Kitselas First Nation
Combined Heat and Power using Wood Residue
Phase 1: Prefeasibility Assessment
Final Report

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Prepared For: Kitselas First Nation &
Natural Resources Canada, Indigenous
Forestry Initiative

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Executive Summary

The Kitselas First Nation has an interest in pursuing a renewable energy solution at their main community, Git'aws, that will bring economic, social and environmental benefits to the community and contribute to their self-sufficiency. Git'aws is located east of Terrace, BC, along the Skeena River. It is the primary community for Kitselas members and includes 81 homes, administration buildings and other community infrastructure. Kitselas is currently planning development of an additional 54 homes at Git'aws. Git'aws is connected to BC Hydro's hydroelectric transmission system and Pacific Northern Gas' natural gas system. Homes are heated electrically or by woodstove.

As the first phase in a proposed three phase project, Westland Resources Limited conducted initial investigations into bioenergy, and more specifically combined heat and power (CHP) using woody residue. Phase 1 was carried out in partnership with Kitselas' Housing Manager and community partners (Pacific North Coast Development Society and the Skeena-Nass Centre for Innovation in Resource Economics). Funding was provided by Natural Resource Canada's Indigenous Forestry Initiative program.

To understand the current heat and electrical profile at Git'aws, preliminary estimates for electrical energy consumption, power demand and firewood use were determined. The average annual electrical energy consumption is 14,887 kilowatt-hour electric (kWh_{el}) per household, with an average cost of $1,900 per year based on BC Hydro residential rates. Base, average and peak power demand are 0.9 kilowatts of electricity (kW_{el}), 1.7 kW_{el} and 2.9 kW_{el} to 9.4 kW_{el} respectively. An estimated 7 cords of wood are burned by each house with a woodstove (44 houses have woodstoves), resulting in an estimated annual cost for firewood of $1,500 per woodstove (or $800 per house when the cost is distributed across all 81 homes). In total, it is estimated that current electrical and heating costs per household average $2,700 per year.

While the scope and intent of this project was to review biomass combined heat and power, other renewable energy options were reviewed including: wind energy, hydrogen fuel cells, solar power, geothermal power, run-of-river hydroelectricity, in-stream turbines, renewable natural gas, renewable diesel and bioheat. Based on this review and given the local availability of woody biomass, it was concluded that a combined heat and power system using woody biomass is one of the most suitable energy options for Git'aws. Combined heat and power produces heat and electricity from a single fuel source, in this case biomass.

Given the anticipated energy requirement at Git'aws of less than 1 megawatt electrical (MW_{el}) for the existing and proposed housing, only small and medium scale combined heat and power systems were considered (between 40 kW_{el} and 1 MW_{el}). Applications involving small loads (below 200 kW_{el}) typically use fixed-bed gasification and internal combustion engine (ICE) systems. Direct combustion and organic Rankin cycle (ORC) units are typical for loads over 200 kW_{el}. Capital, installation, operation and maintenance costs were reviewed and several conclusions were reached:

- gasification and ICE systems are typically more expensive than direct combustion and ORC systems (i.e., capital and installation costs are \$16,900 per kW_{el} for a single 50 kW_{el} gasification and ICE system versus \$10,000 per kW_{el} for a 1 MW_{el} direct combustion and ORC unit);
- the cost of electricity produced by biomass CHP is more than hydroelectricity from BC Hydro (i.e., CHP rates are expected to range from \$0.25 to \$0.56 per kWh_{el} compared to an average BC Hydro rate of \$0.13 per kWh_{el} for BC Hydro); and
- without grant funding or a source of revenue there is not a strong economic case for a CHP system on its own at Git'aws.

With this in mind, revenue generating options that could use bioenergy waste products (either by-products or heat) or that could be paired with a bioenergy system were explored. BC Biocarbon, a company producing biochar and other potentially marketable products from woody biomass and other feedstocks, was identified as having potential for Kitselas.

Biomass availability is a critical factor for the success of a CHP system. There is an abundance of woody biomass close to Git'aws that could be used to run a biomass facility. The many old forest stands of the region are composed of large trees with significant decay resulting in a substantial amount of pulp logs and waste fibre. Kitselas Forestry LP, the forestry arm of Kitselas First Nation, has committed to supply woody residue from their logging operations. It is estimated that 28,300 m^3 per year or 12,700 odt per year could be supplied from Kitselas Forestry LP in the form of pulp or waste material, and it is expected that this material would come at a delivered cost of \$23.50 to \$41.00 to the CHP facility. Depending on the type of facility chosen, garbage and sewage are also a potential feedstock. Kitselas currently pays out \$1,360 per year per house for garbage and sewage disposal. Kitselas could see cost savings if a portion of this waste material could be used to produce energy in a CHP facility.

As with any renewable energy, climate impacts are an important consideration. A preliminary greenhouse gas (GHG) assessment was carried out and found that a CHP system would result in a greenhouse gas benefit when compared to the status quo (status quo is slash pile burning of woody residue, hydroelectricity, and woodstoves). In a scenario in which all biomass would have been burned in slash piles, and all woodstove use is offset, the CHP system could result in a GHG reduction as high as 2,000 tonnes of carbon dioxide equivalent (CO_2e) per year compared to the status quo, which is a 50% reduction in GHG emissions. A more likely scenario in which 75% of biomass is diverted from slash pile burning and 50% of woodstove use is offset, the GHG benefit is about 800 tonnes of CO_2e per year.

As a result of the investigations and research carried out for this project, the following key recommendations are being made to Kitselas.

1. A brief review of other renewable technologies suggests that if a renewable technology were to be utilized, it is a biomass CHP system that would be the most appropriate for Kitselas.
2. A preliminary review indicates that a stand-alone CHP system for Git'aws is not likely viable based on economics alone. However:

   (a) If Kitselas receives a grant for the capital and installation costs of the project, this economic assessment may change.
   (b) In addition, consideration of the full range of economic, social and environmental factors, based on input from the community may also change the viability of the project.
   (c) A stand-alone CHP system may be worth revisiting in a few years' time, at which point CHP technologies may be more established, and the economic case may change.
3. Notwithstanding Recommendation 2, if Kitselas were to proceed with a stand-alone CHP system, a series of small to medium-scale (less than 500 kW_{el}) modularized direct combustion and organic Rankin cycle, or gasification and internal combustion engine systems would likely be the most appropriate given the residential electrical demand at Git'aws. Additional demand from industrial or community infrastructure may change this recommendation.
4. Pairing CHP with a revenue generating process would increase the economic viability of the project. Of the revenue generating processes reviewed, BC Biocarbon is likely the best fit for Kitselas. A CHP system combined with a revenue-generating process may be worth continued investigation.
5. Regardless of whether Kitselas decides to proceed with further feasibility on CHP at this stage, they could consider installing district heating infrastructure for the new subdivision. This would allow a centralized heating system (bioheat or other) or a biomass CHP system to be more easily integrated in the future.

If Kitselas decides to move forward with these recommendations and proceed with the next phase of the project, Phase 2 will involve detailed feasibility and preliminary conceptual design of one or more selected processes.

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1 Introduction

Git'aws[1], a community of the Kitselas First Nation (Kitselas), is approximately 19 kilometres east of Terrace, BC, and borders the Skeena River and Highway 16 (Figure 1). Git'aws is a residential community located on Kitselas IR No. 1, which is also the location of the Kitselas Administration building and the world-famous Kitselas Canyon[2]. Kitselas is considering commercial developments on or adjacent to Git'aws as part of the Nation's efforts to improve and attain social and economic prosperity.

On behalf of Kitselas, Westland Resources Limited (Westland), in partnership with the Pacific North Coast Development Society (PNCDS) and the Skeena-Nass Centre for Innovation in Resource Economics (SNCIRE) conducted initial investigations into bioenergy, and more specifically combined heat and power (CHP)[3] using woody residue for Git'aws. These initial investigations were the first phase in a proposed three phase project. Funding for Phase 1 was provided by the Indigenous Forestry Initiative (IFI) of Natural Resources Canada (NRCan), with additional in-kind contributions from Kitselas, PNCDS and SNCIRE.

Phase 1 of the project spanned two years and involved: the identification of anticipated residential electrical demand at Git'aws; the assessment of alternative renewable energy options; a review of potential CHP processes and revenue-generating options to be paired with CHP; and a preliminary analysis of economic costs, feedstock availability, and greenhouse-gas impacts. This report includes and builds on the outcomes from the interim (first year) report, and summarizes the progress during the 2019-20 fiscal year. Final outcomes and recommendations related to the demand, infrastructure requirements and potential CHP processes are provided.

Should Kitselas decide to move forward with the project, Phase 2 would involve detailed feasibility and preliminary and conceptual design of one or more selected processes, and Phase 3 would involve detailed engineering design and installation.

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[1] Git'aws is also commonly spelled Gitaus. The spelling used in this report is consistent with the Kitselas Land Use Plan (Kitselas First Nation 2019)

[2] "Kitselas" means "People of the Canyon" in Sm'algyax, the language of the Tsimshian people. The canyon area has been continuously occupied by Kitselas for over 5,000 years.

[3] CHP systems can be run using a variety of fuel types. For this report, unless otherwise specified, any reference to CHP indicated a CHP system using biomass as the primary fuel type.

1.1 Community Engagement and Participation

During Phase 1, the project team worked closely with Ulyses Venegas, Kitselas' Housing Manager. Mr. Venegas provided context on community priorities, infrastructure and plans, and was involved in monthly meetings and facility visits. A presentation of the preliminary recommendations from Phase 1 was presented to Kitselas Band Council on March 24, 2020 for their endorsement. A presentation was also made to Kitselas' senior management team.

Engagement with Kitselas members, administrative staff and Band Council will be an integral part of the next phase of the project. Confirming community support and interest in developing a facility will be a requirement for the success of the project.

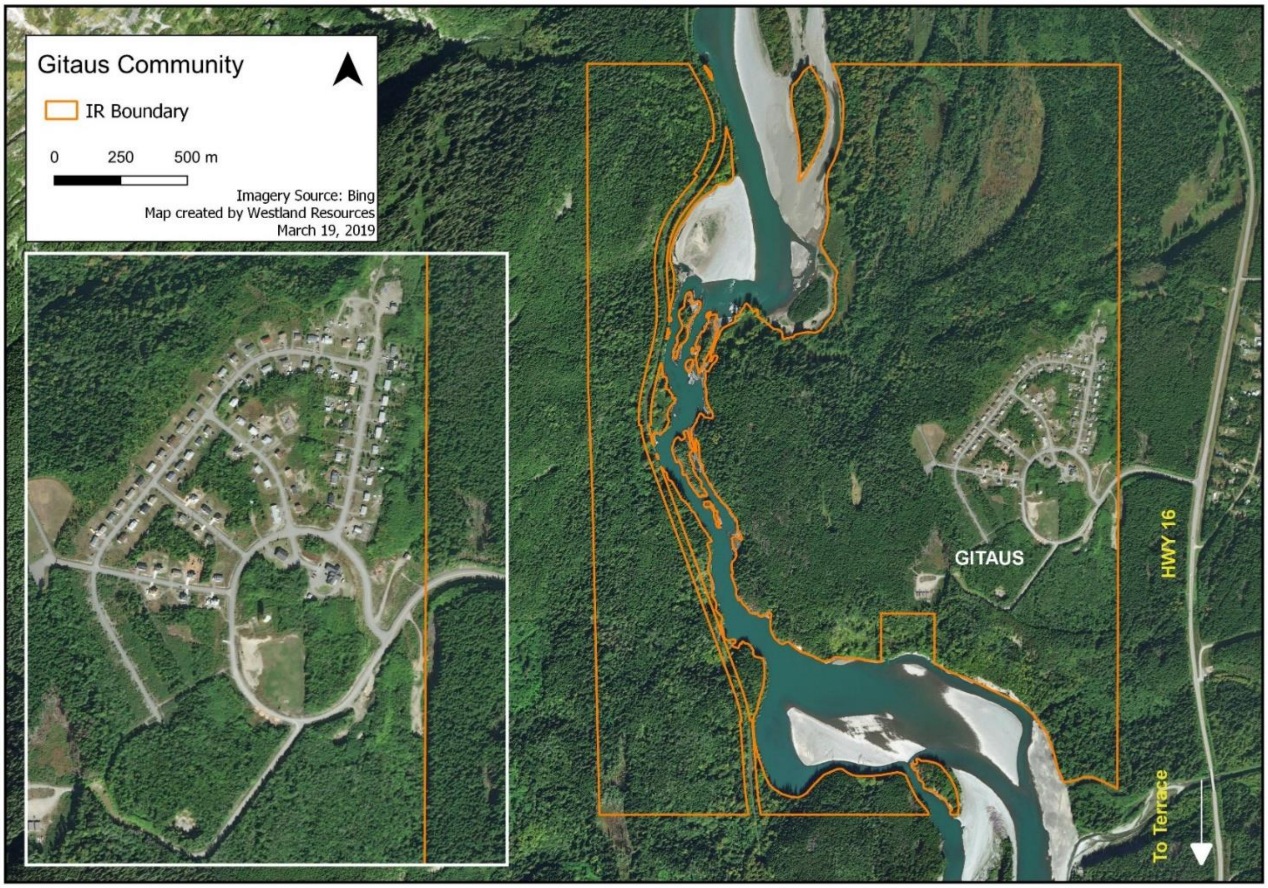

Figure 1. The Git'aws Community is located on Kitselas IR 1

2 Infrastructure and Demand

2.1 Existing and Planned Buildings and Infrastructure

Current development at Git'aws is comprised of 81 homes, and various administration and community buildings. A complete list of the existing development and infrastructure is provided in Table 1.

Table 1. Summary of Existing Development and Infrastructure at Git'aws[1]

Existing Development	Infrastructure
• 81 houses • Kitselas Health and Administration Building • Adult School • Fire Hall • Community Garden • Greenhouse • Smoke House • Youth Centre • Cemetery • Historical Kitselas Canyon • Park • Basketball Court • Soccer Field • Playground	• BC Hydro connection (electrical) • PNG connection (natural gas) • Individual septic systems • Paved roads except for road to Kitselas Canyon and portion of Git'aws Road • Internet/Phone • Cell service • Water distribution system with two on-reserve and three off-reserve communal wells

[1] From Table 2 of the Kitselas Land Use Plan for Reserve Lands (Kitselas First Nation 2019)

Git'aws is connected to the electrical grid through a BC Hydro transmission line and to natural gas via a Pacific Northern Gas (PNG) pipeline. The BC Hydro connection is single-phase (Wolfe pers. comm.). The PNG line reduces from 88 millimetre (mm) at Highway 16 to 60 mm as it enters Git'aws (Patershuk pers. comm.). The PNG distribution system has not been extended to the area of Git'aws zoned as light industrial in Figure 2 (Venegas pers. comm.).

The 81 existing homes in Git'aws are currently heated by electrical central forced air furnaces (37), woodstoves (44), baseboards (number unknown), or some combinations of these three sources. The fire hall uses natural gas heating, and the Administration Building uses electricity and geothermal heating (Venegas pers. comm.). Overall, electricity is the most common heating source.

Development plans at Git'aws include a proposed 54 home housing development (construction to start in 2021) and a potential wastewater and sewage treatment plant (Venegas pers. comm.). Other development referenced in the 2019 Kitselas Land Use Plan includes community spaces (community hall) and commercial development (cannabis production facility); however, at this time no further planning or development is underway for these projects (Venegas pers. comm.).

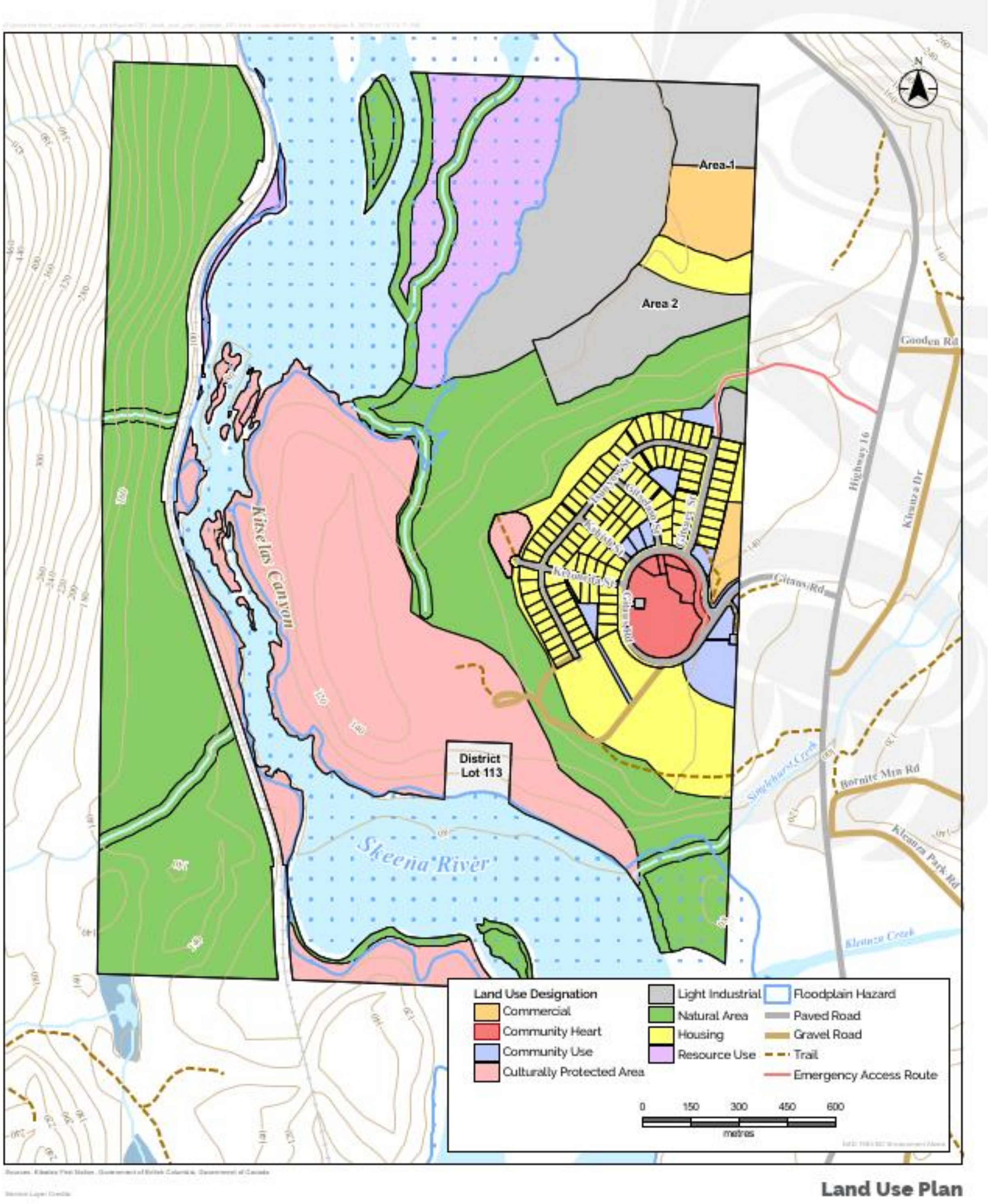

Figure 2. Git'aws Land Use Designations from 2019 Kitselas Land Use Plan

2.2 Existing and Future Electrical and Heating Demand

An understanding of the current and future electrical and heating demand is needed to size a renewable energy system. Preliminary calculations were carried out to estimate the electrical energy consumption and power demand, as well as woodstove use for the residential housing in Git'aws. Demand from community infrastructure or proposed industrial facilities was not factored in at this time. The values are approximate, and, if Kitselas moves on to the next phase of the project, a detailed energy assessment will be carried out.

As stated in Section 2.1, the 81 existing homes in Git'aws are currently heated by electric central forced air furnaces (37), woodstoves (44), baseboards (number unknown) or some combinations of these three sources. Therefore, the heating demand at Git'aws is currently either met electrically or by woodstove. The portion of the heating demand met by woodstoves is not known; however, the approximate amount of firewood used and the associated cost has been estimated at the end of this section. BC Hydro bills were gathered for four houses at Git'aws. Three of the four houses use electric central forced air furnaces and one house uses an electric furnace and a woodstove (Venegas pers. comm.); therefore, the values derived from these sample homes represent a scenario in which most of the heating is provided for electrically.

The following limitations should be kept in mind when reviewing the consumption and power demand estimates.

- Only the residential demand has been considered. The electrical demand associated with administrative and community building (existing or proposed) is not known.
- Each of the four homes was weighted equally in the calculations. Home size, heating source and annual temperature were not accounted for in these calculations but will make a difference in the actual energy consumption by Git'aws homes.
- The calculated amounts represent electrical load required for lighting and appliances, and to some extent for hot water and heating. For a system where district heating is proposed to meet the household heating requirements the electrical demand will likely decrease; therefore, it would be important to understand the electrical load associated with heating (and possibly hot water) separate from the electrical load for lighting and appliances.
- Approximate base and peak loads have been calculated; however, more detailed demand profiles are likely needed to accurately calculate base and peak loads for final facility sizing.

2.2.1 Electrical Energy Consumption

The average annual electrical energy consumption was calculated for the proposed new housing development, and a combination of existing and new housing (Table 2). Electrical energy consumption is the amount of electrical energy used over a period of time to run electrical appliances in a home and is measured in kilowatt-hours (kWh_{el}).

The average annual electrical energy consumption calculated based on the bills provided for the four sample houses in Git'aws is 14,887 kWh_{el} per household. This is higher than the demand based on BC Hydro's average residential customer of 10,800 kWh_{el} per household (BC Hydro n.d. c). There are multiple factors that likely contribute to the difference including: the small sample size from Git'aws; geographical location in the province; and electrical heating use at Git'aws.

Based on the current BC Hydro residential rates, the average household in Git'aws should pay approximately $1,900 per year for electricity.

Table 2. Approximate Average Annual Household Electrical Energy Consumption

Residential Areas	Energy Consumption (kWh_{el}/yr)[1]	Cost of Hydroelectricity ($/yr)[2]
Per House	14,887	$ 1,900
Existing Houses (81)	1,205,877	$ 153,930
New Houses (54)	803,918	$ 102,619
Combined Houses (135)	2,009,795	$ 256,549

[1] Based on BC Hydro bill for four households from August 2018 to July 2019.
[2] Based on current BC Hydro residential rates posted as of December 11, 2019

2.2.2 Electrical Demand

Base, average and peak residential electrical power demand was calculated for the existing residential housing, the proposed new housing development, and a combination of existing and new housing (Table 3).

Power is the energy per unit of time and is measured in kilowatts (kW_{el}). Power demand fluctuates throughout the day and year. Base load is the power demand that occurs on a nearly continuous basis (24 hours a day and 365 days a year). Average load is the average power demand that occurs across a period of time. Peak load is the highest power demand that occurs during the year.

Base, average, and peak electrical demand estimates are provided in Table 3. Base load power per house is 0.9 kW_{el}. Average power demand is 1.7 kW_{el} per house. Peak load power may range from 2.9 kW_{el} to 9.4 kW_{el} per house, depending on the calculation method. For the sample houses in Git'aws, where electricity is being used to provide heat, the peak load occurs during the coldest winter months and in the evening, when people are home and using more lighting and appliances.

Table 3. Approximate Annual Power Demand Requirements

Power Demand	Per House (kW$_{el}$)	Existing Houses (81) (kW$_{el}$)	New Houses (54) (kW$_{el}$)	Combined houses (135) (kW$_{el}$)
Average Load[1]	1.7	138	92	229
Base Load[1,2]	0.9	71	47	118
Peak Load *Method 1: Using highest monthly average* [1,3]	2.9	232	155	387
Peak Load *Method 2: Using highest hourly demand from demand profile* [1,4]	9.4	765	510	1,276

[1] Based on BC Hydro bills for four houses from August 2018 to July 2019.

[2] Base load power was calculated using the 4 lowest monthly averages for the four houses at Git'aws.

[3] Peak load method 1 was calculated using the highest monthly average for the four houses at Git'aws. This method likely underestimates peak demand.

[4] Peak load method 2 was calculated using an hourly demand profile to apportion the daily consumption of each of the four houses at Git'aws (Armstrong et al. 2009). The highest hourly demand reached was taken as the peak demand. This method likely over estimates peak demand.

2.2.3 Firewood Consumption and Costs

Of the 81 homes at Git'aws, 44 currently use woodstoves for at least part of their heating (Venegas pers. comm.). On average, a home with a woodstove uses 7 cords[4] of wood per year, with the cost per cord of wood ranging from $175 to $250, though it is likely that some member are able to obtain firewood at no cost (Venegas pers. comm., Westland 2019). Based on these estimates, Git'aws residents are burning more than 300 cords of wood per year (about 500 oven dry tonnes [odt] per year) and spending up to $65,000 on firewood annually based on an average cost of $213 per cord.

Table 4. Current Annual Firewood Use at Git'aws

	Amount	Unit
Current Usage		
# of houses using wood stove[1]	44	Houses
average annual woodstove firewood use[1]	7	cord/house/yr
total firewood used at Git'aws[2]	308	cord/yr
	1,116	m^3/yr
	502	odt/yr
Cost		
cost per cord (average)[3]	213	$/cord
cost per woodstove	1,488	$/woodstove/year
cost per household (distributed across 81 homes)	808	$/house/year
total firewood cost for Git'aws	65,450	$/year

[1] 44 houses at Git'aws have woodstoves and use approximately 7 cords/house/winter (Venegas pers. comm.).

[2] One cord of wood = 4' by 4' by 8'=3.6 m^3 = 0.6 odt.

[3] Cost per cord has been cited as high as $250/cord at Git'aws (Venegas pers. comm.). Other local firewood costs found are $175 to $200 (Westland 2019)

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[4] A cord of wood is equal to a stacked wood pile with dimensions of 4' by 4' by 8.

3 Alternative Renewable Energy Options

While the scope and intent of this project was to review bioenergy, specifically CHP for Git'aws, a brief review of the suitability of a number of other alternative energy sources for powering the community of Git'aws was considered. Below is a summary of some of the major alternative energy possibilities that were reviewed. While some of these energy sources are well established technologies, they present large financial obstacles. Others are financially feasible but still preliminary in their technical methodology. Others still present possibly viable technologies, but are not regionally suitable.

Based on a brief and preliminary review of other technologies, and given the local availability of woody biomass in the region, it was concluded that a combined heat and power system using woody biomass is one of the most suitable energy options for Git'aws.

3.1 Wind Energy in BC

Wind energy in BC is a viable option, with a number of coastal areas in particular offering sufficient wind speeds for financially and energetically successful projects (Clean Energy BC [CEBC] 2015). Wind energy is often used as a complementary energy source to hydroelectricity in BC, because it offers opportunities for water (and therefore energy) storage in the dam reservoir when wind speeds are sufficient to assist hydro demands (CEBC 2015). In BC, there were three wind projects in the Peace River region and one on Vancouver Island as of 2015 (CEBC 2015). A single turbine can generate 2 megawatts (MW_{el}) of power and displace large amounts of carbon that would otherwise be emitted from traditional energy sources (CEBC 2015). In this way, a single turbine may be useful in powering a small community. However, high development costs and extensive regulatory procedures makes small-scale wind projects a daunting task. The costs for a turbine alone (not including installation, transmission lines etc.) is between \$1.2 and \$1.6 million per MW_{el} in British Columbia (GL Garrad Hassan Canada Inc. 2012).

In terms of wind potential, Git'aws may be situated in a location with sufficient wind potential, but further research would be required to confirm this and the economic feasibility of such a project. Wind energy would provide electricity only, and no heat, and does not offer additional secondary opportunities (e.g., work created to gather biomass and opportunities to create secondary value-added products).

3.2 Hydrogen Fuel Cells in BC

Hydrogen is the most plentiful element on earth, and also one of the cleanest and most efficient sources for energy; however, hydrogen is rarely available in its pure form, as it naturally combines with other elements (Renewable Energy World [REW] n.d.). Current technology has enabled extraction of hydrogen from certain particles, such as water or hydrocarbons, to store in hydrogen fuel cells for later use (REW n.d.). Burning hydrogen as a fuel results in virtually no pollution; the main by-product of the reaction is water (REW n.d.).

Hydrogen offers a conversion efficiency of approximately 33 kWh of energy per kilogram (kg), compared to gas and diesel, which are around 12 kWh per kg (IDEALHY n.d.).

Reforming hydrocarbons to produce hydrogen fuel does not necessarily eliminate the need for fossil fuels, which is why current technology is focussing on retaining hydrogen from other sources. Wind, solar, and geothermal projects are all capable of producing hydrogen fuel through electrolysis of water, which is more energy intensive than the reforming of hydrocarbons, but much cleaner in the production of hydrogen (National Renewable Energy Laboratory n.d., US Department of Energy n.d. a). However, these methods are currently much more expensive in producing hydrogen than through production from fossil fuels (Zen and the Art of Clean Energy Solutions 2019). Further technological advancements may enable the production of hydrogen from renewable sources at more feasible costs.

3.3 Solar Power in BC

Solar power utilizes photovoltaic cells, which capture photons from sunlight and convert them in to electrical currents (BC Hydro n.d. b). The energy produced from these solar panels can be tied into the grid or used to store extra electricity in batteries to use during night or low sunlight times (BC Hydro n.d. b).

BC has very low installation costs compared to the rest of Canada, and also offers incentives like tax exemptions and BC Hydro or FortisBC rebates on home energy efficiency upgrades (Energy Hub 2019). However, BC ranks 11 out of 13 in the country for access to solar irradiation, and the amount received is concentrated largely in southeast BC (Energy Hub 2019). Even in Richmond which has moderately high rates of solar radiation, a 1 kW_{el} system would provide about 1,027 kWh_{el} per year, about 7% of the 14,900 kWh_{el} average annual consumption by a Git'aws household as determined in Section 2.2 (Energy Hub 2019). To meet this demand, a 15 kW_{el} solar system would be required per home (Energy Hub 2019). Even with BC's exceptionally low installation rates of $2.64 per watt on average, a 15 kW_{el} system would cost approximately $38,301 per house and over $5 million to provide power to all 135 existing and proposed houses in Git'aws (Energy Hub 2019). However, smaller systems can be installed that supplement a home's on-grid energy sources. When utilizing both solar energy and grid sources, BC's Net Metering Policy allows homeowners to send excess solar energy into the grid during events or seasons of high solar irradiation from which incentives are earned at the same rate as the homeowner's grid energy costs (Energy Hub 2019).

An alternative to homeowner solar systems are "solar gardens" which are communal systems that feed an entire community (Energy Sage 2019). In a community solar power system, homeowners can only utilize as much as their household energy demands require, and net metering systems are applied to the project as a whole (Energy Sage, 2019). This system generally works in one of two ways: Participants of the community can own part of the power system, and directly benefit in the energy cost savings and net metering, or participants partake as subscribers to the system, receiving solar energy from the system at a lower rate than from the grid (Energy Sage 2019).

Despite the potential for community-sourced solar power, this initial research indicates that solar power does not appear to be a suitable energy alternative for Northwest BC, due to the low amount of solar potential in the region.

3.4 Geothermal Power in BC

Geothermal energy utilizes heat from below the surface of the earth. The energy is utilized by transporting water below the earth's surface through pipes where the water is heated up by the subsurface radiant temperatures (CEBC n.d.). The water is then transported back to the surface to provide heat and/or to be converted to electricity. Lakelse hot springs are currently considered as a potential site for a moderate-scale geothermal facility, with feasibility studies carried out by Kitselas Development Corp. and partners in 2018 (Bender 2018, CEBC n.d.).

A 100 MW geothermal facility would employ around 40 people and face capital costs of approximately $400 million (CEBC n.d.). Additional costs, even for smaller facilities, include the often-extensive explorative drilling costs required to identify suitable sites (Business in Vancouver 2018).

Different kinds of geothermal systems can be used for different purposes. Those with high heat sources such as natural hot springs or geysers (sources over 80°C) can be used to create electricity, while lower heat sources such as the ambient subsurface temperatures below the earth's frostline can be used to heat homes and water (Government of British Columbia n.d.).

While "direct-use" (low heat geothermal), as employed in the geothermal system install at the Kitselas administration building at Git'aws, is a fairly attainable alternative energy source, it does not provide electricity production, which is one of the aims of this project (Government of British Columbia n.d.). High heat geothermal projects, as previously stated, are costly to prepare and install, and are therefore outside the scope of this project.

3.5 Run-of-River Hydro Projects in BC

Run-of-river (ROR) projects are fairly common in BC as alternative small-scale energy options. As of 2014 there were more than 50 independent ROR projects in operation, and that number has continued to grow (CEBC 2014). This form of alternative energy consists of diverting a portion of a stream down a pipe to a turbine which generates electricity (CEBC 2014). From here the water is returned to the stream channel downstream. Very little upstream or downstream hydrology is impacted by ROR projects compared to large hydroelectric projects that involve damming and creating a reservoir (CEBC 2014). However, studies have shown that, although less than hydroelectric dams, RORs still show some impact to fish populations (Anderson et al. 2014, Bilotta et al. 2016, Gibeau et al. 2017). The application process for a ROR project is extensive, with over 50 permits required and usually 3-5 years of preparation in the form of consultations, assessments, and reviews (CEBC 2014). ROR projects are generally located close to the receiving community to minimize transmission losses, and also in river locations that offer steep grades to increase the force of the water on the turbine (CEBC 2014).

RORs may have small weirs to provide a small amount of flow moderation, but these are generally small enough that their benefits are restricted to same-day usage (CEBC 2014). This means that major seasonal changes in stream flow may impact the amount of energy a ROR project can produce at a given time.

RORs usually result in utility bills equal to or higher than BC's grid energy from large hydroelectric dams (Helston & Ferris 2017). This means that ROR is not generally a preferred option when grid energy is available; however, ROR is a much greener option than the traditional diesel generators usually used in remote communities to bring power to homes.

In 2008, a rural small hydro project in BC faced installation costs of around $6 per watt of capacity (Helston & Farris 2017). For a 400 kW_{el} facility that would equate to approximately $2,400,000 of installation costs.

RORs work best on rivers with high elevations changes, which enhances the gravitational force on the flowing water that pushes the turbines (Helston & Farris 2017). Kleanza Creek and Singlehurst Creek are both close to Git'aws, but neither is appropriate: Kleanza Creek's gradient is too low and Singlehurst Creek is within a designated Community Watershed. There is the possibility that another tributary to the Skeena near Git'aws may have the properties required for an ideal ROR plant. Further research would be required to confirm the presence of such a site, and capital construction costs and energy transportation distances from this site to Git'aws would need to be considered.

3.6 In-Stream Turbines

In-stream turbines are power-generating systems that rely solely on kinetic energy as opposed to potential energy, and therefore do not need the extensive infrastructure of traditional dams and ROR facilities (Smart Hydro Power n.d.). For this reason, they are also sometimes referred to as hydrokinetic power (VanZwieten et al. 2014). In-stream turbines can be placed directly in a stream where the water flow turns a set of rotors to generate power. Power output may vary and depends on changes in seasonal water flows, but generally speaking, larger rivers can produce a reliable, year-round source of energy for a hydrokinetic system. One study quantified feasible river systems for this type of energy production as having an average discharge rate of 113 cubic metres (m^3) per second (VanZwieten et al. 2014). The Skeena River at Usk (3.35 km north of the Kitselas Canyon) has a historical average low discharge rate of 153 m^3 per second (in early March) and a historical average high discharge of 3140 m^3 per second (mid-June) (Government of Canada n.d.). The overall average annual mean discharge rate is 910 m^3 per second (de Groot 2005).

Despite sound technology and significant pilot studies completed in the last few decades, there are still few riverine hydrokinetic power projects in operation (VanZwieten et al. 2014). One riverine system in Ruby, Alaska was built on a budget of US$65,000 to test the feasibility of such a system in offsetting diesel-sourced power to the community (VanZwieten et al. 2014). This riverine system and others appear to face significant issues with in-stream debris damaging the turbines, barges, or power lines (VanZwieten et al. 2014). Cages are generally built onto these turbines to decrease damage to the rotors from upstream debris; however, these cages do not generally withstand larger debris flows (Smart Hydro Power n.d., VanZwieten et al. 2014).

Environmental impacts of in-stream turbines are considered a fraction of the impacts caused by dams and run-of-river systems, but not nonexistent (VanZwieten et al. 2014). Single or a small number of turbines are generally limited in their impacts to minor alterations of the water's kinetic properties, which may lead to increased sedimentation and turbulence in the immediate area of the turbines (VanZwieten et al. 2014). This damages aquatic organisms near the turbines. Larger systems with many turbines have the potential to have greater impacts on the river's hydrology by removing a significant amount of kinetic energy from the waterbody; this can cause impacts to stream velocity, sediment deposition, water quality, noise levels, and fish populations (VanZwieten et al. 2014).

Because hydrokinetic technology is still relatively unestablished, more research is required to determine the feasibility of such an energy source on the Skeena River or one of its tributaries. From initial research, it appears to have promise as an energy source; however, both the Skeena River and Kleanza Creek are known to generate significant amounts of debris.

3.7 Renewable Natural Gas

Renewable natural gas (RNG), also known as biomethane, is an alternative form of natural gas that is produced through anaerobic digestion or gasification (Li et al. 2017). It is chemically very similar to its traditional counterpart, liquid natural gas (LNG), and high quality RNG sources can therefore be completely interchangeable with LNG. Existing LNG infrastructure could be used for RNG, allowing for a relatively easy transition from the fossil fuel derived energy to the biological alternative (Canadian Gas Association 2014). RNG, produced via gasification, can be made from waste wood from forestry activities; the fuel source for this production is therefore abundant in Northwest BC. Small-scale RNG facilities generally produce lower quality RNG than larger facilities; the energy ratio is 5 or 6 MJ per kg compared with the natural gas ratio of 35-50 MJ per kg (Energypedia 2018). Case studies indicate very little success with small-scale plants due to lower-than-expected energy outputs, higher-than-expected maintenance requirements, and lack of efficient fuel sources (Energypedia 2018).

A Vancouver based company, G4 Insights Inc. (G4 Insights), recently completed a demonstration field trial in Edmonton, Alberta, turning forestry residues into RNG (Canadian Gas Association 2019). G4 Insights uses a proprietary process call PryoCatalytic Hydrogenation which is a fast pyrolysis conversion process that produced RNG from biomass (G4 Insights 2019). The process is not yet commercialized; however, G4 Insights Inc. intends to develop, own and operate small and large commercial plants with local partners. They state that the small-scale plant will be capable of producing 450 gigajoules (GJ) per day of methane from 36 odt per day of wood biomass (G4 Insights 2019).

As this technology is not yet commercialized, it was not further explored for this project; however, further discussion with G4 Insights may be worthwhile if Kitselas proceeds to the next phase of the project.

3.8 Renewable Diesel Fuel

Renewable diesel fuel (RDF) is a fuel source chemically similar to traditional diesel, and therefore interchangeable (US Department of Energy n.d. b). Not only is the fuel itself interchangeable, but the production of it can be done in the same facility, transportation can occur through the same infrastructure, and use can occur by the same engines (Leanard & Couch 2017). Unlike biodiesel, which is chemically different than RDF or traditional diesel, RDF has been approved for use by most diesel engine manufacturers (Leanard & Couch 2017).

RDF is produced primarily from palm oils, tallow, and used cooking oil. Production of RDF from palm oils is a well-established process, with large facilities and supply existing throughout Europe and some supply developing in the US as well to meet increasing demands (Leanard & Couch, 2017). There are serious concerns about the use of palm oils for the generation of RDF due to deforestation, and research is extensive in developing sustainable alternatives for feedstocks (Gerasimchuk & Koh 2013). As of 2017, Neste, a major European producer of renewable diesel, dropped its palm oil dependence 20% from its historical 95% (Taloussanomat 2017).

A newer method of renewable diesel production is through the gasification of biomass, such as agricultural and forestry residues (Bryan 2011). This process is completed through thermal gasification and gas-to-liquids processing. At a 2017 congress on ligno-fuels in Finland, renewable diesel from woody residues was discussed as an emerging technology (Koester 2017). One European company, UPM Biofuels, developed a process to produce renewable diesel from woody biomass at a commercial-scale capacity (Koester 2017). However, this technology was considered to still be in its market entry stages (Koester 2017). Neste, one of Europe's major renewable diesel producers, has also begun to experiment in the production of renewable fuels from biomass instead of oils or fats (Koester 2017). As of February 2019, Maine researchers were developing technologies to produce renewable diesel and jet fuels from woody biomass (Bowie 2019).

RDF sourced from woody biomass appears to still be in the research and development stage. As this technology is not yet commercialized, it was not further explored for this project.

3.9 Bioheat

Bioheat combustion system technology is well established internationally and within Canada; with more than 400 bioheat facilities under 5 MW_{th} in Canada as of 2017 (Prevost 2020). Within BC, there were 46 bioheat projects as of 2016, 14 of which were community district energy projects. The BC projects range in size from 50 kW_{th} to 5 MW_{th}, and replaced diesel, propane, natural gas and fuel oil (TorchLight Bioresources 2017b). Fink Machine and Evergreen Bioheat were the most prominent bioheat developers and installers in BC as of the 2017 update to the Canadian Bioheat Database (TorchLight Bioresources 2017a).

There are a wide variety of bioheat applications including: stoves, furnaces and boilers that use cordwood, pellets or woodchips. Larger applications use pellet or woodchip boiler systems to provide district heating. These larger applications are generally twice as much as a fossil fuel system to install (Prevost 2020).

As they do not involve electrical energy generation and associated equipment, they are simpler than CHP systems to operate and maintain. Kitselas could consider installing a woodchip boiler bioheat system with the potential of expanding to a CHP system by adding a power generation unit (e.g., organic Rankine cycle unit) at some point in the future.

4 Biomass Combined Heat and Power Options and Considerations

This section summarizes CHP technologies, costs and recommendations for Git'aws. Information on district heating and heat harvesting is also presented, as these will be key design aspects to consider for a CHP system. Brief profiles of various CHP technologies, companies and facilities are provided in Appendix A.

4.1 Biomass Combined Heat and Power

Combined heat and power, also referred to as cogeneration, produces heat and electricity from a single fuel source, in this case biomass. Biomass CHP systems include a conversion process that converts the biomass into energy (typically heat, biogas or biooil) and a power generation process that converts the energy into electricity. Common conversion and power generation technologies used in biomass CHP systems include:

- gasification conversion paired with internal combustion engine (ICE) power generation;
- direct combustion conversion paired with organic Rankin cycle (ORC) power generation;
- direct combustion conversion with steam turbine power generation; and
- pyrolysis conversion that produce biogas or biooil, but typically as a by-product or co-product to biochar (electrical and thermal efficiencies are typically lower than other biomass conversion technologies).

Given the anticipated energy requirement at Git'aws of less than 1 MW electrical for the existing and proposed housing, only small and medium scale CHP systems were considered (between 40 kW_{el} and 1 MW_{el}). Applications involving small loads (below 200 kW_{el}) typically use fixed-bed gasification and internal combustion engine systems. Direct combustion and ORC are typical for loads over 200 kW_{el}. Work done by FPInnovations was used as the primary source for these investigations (Schilling et al. 2017a-d).

In a gasification and ICE system, a gasification reactor produces gas by heating biomass in an oxygen-controlled environment. This gas is referred to by many terms, including producer gas, synthetic gas or syn gas. The syngas is cooled and cleaned and then burned in the ICE which generates electricity. Heat is captured from the system (e.g., from syngas cooling or the ICE unit) for heating applications: either biomass drying or district heating. Biomass moisture content, particle size and uniformity, and contamination are critical factors affecting efficiency and operation in gasification systems. Moisture content is usually required to be less than 20%.

Other key points for gasification and ICE systems are as follows.

- Fixed-bed gasifiers are the most common in small scale applications.
- These systems are common in Europe for electricity generation to local grids and heat to buildings.
- The top five European manufacturers are: Volter (Finland), Spanner (Germany), ESPE (Italy), Urbas (Austria), and Burkhardt (Germany).

- This system is not yet common in Canada, with no mainstream manufacturers. BC examples include: the Kwadacha First Nation which has three 45 kW_{el} Spanner Re^2 units operating in Fort Ware; and the National Research Council of Canada (NRCC) microgrid testing and training facility which has a 40 kW_{el} Volter unit (Radloff 2018, NRCC 2019).
- Feedstock options are wood chips or pellets, and these systems are less tolerant of low quality and high moisture content feedstocks; if using wood chips, the feedstock supply chain is more complicated because storage and drying of logs before chipping is recommended.
- Electrical efficiencies are usually between 20% and 30%, and up to 50% of heat output may be required to dry the feedstock if using wood chips.
- Only one operator is required to produce wood chips, operate and maintain the system.

In a direct combustion and ORC system, biomass is burned in a boiler to produce. An ORC system then generates power by using heat from the boiler to evaporate an organic oil, which is expanded over a turbine to generate electricity. Heat is captured from the system (e.g., when the organic oil is condensed by a closed-loop water system) which can be used in district heating or industrial heat applications. Direct combustion boilers are more tolerant of higher moisture content (up to 60%) than gasification units. They are also generally more tolerant of lower quality biomass, though particle size, particle uniformity and biomass contamination affect boiler efficiency and performance. Compared to a steam turbine, the organic oil does not require superheating and a steam engineer is not required for operation.

Other key points for direct combustion and ORC are as follows.

- Stocker boilers are the most popular for smaller scale applications.
- Most ORCs have been developed in Europe and there are many installed globally.
- Commercially available systems include: Turboden (Italy), Maxxtec (Germany), GMK (Germany), and Triogen (Netherlands – for smaller scale 60-165 kW_{el}).
- There are 6 installations of the Turboden system in Canada and possibly others systems as well.
- More tolerance for biomass quality and moisture content (modern boilers can handle up to 60% moisture content and particle sizes under 4 inches) means they require a less sophisticated supply chain than gasification systems.
- Electrical efficiencies do not typically exceed 15%, and 70% of energy input is available as heat; although another report indicates that electrical efficiencies for Turboden ORC units are around 20% (Fredrickson et al. 2018).
- No steam engineer is required but systems do require frequent maintenance and cleaning (mostly for the boiler) and are likely to require two full time operators.
- ORC systems do not adjust output easily with demand and work best as baseload technology where an electrical grid is in place to meet demand fluctuations.

4.2 District Energy and Heat Harvesting

District Energy

District energy systems provide heating and cooling to buildings from a centralized unit, generally through an underground piping system. District heating to provide space heat, domestic hot water or process heat (the use of thermal energy to prepare material for manufacturing) would likely be the focus of a district energy system at Git'aws. However, Kitselas may also have an interest in using heat to support district cooling through absorption refrigeration, as many members use freezers to store harvested foods.

In addition to heating homes, heat distribution could be used to heat sidewalks, driveways or the greenhouse at Kitselas.

The expense to install a distribution system will vary depending on whether steel or cross-linked polyethylene (PEX) pipe is used, the diameter of the pipe, and whether the installation is for a new or existing development. Retrofitting a community with a district heating system can be expensive: installing a distribution system in an existing community can cost over $1000 per metre of pipe (Community Energy Association 2014, Marinescu, Schilling pers. comm.). Significant cost savings are likely to be seen for new developments because district heating pipe can be included in the engineering design for the development, and costs for excavation and trenching for other utilities can be shared, potentially cutting the cost per metre by more than a third[5] (BC Climate Action Toolkit n.d., Salter 2013). New homes can also be designed for compatibility with district heat.

Kitselas is planning to build additional housing at Git'aws and could consider installing a district heating system during the development. Retrofitting existing housing would be more expensive.

Heat Harvesting

Heat harvesting involves putting heat to use in a heating application or to create mechanical or electrical energy that would have otherwise been unused or wasted (European Thermodynamics Limited 2015). Heat harvesting may or may not be suitable for Git'aws depending on the amount of waste heat available, the temperature of waste heat and the economics of installing a heat harvesting system.

One option for heat harvesting briefly reviewed was the Clean Cycle containerized unit from Heat Recovery Solutions based out of California. The Clean Cycle uses the heat source to generate hot water or steam and convert that to electricity using an ORC unit. Running at full output the ORC unit will product 140 kW of electricity (Heat Recovery Solutions n.d.).

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[5] A district heat feasibility study for the City of Courtney indicated that the cost per metre of for pipe installation was $1129, with $381 required for trenching (excavation, backfill and reinstatement) (Salter 2013).

If this project moves forward into Phase 2, possible waste heat streams from a selected CHP system should be evaluated and the potential for heat harvesting reviewed.

4.3 CHP Capital and Operations and Maintenance Costs

This section gives a brief review of biomass CHP capital, installation, maintenance and operation costs. Detailed financial feasibility, including all costs, revenues and savings should be carried out as part of the next phase of the project. In addition, financial feasibility is only one consideration, albeit an important one, when assessing the feasibility of a CHP system for Git'aws. Social, political and environmental factors will also affect the decision for this project.

Rough costs for a 50 kW_{el} CHP using woodchips, 150 kW_{el} CHP using woodchips, and a 1 MW_{el} CHP are provided in the series of Info Notes on small and medium scale CHP systems by FPInnovations and are summarized in Table 5 and 6 (Schilling et al. 2017b,d). While the appropriate size or number of CHP units has not been determined, looking at standardized costs per kW_{el} or kWh_{el} allows a general comparison of the various technologies. The actual costs may vary greatly depending on the technology chosen, the number of units installed, local delivered biomass costs (as presented in Section 4.4.3) and other site-specific factors.

Capital and Installation costs are provided in Table 5. As electrical output increases, total installation costs increase; however, the installed cost per kW_{el} decreases as the size of the unit increases: $16,900 per kW_{el} for a single 50 kW_{el} CHP system versus $10,000 per kW_{el} for a 1 MW_{el} CHP system. Generally, capital and installation costs would not be expected to increase linearly with the installation of additional units (i.e., the cost for 2 units would be less than double the cost for one unit); therefore, as additional units are installed, the cost per kW_{el} would be expected to decrease and the costs provided in the table are expected to reflect an upper range. If Kitselas were to obtain a grant for the CHP system, it could be assumed that capital and installation costs would be reduced.

Table 5. Capital and Installation Costs

	Gasifier and ICE[1]		**Direct Combustion and ORC[2]**
Installation Costs	**50 kW_{el} CHP Wood Chips**	**150 kW_{el} CHP Wood Chips**	**1 MW_{el} CHP**
Total Installed Cost	$845,000	$1,860,000	$10,000,000
Cost per kW_{el} installed ($/$kW_{el}$)	$ 16,900	$12,400	$10,000

[1] Values provided in Table 3 from Small-Scale Biomass Combined Heat and Power (CHP) Part II – Technical and economic aspects of small-scale CHP systems under 165 kW_{el} (Schilling et al. 2017b).
[2] Values derived from Figure 4 from Medium-Scale Biomass Combined Heat and Power (CHP) Part IV – Organic Rankin Cycle CHP Systems (Schilling et al. 2017d).

Two scenarios for operating and maintenance costs are provided in Table 6.

In scenario 1 it is assumed that Kitselas will be fully responsible for the financial costs associated with purchasing and installing the CHP system and would obtain a loan to cover these costs. Loan interest payments and equipment depreciation costs are included in the total annual operating and maintenance costs, to ensure that the cost per kW$_{el}$ includes a payback to Kitselas for their capital investment.

With these costs included, operations and maintenance costs range from $0.25 to $0.56 per kWh$_{el}$ for the 3 technologies reviewed. Without a source of revenue, the annual operating costs per kWh$_{el}$ are anticipated to be higher for the CHP systems than current average BC Hydro residential rates ($0.13 per kWh$_{el}$) (BC Hydro 2019).

In scenario 2, it is assumed that Kitselas is able to obtain a grant for capital and installation costs. Loan interest payments and equipment deprecation costs were removed from the total annual operating and maintenance costs. With these costs removed, operations and maintenance costs range from $0.15 to $0.32 per kWh$_{el}$. These costs are much closer to the BC Hydro average residential rates.

Table 6. Annual Operating and Maintenance Costs

Annual Operating Costs	**Gasifier and ICE[1]**		**Direct Combustion and ORC**
	50kW$_{el}$ CHP Wood Chips	**150kW$_{el}$ CHP Wood Chips**	**1MW$_{el}$ CHP**
Scenario 1: Kitselas obtains a loan for Capital and Installation Costs			
Total annual operation and maintenance cost without heat savings	$ 184,500	$ 328,000	$ 2,000,000[2]
CHP Electricity generation cost w/out heat savings ($/kWh$_{el}$)	$ 0.56	$ 0.32	$ 0.25[3]
Scenario 2: Kitselas obtains a grant for Capital and Installation Costs			
Total annual operation and maintenance cost without heat savings	$106,000	$153,500	$1,300,000
CHP Electricity generation cost w/out heat savings ($/kWh$_{el}$)	$0.32	$0.15	$0.16
Status Quo: BC Hydro			
BC Hydro residential rates average ($/kWh$_{el}$)[4]	$0.13		

[1] Values provided in Table 4 from Small-Scale Biomass Combined Heat and Power (CHP) Part II – Technical and economic aspects of small-scale CHP systems under 165 kWel (Schilling et al. 2017)

[2] Value is a rough estimate using information provided in Medium-Scale Biomass Combined Heat and Power (CHP) Part IV – Organic Rankin Cycle CHP Systems (Schilling et al. 2017)

[3] Value is an average of the range ($0.10 to 0.40/kWhel) provided in Medium-Scale Biomass Combined Heat and Power (CHP) Part IV – Organic Rankin Cycle CHP Systems (Schilling et al. 2017). It is not known to what degree these values factor in savings from the use of heat energy.

[4] BC Hydro residential rates posted as of December 11, 2019

A comparison of potential annual energy costs for an average household in Git'aws are presented in Table 7. The combined cost for hydroelectricity and firewood for an example house in Git'aws is approximately $2,700 per year. This value is derived from the calculated average energy consumption for a home in Git'aws (based on 4 sample homes), current BC Hydro residential rates and an approximation of current firewood costs at Git'aws. If Kitselas can secure a grant for Capital and Installation Costs and can displace some of the costs associated with firewood use, annual energy costs using a CHP system may be in the range of the status quo.

Table 7. Cost comparison of example CHP Systems vs Status Quo for an Average Git'aws Household

Scenarios	**Rate ($/kWh$_{el}$)**	**Annual consumption/cost Per Household**
Energy Consumption (kWh$_{el}$)[1]	--	14,887 kWh$_{el}$
Scenario 1: Kitselas obtains a loan for Capital and Installation Costs		
50kW$_{el}$ CHP Wood Chips	$ 0.56	$ 8,337
150kW$_{el}$ CHP Woodchips	$ 0.32	$ 4,764
1MW$_{el}$ CHP	$ 0.25	$ 3,722
Scenario 2: Kitselas obtains a grant for Capital and Installation Costs		
50kW$_{el}$ CHP Wood Chips	$ 0.32	$ 4,790
150kW$_{el}$ CHP Woodchips	$ 0.15	$ 2,229
1MW$_{el}$ CHP	$ 0.16	$ 2,419
Status Quo: BC Hydro and Firewood		
Hydroelectricity from BC Hydro[1]	*$ 0.13*	*$ 1,935*
Firewood costs[2]	--	*$ 808*
Status Quo Total	--	$ 2,743

[1] As per Table 2
[2] As per Table 4

The key conclusions drawn from this brief cost review are that: gasification and ICE systems are typically more expensive than direct combustion and ORC systems; the cost of electricity produced by biomass CHP is more than hydroelectricity from BC Hydro; and without grant funding or a source of revenue there is not a strong economic case for a CHP system at Git'aws.

4.4 Feedstock Considerations and Availability

This section reviews key considerations for woody biomass including: supply chain and biomass characteristics, availability, and delivered costs. Other feedstock sources (garbage and sewage) are also briefly discussed.

4.4.1 Biomass Characteristics and Supply Chain Considerations

The biomass supply chain is a critical consideration when it comes to operations and economics of a biomass facility, and can affect the success of a project (Marinescu 2020). FPInnovations has released Best Management Practices to help understand the important biomass quality and supply chain questions: Best Management Practices Guide for Access to Quality Forest Feedstock (Volpe 2018); and Best Management Practices for Integrated Harvest Operations in British Columbia (Spencer 2017).

The following is a list of important biomass characteristics to consider as they relate to a biomass system and the supply chain.

- Particle size requirements, uniformity and sensitivity to oversized or fine particles: bioenergy systems vary in the particle type used (e.g., wood chips, sawdust, wood pellets), particle size requirements and tolerance of variations. Biomass source and chipping or grinding equipment will greatly influence the size distribution of particles. For example, sawdust from a sawmill versus woodchips versus logging residue differ in particle size distribution.
- Moisture content: moisture content is an important consideration for bioenergy efficiency because, for biomass with high a moisture content, energy will be wasted evaporating water in the combustion or gasification process. Wetter wood also means higher trucking costs for the same amount of wood energy delivered (oven dry tonnes).
- Ash content: feedstocks with a lot of bark, dirt or rocks will have higher amounts of ash, which is the amount of residue remaining after combustion. Ash handling and disposal is an operational and cost consideration.
- Contamination: sources of contamination can include rocks, soil, and equipment parts (e.g., chains, track pads) which end up in the ash after biomass is combusted. System operation can be sensitive to contamination levels and contaminant disposal can be costly.
- Bulk density: bulk density is the mass per unit volume of biomass and varies widely with biomass source and processing. Bulk density may greatly affect the transport costs and storage requirements. For example, transporting 1000 odt of unprocessed slash may require twice as many truck loads as an equivalent mass of chips or round wood and twice as much area to store the material (Marinescu 2020). Denser biomass feedstocks will contain more energy per unit of volume.

When sourcing feedstock from roadside residues the following factors will need to be considered:

- if the roadside residue available (tops, long butts, brush) is suitable to meet the desired feedstock characteristics;
- if the roadside piling practices are conducive to passive drying of residues, and to access and loading of residues;
- if the biomass location and access (e.g., road grade, vertical design, turn around areas) will allow for in block processing (grinding or chipping) or if unprocessed biomass can be removed for offsite processing; and
- what type of machinery and transportation equipment is needed to access and process the woody residue (e.g., grinder or chipper; b-train trucks or walking floor hauler or bin truck).

A local example highlighting these considerations is described in Figure 3.

A local example at the Skeena Industrial Park utilized sub-merchantable and waste material from logging of an immature second growth stand near the Northwest Regional Airport. Rather than burning the waste material, it was piled, dried, ground on site and then transported to the Pinnacle Renewable Energy pellet facility in Burns Lake. The waste wood was piled in a haystack fashion and allowed to cure for two seasons, resulting in an average moisture content of 22%. The material was then ground into a b-train truck. With the reduced moisture content, oven dry tonneage per truck was increased from an expected 23 odt to 27 odt of ground material. The average amount of usable biomass (excluding stumps and merchantable timber) generated per hectare cleared was roughly 100 odt or 240 m^3. This example shows the importance of moisture content on trucking costs: with the additional drying time using the haystack technique, moisture content was reduced resulting in more wood energy per truck, 15% fewer truckloads and a 15% savings in trucking costs.

(Jobb 2020)

Haystack piles (left photo) and aerial view of cleared area with roadside haystack piles (right photo).

Figure 3. Biomass utilization at the Skeena Industrial Park lands.

4.4.2 Woody Biomass Availability and Access

There is an abundance of woody biomass close to Git'aws that could be used to run a biomass facility. The older forest stands of the region are composed of large trees with significant decay resulting in a substantial amount of pulp logs and waste fibre. In addition, due to the absence of a pulp mill in the region, there is currently very little market for pulp grade logs. As a result, logging in the region generally results in a large amount of the harvested fibre that is left to waste (sometimes up to 60%), either as dispersed waste or in roadside slash piles (Brouwer pers. comm.). The woody residue in slash piles is normally disposed of by open burning, in accordance with the BC Wildfire Act, resulting in carbon emissions to the atmosphere. Currently in BC, there is a trend to reduce the amount of slash burning and find other uses for woody residue. This trend is being supported by various mechanisms including provincial policy. It is this waste wood that would be targeted for use in a biomass facility.

At a regional level, various studies on biomass availability have been conducted. A study carried out for BC Hydro indicated that there was a biomass electrical generation potential of 209 MW_{el} in the West Prince Rupert Region (Industrial Forestry Services Ltd. [IFS] 2015). Though this study appears to factor in merchantable and waste material. A study of the delivered log costs in the Kalum, Nass and Kispiox Timber Sale Areas (TSAs) estimated that there are 135 million m^3 of mature merchantable timber (over 80 years old) available in the study area with 54 million m^3 in pulp grade logs (Westland 2019). An additional 27 million m^3 may be available if it is assumed that harvested sub-merchantable material and residuals (limbs and tops) provides an additional 20% over and above the merchantable volume. Though clear-cut harvest of immature forests in the region is generally not supported, additional biomass may be sourced from immature forests (generally less than 80 years old) through the use of alternative logging practices such as selection harvest and commercial thinning (Kalum 2nd Growth Working Group 2011).

Other existing or proposed regional facilities using fibre include the Skeena Bioenergy facility, which became operational in 2018 and is producing 75,000 tonnes of pellets annually and may expand to 90,000 tonnes; and a proposed biomass facility in Thornhill to service a planned "village-style" green community providing housing and other amenities (Fredrickson et al. 2018, Home4Good 2020, Skeena Sawmills n.d.). There are two sawmills (Skeena Sawmills in Terrace and small sawmill in Kitwanga; Westland 2019) and no pulp mills in the region. Pulp is typically avoided by primary harvesters, sold to Skeena Bioenergy, or shipped to pulp mills on Vancouver Island from Kitimat (Brouwer pers. comm.). Various other biomass and bioenergy facilities have been proposed in the region over the years, but, at the time of writing, the authors are not aware of any significant developments with any of these proposals. Given the availability of biomass in the region and the currently proposed facilities, fibre availability is not expected to be an issue for this project.

As a first option, biomass for the Kitselas biomass facility would be sourced from Kitselas Forestry LP (Kitselas Forestry), the forestry arm of the Kitselas First Nation. Kitselas Forestry has already agreed to provide logging residues from their operations should this project go forward.

Kitselas Forestry holds a Forest Licence within the Kalum TSA and a Forest Licence to Cut within Tree Farm Licence 1. The combined annual allowable cut (AAC) of the two licences is 43,445 m^3 per year. It is likely given the amount of pulp typical of the area, that 45% of AAC could be used as biomass fuel giving 19,600 m^3 per year or 8,800 odt per year (Westland 2019). In addition, sub-merchantable material suitable for grinding could be assumed to represent an additional 20% over and above the AAC, giving an additional 8,700 m^3 per year or 3,900 odt per year. This percentage is a conservative estimate based on local knowledge (Brower, Jobb pers. comm.). Total available biomass from Kitselas Forestry would be in the range of 28,300 m^3 per year or 12,700 odt per year. In addition, Kitselas is in the process of negotiating a Treaty and, should the Nation vote to move forward with the Treaty, Kitselas will own and manage a significant amount of forest land from which to source biomass.

If an adequate supply of biomass cannot be sourced from Kitselas' own forestry operations, it is likely that an agreement could be reached with other local licensees to gain access to biomass. Sawmill waste (hog fuel) from Skeena Sawmills would also likely be a cost-effective source of biomass; however, Skeena Bioenergy utilizes the sawmill waste material (Skeena Sawmills n.d.). Logging waste from non-forestry developments (e.g., pipeline or transmission line right-of-way clearing) and woody landfill waste are also potential sources, albeit less consistently available. As a worst-case scenario, Kitselas could consider applying for a fibre supply cut licence tenure for the sole purpose of accessing fibre for biomass, though this would have to be reviewed for economic feasibility.

4.4.3 Woody Biomass Delivered Costs

The delivery cost of biomass will depend on variety of factors including:

- Agreements reached with forest tenure holder to utilize waste material from logging operations. Kitselas Forestry has already agreed to provide logging residues from their operations should this project go forward.
- Incentives for forest tenure holders to dispose of biomass through means other than roadside burning. In some regions, current provincial policy requires biomass to be delivered to a local facility able to process biomass; however, this does not currently apply in this region as there is not a facility large enough to handle local biomass (Skeena Bioenergy, Skeena Sawmills' pellet facility, does not have adequate capacity).
- Competition from other fibre users in the region. As discussed on Section 4.4.2, this is not expected to be an issue, given known and proposed uses of fibre.
- Reliability of logging operations in the region from which to source biomass. Sourcing feedstock from existing operations is the best-case scenario; however, logging operations are subject to changes in the market. Kitselas will expect to pay significantly more if they cannot source biomass as a secondary harvester from activities already taking place, and instead have to buy from a chip supplier or carry out primary harvest specifically for biomass. A CHP facility will help stabilize this risk by creating a market for fibre-quality wood.
- Distance to the sources of wood and type of terrain. Delivered costs will increase as the haul distance to the wood increases and with more difficult and steep the terrain.

- The moisture content of the wood and bulk density of the material. Higher moisture content and increased bulk density will increase trucking costs.

Regional studies on delivered biomass or log costs have been carried out. A study carried out for BC Hydro identified a delivered biomass cost of $69 per m^3 or $123 per MWh$_{el}$ in the West Prince Rupert Region (IFS 2015). A study of the delivered log costs in the Kalum, Nass and Kispiox TSAs found that delivered log costs would range from $68 per m^3 to $128 per m^3, with an average of $92.53 per m^3 for merchantable timber (Westland 2019). The costs listed in these studies are associated with primary harvest and include all associated activities. In the context of a bioenergy facility aiming to use residual fibre, these costs are likely to be over estimated; however, if waste material could not be sourced, Kitselas could expect to pay these delivered costs to carry out primary harvest for biomass.

The estimated cost to deliver biomass sourced from waste material within Kitselas' tenure area is presented in Table 8. It is assumed that this waste material could not otherwise be sold and would have been piled and burned on site. The delivered costs include processing, loading, hauling, stumpage, road management, and post-logging cleanup. A basic stumpage charge of $0.25 per m^3 is charged on all material removed from a block, regardless of whether that material is sub merchantable stems, tops or branches. This is a legislative barrier to biomass use that may change with time to encourage biomass use. Delivered costs in Table 8 do not include costs associated with activities already being carried out as part of primary harvest such as: road development, cost to harvest and transport material to roadside, or silviculture. Based on this estimate delivered biomass costs are expected to range from $23.50 to $41.00.

Table 8. Expected delivered biomass costs

	Cost Range	
Activity	**Low end**	**High end**
Processing ($/m^3)	4.00	6.00
Loading ($/m^3)	5.00	7.00
Hauling ($/m^3)	9.75	22.25
Stumpage ($/m^3)	0.25	0.25
Road Management ($/m^3)	4.00	4.00
Post-Logging ($/m^3)	0.50	1.50
Total ($/m^3)	**23.50**	**41.00**

4.4.4 Other Feedstocks

Other feedstocks that could be considered are garbage and sewage. The approximate costs provided by the Kitselas Housing Manager for garbage and sewage disposal are given in Table 9 (Venegas pers. comm.).

Kitselas pays approximately $100,000 per year for garbage collection and tipping fees, and an additional annual fee of about $30,000 to use the Regional District of Kitimat-Stikine waste management facility at Forceman Ridge, for a total cost of $130,000 for garbage disposal. Kitselas is part of a BC material management program and receives some funding for garbage collect and tipping fees: about 80% of the $100,000. The funding does not cover the annual landfill usage fee. Kitselas currently uses a third-party service for garbage collection.

All homes at Git'aws are on septic systems. Kitselas pays approximately $60,000 per year for collection and dispose of sewage to a third-party collection service.

The cost to Kitselas per house for garbage and sewage disposal works out to approximately $1,360.

Table 9. Approximate Garbage and Sewage collection and disposal costs[1]

Activity	Costs ($/year)		
	Total	Funded	Unfunded
Garbage and Sewage			
Collection and Tipping Total	*$ 100,000*	*$ 80,000*	*$ 20,000*
Annual Landfill Usage Fee	*$ 30,000*	*$ -*	*$ 30,000*
Sewage Collection and Disposal	*$ 60,000*	*$ -*	*$ 60,000*
Garbage and Sewage Combined Total	**$ 190,000**	**$ 80,000**	**$ 110,000**
Cost per house[2]			
Garbage Collection and Tipping	*$ 1,235*	*$ 988*	*$ 247*
Annual Landfill Usage Fee[3]	*$ 370*	*$ -*	*$ 370*
Sewage Collection and Tipping	*$ 741*	*$ -*	*$ 741*
Combined Total	**$ 2,346**	**$ 988**	**$ 1,358**

[1] All values are approximate and provided by Ulyses Venegas, Kitselas Housing Manager.
[2] There are 81 homes at Git'aws.
[3] The annual landfill usage fee is not expected to increase with additional housing at Git'aws; therefore, the cost per house would decrease as additional houses are built.

4.5 Recommended CHP System for Git'aws

The main factors influencing the most appropriate CHP system for Git'aws are: feedstock source characteristics, energy demand, available back-up power source, and cost. A comparison of the CHP technologies initially reviewed for this project is provided in Appendix B. While our recommendation has progressed since this initial comparison, the table provides some useful information on the factors considered when making a recommendation.

The likely feedstock for a CHP system is woody biomass sourced from Kitselas Forestry's logging operations. Section 4.4 describes the feedstock availability and costs in more detail. Green wood feedstock in the region is likely to have high initial moisture content (50% to 65%). Selecting a system that is tolerant of higher moisture content and variations in fuel partial size will simplify the supply chain and save Kitselas money.

Sizing the CHP system will depend on the power demand and planned back-up power supply. It would likely make sense for Kitselas to incorporate natural gas as a back-up system. Battery storage or connection to the BC Hydro grid could also be considered; however, entering into an energy purchase agreement with BC Hydro can be costly and time consuming (Radloff 2018).

As described in Section 4.3, CHP costs per kWh_{el} generally decrease as the size of the system increases; and direct combustion and ORC units are typically less expensive than gasification and ICE systems.

Based on the energy and power demand calculations in Section 2.2, if the CHP system is to be sized with for the 135 existing and proposed homes at Git'aws, it would need to meet a base load demand of 118 kW_{el}, an average demand of 229 kW_{el}, and supply approximately 2,000 MWh_{el} per year. Back-up power would likely need to be designed to meet peak load ranging from 387 kW_{el} to 1276 kW_{el}.

A direct combustion and ORC unit is likely the most suitable system for Git'aws given: the greater tolerance for higher moisture content and partial size variation; cost; and the anticipated energy demand at Git'aws. To meet the residential demand for existing and proposed homes at Git'aws, two units in the 200 kW_{el} to 250 kW_{el} range would be suitable, paired with suitable back up system. Multiple 150 kW_{el} gasification and internal combustion engine units may also be suitable, but will complicate the supply chain and increase costs.

5 Biomass Revenue Generating Options

As discussed in Section 4.3, a biomass CHP system is likely not economic feasibility without a source of revenue or cost savings. With this in mind, revenue generating options that could use bioenergy waste products (either by-products or heat) or that could be paired with a bioenergy system were explored.

5.1 Heat Uses

Kitselas could explore options to use heat generated from a CHP system to generate revenue. Examples include using heat for kiln drying of lumber or drying of mushrooms or other botanicals (this is known as process heat). If the heat can be directly sold, or otherwise offset costs in another business venture operated by the band or Kitselas members, this may increase the social and economic viability of the project.

Currently Kitselas operates a greenhouse and a food box program, and synergies between these two processes could be explored.

5.2 CHP Co-products and Companies

There is a growing body of research into the use of combined heat and power by-products or co-products. Biochar is the most often cited by-product or co-product with market potential. Other by-products include ash, tar, and pyrolysis oil. There are also studies that look at the integration of additional processes to make use of by-products or waste products in existing and emerging CHP systems. A study in Sweden has focused on the addition of pyrolysis and gasification units to existing CHP plants to increase the efficiencies of the systems through the use of the fuels produced by these additional units (Gustavsson 2016). Another study looked at combining multiple reactors in a small-scale gasifier system to increase efficiency and make use of the char and flue gas waste products (Vakalis et al. 2016).

In general, these studies indicated that the technologies are still being developed and are not commercially established. Subject matter experts consulted confirmed this and recommended caution when considering by-products, because the technologies that produce marketable by-products such as biochar often require more maintenance and technical expertise and are not well established in BC (or even in Canada) (Hickford-Kulak, Marinescu, Roeser, Schilling pers. comm.). More practical considerations such as feedstock compatibility, maintenance and operational complexity and tried and tested technology options should be considered as more important than potential by-product revenues when assessing feasibility for CHP.

That being said, the following is a summary of research carried out on by-products to date for this project.

The main application for biochar is as a soil amendment, but it is also marketed for water filtration, animal husbandry and air filtration (Crane Management Consultants 2018). Research has also been done into application of biochar in concrete, composites and polymers, and in the field of electrochemistry (Cuthbertson et al. 2019, Giorcelli et al. 2019, Mar Saavedra Rios et al.

2018). Biochar is typically produced through the process of pyrolysis but also through gasification systems (Hansen et al. 2015, Ahmed et al. 2016). Pyrolysis is the oxygen-starved decomposition of a biomass feedstock at increased temperatures, often between 450 ^{o}C and 550^{o}C (Yang et al. 2017). Pyrolysis processes are generally described as slow (slower heating rates and usually lower relative temperatures), fast (faster heating rates and moderate temperatures), and intermediate (a term used less consistently but sometimes refers to a process similar but slightly faster than slow pyrolysis) (Brownsort 2009). A 2017 study on combined heat and power from intermediate pyrolysis indicates that the technology is promising but still developing and that further work is needed on applications of biochar, reactor costs and fuel yields (Yang et al. 2017).

Gasification also produces biochar, though in smaller amounts than pyrolysis due to the fact that gasification produces syngas as the primary product and biochar as a secondary product (Hansen et al. 2015). The biochar produced by various types of pyrolysis and gasification have different physical and chemical characteristics and potentially different applications (Hansen et al. 2015). If Kitselas considers a gasification CHP system, it may be worth looking into gasification biochar further.

Biochar sales have been of interest in other local biomass and CHP feasibility studies. The Thornhill Biomass capstone projects carried out by students at the University of Northern BC cite that biochar sales are a potential revenue stream for the proposed CHP systems (Barlow et al. 2017, Fredrickson et al. 2018). Crane Management Consultant (Crane) carried out a market study for Biochar for the Regional District of Kitimat-Stikine (Crane Management Consultants 2018). The recommended management strategy in the Crane report was to market primary biochar to established biochar companies rather than marketing it for a specific end use purpose.

Another waste product of many CHP systems is ash. AshNet is a national network in Canada looking into application of ash from bioenergy systems, in particular adding ash back to harvested areas as a way to preserve soil carbon and nutrient stocks, and avoid disposal in landfills (Canadian Institute of Forestry 2019). In Canada, there is limited commercial sale of ash with the exception of a few companies in Ontario, though the Canadian Food Inspection Agency is classifying wood ash as a fertilizer, which may open doors for further commercial applications (Hazlett pers. comm.).

Two companies were reviewed that are using a pyrolysis system to convert biomass into biochar and other products: BC Biocarbon and Titan Clean Energy.

BC Biocarbon

BC Biocarbon based out of McBride BC is a company generating biochar and other potentially marketable products from woody biomass and other feedstocks. The company is currently in the pre-commercialization phase of development and has a demonstration plant. The project team visited the demonstration facility in July 2019 and met with the owner/operator of BC

Biocarbon (see Appendix F for summary of the site visit). The following is a summary of that meeting, follow-up discussions and information available on the BC Biocarbon website.

The BC Biocarbon process uses slow pyrolysis to convert feedstock into various products: biochar, distillate, biocoal, and biogas (Fredrickson et al. 2018). The pyrolysis reactor is capable of using a variety of feedstocks (from woody waste to sewage) with a moderate moisture content (less than 30% is ideal). Feedstock type will generally be determined by desired end products.

Currently, BC Biocarbon is selling some of its biochar for use in the agricultural industry as a soil enhancer, but it could also be recombined with distillate to produce biocoal. Other markets for the products are being explored. Gross revenues were cited to be around $150 per tonne of biomass used with potential to reach $500 per tonne; however, this requires validation.

The demonstration plant is rated for one oven dry tonne per hour. Initial capital investment would be expected to be high (over $4,000,000) for a plant of similar size though capital and operating costs are not well understood. BC Biocarbon is currently planning a commercial plant in Delta BC to install three, 2.5 odt per hour units to produce biocoal for a cement plant.

This could be an upstream process that could directly produce heat and electricity or could be paired with a CHP system. Biogas produced as a by-product of the pyrolysis process could be used to produce heat and electricity, but the amount of biogas would depend on the plant size. Biocoal created by BC Biocarbon (by combining biochar and distillate) could also be used in a paired CHP system.

BC Biocarbon proposes a 50/50 partnership for the development of a plant. BC Biocarbon would build and operate the facility and the partner would provide the capital costs, assist in finding feedstock supply and markets. Jobs would likely be created for locals in construction and operation. This presents an advantage over a stand-alone CHP system in that BC Biocarbon would provide the expertise required to operate and maintain the facility.

Titan Clean Energy

Titan Clean Energy Projects Inc. is a company based out of Craik, Saskatchewan that uses a pyrolysis system to convert wood and agricultural biomass to usable products. Their main product market is in biochar for various uses including as a soil amendment, deodorizer and animal and human health product; however, they have potential product streams in biocrude and wood vinegar (Titan 2018, 2019).

Titan appears to utilize a similar technology with similar product streams as BC Biocarbon, as a result, a site visit was deemed unnecessary. It is listed here as an example of the potential marketability of products produced from waste wood through pyrolysis.

5.3 Other Biomass Company Profiles

Advanced BioCarbon 3D

Advanced BioCarbon 3D (ABC3D) based out of Trail, BC has developed a process that extracts lignin from wood to create biodegradable bioplastics. They hope to be a vertically integrated company that will manufacture and market end products. The project team visited ABC3D's research and development location and discussed the technology in October, 2019 (see Appendix F for summary of the site visit).

Currently, the process only uses hardwood chips generally with a moisture content below 20%; however, the Pacific North Coast Development Society had Advanced BioCarbon 3D look into extracting lignin from hemlock chips. The initial test found that their lignin extraction method worked well on hemlock but that further testing was needed to verify the results (ABC3D n.d.). Advanced BioCarbon 3D has also found that alder, a species with limited commercial uses in the northwest, can be used as a feedstock.

ABC3D is currently in the research and development phase but plans to scale up to a 10 tonne per day demonstration plant at an expected cost of $20 million. There are possible synergies between this process and CHP by using excess heat generated from a CHP system for the plant.

Nanaimo International Composting Corporation

Local food and wood waste are used in the Nanaimo International Composting Corporation (ICC) facility to create compost for local users on central Vancouver Island. The facility was originally established (with one unit) in 2004, and then expanded to 3 units in 2011 after the Regional District of Nanaimo (RDN) banned organic waste from its landfill and entered into a contract with ICC to process organic waste collected by RDN. One more unit is planned to be added as supply increases. Each unit can process approximately 7,000 tonnes per year. ICC is currently processing approximately 18,000 tonnes per year. Income is from tipping fees from RDN, private waste companies delivering business waste (restaurant, supermarket, etc.), and a small amount from individuals. SINCRE carried out a site visit of the Redrock Biomass Heat Facility. A detailed description is provided in Appendix F.

5.4 Revenue Generation Recommendation

Based on the technologies and companies reviewed, the project team feels that the BC Biocarbon process holds the most potential for Kitselas for the following reasons:

- the pyrolysis reactor is capable of using a variety of feedstocks (from woody waste to sewage) with moderate moisture content;
- revenue from products (biochar, wood vinegar, distillate, biocoal) is anticipated; and
- biogas or biocoal produced from BC Biocarbon could be used in a paired CHP system.

While promising, draw backs to pursuing a partnership with BC Biocarbon include:

- the technology not yet proven at a commercial scale;
- product markets are promising but not yet proven; and
- capital and operating costs are not understood, but initial capital investment would be expected to be high (over $4,000,000).

The timeline for additional investigation and feasibility study has a good likelihood of aligning with BC Biocarbon achieving commercial viability and becoming ready for an actual build-out; therefore, it may be worth continuing investigation into a CHP system combined with this revenue-generating process. The owner of BC Biocarbon has indicated that they are willing to further discuss a joint project with Kitselas.

Appendix B provides a comparison of CHP systems, BC Biocarbon and Advance Biocarbon 3D as revenue generating options for Git'aws. While our recommendation has progressed slightly since this initial comparison, the table provides some useful information on the factors considered when making the recommendation to explore opportunities with BC Biocarbon further.

6 Greenhouse Gas Impacts

The greenhouse gas (GHG) impact of energy produced from biomass is complex. Bioenergy is often identified as carbon neutral because the carbon from trees already exists in the biosphere in comparison to fossil fuels which add carbon to the biosphere (Buchholz et al. 2016, Washington State Department of Natural Resources [WSDNR] n.d.). Under a sustainable forest management regime where forest stocks are generally maintained, carbon dioxide (CO_2) released to the atmosphere during the burning of biomass for energy can be recaptured over time through photosynthesis as trees grow. However, the claim of carbon neutrality is brought into question for the following reasons: the fact that wood fuel is less efficient than fossil fuels and produces more CO_2 to produce the same amount of energy; release of CO_2 to the atmosphere through natural death and decay of trees occurs much more slowly than through burning; and it can take decades or centuries for the CO_2 released by burning to be recaptured by photosynthesis (Laganiere et al. 2017).

Slash pile burning is a significant source of GHG emissions in BC: in 2017, slash pile burning was estimated to contribute 3,990 kilotonne (kt) CO_2 equivalent (CO_2e), which is 6% of the total reportable GHG emissions (64,462 kt CO_2e) for that year (BC Ministry of Environment and Climate Change Strategy 2019). Regardless of the perspective on carbon neutrality of bioenergy, GHG benefits can be expected if the biomass is sourced from logging residues that would have otherwise been burned in roadside slash piles. In this case, a GHG benefit is likely to occur immediately as biomass that would have been burned in slash piles is instead used to produce energy (Laganiere et al. 2017, Springsteen et al. 2011, WSDNR n.d.). The combustion process in a CHP system results in fewer emissions in the form of methane (CH_4) and nitrous oxide (N_2O) than open burning in slash piles, while also using the energy generated from burning to replacing emissions associated with the status quo energy source (Environment and Climate Change Canada (ECCC] 2019, Springsteen et al. 2011). Based on the emission factors selected for this analysis, open burning results in 20 times more CH_4 emissions and 3 times more N_2O emissions than industrial combustion in a bioenergy facility (ECCC 2019, Springsteen et al. 2011).

On the other hand, if biomass is instead sourced from merchantable greenwood typical of our local forest, which typically takes 80 to 120 years to reach maturity again, there may be a negative GHG benefit compared to the status quo (Laganiere et al. 2017).

When reviewing the GHG impact of a biomass facility at Git'aws, it was assumed that the bioenergy facility would mostly use waste wood sourced from local logging or other development that would have otherwise been burnt in slash piles. It was also assumed that the primary purpose of the selected biomass facility is energy production (rather than the production of wood products such as biochar or bioplastics), which will replace hydroelectricity and heating from woodstoves for the current and proposed homes at Git'aws.[6] A fulsome

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[6] This is a 'dynamic' assessment as defined by Buchholz et al. in which a status quo scenario (using hydroelectricity and woodstoves, and slash pile burning) is compared to the bioenergy scenario (2016).

lifecycle account of the GHG impacts of this project would require a detailed assessment of many factors including forest carbon dynamics, transportation, leakage, and others (Buchholz et al. 2016). Instead, for this assessment, the expected emissions produced by the conversion of biomass in the bioenergy facility were compared to the emissions from slash pile burning and the status-quo energy source (woodstoves and hydroelectricity). Only GHG source gases (CO_2, CH_4, and N_2O) were considered (US Environmental Protection Agency [US EPA] n.d.). Other forms of pollution that may impact air quality were not accounted for (nitrogen oxides [NO_x], carbon monoxide [CO], particulate matter etc.)

This assessment considered a CHP system utilizing two 150 kW_{el} gasification and internal combustion engine units running on wood chips producing 2,082 MWh_{el} per year at 90% operation, and using 1,734 tonne of wood chips at a 18% moisture content. This CHP configuration was assumed adequate to meet the 2000 MWh_{el} per year average demand for electricity (as per Table 2) for the existing and proposed homes at Git'aws (assuming homes are heated electrically[7]). This CHP configuration was estimated to produce around 1,900 tonnes of CO_2 equivalent emissions (not accounting for biomass transportation, handling and chipping etc.). Open burning of the same amount of woody biomass produced roughly 2,800 tonnes of CO_2 equivalent emissions.

The CHP system was expected to offset the GHG emissions associated with producing 2000 MWh_{el} per year from hydroelectricity (roughly 20 tonnes of CO_2e) (BC Hydro n.d. a). It was also expected to offset a portion of the woodstove use at Git'aws. It has been approximated that Git'aws currently uses 502 odt per year for the 44 woodstoves generating about 1100 tonnes of CO_2e.

While many assumptions had to be made and not all carbon emissions are accounted for, it is likely that the stated CHP system would result in a GHG benefit. In a scenario in which all biomass would have been burned in slash piles, and all woodstove use is offset, the CHP system could result in a GHG reduction as high as 2,000 tonnes of CO_2e per year compared to the status quo, which is a 50% reduction in GHG emissions. A more likely scenario in which 75% of biomass is diverted from slash pile burning and 50% of woodstove use is offset, the GHG benefit is about 800 tonnes of CO_2e.

The GHG emissions associated with the CHP unit and the status quo scenarios are presented in Table 10. Detailed calculations and methodology are provided in Appendix D.

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[7] The basis for this assumption is due to the fact that three of the four BC Hydro bills were from houses using electric heat (electric forced air furnaces).

Table 10. Greenhouse Gas Analysis: CHP vs Status Quo

	CO_2 Equivalent (kg/yr)		
Activity/GHG	Scenario 1: 100% feedstock from burn piles, no woodstove use	Scenario 2: 75% feedstock from burn piles, woodstove use cut in ½	Scenario 3: 50% feedstock from burn piles, woodstove use cut in ½
Bioenergy Facility Alternative			
CHP 150 KW_{el} Gasification +ICE x2			
CO_2e from CO_2	1,851,559		
$CO2_e$ from CH_4	4,960		
$CO2_e$ from N_2O	39,412		
Total	**1,895,931**		
Status Quo			
Open Pile Burning			
CO_2e from CO_2	2,558,899	1,919,174	1,279,449.53
CO_2e from CH_4	104,701	78,526	52,350.64
CO_2e from N_2O	129,634	97,225	64,816.91
Total	**2,793,234**	**2,094,926**	**1,396,617**
Residential Combustion Conventional Woodstove at 19% MC			
CO_2e from CO_2	874,033	437,016	437,016.38
CO_2e from CH_4	183,155	91,578	91,577.51
CO_2e from N_2O	20,309	10,154	10,154.45
Total	**1,077,497**	**538,748**	**538,748.34**
Hydroelectricity			
CO_2e	20,098		
Total	**20,098**		
CHP Total	**1,895,931**	**1,895,931**	**1,895,931**
Status Quo Total	**3,890,829**	**2,653,772**	**1,955,463**
GHG Benefit = CHP – Status Quo	**-1,994,898**	**-757,841**	**-59,533**

7 Summary and Recommendations

7.1 Summary and Recommendations

The Kitselas First Nation has an interest in pursuing a renewable energy solution for Git'aws that will bring economic, social and environmental benefits to the community and contribute to their self-sufficiency.

This project focused on options to meet the electrical and at least part of the heating demand of the existing and proposed housing at Git'aws. Biomass combined heat and power was found to be a suitable renewable energy option for Git'aws considering the availability of woody biomass in the region and the fact that Kitselas Forestry LP will likely be able to provide low cost waste material from their logging operations.

As Git'aws is currently connection to hydroelectricity and natural gas, a CHP system may not be economically viable without other influencing factors. The main factors being access to grant funding for capital and installation costs and/or viable opportunities that will generate revenue from the CHP system or can be paired with the system. Economic considerations need to be balanced with other benefits including job creation, skills development and a reduction in greenhouse gas emissions.

As a result of the investigations and research carried out for this project, the following key recommendations are being made to Kitselas.

1. A brief review of other renewable technologies suggests that if a renewable technology were to be utilized, it is a biomass CHP system that would be the most appropriate for Kitselas.
2. A preliminary review indicates that a stand-alone CHP system for Git'aws is not likely viable based on economics alone. However:
   - (d) If Kitselas receives a grant for the capital and installation costs of the project, this economic assessment may change.
   - (e) In addition, consideration of the full range of economic, social and environmental factors, based on input from the community may also change the viability of the project.
   - (f) A stand-alone CHP system may be worth revisiting in a few years' time, at which point CHP technologies may be more established, and the economic case may change.
3. Notwithstanding Recommendation 2, if Kitselas were to proceed with a stand-alone CHP system, a series of small to medium-scale (less than 500 kW_{el}) modularized direct combustion and Organic Rankin Cycle, or gasification and internal combustion engine systems would likely be the most appropriate given the residential electrical demand at Git'aws. Additional demand from industrial or community infrastructure may change this recommendation.
4. Pairing CHP with a revenue generating process would increase the economic viability of the project. Of the revenue generating processes reviewed, BC Biocarbon is likely the best fit for Kitselas. A CHP system combined with a revenue-generating process may be worth continued investigation.

5. Regardless of whether Kitselas decides to proceed with further feasibility on CHP at this stage, they could consider installing district heating infrastructure for the new subdivision. This would allow a centralized heating system (bioheat or other) or a biomass CHP system to be more easily integrated in the future.

7.2 Considerations for Phase 2

If Kitselas decides to move forward with the recommendations in the previous section and proceed with the next phase of the project, Phase 2 would involve detailed feasibility and preliminary conceptual design of one or more selected processes. More specifically, Phase 2 should include:

- confirmation of Council support and identification of community champion;
- a detailed energy audit;
- confirmation of fibre needs and associated supply;
- a detailed feasibility assessment of one or more heat and/or power processes;
- selection of process with community buy in; and
- preliminary conceptual design.

A brief list of items that should be considered in Phase 2 that came up through the course of this phase of the project is provided here.

Cost Benefit Analysis

Should Kitselas move forward with a full feasibility study for this project, a fulsome review of all of the potential costs and benefits of a CHP system for Kitselas should be accounted for and community input should be gathered.

Additional economic factors to be considered in a detailed financial feasibility assessment include:

- determining what Git'aws is actually paying to BC Hydro at this time;
- cost of upsizing BC Hydro grid connection to meet demand of new housing development and/or supply 3-phase power for industrial uses[8];
- cost of installing district heating (a brief discussion of costs is included in Section 4.2);
- cost of installing additional heat harvesting equipment;
- money to be generated from potential revenue streams; and
- cost savings associated with displacing firewood costs and garbage and sewage disposal costs.

Other factors to be considered include:

- employment and capacity building: creation of local jobs, skills development, and training opportunities for Kitselas Members;

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[8] Git'aws currently has a single-phase grid connection, 3-phase power would be required for proposed industrial facilities (e.g. sewage treatment) (Lanctot pers comm. 2019).

- contribution to local economy: though potentially more expensive, the money used to generate heat and power through a CHP system would largely stay in the community in the form of capital assets and wages;
- self-reliance: Kitselas would be capable of producing a portion of their own electricity and heat, reducing reliance on the provincial grid system and promoting a circular economy in Git'aws; and
- sustainability: a CHP system would provide a use for woody waste products that are locally available and divert emissions associated with the burning of slash piles of woody waste in the bush.

Location

The location of the CHP system will depend on the footprint of the facility, utilization of district heating, tie in with existing BC Hydro and PNG infrastructure, and air quality and noise impacts to residents. A facility would likely be located within the 'light industrial' land use designation as shown on Figure 2.

Area

The area requirement for a CHP facility will vary depending on the type of system and the feedstock handling, processing and storage requirements. For instance, if timber is hauled from cutblocks to Git'aws for chipping, an area will be needed for log storage, chipping, chip drying and storage.

Back-up System

Natural gas or propane could be used as a back-up fuel in the event of a biomass supply issue. Natural gas or propane will also likely be required for initial start-up of the system. Git'aws has an existing connection to natural gas through Pacific Northern Gas. The line would need to be extended to the CHP facility location.

Hydroelectricity should also be explored as a back up system because Git'aws is also connected to the BC Hydro distribution system. However, the logistics of using BC Hydro as a back-up system may be complicated. Other CHP projects in the province have indicated that establishing an agreement with BC Hydro has been a costly and lengthy process: see the lessons learned at the Kwadacha CHP Project in Figure 4. In addition, the BC Hydro distribution system to Git'aws is single phase. As development occurs at Git'aws there may be a requirement for three phase power to carry larger commercial or industrial loads. Engineering designs will need to address the requirement for single phase or three phase power from the CHP and backup system.

BC Hydro Interconnection: lessons learned at Kwadacha:

- Developing agreements and getting approvals is lengthy and costly:
  - Energy Purchase Agreement (EPA): The key agreement for interconnection; requires approval from BC Utilities Commission. The Kwadacha EPA took years to finalize and set a purchase price of $0.35 per kWh_{el} supplied by Kwadacha CHP.
  - Distribution Generator Interconnection Agreement (DGIA): Outlines the requirements for delivery of electricity to BC Hydro. The Kwadacha DGIA took many months to complete.
  - Fee to BC Hydro for their involvement in project was more than $400 000.
- Meeting BC Hydro's strict standards for power quality and reliability is onerous. Onus was on Kwadacha to prepare studies and assessments and purchase additional protection equipment to meet these requirements.
- Hiring an experienced electrical power-supply engineer to work with BC Hydro is very important.
- BC Hydro does not provide technical support, only regulatory information, reviews and approvals.

Source: Radloff 2018

Figure 4. BC Hydro Interconnection: lessons learned at Kwadacha

CHP System Considerations

When selecting a CHP system, Kitselas will need to consider the following:

- determine whether the system will need to be adapted from European electrical standards (50 hertz [Hz], 440 volts [V]) to North American standards (60 Hz, 600V), requiring a step-down transformer;
- ensure adequate spare parts are ordered up front and considered in costs (e.g., one year's worth);
- ensuring the prepared feedstock will meet required specifications with the supplier (send a sample to supplier); and
- confirm delivery time and customs requirements for systems from outside of Canada.

District Heating

The following factors should be considered for district heating installation. These factors are largely based on lessons learned from the district heating system installed by Kwadacha (Radloff 2018).

- Make sure proximity and spacing of target areas to CHP system is appropriate for district heating.
- Understand and confirm temperature provided by CHP system when designing district heating system (Kwadacha designed their system based on promised temperature of 85°C, but the actual temperature delivered by Spanner system was 75°C).
- Investigate the suitability of PEX distribution piping versus steel piping.
- Schedule construction and installation in warmer months if possible.

Local Impacts

Impacts to the residents of Git'aws will need to be considered including the noise associated with the facility and air quality impacts.

Phased Construction

Phased construction should be considered when designing the facility to allow the capacity of the facility to expand with increased community development and demand. Installing a series of CHP units, with the option to add in additional units may be an appropriate option for Kitselas. This approach would also result in upfront capital cost savings.

Commissioning and Training Considerations

Some considerations related to commissioning and training are as follows (as outlined in Radloff 2018).

- Ensuring that there is enough local support for the ongoing operation and maintenance of the units: ideally, enough community members will be trained, and ongoing training will be provided to new members.
- Ensure training is planned and can be provided by a supplier and ensure training can be effectively provided in English.
- Understand the support provided by the supplier after testing and commissioning is complete. Securing local support for maintenance and operation is ideal. Remote support can usually be provided by the supplier or manufacturer but may be costly.

8 Glossary, Acronyms, Units and Conversions

Table 11. Glossary of Terms

Term	Definition
Absorption Refrigeration	Absorption refrigeration is a process that uses heat to provide the energy needed to drive the cooling process.
Atmosphere	Layers of gases (commonly known as air) that surround the Earth and are held down by gravity.
Average Load	The average power demand that occurs across a period of time.
Base Load	The power demand that occurs on a nearly continuous basis (24 hours a day and 365 days a year).
Biochar	A carbonaceous substance, solid in form, which is created from biomass in the absence of oxygen. Biochar has a variety of potential uses including enhancing soil, resource use efficiency, and potential for greenhouse gas mitigation (International Biochar Initiative 2012).
Bioenergy	Renewable energy derived from biological sources and/or their by-products. Examples include wood for heating, biodiesel to fuel vehicles, and methane gas to produce electricity (Natural Resources Canada 2020).
Biofuel	Biofuel is biomass that is processed and used as fuel to produce heat and/or power.
Bioheat	The heat produced from the burning of biofuel.
Biomass	Organic matter, typically plant-based, that is a renewable or recurring resource. There are numerous forms of biomass resources available such as wood products, forest and mill residues, animal wastes, aquatic plants, livestock operational residues, and small-to-large scale industrial wastes. Biomass is capable of being used in solid, gaseous, or liquid states depending on the type of energy to be produced (Energy and Environmental Analysis Inc. and Eastern Research Group 2007).
Biomass conversion	The process of biomass feedstocks being converted into an energy source that produces electricity and/or heat (Energy and Environmental Analysis Inc. and Eastern Research Group 2007).
Biosphere	The regions (water, soil and air) on Earth inhabited by living organisms (National Geographic n.d.).
Boiler efficiency	Fuel energy proportion (in percentage) that changes to steam energy (Energy and Environmental Analysis Inc. and Eastern Research Group 2007).
Bulk Density	Bulk density is the mass per unit volume (e.g., tonner per cubic metre) of biomass and varies widely with biomass source and processing.
Carbon dioxide equivalent (CO_2e)	A common unit of measurement used to describe the global warming impact of different greenhouse gases (e.g., CO_2, CH_4, N_2O). An amount of GHG can converted to CO_2e by multiply it by its Global Warming Potential.
Combined Heat and Power	Combined heat and power, also referred to as cogeneration, produces heat and electricity from a single fuel source. CHP systems include a conversion process that converts the fuel into energy and a power generation process that converts the energy into electricity.
Cord	A cord of wood is equal to a stacked wood pile with dimensions of 4' by 4' by 8' and is equal to 3.6 m^3.
District Heating	District energy systems provide heating and cooling to buildings from a centralized unit, generally through an underground piping system.
Electrolysis (of water)	The breakdown of water, from an electrical current, into hydrogen and oxygen (Chaplin 2020).
Emission Factor (EF)	The emission factor is a value that describes the amount of a greenhouse gas released to the atmosphere by a particular activity.
Energy Consumption	Electrical energy consumption is the amount of electrical energy used over a period of time to run electrical appliances in a home and is measured in kilowatt-hours (kWh_{el}) in this report.
Global Warming	The amount of warming a greenhouse gas causes over a given time period (typically 100 years).

Term	Definition
Potential (GWP)	
Green tonne (GT)	Weight of wood at “green” moisture content (e.g., 50%).
Hauling Time	The amount of time a logging truck takes to deliver logs; this includes loading, unloading, and any delays. The hauling time commences from the log delivery site to the specific cutblock and back to the log delivery site. Also referred to as the “cycle” time.
Heat Harvesting	Heat harvesting involves putting heat to use in a heating application or to create mechanical or electrical energy that would have otherwise been unused or wasted (European Thermodynamics Limited 2015).
Lignin	A type of polymer in vascular plants that develops and forms the cell wall structure.
Moisture content (of wood)	The weight of water in wood in comparison to dry weight of wood. The unit of measurement of moisture content is by percentage. The moisture content of dried wood is 0% while a freshly cut tree may have a moisture content of 200% (RLC Engineering n.d.).
Oven Dry Tonne (odt)	Weight of wood at 0% moisture content. Note this is not a natural state for wood and as soon as it is exposed to air it will take on moisture (Reeb 1995). Also referred to as bone dry tonne (bdt).
Peak Load	The highest power demand that occurs during the year.
Photosynthesis	The process that is used by green plants (including trees), phytoplankton, and cyanobacteria, to convert light energy (from the sun) via respiration into chemical energy (Scitable 2014).
Power	Power is the energy per unit of time and is measured given in kilowatts electric (kW_{el}) in this report. Power demand fluctuates throughout the day and year.
Process Heat	Process heat is the use of thermal energy to treat or prepare materials that will be used to manufacture products.
Pyrolysis	Pyrolysis is the oxygen-starved decomposition of a biomass feedstock at increased temperatures.
Single Phase power	An alternating current electrical power distribution system that delivers power at an inconsistent rate. Single phase power is typically used for lighting and heating loads (e.g., household uses) and is generally not suitable for large electric motors (Wikipedia 2020c).
Three phase power	An alternating current electrical power distribution system that delivers power at a constant rate, allowing the system to carry higher loads. Three phase power is typically used for business and commercial applications with higher loads (Aegis Power Systems Inc. n.d.).

Table 12. Acronyms

Acronym	Meaning	Acronym	Meaning
AAC	Annual Allowable Cut	LHV	Lower Heating Value
ABC3D	Advanced BioCarbon 3D	LNG	Liquid Natural Gas
BC	British Columbia	MC	Moisture Content
CEBC	Clean Energy BC	N_2O	Nitrous Oxide
CH_4	Methane	NO_x	Nitrogen Oxides
CHP	Combined Heat and Power	NRCan	Natural Resources Canada
CO	Carbon Monoxide	NRCC	National Research Council Canada
CO_2	Carbon Dioxide	ORC	Organic Rankine Cycle
CO_2e	Carbon Dioxide Equivalent	PEX pipe	Cross-Linked Polyethylene Pipe
DGIA	Distribution Generator Interconnection Agreement	PNCDS	Pacific North Coast Development Society
ECCC	Environment and Climate Change Canada	PNG	Pacific Northern Gas
EF	Emissions Factor	RDF	Renewable Diesel Fuel
EPA	Energy Purchase Agreement	RDN	Regional District of Nanaimo
FTE	Full Time Equivalent	REW	Renewable Energy World
GHG	Greenhouse Gas	RNG	Renewable natural gas
GWP	Global Warming Potential	ROR	Run-of-River
HHV	Higher Heating Value	SNCIRE	Skeena-Nass Centre for Innovation in Resource Economics
ICC	Nanaimo International Composting Corporation	TSA	Timber Sale Area
ICE	Internal Combustion Engine	UBC	University of British Columbia
IFI	Indigenous Forestry Initiative	US EPA	United Stated Environmental Protection Agency
IFS	Industrial Forestry Service Ltd.	WSDNR	Washington State Department of Natural Resources
IPCC	Intergovernmental Panel on Climate Change		

Table 13. Important Units of Measurement

Unit Abbreviation	Meaning
Length and Volume	
mm	millimetres
m	metres
m^3	cubic metres
Mass	
g	grams
kg	kilograms
t	tonnes
kt	kilotonnes
odt	oven dry tonne
Power	
$kW_{el/th}$	kilowatts (electric/thermal)
$MW_{el/th}$	megawatts (electric/thermal)
HP	horsepower
Energy	
$kWh_{el/th}$	kilowatts-hours (electric/thermal)
$MWh_{el/th}$	megawatts-hours (electric/thermal)
J	joule
MJ	megajoule
GJ	gigajoule
Other	
Hz	hertz (a measurement of frequency)
V	volts (a measurement of electrical potential)

Table 14. Important Unit Conversions

Unit	Equivalent to
1 kg	1000 g
1 t	1000 kg
1 Mt	1000 t
1 cord wood	3.62456 m^3
1 m^3	0.45 odt[1]
1 MW	1000 kW
1 MWh	1000 kWh
1 MWh	3600 MJ

[1] Based on an average wood density of 0.450 oven-dry tonnes per m3 of freshly harvested logs. (Schilling et al. 2017c).

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Appendix A: Other Bioenergy Technologies and Bioenergy Facility Profiles

Other bioenergy technologies and bioenergy systems or projects were reviewed to understand existing technologies used in BC and possible lessons learned for Git'aws.

Air curtain burner and ORC

The PG Firebox is a biomass disposal system that uses an air curtain burner paired with an ORC system to harvest the heat generated by the combustion in the air curtain burner. The primary purpose of the system is to dispose of woody debris and reduce particle emissions, and it has very low electrical generation efficiencies (Schmitt pers. comm.). For example, the PGFireBox 100 can consume 9,100 kg per hour of biomass and produce up to 100 kW_{el} (AirBurners n.d.). Compare this to a small-scale gasification and ICE unit that consumes about 50 kg per hour and produces 50 kW_{el}. This technology was not deemed suitable for Git'aws.

Eliza's Village

Eliza's Village is a "village style" green community providing housing and other amenities proposed in Thornhill, located approximately 20 minutes west of Git'aws on Highway 16 (Home4Good 2020). Initial studies have been done into a bioenergy facility to provide heat and power to Eliza's Village. A capstone project carried out by students from the Environmental Engineering program and the University of Northern British Columbia assessed the use of two 1 MW_{el} ORC and four 0.5 MW_{el} gasification systems to provide an estimated 1.8 MW_{el} demand, and recommended the ORC units for implementation (Fredrickson et al. 2018). Members of the project team, Floyd Wickie and Allan Lanctot, are involved in this project with the Pacific North Coast Development Society.

Dockside Greens District Energy Plant

The Dockside Greens Plant is owned and operated by Corix Utilities (Corix). The system was intended to burn syngas (produced by a biomass gasification system) or natural gas to produce hot water for a district heating system. It is currently only running on natural gas (Dockside Green Energy 2008). The biomass gasifier (installed by Nexterra) has never properly worked and Corix is planning to remove it and upgrade the plant to a natural gas only system (Hickford-Kulak pers. comm.). The plant has been operating at a loss because it was designed to service the entire proposed development of Dockside Greens (1,500 residential and commercial units) but only 300 units have been built so far (Bennett 2012). This example shows that a scalable system that can be added to as a community grows may be more appropriate when expanding energy needs are anticipated.

Kwadacha Bioenergy Project

Three Spanner Re^2 units at Kwadacha gasify wood chips to produce syngas and run an internal combustion gas engine for heat and power. Each Spanner Re^2 produces 45 kW_{el} of electricity and 100 kW_{th} of thermal energy. The thermal energy will heat water in a district heating system to be connected to the school and teacher residences. The electrical energy is used for buildings and residences through a 20-year Electricity Purchase Agreement between Kwadacha and BC Hydro. The CHP system replaces and or supplements electricity from diesel generators and heat provided by propane (Radloff 2018).

National Research Council Microgrid Facility at UBC

The National Research Council of Canada, in partnership with FPInnovations, is developing a microgrid testing facility at the University of British Columbia in Vancouver. The facility is intended to test pre-commercial power generation and storage technologies before installation in remote communities. NRCC may also be able to provide training and remote monitoring to communities once technologies are installed (NRCC 2019, Rossetto, Skrivan pers. comm.).

In 2019, a 40 kW electric and 100 kW thermal Volter gasification and ICE unit was installed for testing. The system includes a wood chip drying shed, feedstock shed and auger, the containerized CHP unit, an additional container for voltage conversion and switching and an ash bin. The unit runs off wood chips and requires a low moisture content and has low tolerance for chip size variation. Chip drying is intended to occur using heat from the CHP system (Rossetto, Skrivan pers. comm.).

The project team carried out a site visit of the Microgrid Facility in October 2019. A detailed description is provided in Appendix F.

Redrock Biomass Heat Facility

This operation uses locally sourced wood chips to heat multiple greenhouses to grow seedlings for the forest industry. It has been operating successfully since at least 2010. The system easily heats two large (60m by 80m) greenhouse ranges year-round. The system burns woody waste to heat 14,000 litres of water (6,000 litres in the boiler with 8,000 litres in circulation and in a buffering tank). The unit burns wet woody waste as well (they have burned up to 65% moisture content, though of course that is not preferred). The system meets all the stack emission requirements without a filtering system. They are burning about one 53-foot trailer’s worth of woody waste per day (on average – of course that changes with the temperature).

SINCRE carried out a site visit of the Redrock Biomass Heat Facility. A detailed description is provided in Appendix F.

Tsay Kah Dene Nation CHP Plant

The Tsay Kah Dene Nation in interior BC is starting development on a 1.2 MW CHP plant using direct combustion and a Turboden ORC to produce heat and power and offset the diesel use by the community. Construction is to begin in late 2020 or 2021 and the plant should be operational by 2022. The plant will use logging residues and deadwood from the Williston

Reservoir. A battery system will eventually be incorporated and the diesel system will act as a back-up only. The system was designed by Chu Cho Environmental (an environmental consulting company owned by Tsay Kah Dene) and Clean Energy Consulting out of Prince George (ICE Network 2019, Church 2020).

Teslin Tlingit BioHeat

A Teslin Tlingit Nation village in the Yukon installed biomass boilers in 2018 to heat 10 major buildings in the community to replace propane and electrical heat. The boilers run off chipped waste wood. The community hopes to expand to produce electricity as well. Funding was received from the Yukon Government and Natural Resources Canada's Indigenous Forestry Initiative (Byers 2019).

UBC Bioenergy and Demonstration Facility

The University of British Columbia (UBC) Bioenergy and Demonstration Facility began operation in 2012 and cost $27.4 million. There are two operation modes: thermal-only (6 MW_{th} gasification system producing syngas); and cogeneration mode (refines the syngas to produce engine-grade, clean syngas for 2.4 MW of thermal and 2 MW of electrical) (UBC n.d.). The cogeneration mode, built by Nexterra, has had issues and is currently not operational (Roeser, Hickford-Kulak pers. comm.).

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Appendix B: Comparison of Options

As an early step in this project, the following table was created to assess three example CHP systems and two value added processes based on a number of criteria. While a direct combustion +ORC system in the 200 to 500 kW_{el} ranges (one of the CHP systems suggested for Kitselas is Section 4.5) was not assessed, the general outcomes of this table are still useful for a high-level comparison of the various options.

For each criterion, each system/process is given a ranking from 1 to 5, with 5 being the most suitable or best option and 1 being the least suitable. All criteria are weighted equally, though in reality some would prove more important to Kitselas than others. These are qualitative rankings based on the authors judgement and research, and a rationale is provided for each.

BC Biocarbon has been ranked highest with 34 points, ABC3D is ranked lowest with 24 points, while the three CHP systems are ranked very close to one another with 30 to 31 points.

Table 15. Comparison of Options

Assessment Criteria	**Small scale CHP – gasification and internal combustion engine (e.g. ESPE ChiP50, 50kW_{el}) [1]**		**Small scale CHP – gasification and internal combustion engine (e.g., Urbas, 150kW_{el}) [1]**		**Medium scale CHP – direct combustion and ORC (1MW_{el}) [5]**		**BC Biocarbon (1 Odt/hr plant) [7]**		**Bioplastics – ABC3D (10 tonne/day demo plant) [8]**	
	Ranking	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**
Total Ranking	**31**		**30**		**30**		**34**		**24**	
Suitability of local feedstock *(ranking based on suitability of local feedstock e.g., woody residue from logging operations, softwood, high moisture content, branches/tops/stumps/pulp logs)*	2	Woodchips Low MC (<18%) Restriction on size and fines Use of branches/slash discouraged Screened chipper required	2	Woodchip Low MC (<18%) Restriction on size and fines Use of branches/slash discouraged Screw/screen chipper required	4	Depending on boiler type, accepts various fuel types (woodchips, hog fuel, bark etc.) Higher MC tolerated (<60%) Lower quality tolerated	5	Accepts woodchips, tires, sewage sludge (feedstock dictated by desired output) Higher MC tolerated (<30% ideal) Lower quality tolerated Limbs and tops okay	1	Currently only using hardwood – lignin from softwood has different properties/uses Single species is best Various sizes okay (sawdust to chips)
Annual biomass consumption (Odt) *(ranking based on whether woody waste could likely be supplied by Kitselas Forestry –approx. 8,800Odt/yr [2])*	4	One unit: 328 Odt at 90% utilization rate [3] Even with multiple units installed, biomass supply not likely to be an issue	4	One unit: 867 Odt at 90% utilization rate [3] Even with multiple units installed, biomass supply not likely to be an issue	1	One unit: 10, 500 Odt at 90% utilization rate Additional sources of biomass may be required	3	For a 1 Odt/hr plant running at 90% = 7884 hrs/year * 1 Odt/hr = 7884 Odt This is close to the estimated annual amount that could be supplied by Kitselas. In some years with less logging, supply may be an issue	2	For a 10 tonne/day (assuming Odt) plant running at 90% = 328.5 days/year *10 Odt/day = 3285 Odt If softwood became a viable feedstock, biomass supply not likely to be an issue

Assessment Criteria	Small scale CHP – gasification and internal combustion engine (e.g. ESPE ChiP50, 50kW$_{el}$) [1]		Small scale CHP – gasification and internal combustion engine (e.g., Urbas, 150kW$_{el}$) [1]		Medium scale CHP – direct combustion and ORC (1MW$_{el}$) [5]		BC Biocarbon (1 Odt/hr plant) [7]		Bioplastics – ABC3D (10 tonne/day demo plant) [8]	
	Ranking	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**
Suitable size for Git'aws *(ranking based on whether CHP is an appropriate size to supply 455kWel of gross output to meet peak electrical demand for 135 homes (current and future housing))*	4	Likely too small to meet current and future electrical demand for Git'aws housing If multiple units combined, may be suitable to meet the requirement in the proposed development of 54 homes	5	A series of modularized units in the ~150kW output may be the best fit for Git'aws current and future housing	3	Likely too large for Git'aws current and future housing needs If providing electricity to administrative and community buildings, or for future commercial development, this may be a more appropriate size	2	Based on some very rough calculations, assume gas produced by plant could supply approximately 70 kW gross electrical output [9]. BC Biocarbon would be too small on its own to supply electrical demand for Git'aws housing.	1	This is a downstream process that does not produce heat or power.
Total Capital and Installation Costs *(total capital and installation costs calculated based on the number of units required to supply 455kWel of gross output to meet peak electrical demand for 135 homes (current and future housing))* *(ranking is from least expensive to most)*	4	Estimate 10, 50kW units required to supply 455kW; 10 x $845, 000 (capital and installation cost for one unit) = $8,450,000	5	Estimate 4, 150kW units required to supply 455kW; 4 x $1,860,000 (capital and installation cost for one unit) = $7,440,000	3	Estimate one unit: $10,000,000	3	Estimate: Likely $10,000,000+ BC Biocarbon indicated $1 MM for 1Odt/hr plant not including land, building, or generator to product electrical energy. As a very rough estimate we have quadrupled that estimate. Additional pyrolysis unit would also be required as a backup for maintenance and downtime, resulting in cost increases.	1	Estimate: $20,000,000 ABC3D indicated that a 10 tonne/day demo plant would be ~$20 MM Additional costs associated with CHP unit not included.

Assessment Criteria	Small scale CHP – gasification and internal combustion engine (e.g. ESPE ChiP50, 50kW$_{el}$) [1]		Small scale CHP – gasification and internal combustion engine (e.g., Urbas, 150kW$_{el}$) [1]		Medium scale CHP – direct combustion and ORC (1MW$_{el}$) [5]		BC Biocarbon (1 Odt/hr plant) [7]		Bioplastics – ABC3D (10 tonne/day demo plant) [8]	
	Ranking	Rationale	Ranking	Rationale	Ranking	Rationale	Ranking	Rationale	Ranking	Rationale
								Since BC Biocarbon cannot meet electrical demand, would need to be paired with another CHP unit, further increasing capital costs.		
CHP Electricity generation cost per kWh *(ranking is from least expensive per unit to most, not factoring in heat savings or revenue sources)*	3	\$0.56/kWh$_{el}$	4	\$0.32/kWh$_{el}$	5	\$0.25/kWh$_{el}$ [6]	2	Unknown but without factoring in revenue generated, cost to produce electricity would be higher than the CHP options	1	This is a downstream process that does not produce heat or power
Expected revenue source *(ranking is from most likely to generate additional revenue to least likely)*	2	Some potential to sell excess process heat	2	Some potential to sell excess process heat	2	Some potential to sell excess process heat	4	Revenue from products expected	4	Revenue from products expected
Proven Technology *(ranking is based on Canadian/BC presence and weather technology is commercially proven)*	5	Proven in Europe Some BC and Canada examples: Kwadacha and NRCC Microgrid	3	Proven in Europe No known BC/Canada examples	4	Proven in Europe Existing installations of Turboden in Canada	2	Currently in demonstration and research and development phase	1	Currently in research and development phase
Local Expertise *(ranking is based on whether expert technical assistance will likely be available in BC/Canada)*	3	European technology with different standards NRC in Vancouver gaining experience and expertise in this size of unit [4]	1	European technology with different standards Presence of BC/Canada expertise unknown	2	European technology with different standards Presumably some Canadian expertise	5	BC Biocarbon, a BC based company, proposes to build and operate facility, so will provide expertise	4	ABC3D is a BC based company and will likely provide required expertise

Assessment Criteria	**Small scale CHP – gasification and internal combustion engine (e.g. ESPE ChiP50, 50kW$_{el}$) [1]**		**Small scale CHP – gasification and internal combustion engine (e.g., Urbas, 150kW$_{el}$) [1]**		**Medium scale CHP – direct combustion and ORC (1MW$_{el}$) [5]**		**BC Biocarbon (1 Odt/hr plant) [7]**		**Bioplastics – ABC3D (10 tonne/day demo plant) [8]**	
	Ranking	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**	**Ranking**	**Rationale**
Operational Complexity and Maintenance Requirement *(ranking is based on requirement of Kitselas to supply highly skilled personnel, i.e. steam engineer)*	2	No steam engineer required More maintenance/ shorter life span than direct combustion and ORC units 10-30 hr/week of maintenance	2	No steam engineer required More maintenance/shorter life span than direct combustion and ORC units 20-25 hr/week of maintenance	3	No steam engineer required Complex System Requires frequent maintenance and cleaning (mostly for boiler)	4	Complex and proprietary process Maintenance shutdown every 3 to 6 months BUT BC Biocarbon will operate and maintain	4	Complex and proprietary process Power engineer not required Maintenance requirement unknown BUT ABC3D will likely operate and maintain
Jobs created *(ranking based on number of jobs likely to be created)*	2	Construction jobs: amount unknown; 1 operator to produce woodchips, operate and maintain; Estimate 0.10 full time equivalent (FTE) for coordination and confirmation of woody material supply	2	Construction jobs: amount unknown; 1 operator to produce woodchips, operate and maintain Estimate 0.10 FTE for coordination and confirmation of woody material supply	3	Construction jobs: amount unknown; 2 FTE employees for operation and maintenance of the plant Estimate 0.10 FTE for coordination and confirmation of woody material supply	4	BC Biocarbon proposes a 50/50 ownership between BC Biocarbon and partner and that they will build and operate the plant – possibility for locals to work on construction and operation	5	~ 25 FTE jobs for lignin and polymer extraction (more for construction and manufacturing)

Sources and Notes:

[1] Unless otherwise specified, information sourced from: Small-Scale Biomass Combined Heat and Power (CHP) Part II – Technical and economic aspects of small-scale CHP systems under 165 kW$_{el}$ (Schilling et al. 2017b)

[2] Kitselas Forestry has an AAC of 43 445m^3/year; assuming 25% of AAC could be used as biomass fuel gives 10 860 m^3/yr *0.450 Odt/m^3 of freshly harvested ("green") logs =4 887 Odt. Plus, sub-merchantable material suitable for grinding = ~ 20% of AAC = ~8 689 m^3/yr *0.450 Odt/ green m^3 = 3 910 Odt, for a total of 8 797 Odt. (Note this was an initial calculation done and is slightly lower than the estimate provided in Section 4.4.2).

[3] From Table 1. in Small-Scale Biomass Combined Heat and Power (CHP) Part III – Design and economics of biomass supply chains for small-scale CHP systems under 165 kW (Schilling et al. 2017b)

[4] Summary of NRC Microgrid Facility Tour, October 9, 2019 (see Appendix F).

[5] Unless otherwise specified, information sourced from: Medium-Scale Biomass Combined Heat and Power (CHP) Part IV – Organic Rankin Cycle CHP Systems (Schilling et al. 2017d)

[6] Value is an average of the range ($0.10 to 0.40/kWh$_{el}$) provided in Medium-Scale Biomass Combined Heat and Power (CHP) Part IV – Organic Rankin Cycle CHP Systems (Schilling et al. 2017d). It is not known to what degree these values factor in savings from the use of heat energy.

[7] Unless otherwise specified, information sourced from: Summary Notes on Site Visit to BC Biocarbon Facility in McBride on July 18, 2019 (see appendix F).

[8] Unless otherwise specified, information sourced from: Summary Notes on Site Visit to Advance Biocarbon 3D in Trail, on October 8, 2019 (see appendix F).

[9] BC Biocarbon gave estimate of 7Gj produced by 1 Odt feedstock. Assuming this is thermal output from gas produced, 7GJ/ODT= 7GJ/hr in a 1 ODT/hr plant;7GJ/hr=278 kWh/hr =278kW thermal. Given a rough ratio of 4:1, thermal output to electrical, assume 70kW$_{el}$ could be produced.

Appendix C: Electrical Demand Methodology

This appendix described the methodology used to determine average, base and peak demand. BC Hydro bills were provided for four houses at Git'aws by the Kitselas Housing Manager, Mr. Ulyses Venegas. The energy consumption data from these 4 houses were compiled, and is provided here.

Terms:
Energy Consumption= the amount of energy used measured in kWh_{el}
Power = the energy being supplied/demanded in kW_{el}
Base load = is that demand that occurs on a nearly continuous round the clock, 365 days per year basis.
Peak load = the highest power demand that occurred during the year

Steps:

1. Input energy consumption data for four houses in Git'aws from BC Hydro Bills (Table 16).
2. Calculated Average Daily Consumption for each house for each month = monthly consumption/number of days in the month (Table 16).
3. Calculate Average Power demand for month = average daily consumption/24h (Table 16).
4. Calculate the aggregate average consumption and power demand for the four houses (Table 17)
5. Calculate Base Load power demand = the average of the four lowest months (Table 17)
6. Calculate Peak Load power demand using two methods:

   Method 1: Peak demand = highest average monthly power demand (Table 17)
   Due to averaging, this method smooths out the peaks, and likely underestimates peak demand.

   Method 2: Peak demand = max demand based on hourly demand profile.
   The average daily consumption was apportioned hourly based on an hourly demand profile (Armstrong et al. 2009). The maximum demand from all 4 houses for all of the service periods provided was taken as the Peak Demand/ house and then multiplied by 81 houses to get the total Peak Demand (kW_{el}). This acknowledges that power demand will spike at certain times of day and put a greater draw on the system. This number could be high, because it assumes that all houses would put the maximum demand on the system at the same time. Due to the complexity of the computations, a copy of this has not been provided here, but can be made availability on request.

Table 16. Energy Consumption Data from BC Hydro for Four Houses at Git'aws

House No.	Energy Source	Approx. Square Footage	Month	Days of Service	Energy Consumption during Service Period (kWh$_{el}$)	Average Daily Energy Consumption for Service Period (kWh$_{el}$)	Average Power across Service Period (kW$_{el}$)
House 1	Electrical Central Forced Air	2000	Aug-18	31	708	23	1.0
			Sep-18	30	899	30	1.2
			Oct-18	31	851	27	1.1
			Nov-18	30	1069	36	1.5
			Dec-18	31	1252	40	1.7
			Jan-19	31	1039	34	1.4
			Feb-19	28	1125	40	1.7
			Mar-19	31	919	30	1.2
			Apr-19	30	913	30	1.3
			May-19	31	753	24	1.0
			Jun-19	30	720	24	1.0
			Jul-19	31	556	18	0.7
House 2	Electrical Central Forced Air	2000	Aug-18	31	551	18	0.7
			Sep-18	30	932	31	1.3
			Oct-18	31	1859	60	2.5
			Nov-18	30	2287	76	3.2
			Dec-18	31	3107	100	4.2
			Jan-19	31	2872	93	3.9
			Feb-19	28	1290	46	1.9
			Mar-19	31	1876	61	2.5
			Apr-19	30	1729	58	2.4
			May-19	31	745	24	1.0
			Jun-19	30	708	24	1.0
			Jul-19	31	493	16	0.7
House 3	Electrical Central	900	Aug-18	31	627	20	0.8

House No.	Energy Source	Approx. Square Footage	Month	Days of Service	Energy Consumption during Service Period (kWh$_{el}$)	Average Daily Energy Consumption for Service Period (kWh$_{el}$)	Average Power across Service Period (kW$_{el}$)
	Forced Air + Woodstove		Sep-18	30	480	16	0.7
			Oct-18	31	990	32	1.3
			Nov-18	30	1240	41	1.7
			Dec-18	31	1753	57	2.4
			Jan-19	31	1783	58	2.4
			Feb-19	28	1916	68	2.9
			Mar-19	31	1525	49	2.0
			Apr-19	30	1113	37	1.5
			May-19	31	526	17	0.7
			Jun-19	30	441	15	0.6
			Jul-19	31	443	14	0.6
House 4	Electrical Central Forced Air	2000	Feb-19	28	3368	120	5.0
			Mar-19	31	2357	76	3.2
			Apr-19	30	1236	41	1.7
			May-19	31	900	29	1.2
			Jun-19	30	750	25	1.0
			Jul-19	31	750	24	1.0

Table 17. Average Annual Household Consumption, Base Demand and Peak Demand (Method 1)

Month	Days of Service	Average Power across Service Period (kW$_{el}$)	Average Daily Energy Consumption for Service Period (kWh$_{el}$)	Average Monthly Consumption for Service Period (kWh$_{el}$)
Aug-18	31	0.84	20	628
Sep-18	30	1.07	26	770
Oct-18	31	1.66	40	1233
Nov-18	30	2.13	51	1532
Dec-18	31	2.74	66	2037
Jan-19	31	2.55	61	1898
Feb-19	28	2.86	69	1925
Mar-19	31	2.24	54	1669
Apr-19	30	1.73	42	1248
May-19	31	0.98	24	731
Jun-19	30	0.91	22	655
Jul-19	31	0.75	18	560
			Average Annual Consumption	**14887**
Base load demand		***0.87***		
Peak load demand (method 1)		***2.86***		

Appendix D: Detailed Greenhouse Gas Calculations

This Appendix describes the methodology used to calculate greenhouse gases.

Overview of steps:

1) Emission factors (EF) researched and selected. See Table 18.
2) Size an example bioenergy facility selected to meet annual demand. A CHP system utilizing two 150 kW_{el} gasification and internal combustion engine systems (based on Urbas 150) running on wood chips at 90% operation was selected to meet the need for the annual electricity demand at Git'aws for existing and proposed housing (135 homes). See Table 19.
3) Determine annual firewood use at Git'aws. See Table 20.
4) Determine the reference fuel amount for each activity considered in GHG scenarios. This involved converting the fuel amounts for the CHP system, in open pile burning and for woodstove use to the moisture content identified for each emission factor. The fuel amounts were also adjusted using a burn efficiency percentage.
5) Determine the GHG emissions for each activity and compare the status quo emissions to the CHP emissions. Scenarios in which only part of the status quo emissions were displaced were explored. The Fuel Analysis Method, Equation 1 as described in the US EPA Greenhouse Gas Inventory Guidance Direct Emissions from Stationary Combustion Sources was used to calculate GHG emissions (2016). See Table 21.

Equation 1:

Emission = Fuel x Emission Factor (EF)

Where:

Emissions = mass of CO_2, CH_4, or N_2O emitted

Fuel = mass of fuel combusted

EF = CO_2, CH_4, or N_2O per unit mass

Table 18. Step 1: Select Emission Factors

Activity	EF from Source		Standardized Units		Notes
	EF	Unit	EF	Unit	
Open Pile Burning at 0% MC [1]					[1] Emission Factors are listed for dry wood which is assumed to mean 0% moisture content.
CO_2 [2]	1833	g/dry kg wood	1833.0	kg/tonne	[2] Emission Factors for CO_2 and CH_4 are from a study that provided factors for open pile burning of conifer biomass (Table 3 in Springsteen et al. 2011). Note: no EF provided in the Canadian National GHG Inventory, so this alternate source used.
CH_4 [2]	3	g/dry kg wood	3.0	kg/tonne	
N_2O [3]	0.00017	kg N_2O/kg CO_2	0.3	kg/tonne	[3] N_2O emissions from open pile burning were calculated to be 0.017% of emissions from CO_2 as per Annex 6, Table A6-56, page 243 of Part 2 of the National Inventory Report 1990–2017: Greenhouse Gas Sources and Sinks in Canada (ECCC 2019). *"N_2O emissions from wildfires and controlled burning are equal to 0.017% vol/vol of CO_2 emissions. Since both gases have the same molecular weight, the same ratio can be applied on a mass basis (see Section A3.5.2)."* Note Springsteen et al. 2011 does not provide an EF for N_2O.
Burn pile consumption efficiency rate [4]	0.95	kg burned/ kg unburned	0.95	kg burned/ kg unburned	[4] 95% was used as the burn pile efficiency rate in Springsteen et al. 2011.
Industrial Combustion of wood fuel/wood waste at 50% MC (i.e., CHP)					--
CO_2 [5]	840	g/kg	840	kg/tonne	[5] Emission factors are from Annex 6, Table A6-56, page 243 of Part 2 of the National Inventory Report 1990–2017: Greenhouse Gas Sources and Sinks in Canada (ECCC 2019). *"Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The CO_2/CH_4/N_2O emission factor (Table A6–56) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (one million British thermal units; U.S. EPA 2003). The U.S. EPA data were converted to kg/tonne at 50% moisture content (m.c.) using a higher heating value (HHV) of 10.47 MJ/kg at 50% m.c., which was developed from an internal review of available moisture content and heating value data."*
CH_4 [5]	0.09	g/kg	0.09	kg/tonne	
N_2O [5]	0.06	g/kg	0.06	kg/tonne	
Residential Combustion in Conventional Woodstove at 19% MC					--
CO_2 [6]	1539	g/kg	1539	kg/tonne	Emission factors are from Annex 6, Table A6-56, page 243 of Part 2 of the

Activity	EF from Source		Standardized Units		Notes
	EF	Unit	EF	Unit	
					National Inventory Report 1990–2017: Greenhouse Gas Sources and Sinks in Canada (ECCC 2019). *“CO_2 emission factor for residential combustion (Table A6–56) is based on the default 2006 IPCC guidelines. The IPCC data were converted to g/kg at 19% moisture content using a lower heating value (LHV) of 13.2 MJ/kg, which was calculated based on the assumption that LHV is 20% less than the HHV (FPL, 2004). The HHV was developed from an internal review of available moisture content and heating value data.”*
CH_4 [6]	12.9	g/kg	12.9	kg/tonne	*“Emissions of CH_4 from residential combustion of firewood are technology-dependent. The CH_4 emission factors are based on the default 2006 IPCC guidelines. The IPCC values were converted to g/ kg at 19% m.c. using the same method used for the CO_2 conversion.”*
N_2O [6]	0.12	g/kg	0.12	kg/tonne	*“Emissions of N_2O from residential combustion of firewood are technology-dependent. The N_2O emission factors are based on the default 2006 IPCC guidelines. The IPCC values were converted to g/ kg at 19% m.c. using the same method used for the CO_2 conversion.”*
Hydroelectricity [7]					[7] Averaged GHG Intensity from 2011 to 2015 (BC Hydro n.d. a)
Annual GHG Intensity	10	tonne CO_2e/kWh_{el}	0.01	kg CO_2e/kWh_{el}	
Global Warming Potential (GWP) [8]					[8] From the 2007 IPCC Fourth Assessment Report (AR4) as cited in US EPA 2016
CH_4	25	kg CO_2e/kg CH_4	25	kg CO_2e/kg CH_4	
N_2O	298	kg CO_2e/kg N_2O	298	kg CO_2e/kg N_2O	

Table 19. Step 2: Example CHP System Sized for Annual Electricity Use at Git’aws

	Amount	Unit	Notes
Annual Hydroelectricity Demand at Git’aws [1]			[1] Based on BC Hydro bill for four houses at Git’aws from August 2018 to July 2019.
Existing and proposed housing (135 homes)	2010	MWh_{el}	
CHP Specifications [2]			[2] Urbas 150kW_{el} gasification and internal combustion engine unit running on wood chips, at 90% utilization rate and using biomass at 18% MC were used for this example (from Table 2 of Schilling et al. 2017).
Annual electricity generation based on 90% utilization rate	2082	MWh_{el}	
Annual biomass consumption at 18% MC	1734	tonne	
Annual biomass consumption at 50% MC [3]	2204	tonne	[3] As per Table 14, the emission factors for industrial combustion are based on biomass with 50% MC; therefore, the annual biomass consumption was converted from 18% MC to 50% MC. Mass of wood at 50% MC = Mass of wood at 18% x (1.5/1.18)
Burn efficiency [4]	100	%	[4] It was assumed that the CHP system has 100% burn efficiency.

Table 20. Step 3: Current Annual Firewood Use at Git’aws

	Amount	Unit	Notes
Number of Houses Using Woodstove [1]	44	houses	[1] 44 houses at Git’aws have woodstoves (Venegas pers. comm.).
Annual Household Firewood Use			--
Cord [2]	7	cord/house/yr	[2] The average household at Git’aws uses approximately 7 cords/house/winter (Venegas pers. comm.).
Cubic Metres [3]	25	m^3/house/yr	[3] Cubic metres of firewood = cord of firewood x 3.624 m^3/cord
Odt [4]	11	odt/house/yr	[4] Based on an average wood density of 0.450 oven-dry tonnes per m^3 of freshly harvested logs. (Schilling et al. 2017c). Actual value will vary regionally and by moisture content.
Tonnes @ 19% MC [5]	14	tonne/house/yr	[5] As per Table 14, the emission factors for woodstove combustion are based on biomass with 19% MC; therefore, the annual biomass consumption was converted from 0% MC to 50% MC. Mass of wood at 19% MC = Mass of dry wood x (1.19)
Tonnes @ 95% burn efficiency [5]	13	tonne/house/yr	[5] Assumed the woodstoves have a 95% burn efficiency.
Total Firewood Used at Git'aws [6]			[6] Total firewood used at Git'aws = Annual household Firewood Use x 44 households
Cord	308	cord/yr	
Cubic Metres	1116	m^3/yr	
odt	502	odt/yr	
Tonnes @ 19% MC	598	tonne/yr	
Tonnes @ 95% burn efficiency	568	tonne/yr	

Table 21. Step 5: GHG Calculations

Activity/Emission	Reference Fuel Amount Burned at Specified MC (tonne/yr)	EF (kg/tonne)	Emissions (kg/yr)	GWP	Electrical Demand (kWh$_{el}$/yr)	Annual GHG Intensity (kg CO$_2$e/kWh$_{el}$)	CO$_2$ Equivalent (kg/yr)		
							Scenario 1: 100% feedstock from burn piles, no woodstove use	Scenario 2: 75% feedstock from burn piles, woodstove use cut in 1/2	Scenario 3: 50% feedstock from burn piles, woodstove use cut in 1/2
Bioenergy Facility Alternative (Wood Fuel/Wood Waste Industrial Combustion at 50% MC)									
CHP 150KW Gasification +ICE x2									
CO_2	2,204	840	1,851,559	1	--	--	1,851,559	1,851,559	1,851,559
CH_4	2,204	0	198	25	--	--	4,960	4,960	4,960
N_2O	2,204	0	132	298	--	--	39,412	39,412	39,412
Total							**1,895,931**	**1,895,931**	**1,895,931**
Status Quo									
Open Pile Burning at 0% MC									
CO_2	1,396	1,833	2,558,899	1	--	--	2,558,899	1,919,174	1,279,450
CH_4	1,396	3	4,188	25	--	--	104,701	78,526	52,351
N_2O	1,396	0	435	298	--	--	129,634	97,225	64,817
Total							**2,793,234**	**2,094,926**	**1,396,617**
Residential Combustion in Conventional Woodstove at 19% MC									
CO_2	568	1,539	874,033	1	--	--	874,033	437,016	437,016
CH_4	568	13	7,326	25	--	--	183,155	91,578	91,578
N_2O	568	0	68	298	--	--	20,309	10,154	10,154
Total							**1,077,497**	**538,748**	**538,748**
Hydroelectricity									
CO_2e	--	--	--	--	2,009,795	0	20,098	20,098	20,098
Total							**20,098**	**20,098**	20,098
						CHP Total	**1,895,931**	**1,895,931**	**1,895,931**
						Status Quo Total	**3,890,829**	**2,653,772**	**1,955,463**
						GHG Benefit = CHP - Status Quo	**-1,994,898**	**-757,841**	**-59,533**

Appendix E: Conversation Summaries with Subject Matter Experts

Unless otherwise indicated, the following are summaries of conversations between Brittany Dewar from Westland Resources Limited and various industry and academic contacts.

Travis Hickford-Kulak

Vice President, Contract Utilities and Energy Systems
Corix Utilities Inc.
Phone 604.455.3649 | Cell 604.786.2040 | Fax 604.455.3628
Travis.Kulak@corix.com

After calling Dockside Greens, I was directed to speak with Travis Hickford-Kulak the Vice President of Contract Utilities and Energy Systems at Corix Utilities Inc. Corix is the owner and operator of Dockside Greens District Energy Plant. I had a 30-minute conversation with Mr. Hickford-Kulak on March 4, 2019. The following are the key messages from our conversation:

- He also indicated that BC Hydro poses an impediment to CHP systems in BC because they no longer buy back residual power. They used to and there are two power only legacy projects in Merit and Fort St. John that use biomass and sell back to the grid. Because of this CHP really only works on a community micro grid.
- Dockside greens:
    - Corix has obtained full ownership as of September 2018 (used to be limited partnership between Corix, Vancity and Fortis).
    - The developer of Dockside Greens decided to build the biomass facility for full capacity of development and Installed a Nexterra Gasification Combustor.
    - Corix was only able to run the Nexterra Gasifier for 6 months because of technical issues, and issues with the feedstock (tried various feedstock and could not get it to run properly). They have decided to permanently decommission the biomass system and rebuild the natural gas system to adequately supply the community.
    - Nexterra has had a lack of success: Dockside Green gasifier not working, UBC demonstration facility also Nexterra, also not working.
- Corix is building another District Energy system at Simon Fraser (and for surrounding community), initially will only be District Energy direct combustion system (thermal oil based) producing 13 MW_{th}, but could be coupled with an ORC for electricity ($2MW_{el}$) if BC Hydro changes their policy
- Corix has looked into by-product use and marketing but in the past by-products required a lot of testing before they could be sold. They are looking at marketing by-products with the Simon Fraser system because they are considering this a living lab.
- District heating is on the rise in BC: most Municipalities are looking into district heating. Corix has helped install a number of system and they are all seeing cost savings according to Travis.
- Advice for a community looking into CHP was to be practical and set firm objectives. He noted that for every successful system there are 5 or 6 that do not have a sustainable or achievable business case.

- Recommended contacting UNBC: they have a working Nexterra biomass plant.
- A bioenergy facility in Revelstoke was given as another example
- Recommended Fink Technologies out of Enderby BC. They produce very practical boilers for small scale.
- Corix designs district heating and CHP systems they can partner with communities to design systems and can carry out feasibility studies.

Dr. Dominik Roeser

https://profiles.forestry.ubc.ca/person/dominik-roeser/
Associate Professor Forest & Wildfire Operations | Dept of Forest Resources Management
Director Forest Operations Program
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I was directed to talk to Dr. Roeser by the UBC Centre for Advanced Wood Processing. Dr. Roeser is an associate professor at UBC and a Senior Associates with FPInnovations. I had a 30-minute conversation with Dr. Roeser on February 28, 2019. The following are the key messages from our conversation:

- His background is in supply chain management. He worked in Europe for a number of years in supply chain for District Heat systems and then moved to Canada in the 2000's and has worked on small scale District Heat and CHP systems, often with communities using them for municipal buildings.
- Noted that there are a lot of heat only installations across BC compared to heat and electric.
- Listed Kwadacha as an example of medium scale facility in BC and noted that they had issues with BC Hydro.
- UBC and NRC are building a CHP demonstration site (on the NRC location at UBC Vancouver) showing the full supply chain. It will be a Finnish Volter System – Dr Roeser noted that this type of system could be modularized and scaled up. Should be installed late March/early April. The vision is to provide remote communities with an example of supply chain and possibly some training.
- Challenges for biomass facilities in BC:
  - Biggest challenge has been with BC Hydro because it is easier for BC Hydro to keep remote communities on diesel and BC Hydro has a lack of experience with CHP.
  - Dr. Roeser noted that it is easier for communities that are not reliant on BC Hydro.
  - Issues with expertise in installation and technology providers in BC: European companies are interested in the market, but don't necessarily understand the market issues here.
- The work done by FPInnovations has been focused on small scale (less than $1MW_{el}$) rather than medium/large scale CHP systems.
- For emerging technologies, he noted that ORC is becoming prominent at smaller scales.
- We discussed by-product possibilities:

  - He said to be very cautious about this, and that trying to produce by-products does not usually make sense for communities.
  - Often the technology needed to produce by-products (biochar, pyrolysis oil) requires more maintenance and technical expertise and there is a lack of qualified labour in BC.
  - He noted that he has been hearing about biochar opportunities for the last 18 years, but feels that we are no further ahead.
- His biggest recommendation for more remote communities is to go with a proven technology that requires less maintenance so that when there is an issue, there are people with the technical expertise to work on the system.
- He also recommended I talk to Christoph Schilling at FPInnovations.

Christoph Schilling and Dr. Marian Marinescu

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Researchers
FP Innovations

Phone Conversation, March 6, 2019

I was directed to Christoph Schilling by both Professor Sokhansan and Dr. Roeser and reception at FPInnovations passed my request on to Dr. Marian Marinescu. Mr. Schilling and Dr. Marinescu are both working on CHP at FPInnovations. Rick Brouwer and I had a call with them on March 6, 2019. The following are the key messages from our conversation:

- They indicated that the organic Rankine cycle (ORC) systems is the most appropriate technology for a community looking to generate between 1 and 3 MW electricity, and the main advantage of ORC is that it does not require a field operator like a steam system would. ORC’s, while slightly more efficient than steam turbines, still have low electrical efficiency.
- District heating is very expensive (they indicated that costs can are typically between $500 – $1000 per metre of piping or more).
- After explaining that the Kitselas Community is on the BC Hydro grid and connected to natural gas, Mr. Schilling and Dr. Marinescu indicated that CHP is less economically advantageous than for off-grid communities and that, unless the heat from CHP can generate revenue (as process heat) there is little chance that energy rates can compete with BC Hydro rates. Potential uses for heat that may create revenue:
  - Drying sawdust for pellets and charging the pellet manufacture for the heat (they indicated that there is a First Nations community north of Prince George that is/will be doing this). Rick indicated that it may be worth contacting Skeena Sawmills to see if they would have any interest buying pre-dried chips for their pellet pant.
  - Kiln drying.
- Recommended talking to WGL Engineering (Grant Lindsay) who has experience with ORC and pellet drying.

- Brittany asked if gasifiers and ICE technology that could be scaled up might be an option. Mr. Schilling and Dr. Marinescu indicated that the electrical efficiencies on these systems are better than ORC, but they also require better quality feedstocks. They said it would be worth looking into.
- Mr. Schilling and Dr. Marinescu directed us to look at the CHP Info Notes they have produced for FPInnovations. The Info Notes provide cost estimate information that will give a rough idea of the costing for the CHP systems.
- We discussed other complementary revenue streams for CHP. They said they cannot recommend biochar production because the market and technology are too difficult at this time.
- They indicated that BC Hydro is a major hurdle and that they feel that there is very little chance of getting a power purchase agreement with BC Hydro. Listed Kwadacha as an example of how BC Hydro can be an impediment to CHP.
- FPInnovations has an Indigenous Forestry Program that gives access to expertise and funding for First Nations Communities and FPInnovations can partner on CHP projects and conduct feasibility studies.

Meeting at FPInnovations, 2665 East Mall, Vancouver, October 9, 2019

In Attendance: Christoph Schilling; Dr. Marian Marinescu; Floyd Wickie, PNCDS; Rick Brouwer, Westland Resources; Brittany Dewar, Westland Resources

Floyd, Rick and Brittany met with Marian and Christoph at the FP Innovations office in Vancouver. The purpose of the meeting was to give an update to on the Kitselas CHP project and discuss CHP in BC.

Key Discussion Points:

- Discussed option to install district heating in new development at Gituas – Christoph/Marian indicated that this is much more feasible than retrofitting an existing community
- Marian asked about the fibre supply for Gituas – Rick indicated that there is an agreement in place with Kitselas' forestry company and alternative options in the region
- Some lessons learned from CHP units in BC – mainly that European systems may require European parts (bolts/oil)
- Most small-scale CHP in Europe/Asia exist on subsidies
- In BC, for communities where Indigenous and Northern Affairs Canada is paying the electrical/heating costs for off grid communities, there is more incentive to switch to another system
- The Volter system at NRC will use 50% of heat output in the drying shed and 50% will be used to heat a new building
- For small-scale CHP with specific feedstock requirements, finding a chipper appropriate for the specific system is important

Outcomes:

- Christoph to send information on the FPInnovations First Nations Program
- Christoph to share costing/report on Kluskus system (if permission granted by community)

Michael Schmitt

Airburners
North America
Sales Manager
Cell 772-631-8140

I (Brittany Dewar) had a call with Michael Schmitt on February 19, 2020. I was calling for more information on the PGFireBox (an air curtain burner pared with ORC unit). Michael clarified that the PGFireBox is not intended to be an efficient biomass plant, it is designed to burn a lot of wood quickly and adding the ORC unit allows some of the thermal energy to be converted to electricity – efficiencies are very low.

Key points of conversion:

- PGFireBox has been on the market for a few years and 2 machines have been sold in Southern California (for landfill credits)
- Firebox is designed to burn wood waste quickly and reduce particle emissions, they are not designed to efficiently convert to usable electrical or thermal energy
- Firebox (without ORC unit) is widely used in the US by/for:
    - Municipalities to replace grinding and hauling of wood waste to landfills (30 % of sales)
    - Land clearing
    - Companies getting rid of pallet or other wood waste
    - Farms, vineyards
    - Nation Parks/State Parks in California to deal with wood waste removed for fire management
    - US Forest Service has partnered with Air Burners to burn post-harvest wood waste and produce biochar to leave on harvested areas
- Michael indicated that there is interest in BC to use FireBoxes to burn waste produced close to towns (he said this was a new regulation in last few months)
- FireBurner costs $5-$9/hr to run including maintenance and diesel costs

Professor Shahab Sokhansan

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The Biomass and Bioenergy Research Group through UBC conducts a wide range of biomass research including some CHP research. I was directed to contact Professor Sokhansan, the Director of this Group. I had a 30-minute conversation with Professor Sokhansan on February 26, 2019. The following are the key messages from our conversation:

- He indicated that he is not an expert on CHP. His research focuses on pelletization, storage and shipping of material.
- Indicated that there may be alternative option for use of woody residues in a small-scale pellet operation. Pellets could be marketed to larger vendors (e.g. Pacific Bio, Vanderhoof Pellets) that are having issues getting access to good quality wood to make into pellets. There are some small pelletization options, but not many in BC yet. He has heard of some options from China.
- His lab is looking at options for a mobile unit so they can travel to communities.
- Things to consider with pelletization: Moisture content of 15-16% usually makes them ok for storage and use. Issues with dust from grinding wood chips. Need to be careful using low quality wood with too much sand or gravel (can damage systems).
- Recommended I talk to Christoph Shilling at FP Innovations, for information on CHP in BC.
- Recommended looking at CHP system at a College in Thunder Bay (I believe he was referring to Confederation College).

Appendix F: Detailed Biomass Facility Site Visit Summaries and Profiles

May be provided upon request