr
36	Life cycle landfill diversion, tonnes	112,200 t	140,100 t	174,900 t	214,500 t	267,900 t	334,500 t

Figure 43: Scenario Summary – Public Option

Figure 43 shows the results for each main scenario tested using the metrics in section 6.2.1 based on the plant being publicly financed and operated, with the recommended option highlighted in light green. In summary, we comment as follows:

- The scenarios are tabled in ascending order of waste volume from left to right (shown in lines 03, the wet waste volume and 04, the average dry tonnage processed daily). From a taxpayer perspective, viability is also arranged in ascending order from left to right with the least viable on the left and most viable on the right (note lines 05, 08 and especially line 11, which estimates the approximate taxpayer dividend or cost per door).
- The three scenarios with Township wastes (1a, 2a and 3a) are the most marginal and two may well require some taxpayer support (1a and 2a), with 3a viable, i.e. if community

and/or waste growth exceeds projections – and the likely maximum buildout – a plant would be viable with the Township's waste alone. It would nevertheless be possible to proceed only processing the Township's collected wastes, assuming careful management to avoid fiscal impact, but this would only address ≈52% of the community's waste.

- The extent of possible taxpayer support is not substantial in most scenarios, in part because we expect growth to exceed the minimum (≈0.3%) threshold. There will also be external savings not accounted for in this analysis (e.g. meeting corporate emissions targets without further cost, landfill diversion benefits, under-valued benefits from resource recovery price stability, sequestration etc.). The three Township-only waste scenarios are thus possible with minimal potential taxpayer exposure, but are more likely to result in taxpayer support at some stage, especially in the early years.

- All the scenarios with combined public and private wastes are expected to be profitable, with superior resource recovery and GHG/CO_2e reductions. Of these three scenarios, Scenario 1b uses the least growth experienced in 25 years and in our view could lead to under-assessing the capacity of waste going to an IRM plant. By contrast Scenario 3b assumes continued growth at one of the highest rates in recent years and probably over-estimates future waste growth. Note that the approach used allows for phasing to suit a variety of growth scenarios, allowing for phased expansion as growth occurs.

- The population and waste growth assumptions driving scenario 2b are considered the most realistic, not least because this assumes population growth roughly equal to the Township's current buildout projection estimates, and is in line with the regional trend. 2b is viable and is our recommended planning model should IRM proceed further. Note however that Scenario 1b shows that even in a worst case scenario with combined wastes, an IRM plant should exceed breakeven. These projections should be reviewed following receipt of better detail if the project proceeds.

- All scenarios are expected to be able to eliminate the Township's corporate GHG emissions. Scenario 2b should yield GHG reductions of ≈4½ times the corporate emissions profile and represents GHG reductions equivalent to ≈12% of the entire community's waste – roughly equal to taking 970 cars off the road or over 29,000 cars over the 30 year projection. This is a significant contributor to the Township's declaration in 2019 of a Climate Emergency and target of carbon neutrality by 2050. We are not aware of similar progress by other Canadian communities, except at appreciable cost or other impact, whereas this has the potential to generate a dividend.

- Option 2b is expected to generate an additional sequestration potential in the range of ≈3,600 tCO_2e annually or ≈107,000 tCO_2e over the 30-year projection period. While the carbon credit value is included in the model (at $25/t$CO_2$e), sequestration is more significant than accounted for by carbon credits, as it takes carbon out of the atmosphere. This is one of thee few mechanisms able to achieve this.

- In all scenarios the major resources recovered are heating, cooling and biochar with primary revenues from biochar, tipping fees and energy sales. The main costs are the gasifier and related plant and equipment. Most of the key costs can be controlled from an early stage through fixed price contracts, guarantees and bonding, including guarantees on system yield (on which the business case relies). This will limit cost impacts. Similarly, most of the main revenues can be managed through contracts signed prior to proceeding, again stabilising the business case and managing risk. Phasing is discussed as part of the concluding comments in section 7 on page 71.

- Landfill diversion varies but is positive under all scenarios, with initial laboratory and demonstration tests running local wastes (Figure 27) confirm the systems can work with the proposed wastes. Under the recommended scenario (2b) diversion is estimated at ≈8,930 tonnes per year or almost ≈270,000 tonnes over the plant's initial projected life cycle. The review of technologies here and previously by CRD concluded there are few options as viable or as complete in handling wastes, which mirrors European and Asian experience.

- Waste volume fluctuations and population growth uncertainties affect viability. The scenarios were therefore mostly priced based on 5 tonne units, to allow for flexibility to increase capacity, as and when warranted. This allows for scaling to happen in pace with community changes, minimizing initial costs, but it increases smaller plant costs because 5 tonne units are more expensive than tailoring units to meet volume. Further review is expected to reduce costs further, which would improve viability and accuracy. In short Figure 43 and Figure 45 will tend to be somewhat conservative and should Council decide to progress further, further assessment and pricing should be beneficial.

- Although Scenario 3b is designed to assess a high population growth scenario, it also assesses the impacts of having a larger plant. It suggests that working with neighbouring communities to accept their wastes would improve viability, resource recovery and environmental results, as would potential dividend and risk buffer. The difference might imply allowing up to two extra trucks per day, but be more economic and efficient. In the event that private sector engagement is pursued we expect this will be proposed.

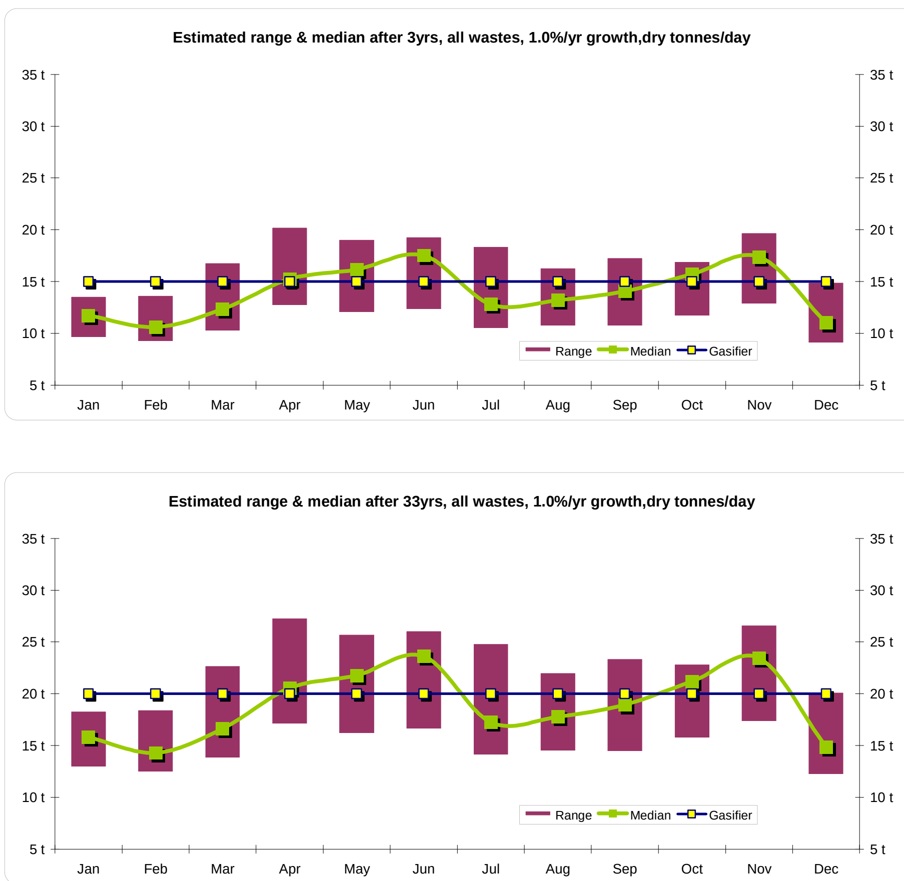


Figure 44: Phasing estimates, Scenario 2b

- Figure 43 scenarios show a plant could be viably phased to minimize cost and risk. The initial plant would likely be based on Scenario 2a (Township waste), which would operate at breakeven. As private haulers confirm their wastes an extra unit would be added (Scenario 2b), which improves viability. This should be possible to conclude during the initial planning period. Depending on how growth proceeds, extra 5 tonne units can then be added as the community grows, so if growth exceeds expectations units can be added or if needed, resized and replaced. The potential maximum gasifier capacity on the site exceeds the Public Works site's ability to receive and process wastes without re-planning the site, so the constraints on waste handling and viability are more site-related, not technology- or viability-related. Note that should Council decide to proceed to a next stage of assessment, a more detailed review of wastes and phasing will be needed.

Figure 44 shows Scenario 2b initial volumes with three 5 tonne units (upper graph). A fourth unit can be added as required (lower graph). Projections indicate that if growth continues at the current high rate, extra units may be required within 5 years, but that extra units improve viability, environmental and resource recovery. Extra units can be added as needed in response to demand, peak flows or maintenance needs. Further assessment of this should be included in planning, assuming the decision is taken to proceed to the next steps.

6.2.3 OVERALL VIABILITY

We also ran the same scenarios, adjusting the financials for possible private procurement, where the operator would also finance the project. This represents the viability as it might be assessed from a private sector perspective, summarized in Figure 45, with the recommended option highlighted in light green.

		Township waste collections only			Combined Township/Private Waste Collections		
	Scenario	1a	2a	3a	1b	2b	3b
	Growth %	0.3%	1.0%	1.7%	0.3%	1.0%	1.7%
B2) Financial : Private delivery : Inflation-adjusted, leveraged, 30% equity							
12	IRR	6%	13%	28%	40%	48%	49%
13	NPV	≈$0.7m	≈$11.0m	≈$28.8m	≈$51.7m	≈$70.8m	≈$94.0m
14	ROI (life cycle)	450%	1,020%	1,860%	2,620%	3,550%	3,950%
15	Life cycle profit/loss	$23m	$55m	$102m	$173m	$235m	$311m
16	EBITDA	$1.2m	$1.8m	$2.4m	$3.7m	$5.0m	$6.4m
17	Simple payback	≈28yrs	≈11yrs	≈5yrs	≈4yrs	≈3yrs	≈3yrs
18	Equity invested	≈$5.1m	≈$5.4m	≈$5.5m	≈$6.6m	≈$6.6m	≈$7.9m

Figure 45: Scenario Summary – Private Option

- Results from indicators 12-18 show that it should be possible to attract private sector participation if desired, but with caveats.

- Pursuing a plant that only processes the Township's wastes is likely to be more difficult as the financial metrics are generally below the level a private partner might want, without guarantees of some form. We expect private investors will typically wish to see leveraged returns in the order of 25% or better, subject to how risk is managed, so 1a, 2a and 3a are likely to require guarantees or other structures to help manage risk.

- Combined waste scenarios raise both issues and opportunities for the private sector:

  - All metrics for Scenarios 1b, 2b and 3b are positive for private involvement. Again, the Township is recommended to resolve issues it can control to reduce risk, maximize the system and the opportunity. Full privatisation while possible, may reduce control and flexibility, not just taxpayer dividend. Metrics 12-18 generally show that Council has options, but we caution that standard procurement processes are problematic due to limited suppliers with few qualified and experienced advisors, as noted in section 5.6 *Risk & Procurement* on page 50.

- Leveraged returns are attractive with equity contributions of ≈$5-8m and total net life cycle returns (undiscounted, inflation-adjusted) of ≈$247m and net present value of ≈$77m for the recommended scenario. These are attractive numbers, however the project size is smaller than most suitable private partners would consider, thus potentially limiting the ability to attract a private partner unless a larger plant taking extra local wastes is considered acceptable.

- The private sector scenarios show that if higher waste volumes are acceptable, profitability improves, with similar environmental and resource recovery benefits. Should Council decide to engage the private sector in some form, there will likely be interest in taking more waste than purely Esquimalt's, to improve economies of scale. Should Council choose to limit this or other innovation, both interest and viability will be more difficult to attract.

In summary the higher waste volumes of combined Township and private waste scenarios are more likely to attract a private partner, if the Township considers this desirable to explore further. This is mostly because the improved viability with larger volumes helps with plant size in addressing fixed costs specific to this project (DES costs, rock, complex site etc.).

6.3 Initial Sensitivity Assessment

IRM models are generally less sensitive to assumptions than other infrastructure projects, largely because of the more varied range of possible revenues and ability to control costs through fixed price contracts, revenue- pre-contracting and technology guarantees. While reviewers may believe that specific assumptions have major impact on results, we generally find that the models are considerably less sensitive than first perceived. We have therefore run basic sensitivity analyses using the recommended scenario (Scenario 2b) as a basis, varying selected input assumptions by 20% in each case and measuring the impact on: (1) average net dividend per year over the first ten years; (b) total net profit over the life cycle; and, (3) the Internal Rate of Return. Comparisons used the public sector finance recommended model, debt financed.

Sensitivity to 20% change	Avg. profit/yr	Life cycle profit	IRR
Capex	-12%	-3%	-15%
O&M	-9%	-10%	-3%
Debt rate	-5%	-1%	0%
Tipping fees	-7%	-5%	-4%
Heating	-6%	-4%	-3%
Cooling	-7%	-5%	-4%
Biochar	-32%	-22%	-14%
Carbon credits	-1%	-1%	0%

Figure 46: Preliminary Sensitivity Analysis

Figure 46 shows the sensitivity of the items listed to a 20% "worst case" change (i.e. costs increased; revenues reduced). In Figure 46 a 20% increase in capex results in a 12% drop in average profit per year over the first ten years with only a 3% drop on overall net profits over the projection life (30 years) and a 15% drop in the IRR. Note however that this shows the *percentage drop*, so while the capex changed by 20%, the original IRR fell from 22.3% to 19.0%, which is equal to the 15% drop in IRR shown in Figure 46.

While the "Average profit/.yr" column shows the change in average profit over the first ten years of operation, the "Life cycle profit" column shows the change over the entire projection (33 years). The IRR column is more helpful in understanding conventional market understanding of viability, which emphasizes early profits and is the reason we recommend relying on DCF indices for assessing long term infrastructure projects of this nature.

Biochar is the largest single revenue generator in the models and most sensitive aspect, and thus a key target for early risk reduction. Figure 46 shows that a 20% drop in biochar value results in up to a 32% drop in the average profit over the first ten years, with smaller but still appreciable impacts on the life cycle profit and IRR. It equates to a drop from $3.2m/year average profit down to $2.4m/year. It is thus important to confirm biochar revenues and mitigate this risk by pre-contracting revenues as soon as possible. It is also the reason we adopted low values for this item compared to market evidence noted in Figure 54 (we used US$2,000/tonne based on industry expert recommendations whereas retail is up to US$48,000/tonne). Thus while this is an important risk item to resolve early on, the potential exists for a plant to be more viable than assumed in all models. Elimination of any revenues whatsoever from biochar suggests a plant would be viable but marginal. No expert we consulted expects biochar to be unsalable.

Other items with sensitivity are the capital, operating and maintenance costs, which is to be expected. Strategies to deal with capital costs (and related performance and yield guarantees) have been explained. Operating costs will need continual diligence to maintain at manageable levels but are not a major item on their own. Maintenance will over time be important to maintain but again is manageable providing planned preventive maintenance is undertaken. A long term allowance for this has been made in the budget.

This is not intended to be an exhaustive assessment of the main sensitivities in the model, but is taken into account in the risk section (on page 50). The model and related recommended planning sequences are structured to try and mitigate risk, with implementation intended to address or quantify and mitigate the main risks before major financial commitment.

7 Conclusions & Recommendations

We conclude that IRM can be implemented in Esquimalt, with appropriate care and due diligence. The existing Public Works site appears to have sufficient space to be able to accommodate a plant of the scale needed to address the wastes currently in Esquimalt, and be able to cope with expansion of the plant to meet increased waste volumes, as the community grows and for the foreseeable future.

The Township collects ≈52% of the identified waste streams and while a plant could be implemented solely addressing this volume of waste, doing so is only anticipated to achieve breakeven and is likely to continue to be marginal. However discussions with haulers indicate they are willing to contribute their Esquimalt wastes under contract, which would raise both economies of scale and viability. We recommend pursuing this further as it helps pay for fixed costs such as site preparation, DES etc. while improving environmental results.

Uncertainties about waste volume, content and fluctuation in flow, as well as population growth, mean that a flexible implementation approach to IRM is important but achievable by phasing the plant. On this basis most scenarios are expected to be viable and could potentially yield a substantial dividend. A phased plant would likely start at ≈$15m but rising to ≈$21m as the waste volumes and community grows. This cost could be reduced or even eliminated, depending on: (a) procurement approach; and, (b) grants. Any financial shortfalls could be addressed by temporarily accepting waste from adjacent communities.

Under all scenarios the environmental benefits are potentially significant. The Township's declaration of a Climate Emergency and commitment to GHG reduction are reasons to consider IRM because the recommended scenario can yield GHG reductions of ≈12% of the entire community's GHG profile and ≈4½ times the Township's corporate GHG profile, i.e. ≈4,500 tCO_2e annually, ≈223,000 tCO_2e over the life cycle. It is also expected to sequester ≈40 tonnes (CO_2e) for every 100 tonnes of waste received, or ≈107,000 tCO_2e over the project's 30 year life cycle. This is a very significant advance in carbon reduction.

Ministry of the Environment guidelines revolve around the 5Rs process. The steps already taken by Esquimalt and reduced waste volumes already meet the guidelines, and technology reviews over the past decade, and this study, mean that Esquimalt is using best practices and technology. This means Esquimalt should be able to proceed to the next steps from a regulatory standpoint. MoE will have continued involvement through permitting, but gasification is a known item and permitted by them, so while there will be a rigorous permit and monitoring process, we do not expect this to be an overwhelming impediment.

In conclusion, a viable initial plant is likely to require a capital commitment in the order of ≈$15m (±15% on capital), but be expanded to ≈$19m (±15%) once other Esquimalt wastes are confirmed. Adding extra units to address larger waste volumes can be undertaken as and when required and while the initial plant is expected to only yield a small dividend, expansion thereafter is expected to be increasingly viable, with commensurate improvements in environmental benefits.

In closing it is important to note that engagement was undertaken to confirm key aspects such as the potential to contract with haulers, manufacturer pricing and procurement options with alternate service delivery. Implementation is thus considered feasible and if undertaken appropriately, is expected to be both financially and environmentally beneficial for the Township and Esquimalt taxpayers.

Appendix 1: Glossary

5R's hierarchy	The 5 R's hierarchy is a pollution prevention principle to guide the recovery of wastes according to Reduce, Reuse, Recycle, Recover and Residuals Management
AD	Anaerobic digestion (see below)
Anaerobic digestion	A system where microbes are used to convert feedstock into gas, usually with a high methane content ("biomethane"), usable instead of natural gas. The digestion by the microbes happens in a sealed vessel where oxygen is minimized
Alternate Service Delivery	Different way of delivering services where a private company participates in the service delivery. Can range from full outsourcing through hybrid contracting and/or partnering, including funding variations
ASD	See Alternate Service Delivery above
Biochar	Biochar is charcoal like substance that is made by burning organic material in a controlled low or zero oxygen process and used as a soil amendment for both carbon sequestration and addition of minerals
Biogas	Product (usually but not exclusively) from an anaerobic digester. Typically contains contaminants (water, carbon dioxide etc.)
Biomethane	Methane generated from biogas after it has been 'cleaned' for use as natural gas
Biosolids	Solid portion of liquid waste
Carbon credits	A carbon credit is a tradable certificate that allows the company that holds it to emit a certain amount of greenhouse gases. One credit is equal to equivalent emission of one tonne of carbon dioxide (tCO_2e)
Carbon footprint	A carbon footprint is the amount of greenhouse gases, usually measured as an equivalent in terms of tonnes of carbon dioxide, released into the atmosphere by a particular human activity
Carbon neutral/negative	Reducing carbon footprint either to zero (i.e. Carbon Neutral) or where carbon is sequestered (carbon negative)
Capex	The capital costs

Circle Draft	Type of gasifier modified from normal up/downdraft systems where the syngas is recirculated to reduce tars and raise yields
DCF	See section 6.2.1 starting on page 61
DES	District energy system usually distributing heat in hot water pipes
DTPD	Dry tonnes per day
EBITDA	See section 6.2.1 starting on page 61
ESP	Electrostatic precipitator – used to remove particulate matter from air emissions
Feedstock	Feedstock is the processed waste stream material mixed for input into the dryer and gasifier systems. It may consist of municipal waste, food scraps, and yard and garden waste but can also include selected construction and demolition waste
Fluidized bed	A gasification system where a bubbling bed of sand or other similar material is heated to a high temperature and turns the feedstock into syngas
Gasification	Is a thermochemical and mechanical process where the feedstock is heated in a chamber with zero or minimal oxygen to produce a synthesis gas ("syngas")
GHG	Greenhouse Gas
GJ	Gigajoules, a unit of energy often applied to natural gas
Integrated Resource Management	Is an approach to water, energy and waste management that stops viewing them as wastes, and instead aims to maximise their use and value as resources, in ways that reduce costs to taxpayers (or even create profit) and reduce greenhouse gas emissions (GHGs) and pollution
IRM	See Integrated Resource Management above
IRR	See section 6.2.1 starting on page 61
MoE	Ministry of Environment and Climate Change Strategy
MSW	Municipal solid waste
MW	Megawatt, a unit of energy usually applied to electricity
Net Zero	Refers to buildings that generate 100% of their energy needs, either on- or off-site, from renewable energy sources. See World Green Building Council explanation. IRM generates renewable energy
NPV	See section 6.2.1 starting on page 61

OCP	Official Community Plan
Opex	The operating costs, usually including maintenance costs
Outsourcing	Arrangement with a private sector company where the private entity delivers some component a government need or service, either in whole or part. May or may not include finance, usually includes performance criteria
P3	See Public-Private Partnership below
Plasma & plasma arc	A system of gasification where the feedstock material is heated to a high temperature so that it creates a gaseous plasma. Typically high yielding but requiring high energy inputs to generate and sustain plasma generation
Public- Private Partnership	Contractual arrangement between government and a private sector company where services are delivered by the private party. Typically includes some form of private financing, either interim or long term
Renewable natural gas	Methane generated from processing a feedstock that is largely "atmospheric" in nature, i.e. is not extracted from mining or similar methods, and thus avoids being a "fossil fuel"
RNG	Renewable Natural Gas see above
ROI	See section 6.2.1 starting on page 61
SWMP	Solid Waste Management Plan
Syngas	A mixture of hydrogen, carbon monoxide and carbon dioxide plus small amounts of methane, butane, propane and pentane
Swiss Challenge	Procurement approach where government works with an identified proponent, then seeks bids based on the developed project to safeguard best value for the taxpayer
TPD	Tonnes per day
Tipping fees	Tipping fees are the charges applied by CRD for the disposal of waste types at Hartland landfill
Updraft	A gasification system where ≈10% air is introduced from the bottom and syngas comes of the top
Downdraft	A gasification system where ≈10% air is introduced from the top and syngas comes of the bottom

Appendix 2: Advanced Gasification

Gasification is a process that converts carbon-based materials into a mixture of carbon monoxide, hydrogen and carbon dioxide gases. Gasification is achieved by reacting the feedstock material at high temperature (above 500 degrees Celsius) with a controlled low amount of oxygen and/or steam. The molecules separate from the carbon containing material and form a gas mixture called synthesis (syngas) gas or producer gas which is itself a fuel. The energy or power derived from gasification and combustion of the syngas is considered to be a source of renewable energy if the gasified compounds were obtained from biogenic material like wood, food scraps, yard waste, biosolids etc.

During gasification the carbon containing material goes through two stages to efficiently extract its energy. In the first step, called pyrolysis, the material is heated to around 250 ˚C to produce volatile hydrocarbon gases and biochar. Then as the temperature increases the hydrocarbons and biochar with the proper mixture of oxygen or high temperature steam, produces syngas and crystalline biochar.

The advantage of gasification is that using syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at higher temperature where the upper limit of the thermodynamic efficiency is higher. Syngas can also be converted into hydrogen, methane and other fuels and chemicals via various additional processes.

We selected the Advanced RotoGasifier developed by TSI (Figure 47) as the technology the Township would use. The RotoGasifier is an improvement to up/down draft gasifiers and used in TSI's existing torrefaction systems[41] systems where the pyrolysis process is controlled to maximize biochar production. The first was built in 2010 in Everett, Washington to demonstrate operations and test feedstocks, with systems based on similar design in successful operation in the forest and agriculture industry across the USA, in Canada and internationally.

Figure 47: Plants in Georgia, California & Louisiana

[41] Torrefaction uses only the pyrolysis stage of gasification where the process is controlled to maximize biochar production.

Figure 47 includes (middle picture) a mobile demonstration unit with a capacity of 240kg/day (dry weight), with the largest current plant in Waycross Georgia (1,860 tonnes/day, 680,000 tonnes/year – pictured on the left). More typical systems will have multiple units to support maintenance to allow for peak volumes and 24/7/365 operations (e.g. the 44 tonne/day plant in Louisiana, right).

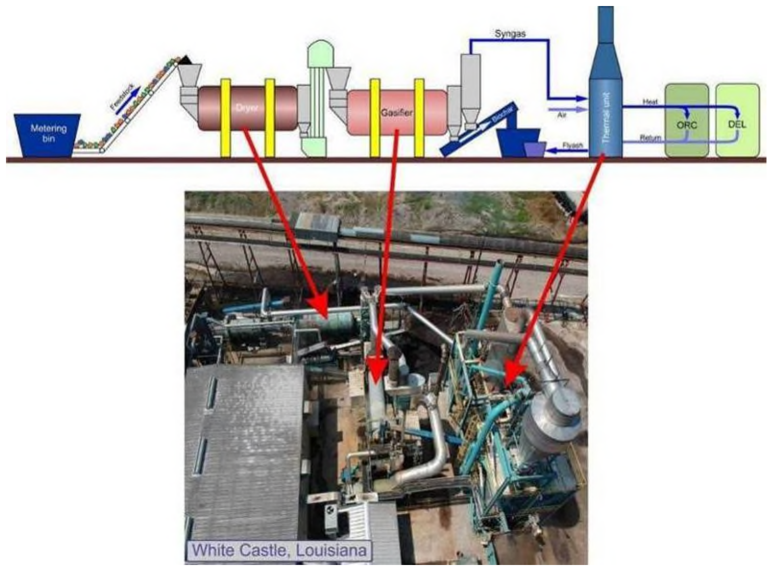


Figure 48: Schematic Overlay of White Castle Plant

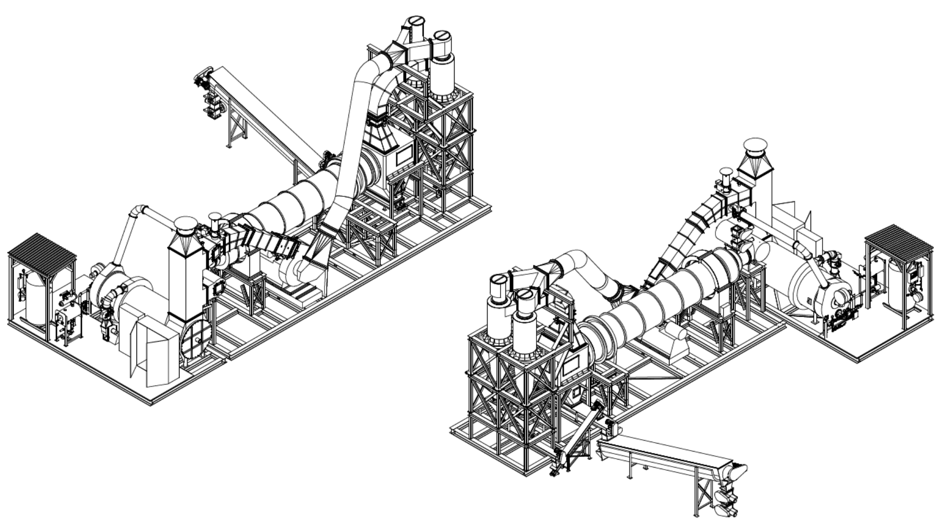


Figure 49: Gasifier Schematic

The horizontal rotating design addresses vertical processing issues by eliminating channelling and bridging, which can require shutdown to clear, thus improving operational efficiency. The RotoGasifier's horizontal rotating chamber improves flexibility in feedstock types and with its double airlock feed system, results in improved gas quality, better performance and overall improved efficiency, with its reduced downtime. The plant can be scaled to feedstock availability, implemented in stages to meet growing demand, is simple to operate and has a high level of automation.

Appendix 3: Biochar

An initial introduction to biochar is provided on page 79, with the following providing additional detail.

Background & Uses

Biochar is created by heating organic materials to produce something similar to barbecue wood charcoal. It has multiple uses and more are being identified, so both demand and value are increasing. Gasification is able to produce a quality biochar since it heats the feedstock without oxygen, thus avoiding combustion and producing biochar's crystalline carbon structure with other minerals.[42] While the quality, size, nature and granularity of biochar depends on the products it is created from, the main uses include:

A. Use as an energy storage material. Because carbonic material is combustible, biochar is a relatively high density means of storing energy;

B. Use as a filtration medium. At its most pure, "activated charcoal" or "activated carbon" but also used for lower-purity filtration. Uses include the medical, scientific, industrial and commercial sectors for odour management, particulate containment, but also water filtration and applications that don't require high purity, e.g. liquid waste etc.;

C. Use as a soil amendment to rehabilitate soils lacking structure or requiring improved water and nutrient retention, including use as a natural, organic fertilizer. Biochar's moisture retention capabilities supports communities with water scarcity or where nutrients are being washed out of the soils;[43]

D. Use as a mechanism to sequester carbon. It is one of the few viable and proven ways to be carbon negative, especially for Municipal Solid Waste, which is mostly atmospheric carbon. For every 100 tonnes of sorted MSW or food scraps for example, biochar can

---

[42] Char or charring refers to the darkening of a surface from combustion. It may be a charring of non-organic matter whereas biochar relates specifically to organic matter as described above. Some consider biochar as designating its use for organic purposes.

[43] An Overview of the Current Biochar and Activated Carbon Markets (Hugh McLaughlin, PhD, PE — Lee Enterprise Consulting, Inc. BioFuels Digest October 11, 2016).

sequester up to ≈35 tonnes CO_2e, which is a substantial potential contributor to GHG reduction commitments given this can be achieved incidentally to processing municipal biosolids or solid wastes.

While biochar's use can be traced back over 2,500 years, its wider utility has only recently been understood as a way to reduce Green House Gases.[44] Unlike many other approaches to GHG reduction through sequestration – which incur costs – biochar is a saleable, organic commodity, which reduces sequestration costs. It is also less energy-intensive to produce and qualifies as a "green energy" source, with lower GHGs.

Advanced Gasification biochar will vary depending on the source material, so the feedstock has to be assessed and tested to determine the most suitable market and process. Based on tests, sales can then be pre-contracted to reduce risk in the business case.

Primary uses for char & biochar

1. Animal farming – ≈90% of the market in Europe
   - Litter, silage and slurry agent/treatment
   - Feed additive / supplement
   - Manure composting agent
   - Water treatment in fish farming
2. Soil conditioner
   - Fertilizer, compost additive or substitute
   - Plant protection
   - Trace element substitute/rehabilitation
3. Building sector
   - Insulation material & humidity control
   - Air and sub-soil decontamination
   - Electromagnetic radiation barrier
4. Decontamination
   - Soil remediation (mine-works, military bases, landfill etc.)
   - Soil and wastewater filtration
   - Pesticide barrier
   - Pond and lake water aeration & filtration
5. Anaerobic digestion & biogas production
   - Biomass additive in anaerobic digesters
   - Biosolids and digestate treatment/filtration
6. Water & wastewater
   - Active carbon filter for wastewater treatment
   - Pre-rinsing additive for wastewater treatment
   - Soil substrate for organic plant bed wastewater treatment
   - Composting toilet wastewater treatment
   - Micro- and macro-filters for potable water
7. General commercial & industrial
   - Exhaust filters for emissions and intake
   - Industrial material – carbon fibres, plastics etc.
   - Electronics – semiconductors, batteries etc.
   - Metallurgy and metal reduction*
   - Cosmetics – soap, skin-cream, bath additives etc.
   - Paints and coloring, e.g. colorants, industrial paints
   - Energy storage/production* – pellets, lignite substitute
8. Medical - Detoxification, pharmaceutical carrier, topical etc.
9. Fabric additive – underwear, insulation, deodorant etc.
10. Wellness
    - Mattress/pillow filling to address odour, toxins etc.
    - Electromagnetic radiation shield – microwave ovens etc.
    - Food Conservation

*All uses are considered to sequester carbon except as noted by **

Figure 50: Biochar Uses

Market

The biochar market is expanding as new uses are identified and while supply is also increasing, demand is currently outstripping supply, resulting in rising prices. The following comments on the nature of the market as at late 2019.

The price of biochar varies depending on its characteristics and by market. There have been several qualified assessments of biochar markets, mostly focussed on activated carbon (i.e. the filtration market) because this is better developed with known retailers.

The "Global Activated Charcoal Market" report[45] assessed revenues and volumes from 2013 with projections through 2025. It concludes the activated carbon market was estimated at

[44] See the International Biochar Initiative (IBI) and the United States Biochar Initiative (USBI).

[45] Global Activated Charcoal Market (Androit Market Research, 2019).

US$4.72 billion in 2018 and is likely to exceed US$6.60 billion by 2025 with a broad array of sector demand for activated carbon, shown in Figure 51.[46]

A 2013 survey conducted by the International Biochar Initiative ("IBI") indicated prices between US$73/tonne and US$12,267/tonne, but did not distinguish biochar quality or whether the product is wholesale or retail. A 2014 IBI study found the mean price to be US$2,286/tonne[47] and by 2016, as demand and supply expanded in lower value ranges, that the mean price dipped to US$1,820/tonne.[48]

Roskill Market Reports[49] noted that internationally, the average value of shipments from the USA increased from US$2,700/tonne in 2012 to US$3,822/tonne in 2016. They expect international demand will raise US prices for speciality biochar grades, pressured by this international demand.

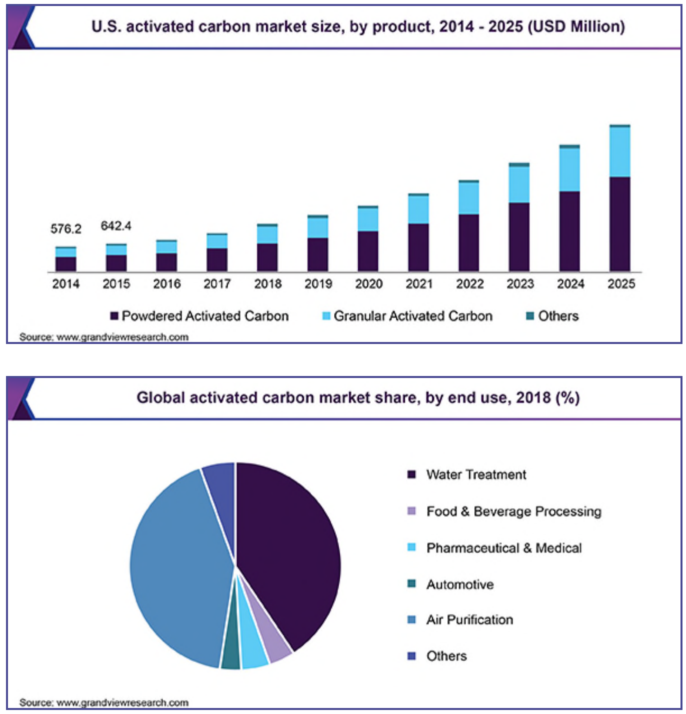


Figure 51: Activated Carbon Value & Demand

A 2018 US Forest Service analysis,[50] reported prices paid for biochar upward from US$660/tonne with an average price was US$1,134/tonne, but with US$1,758/tonne the most often cited price. This mostly considered soil amendment biochar however, which typically achieves lower values than filtration biochar. The report expects demand to continue to rise, outstripping supply, so prices are expected to rise despite expanding supply.

In summary, recent studies have shown an increasing demand and price for qualified biochar with the most recent studies showing it at a minimum US$2,000/tonne for soil amendment and lower quality biochars, with higher values paid for filtration medium. Wholesale prices are typically 25-50% of retail, subject to certification, and demand and prices are expected to rise for the foreseeable future.

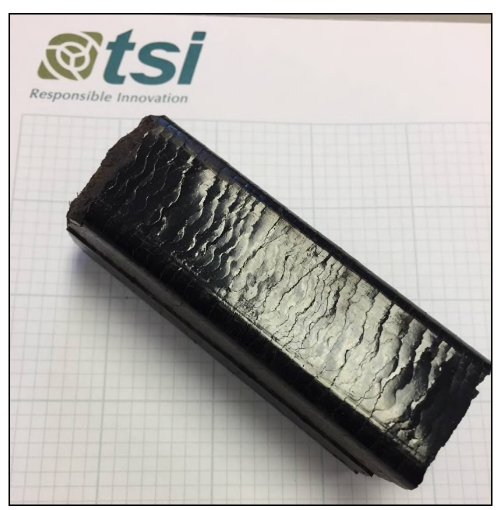


Figure 52: Rotogasifier Biochar

In November 2019 we reviewed online biochar sales, mainly in the US. Listings are mainly for small retail packages of char sold as an amendment or for filtration, shown in Figure 54. Listings averaged ≈US$15,000/tonne for filters, ≈US$7,550/tonne for

[46] Grand View Market Research study summary.

[47] Applied Energy study, (Campbella, Anderson, Daugaard & Naughton, 2

[48] Biochar vs Activated Carbon (Finger Lakes Biochar, 2016).

[49] Roskill Market Reports (2017 activated carbon forecasts to 2025).

[50] Survey and Analysis of the US Biochar Industry (Preliminary Report, 2

soil amendments and the overall median is ≈US$10,000/tonne. 78% of list prices exceed US$5,000/tonne.

Generally, the higher quality biochar requires certification and attracts a higher price as filters than as a soil amendment. Note also that gasifiers can recycle filters and resell or improve energy yield, increasing productivity and value.

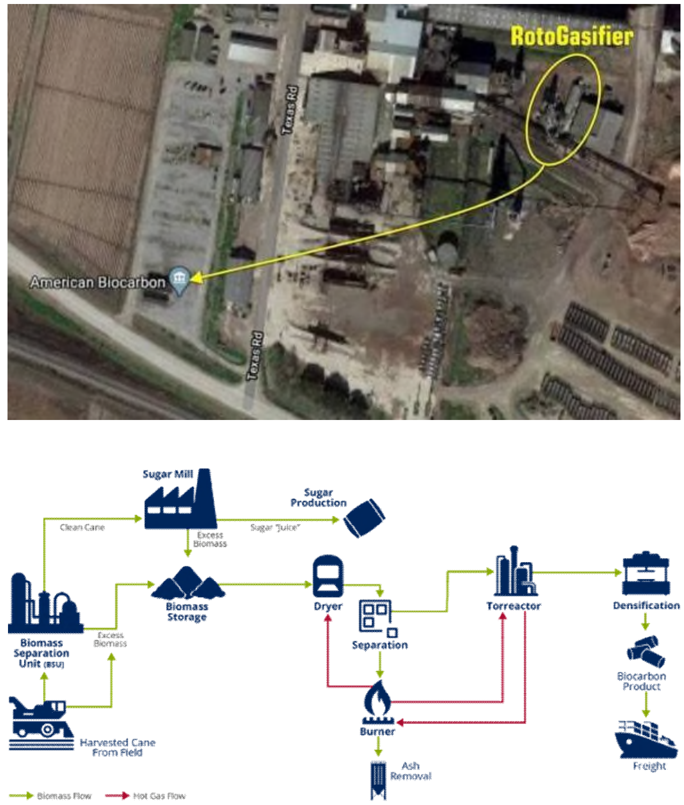


Figure 53: American Biocarbon Process, Louisiana

Sale price differences are mainly influenced by: (a) impact of product branding, marketing and market dominance of specific brands; (b) size of the individual package being sold – with smaller packages commanding a higher price per metric tonne; (c) the quality and certification, with filtration typically using a higher quality, more expensive biochar. Where used as an energy fuel the price is expected to relate to the price of electricity. The White Castle, Louisiana RotoGasifier plant produces biochar able to be used either for generation or other highest and best uses, making it a flexible product saleable into multiple markets (Figure 53[51]).

A characteristic of biochar is that it sequesters carbon when used as a soil supplement or 'buried'. Since municipal waste (liquid and solid) are largely atmospheric carbon in nature, biochar can sequester approximately 2.9336x its tonnage as tCO_2e (per academic assessments). This not only applies to soil supplements, so only energy use of biochar would fail to sequester carbon. The market benefit of sequestration is currently not being fully reflected in either market demand or pricing.

Quality

Currently, most biochar is sold without compliance with standards, which are increasingly developed around the International Biochar Initiative (IBI). This covers aspects such as chemical parameters, toxic elements, origin, feedstock, composition, metal and other properties (such as, moisture, organic carbon, C:H ratio, ash, nitrogen, pH, electrical conductivity, lime content and particle size distribution). Certification carries the "IBI Certified™" seal. Going forward we expect certification will be more important for uses that require quality control, e.g. laboratory or medical uses, than other uses.

With variable feedstocks, biochar is tested regularly to asses whether its properties create challenges with the intended use. Advanced Gasifiers can be adjusted to improve biochar

[51] See also American Biocarbon web site. Process diagram courtesy of American Biocarbon.

quality and volume, or to reduce aspects such as volatile organics. Organic feedstocks (wood, kitchen scraps and other organics) may mean adjusting separation to meet the quality required for specific markets. This means that the biochar's value can vary but is controlled through ongoing testing and specific application.

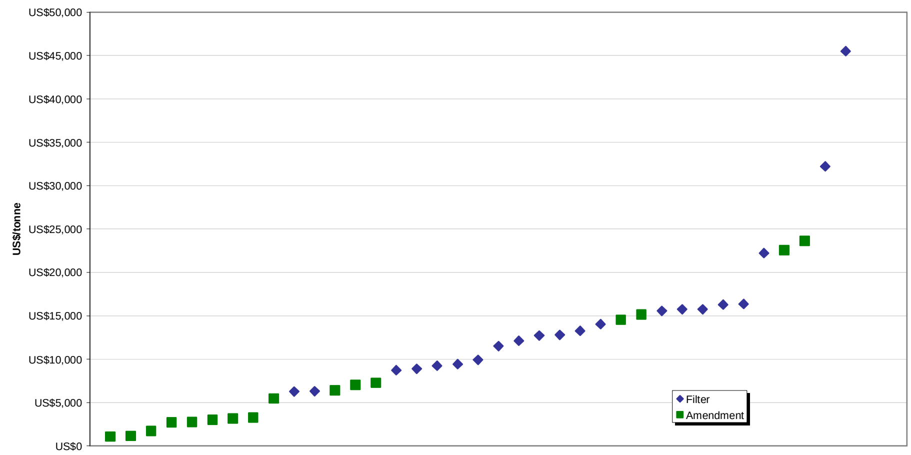


Figure 54: Retail Biochar Prices, 2019

Advanced Gasification biochar (from wood chips) has been tested against IBI Standards and while they did not seek certification, the biochar is sold to the City of Woodland, CA for US$750 per ton. TSI tested organic-based biochar with electron microscopy and confirmed the high quality lattice required for quality biochar. Pivotal also supplied samples to University of Calgary researchers who considered it would be suitable as a soil amendment, with final confirmation being project- and feedstock-specific.

Conclusion

Biochar is a product and market that is gradually maturing. A range of values are proving feasible, with increasing demand, linked to biochar quality and volume, which varies by feedstock and yield, so biochar futures are currently limited. Advanced Gasification biochar can improve revenues while potentially sequestering carbon, making it an area of rising interest. Because biochar value can affect Advanced Gasification project viability, biochar potential should be assessed through testing and using Pivotal's IRM model, so the project, feedstock, operations and contracts can be aligned to optimize potential.

Appendix 4: Grants

FEDERAL

1. Federal Infrastructure Fund – started in 2016 with $518m, and now has committed $9.2 bn for green infrastructure and clean technology projects that stimulate the economy with a focus on GHG emission's reduction and economic development at the community level, and includes solid waste management projects. The fund is open for applications. The IRM project would qualify for this funding.

    a. Green Infrastructure Fund – The current Phase II round of funding has been allocated, however, there are likely to be follow-on programs for renewable energy from solid waste management, GHG reduction and community climate action programs. The IRM project would be a suitable project for this funding.

    b. Municipal Climate Innovation Program is delivered by FCM and extends through 2022. It is designed to assist communities to adapt to the impacts of climate change and assist with GHG emissions reduction. The IRM project would qualify for funding under this program.

    c. Gas Tax Fund focuses on core infrastructure needs but does not specifically mention solid waste management but it may be applicable for the Township's IRM program with its benefits in resource recovery from wastes, GHG emissions reduction and potential revenue streams.

    d. Natural Resource Canada – The Clean Growth Program has $155 million for investment in the demonstration of projects in clean energy with an emphasis on GHG reduction. They are currently not accepting applications but are to in the future.

2. Western Economic Diversification program funds innovation initiatives for clean tech. The funding calls have very short application time frames. The IRM program would appear to qualify under the acceptance criteria for funding.

3. Green Municipal Funding Program has $120 million for feasibility studies, sustainability plans and waste management projects making it ideal for the IRM program. It is open for application.

New grants have been publicly mentioned, related to COVID-19 measures. These are changing rapidly so are not detailed here.

Provincial

1. Energy Mines AND Petroleum Resources – Community Energy Leadership Program provides funding for clean energy project owned (incl. partial ownership) by local Government or First Nations. Funding supports communities to reduce GHG emissions reduction, stimulate economic development and promote partnerships with industry to advance the clean energy sector. Going forward funding will be on a project by project basis. Previous funding ranged from $10,000 to $175,000 per project for construction costs. Contact is Nairn Albrecht, Ph: 1.778.698.7166; email is celp@gov.bc.ca.

2. Ministry of Environment and Climate Change Strategies and Municipal Affairs administer the CleanBC Communities Fund (CCF) which target capital infrastructure projects for public use and benefit to meet the following outcomes: increased capacity to manage renewable energy; access to clean transportation; energy efficiency of buildings and generation of clean energy. Calls for applications are not scheduled at this time. Available funds total $63 million. Contact: Municipal Affairs at 1.250.387.4060; email is infra@gov.bc.ca.

3. Municipal Affairs and Housing – Infrastructure Planning Grant Program offers funding to local government that supports energy and climate change action. Grants are provided for projects to study the feasibility costs and technology options. The funds are available to match funding up to $10,000. Contact: Municipal Affairs at 1.250.387.4060; email is infra@gov.bc.ca.

Municipal

1. Western Economic Diversification – Regional Inn ovation Ecosystems Program provides funding to municipalities for clean energy and added value agriculture projects. The IRM project would qualify for the clean energy and biochar production which could be used as an advanced soil supplement. Contact: Ph 1.604.666.6256.

2. Federation of Canadian Municipalities (FMC) – The Green Municipal Fund supports projects that reduce energy consumption (generating GHG reductions) and improve air, water and soil quality. Funds are available for planning, feasibility studies and pilot projects. Low interest loans and grants are available for capital projects. The IRM project would qualify for this funding program. Applications are open on a project by project basis.

3. Union of BC Municipalities (UBCM) provides funds for capital and planning projects for energy, sustainability planning, solid waste management, transit, water and wastewater. The IRM project would qualify for this funding. Contact: Ph. 1.250.356.5134; email ubcm@ubcm.ca.

4. Real Estate Foundation of BC provides matching funds for planning studies with single or multiple phases for renewable energy projects. Applications are due in February and August annually. The IRM project would qualify for this funding but call before submitting application. Contact: Ph. 1.866.912.6800; nick@refbc.com.

5. VanCity Credit Union – Community Partnership Program provides funding for planning and assessment of community based clean energy projects that address sustainability and climate change action. The IRM project meets those criteria. Funding maximum is $10,000. Applications are open.

6. Columbia Basin Trust provides funding for community based clean energy project development up to $50,000. The IRM project qualifies for this funding. Contact: Ulli Mueller; Ph. 1.800.505.8998; email umueller@ourtrust.org.

7. BC Bioenergy Network provides funding for municipal projects on a project by project basis including partnership funding. Funding is focused on technology feasibility, development engineering design, project management t, and capital costs. The IRM project would likely qualify for this funding. Contact: Scott Stanners; Ph. 1.604.889.4549; email scott.stanners@bcbionetwork.ca.

Appendix 5: Study Team

Person	Role & Qualification
Graeme Bethell	Graeme is a gasification specialist, President and co-founder of Pivotal IRM. He specializes in the integration of solid and liquid wastes and biomass to produce clean heat (cooling) and power (CHP); biochar markets; and district energy systems. As a Technical Specialist, he specializes in advanced gasification, sustainability and climate change, with a focus on community invigoration through job creation, integrated energy resources, carbon reduction, environmental sustainability and economic development.
Chris Corps	Chris is a Land Economist and is CEO and co-founder of Pivotal IRM. His experience has included feasibility and viability assessments for sustainable land development, economic development and energy projects. He specializes in complex business cases and has worked on some of the largest and most difficult projects in Europe and Canada. He has lead international projects and set financial standards in current use in 132 countries covering sustainability and valuation, and has been a leading member establishing government financial standards. Chris originally recommended BC government investigate IRM, which led to the Provincial Integrated Resource Management study, liaising with Treasury Board and Climate Action Secretariat staff. Chris advised multiple ministries and agencies on how to embed sustainability into capital planning and advised on sustainability revisions to the Capital Asset Management Framework, which is BC's procurement policy.
Dr. Matt Summers	Dr. Summers is a professional engineer with a background in both the liquid waste treatment and Advanced Gasification. He specializes in bio-energy system design and analysis and is a Specialist in kinetic and thermodynamic measurement and modeling; manufacturing systems design and analysis, and precision sensors and control systems. He is Chief Operations Officer, West Biofuels, LLC, with responsibilities for design, construction, and start-up of commercial biomass gasification systems, plus he supervises staff, contractors and project partners to coordinate projects and directs the research at their Research Center used for testing technology performance, controls and emissions.
James Pratt	James is a Registered Professional Planner, James brings 25 years of experience as an independent consultant serving governments, First Nations, non-profits, and network organizations. A specialist in

Person	Role & Qualification
	participatory engagement, he facilitates opportunities for meaningful involvement of residents and affected parties who can provide valuable feedback and input. He has provided consultation services as part of planning in local and regional governments, as well as First Nations and non-profit organizations. Based in Victoria since 1995, he has a reputation as a principled, dedicated professional.
Albert Bicol	Albert Bicol PEng LEED AP is internationally experienced in energy systems and sustainable energy master planning and development. Albert's background with Energy Net Zero master planning and development led him to conclude that Advanced Gasification is one of the only ways that buildings can be self-sustaining in term of energy, while reducing carbon. Albert has advised on Vancouver's False Creek development, Shangri-La Hotels in East Asia and is currently advising on projects including a major global airport, a 1m sq ft Vancouver development, a major multinational with 26 outlets in the Lower Mainland alone, and a 1m sq ft multiplex entertainment centre in Japan, all sole sourced and direct awarded and assessing Advanced Gasification. This includes Canadian federal agencies.
Michael Wolinetz	Michael is a Partner at Navius Research Inc., who helped develop the GHG automated calculations in Pivotal's IRM model. We expect to use this in developing GHG assessments relative to Esquimalt's 2030 and 2050 GHG reduction goals where Michael will help evaluate Pivotal's GHG modelling and will review the model's estimates. It is envisaged that this summary reporting will be sufficient at this stage, but Michael would then be able to provide more complete assessment as part of a separate study. Michael specializes in quantifying greenhouse gas emissions and their impacts from actions and policies undertaken by government. He specializes in CIMS energy-economy modelling, in designing and executing energy and air emissions forecasting analyses with this model.