SYNERGIZING COMMUNAL SERVICES

A Feasibility Report prepared for Cortes Community Housing Society.
Assessing integrated infrastructure services options for Rainbow Ridge, Cortes Island's new net-zero affordable housing development in Strathcona Regional District, BC.

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1.0 ABSTRACT

This feasibility study provides an assessment of a novel approach to providing site services in rural areas. Typically, individual lots require separate electricity, water, wastewater treatment, and heating and cooling systems. To address sustainability, health, affordability, resilience, and environmental (SHARE) goals, an integrated utility approach is proposed.

The Cortes Island Housing Society, a nonprofit organization serving community housing needs, requested the services of Rivercourt Engineering to develop shared infrastructure services that would serve their objectives. Several synergies between utility services were identified and developed into systems of overlapping functions that improved SHARE outcomes.

These interconnected subsystems consist of:

1. community thermal services provided by central heat pumps connected to treated wastewater and delivered via potable hot and cold water distribution;

2. a community greenhouse that provides treated wastewater dispersal, geostorage heat exchange, photovoltaic glazing, and horticultural production; and

3. a utility-connected micro-grid and community electric vehicle that utilizes site solar power, batteries, load shifting, and biofuel cogeneration, to reduce electricity costs and provide continuous power during outages.

The capital and operating costs are compared with a business-as-usual approach to site servicing and the report demonstrates the potential for improved outcomes applicable to many locations across Canada.

2.0 PROJECT BACKGROUND

2.1 The Rainbow Ridge Project

Cortes Island is two ferry trips east of Campbell River, Vancouver Island, with over 1,000 permanent residents. Property and housing costs have risen as vacationers and seasonal dwellers have been attracted to the island's pristine wilderness. In response to the need for affordable housing, the Cortes Island Housing Society was founded and a tract of land, named Rainbow Ridge, adjacent to the village of Mansons Landing was granted for the construction of various forms of housing. The first built project provided housing for seniors and this study's proposed project is for family housing. The plan is to build a cluster of 24 units as duplexes and triplexes. The possibility of reducing the cost of servicing the houses while improving performance and amenities brought Rivercourt Engineering to be engaged in developing an innovative, integrated utilities approach. The Federation of Canadian

Municipalities' Affordable and Sustainable Housing Pilot Projects approved this feasibility study to assess the merits of the proposed strategy.

2.2 Applicability

Infrastructure in rural and remote areas typically consists of utility electrical connections to each property, individual wells, and individual septic tanks discharging to dispersal systems. Lots are sized large enough to enable adequate separation of wells and wastewater discharge. Electrical service interruptions are more frequent than in more built-up areas near power transmission access and customers often purchase back-up generators. An integrated utility system involves the synergistic planning of water, waste, and energy infrastructure.

As rural population grows around villages, centralized water supply and sewers may be extended, but due to the low density caused by lot sizes previously on septic systems, the conveyance of water and wastewater can cost more than the treatment facilities. Where housing is clustered, small scale communal utilities may be a more economical solution. Medium density clustered development can also benefit from shared energy infrastructure, justifying technology unattainable with low density individual lots.

Integrated utility systems are beneficial to developments of sufficient scale and density such as trailer parks, First Nations communities, rural resource and manufacturing complexes and housing, and remote resorts. Even within larger municipalities, there are often settlement areas that are difficult to connect due to geological conditions. In addition, the distributed infrastructure compliments centralized infrastructure by introducing some degree of autonomous operation and demand management.

The Rainbow Ridge affordable housing project, with 24 housing units planned in a cluster, exemplifies the moderate density and scale that makes central servicing advantageous over large rural lots with individual residences and provides a template for strategies applicable to a broad spectrum of development conditions.

3.0 PERFORMANCE OBJECTIVES

The project team has adopted the SHARE objectives to assess alternative solutions and the proposed strategy. SHARE is an acronym for sustainable, healthy, affordable, resilient, and ecological. Here are some questions for assessing design elements.

3.1 Sustainable

Will the freshwater resource be maintained in quality and quantity?

Will the system components be long-lived, easily maintained, and repairable?

Will materials and soil nutrients be continuously recyclable?

Will the community's shelter and food needs be provided over the long term?

3.2 Healthy

Will the indoor environment quality support wellbeing?

Will disabilities and impairments be accommodated?

Will facilities support healthy activities and community building?

3.3 Affordable

Will the target income level renters be able to afford the housing provided?

Will inflation of operating and maintenance costs be mitigated?

Are there ways for inhabitants to reduce household costs?

Will the project be able to raise sufficient funds?

3.4 Resilient

Will the community be capable of responding to natural disasters?

During protracted power outages, will occupancy be disrupted?

Will the construction resist damage from fire, wind, deluge, and earthquakes?

3.5 Ecological

Will the development support local wildlife and forest health?

Will the construction utilize local material resources without damaging the sources?

Will aquifer, soil, and nutrient recycling benefit from the development?

4.0 BASELINE INFRASTRUCTURE

To assess the value of the proposed integrated infrastructure, it is necessary to define a more standard manner of servicing. Assumptions of baseline services and loads are described as follows:

1. There are 24 housing units with a total area of 1,700 m^2 being served which are semi-detached with building envelopes that achieve Passive House maximum space heat loss of 10 W/m^2. There is one additional building which includes offices, utility/equipment/storage room, laundry, bathrooms and a guest/visitor bedroom.
2. Total number of occupants is 75, and for a water efficient household each person uses 70 L/d at 10°C and 30 L/d of domestic hot water (DHW) at 50°C for a total of 100 L/d/p. For equipment sizing, however, a higher volume of DHW of 75 L/d/p will be assumed.
3. The average electrical load for lighting and appliances per dwelling is 15 kWh/d.
4. DHW heating is by a heat pump water heater (using indoor air as the heat source) for each unit capable of reaching 65°C at an average coefficient of performance (COP) of 2.5 (meaning 1 unit of electricity used by the heat pump system delivers 2.5 units of DHW heating).
5. The space heating and cooling is a split-system air heat pump for each unit with an average COP heating 3 (a split system has the outdoor air exchange unit on the exterior and the indoor air handling unit on the interior, connected by refrigerant lines).
6. The electrical service consists of 100 A, 220 V overhead connections to each unit.
7. The wastewater treatment system consists of shared septic tanks, Orenco Advantex® filters with multiple dispersal areas.
8. Potable water supply is pumped from a shared well with a UV sterilization treatment facility.

5.0 PROPOSED INFRASTRUCTURE INTEGRATIONS

By examining potential synergies between services, this study sets out opportunities to improve SHARE objectives and reduce the cost of housing. These may result in lowering overall capital costs, improving material and energy use efficiency, providing greater resiliency, facilitating maintenance, and supporting more sustainable operations.

The building services considered are electricity, space heating and cooling, DHW, wastewater treatment, potable water supply, and organic waste management. In addition, shared facilities, including food production, community gathering, laundry, electric vehicle sharing and charging are considered.

In cities, these utilities and services are typically provided by central municipal departments while rural and remote settlements are typically reliant on lot-level installations. In multi-unit residential buildings, connections to water and energy infrastructure are often at the building level and thermal energy distribution is typical. The proposed approach for a housing cluster seeks to demonstrate the advantages of shared amenities and utilities configured to take advantage of coordination of site servicing.

The following subsystem descriptions provide insight into the synergies. Where specific technology providers are identified, they were contacted to assess availability, costs, and suitability and are not necessarily the only or preferred suppliers.

5.1 Central Facilities Buildings

To coordinate material and energy flows and provide social and horticulture support, a greenhouse with community amenities is proposed. The enabled synergies include:

- agrivoltaics combine photovoltaic (PV) power and agriculture, enhancing plant growth;
- treated wastewater provides subsurface irrigation with nutrient take-up, potentially replacing outdoor effluent dispersal beds;
- irrigation drains through a capillary tube mat below, maintaining moderate soil temperatures;
- capillary tube mats (geoexchange tubing) provide thermal exchange with the earth and with the effluent for heat pumps;
- excess greenhouse heat is stored in the ground via the geoexchange tubing;
- central heat pumps produce hot and cold water which are circulated to loads;

- microgrid PV equipment, battery, biofuel cogenerator, and energy control centre are housed together;
- electric vehicle smart charging is integrated with microgrid operation;
- community amenities such as shared laundry, childcare, meeting space, food processing, etc. (extra loads and floor area are not considered in this report).

5.2 Shared Utilities Trenching

Instead of connecting electricity with overhead lines, potable water piping from separate wells, and wastewater sewers to distributed treatment tanks and their dispersal systems, trenching between central facilities that carries these services as well as thermal energy piping together reduces cost of buried infrastructure and facilitates access for maintenance. By combining the trenching with pathways, their location is identified and unintended damages from digging, planting, or post drilling is avoided. Synergies include:

- coordinated excavating, insulating, and covering of services;
- single water source, wastewater treatment, and utility connection;
- potable hot and cold water supply used for space heating and cooling; and
- shared microgrid connections replacing individual power line connections.

5.4 Combined Thermal and Domestic Water System

Using DHW to supply space heating directly or indirectly connected to hydronic (water-based heat transfer) systems has been applied widely. Domestic cold water (DCW) has sometimes been used for cooling purposes but has generally entailed discharging potable water to drains. In cities, potable water is typically distributed in loops so that if a pipe requires repairs, the section of pipe can be isolated without disrupting supplies to the area. Another analogous practice, applied to multi-unit buildings, is to have a central boiler heat a tank and to pump hot water with a return line so that each unit has hot water available, without long delays.

The proposed combined services provide hot and cold water on demand which can be circulated through space heating and cooling devices and returned to the community recirculating loop. The loop return water temperature may be raised or lowered by the central heat pumps via their hot and cold storage tanks.

With low space heating and cooling peak demands, the temperature of air supplied via a heat recovery ventilator can be sufficiently raised or lowered through a finned-tube heat exchanger.

The synergistic advantages include:

- avoidance of redundant hydronic circuits, potable water circuit, and individual unit DHW tanks and heat exchangers;
- recirculation of potable water enabling continuous UV sterilization; and
- avoidance of individual household space heating and cooling systems.

5.4 Microgrid

An assembly of local renewable generation, electricity and thermal energy storage, capable of enabling autonomous energy supply, called islanding, provides load modulation or export dispatch capability of benefit to grid operation. For remote and rural communities, the dependency on grid availability is more tenuous and often results in individual customers opting for back-up generators. The alternative of off-grid operation is sometimes adopted, resulting in high capital costs. Optimally, grid connection of site energy supplies provides benefits to the utility, which may provide financial incentives.

The synergies in the proposed system include:

- the co-location of PV (photovoltaics), batteries, vehicle charging, and grid connection reducing AC/DC (alternating current/direct current) conversions and cables;
- cogeneration supplying heat to the hydronic system and greenhouse operations;
- shared electrical vehicle providing auxiliary battery storage; and
- thermal storage, with the diversity of electricity assets enabling load shifting to off-peak rates, demand response services for the utility, and continuous operation during power outages.

5.5 Alternative Heat Pump System

Open loop heat pumps use well water as source and sink and require injection wells to return the water. It is feasible to use the potable water supply pump to connect to a reversible water-to-water heat pump. This would entail drilling a well or wells capable of returning the water at the rate required. Injection wells must be tested as the rates are typically lower than for supply wells.

The supply water temperature is colder than with wastewater heat pumps (WWHP) and would likely require 2-stage heat pumps to supply domestic hot water at the required temperature. For heating, the COP is approximately 2.5, so is less efficient and requires a higher capacity than a WWHP. However, the greenhouse-based WWHP system would not be required.

Although not a new concept, the open-loop heat pump provides a worthwhile alternative to compare capital and operating costs. The innovative combined thermal and potable water distribution system and the microgrid attributes could also be retained, albeit without the greenhouse PV glazing component. The treated wastewater would be discharged by conventional dispersal systems.

6.0 CENTRAL FACILITIES

6.1 The Greenhouse

The central building design may use a commercial provider, such as Ceres Greenhouses, to supply a 300 m^2 growing area and 50 m^2 area for mechanical, water, electrical, and community services. Its geometry and orientation should optimize direct solar exposure.

Their technology employs the Ceres EcoLoop™ [1] concept that uses subsurface capillary tube mats for heat transfer with the ground and heat pumps to regulate greenhouse temperature and humidity by exchanging heat with the ground loop. Ceres has expressed interest in the expansion of the application to include effluent as described in this proposal and are developing thermal modelling software that could be applied for further verification of technical feasibility.

Figure 1 Ceres EcoLoopTM greenhouse with heat exhange layer in soil under greenhouse floor [1]

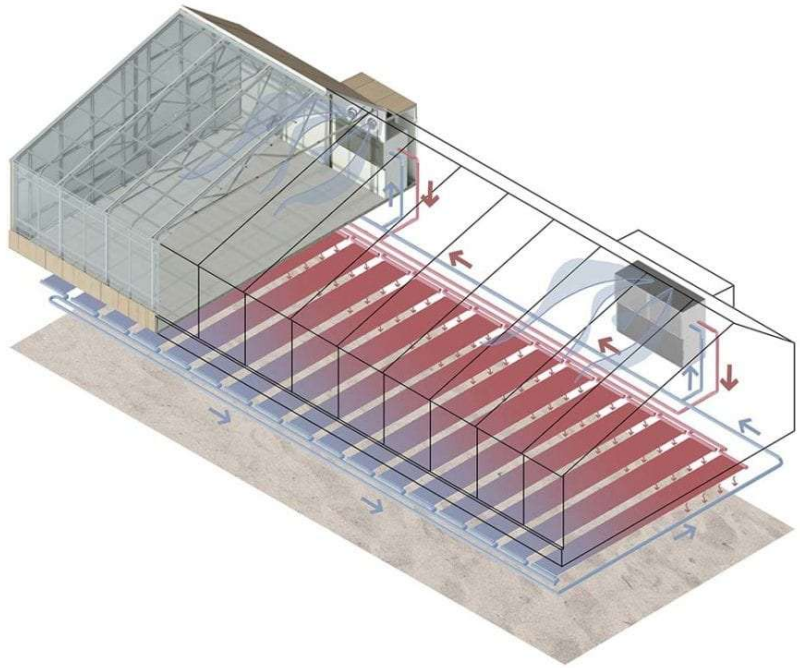


Figure 2 Ceres EcoLoopTM greenhouse (end view) [1]

In the Ceres/EcoLoop™ greenhouse example, the soil below the greenhouse is used like a standard horizontal ground source heat pump system to move heat to and from the earth and uses the earth as a long-term thermal battery by storing excess solar gain. Depending on conditions in the greenhouse, the heat pump system heats, cools and dehumidifies.

The proposed wastewater geostorage heat pump option for Rainbow Ridge introduces highly treated wastewater effluent into the soil above the heat pump exchange tubing, both layers embedded in the soil below the floor of the greenhouse. Water has over twice the heat capacity (energy stored per kg per °C) as soil and treated effluent may be 10°C warmer than soil, which greatly increases the energy available to the heat pumps. The extra daily energy addition from effluent is sufficient to meet the DHW heating demand of the housing units (adding electricity used in the heat pump). By connecting this greenhouse system to the housing units, units can be heated from excess solar gain in the greenhouse and heat from the water/soil. Housing units can be cooled by adding heat to the water/soil under the greenhouse.

6.2 Wastewater Geostorage Heat Pump

The energy transfer to wastewater concept demonstrates a method of heat exchange that does not foul and does not require specialized equipment beyond what is currently used in on-site sewage treatment and horizontal ground source heat pump systems.

Using highly treated effluent results in a slight loss of temperature compared to exchanging with raw sewage due to heat loss to the soil from the wastewater tanks and conveyance, but largely avoids the buildup of bacterial growth (biofilm) that fouls a raw wastewater heat

exchanger. Fouling lowers efficiency as the biofilm thickness increases due to its insulative effect. Heat pump systems that exchange heat with raw sewage require methods to minimize fouling of heat exchangers, such as by using active cleaning methods to remove fouling. Coarse solids in raw wastewater are typically screened out to reduce fouling, but the dissolved organics left will stimulate biofilm growth on the metal surfaces of the heat exchanger on the wastewater side. Mechanical scrapers may be employed to remove accumulated biofilm. This makes them an expensive and high maintenance option, although they are more energy efficient than air-source heat pumps.

In the default communal wastewater treatment system, solids and organics are already removed from the wastewater through the septic tanks and treatment filters. By exchanging heat with the treated effluent in the soil matrix using conventional ground source heat pump antifreeze tubing, fouling is essentially eliminated and none of the specialized equipment and maintenance related to exchanging heat with raw sewage is required.

To reduce heat loss to the environment, the wastewater conveyance and treatment tanks should be insulated. Warmer water temperature will also accelerate biological treatment. Shallow dispersal of effluent into soil requires that the effluent remain warm enough to percolate downwards to below the frost line in winter. At the standard design loading rates, there is more heat introduced by the effluent than heat loss upwards to the surface in winter, allowing water to flow freely downwards. The removal of heat by a heat pump must be limited to maintain the flow of liquid water into the soil and so the effluent temperature must remain significantly above freezing, e.g. min. 5°C, following heat exchange. In the ocean tempered mild climate of Cortes Island, however, the risk of freezing even cooled water is low.

This proposed innovation is to disperse the effluent into the earth beneath a community greenhouse, eliminating the heat loss in winter of a conventional bed and adding heat in times of excess solar gain. The effluent is introduced into the soil using practiced methods for shallow dispersal in sewage systems, using wastewater specific drip lines or dispersing via orifices protected by air cavities (with caps or chambers or larger perforated pipe, possibly combined with gravel) to eliminate root intrusion. Excess water not taken up by the plant roots drains through the soil surrounding the geoexchange mat which augments the heat extractable by the heat pump, improving the heating COP. Nutrients such as nitrogen and phosphorus are removed by plants with the dual benefit of displacing fertilization while reducing impacts on the aquifer.

Dispersal under a greenhouse has the potential to partially or completely replace a conventional dispersal bed, offsetting cost and freeing up land. The design of sewage dispersal beds, however, involves site-specific considerations taking into account the

percolation rate of the native soil, ground slope, separation to high groundwater or to another limiting layer such as bedrock or very tight soil, and keeping stormwater or other water sources away from the unsaturated treatment layer. Furthermore, the beds may need to be positioned on the property to maximize dilution from the infiltration of precipitation to minimize the impact from nitrate to groundwater. The siting of a greenhouse for solar orientation and access may not correspond to the optimal location for a sewage dispersal bed.

The subject property is favourable for this application as it offers unsaturated coarse sandy native soil with good vertical clearance to high groundwater. At the other extreme, sites with fine-grained native soil of low permeability with high groundwater could still employ the WWHP and irrigation approach but the system may need to be contained within a liner to exclude high groundwater being added to the subsequent dispersal bed step. A site with challenging conditions using a liner would have no reduction in the theoretical sizing of the dispersal bed area if no net evapotranspiration is conservatively assumed.

Beneficial use of treated wastewater effluent is regulated as to permissible uses, each use having a corresponding level of effluent quality and coliform bacteria [2]. The proposed design promotes the concept of using the water and nutrients in treated wastewater, but what plants might be irrigated with what water quality is left to the B.C. qualified professional and regulator. Long-term testing of effluent from Advantex® systems [3] generally shows less than 10 mg/L (or parts per million) CBOD5 (carbonaceous biochemical oxygen demand) and TSS (total suspended solids), which is competitive with any non-membrane on-site treatment technology. In terms of nutrients, tests show TN (total nitrogen) in the range of 12-18 mg/L and TP (total phosphorus) in the range of 8-10 mg/L. Fecal coliforms in the effluent are in the range of 100-1,000 cfu/100 mL (colony forming units per 100 mL sample), but <2 MPN/100 mL (most probable number of colony forming units per 100 mL sample) for one test site that used UV. The B.C. Reclaimed Water Guideline [2] in the strictest “Greater Exposure Potential” (i.e. possibility of exposure to the public) requires no more than 1 cfu/100 mL or 2 MPN/100 mL *E. coli*.

A UV sterilization system (e.g. two physical prefilters and UV sterilization unit) can be used to achieve the bacteria targets for reclaimed water. Nevertheless, current practice would likely restrict irrigation with effluent to subsurface contact with the roots of ornamental plants or food crops that bear above ground. There is no aerosolization due to the low velocity subsurface dosing of effluent, so plants grown above the floor are not in contact with effluent. Food plants could be grown on tables or raised beds and irrigated with conventional water sources. Ultimately, with proper safeguards and further vetting by a qualified professional and regulator, effluent of an appropriate quality could directly irrigate

some types of edible plants and dispersal to the soil under the greenhouse could be an accepted on-site sewage approach, partially or fully replacing conventional beds.

The following images show examples of planting non-edible moisture tolerant plant species over a vertical flow treatment wetland where dosing is approximately 0.2 m below the surface (the Aqua Wetland System, developed by Aqua Treatment Technologies [4] of Ontario). The Aqua Wetland System protects the pressurized dosing pipe (typically 1" diameter) inside of a 3" perforated tube to discourage root intrusion.

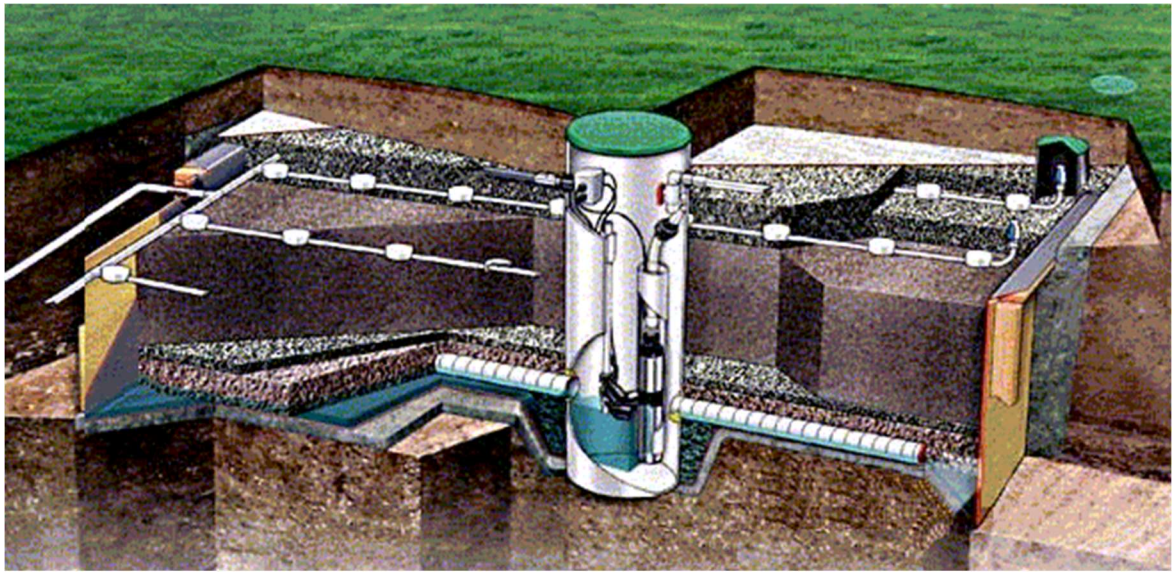
Figure 3 Aqua Wetland System at Amo Winery Niagara ON [5]

Figure 4 Aqua Wetland System 16 Mile Cellars, Niagara ON [5]

Figure 5 Aqua Wetland System Redstone Winery, Niagara ON [5]

The dosing concept is also similar to the former Orenco sand or gravel filter (see image below), which Orenco promoted before they developed the more compact Advantex® textile trickle filter. The white caps are positioned over orifices in the dosing laterals, which, along with voids in the gravel, protect the orifices from root intrusion. A long sweep elbow with removable cap inside of a valve box allow flushing of the laterals.

Figure 6 Orenco sand filter [6]



The proposed greenhouse wastewater option uses a shallow dosing system similar in placement to the Aqua Wetland System or Orenco sand filter, but could use a range of dispersal approaches: pressurized dosing pipe with orifices inside a larger perforated pipe sleeve; dosing pipe with orifice caps; or narrow diameter drip irrigation tubing. Soil is excavated to place the geoexchange mat layer within the native coarse soil [7], then a layer of native coarse soil is placed up to the effluent dosing layer where the effluent dosing tubing or piping is placed. Coarse native material and topsoil as desired are used to cover the effluent dosing layer up to the greenhouse floor.

The geoexchange mat or array of tubing comes into contact with the effluent as it percolates down through the coarse soil. The geoexchange tubing will at times pull heat from the water (when heating a load) and at other times add heat to the water (when cooling a load).

Figure 7 Overhead view of dosing array inside greenhouse [5]

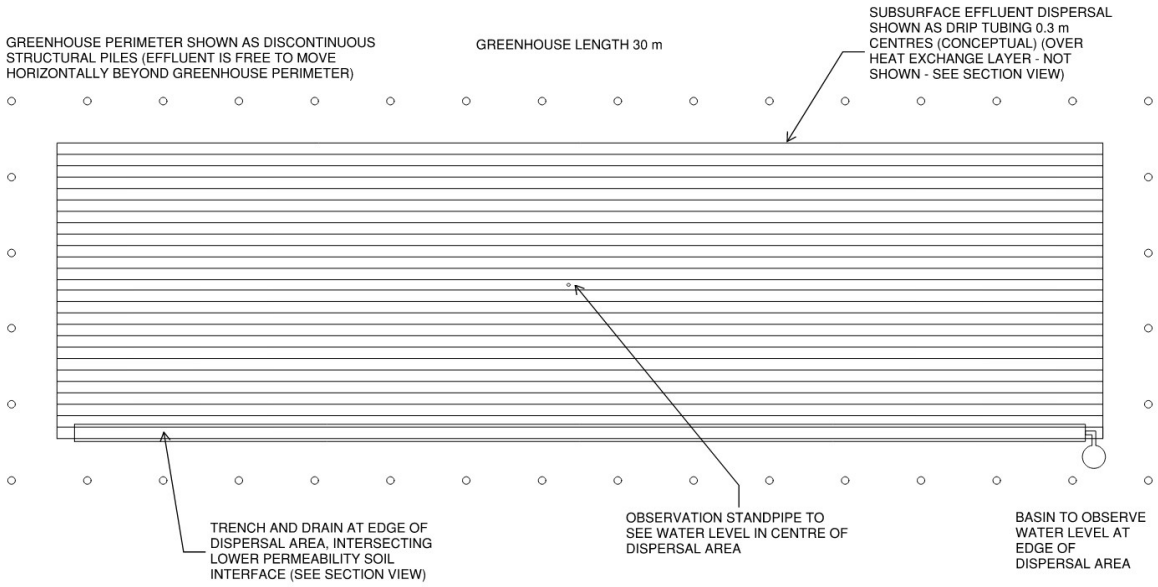


Figure 8 Side view of greenhouse dispersal and heat pump exchange layers [5]

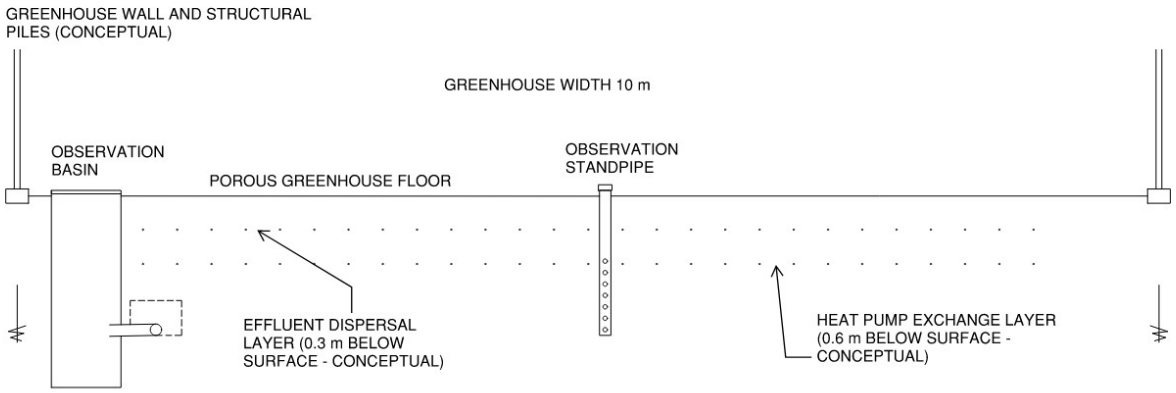
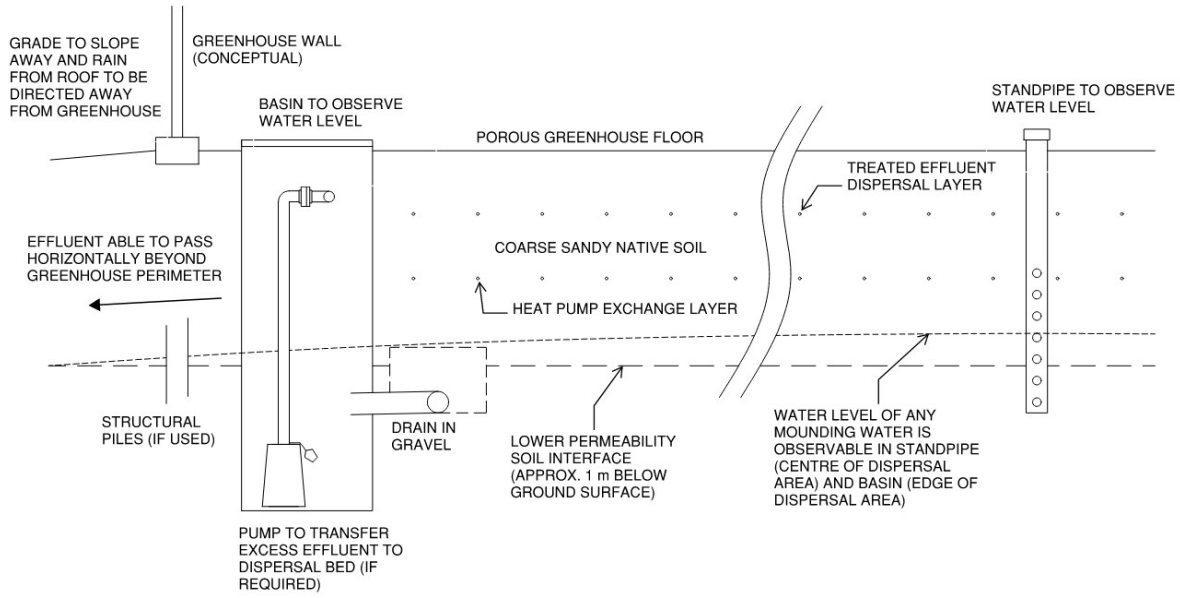


Figure 9 Detailed side view of greenhouse subfloor [5]



The water dosed to the exchange system is highly treated sanitary sewage. A variation on this is to use only greywater (i.e. excluding toilets), which is the warmest and largest fraction of sewage. In contrast, blackwater (toilets) is the coolest fraction of sewage. Greywater can contain all parameters found in sewage, but they are generally at lower

concentrations. Blackwater may be useful to separate for direct nutrient capture and stabilization, as in urine diversion or chemical recovery of nitrogen and phosphorus. Combined sewage (greywater mixed with blackwater) is nutritionally balanced (nitrogen and phosphorus from blackwater balancing carbon heavy compounds in greywater). Although there is a slight decrease in COP due to the cooler temperature of combined sewage compared to just the greywater fraction, there is a larger mass in the combined sewage to exchange energy with. This report assumes treatment and exchange with combined sewage.

The heat capacity of the mass around the geoexchange layer is that of a combination of the coarse native soil and water. Water has about double the heat capacity per mass compared to soil. The soil remains, while the water is entering and leaving the heat exchange layer, so as a thermal battery it is partially static (soil, water held by surface tension) and partially dynamic (water moving downward due to a dosing event). The filter is also exchanging heat by conduction with the soil below the liner, just as a conventional horizontal ground source system would. The calculations below simplify the system as taking heat from the water only. A complete modelling of this dynamic system would require further study.

If we assume that domestic hot water at 50°C comprises roughly 30% of indoor water demand and that cold water at 10°C comprises the remaining 70%, the temperature of sewage exiting the residential units is about 20°C. Sewage is conveyed in pipes in the ground to common septic tanks, then conveyed to the Orenco Advantex® units, then conveyed to the energy exchange system. The soil in contact with the conveyance pipes and tanks may approach a steady state with some seasonal variation. Even with no added insulation, the sewage temperature will not drop to the bulk soil temperature some distance from the sewage because soil is both an insulator and a conductor of heat, but in the interest of keeping the highest water temperature to attain the highest heat pump COP, insulation is recommended over the top of tanks and conveyance. Allowing for a 3°C drop in water temperature between leaving the residential units and arriving at the greenhouse, the temperature of the water will be 17°C.

The 30 L/d/p of DHW needs to be heated 40°C (from about 10 to 50°C). If the heat pump were only supplying DHW heating, the total heat requirement would be like cooling the total 100 L by 12°C. With an estimated COP of 4 (anticipated due to the relatively warm heat source at 17°C compared to the normal ground heat source at 10°C), the water needs only to provide 75% of the heat and so needs to be cooled by only 9°C, the rest of the heat being provided by the electricity to the heat pump system.

If we assume a water efficient total indoor water use of 100 L/d/p x 75 residents, we have 7,500 L which is 7,500 kg/d of water flowing through the exchange system. Water has a heat capacity of 4.184 J/kg°C (Joules per kg per degree Celsius). 7,500 kg/d of water has a heat capacity of 31,380 J/d°C. If the exchange system extracted heat and thereby cooled the water to 8°C, the decrease in temperature is 17 – 8 = 9°C, and the amount of energy obtained is 188,280 J in a day. In addition, electricity to the heat pump system is adding heat to provide the total demand for DHW heating. The effluent at 8°C is well above freezing and should not adversely affect the hydraulics of the on-site sewage dispersal bed.

This demonstrates that all DHW heating can come from one unit of electricity supplied to the heat pump system plus 3 units of heat from the treated sewage effluent (a COP of 4), while delivering an effluent to the on-site sewage dispersal bed that is still warm enough for winter infiltration. The greenhouse system could be further modelled, taking into account dynamic and complex dimensions including short-term thermal storage, soil head conduction, solar gains, moisture transfer and phase change, heat loss through the greenhouse envelope, and seasonal storage in surrounding soil, but this is unlikely to change the basic conclusion that DHW heating can be supplied only from cooling the sewage effluent. Other factors like excess solar gain are, on the balance, likely to add heat where the geoexchange layer is located.

If more than 30 L/d/p DHW is used, i.e. if it is not a water efficient household, there will be more thermal energy available overall with the increased mass of cold water but the increased DHW in and out will balance energetically. As there will be more mass of cold water for the heat pump to exchange with, there will be more heat available for space heating. There will be an increase in electricity used as the load increases and possibly the COP decreases to the extent the cold water fraction is a heat source.

6.3 Building Envelope

Horticultural greenhouses are typically designed to maximize plant growth rates at a low cost of construction. Heating and auxiliary lighting loads are high and rely on high price value produce. Glazing is usually selected for light weight and ease of construction.

For the Ceres-type greenhouse, the north wall and sloped roof are well insulated. It is proposed to use glazing with advantageous performance. The outer lite is a LUMO PV panel that has a fluorescing dye shifting sunlight into a magenta spectrum that optimizes for photosynthesis and internal refraction directs some of the light onto selective photovoltaic cells. The result is that electricity can be generated without compromising plant growth.

Heliene Inc. has developed bifacial PV glazing for greenhouses [8]. Combined in a LiteZone [9] low-E IGU, insulation of RSI 0.9 is achievable. This innovation would potentially result in no heating load in southern coastal climates due to surplus solar heat. The PV output

would produce surplus electricity if auxiliary lighting and HVAC systems are modest. For most of the spring through fall, the net electricity output would be in the range 15 kW peak. Because the PV removes certain wavelengths of light (that the plants don't need), a significant reduction in solar gain will reduce overheating of the greenhouse.

6.4 Greenhouse HVAC System

The greenhouse environment can tolerate swings in temperature, the degree depending on the crops' requirements. For moderate climates like Cortes Island, the greenhouse will require little if any heating with the proposed glazing. Active heating may be provided by the central heat pumps delivered by a radiant backwall rather than fan-coils that require much larger electrical usage.

Cooling loads, when the temperature exceeds 28°C, may be met by active cooling via the radiant panel when the heat rejected by the heat pump can provide useful hot water; otherwise, exhaust stacks with low outdoor air entry vents are opened.

Humidity control in cold weather is necessary to avoid crop damage and condensate dripping. Plant transpiration and soil moisture evaporation constantly supply water vapour. Heat recovery ventilators remove moisture while retaining most of the heat required for make-up air. The ventilation rates can be controlled on moisture levels and dew point.

Plants, when illuminated, absorb CO_2 which must be replaced for plant growth. Some operations inject commercial CO_2; however, operation of the heat recovery ventilator will maintain CO_2 supply from outside air.

By serving the greenhouse HVAC heating and cooling loads with the community heat pump system, there are equipment capital cost savings. When water heating is required and there is sufficient solar heat gain, the heat pumps can cool the greenhouse and supply hot water at a higher COP than a conventional system exchanging heat with cooler ambient air or groundwater.

6.5 Local Food Security

SHARE goals are served by the ability to produce, process, and preserve food on site. The greenhouse provides essential fresh produce year-round which would otherwise require long distance shipping of expensive imports. To adequately address affordability issues, housing, utilities, and food must be addressed.

Localization of food supply facilitates nutrient recycling, an essential element of agricultural sustainability and protection of freshwater sources. Fresh, organic food free from preservatives support health. Community food activities enhance social cohesion. Productive labour may help members to improve economic security. Disruptions to food

supply chains are mitigated by local sourcing. With the adoption of permaculture practices, the restoration and preservation of ecosystems are achieved.

6.6 Water Supply

Potable water for the housing complex will be supplied by a single well in the base case. A second well could offer an alternative water source in the event of maintenance on the primary well pump or equipment. A spare well pump could be kept locally to speed up the replacement time. This second well could also be adapted to use as an injection well (see Section 5.5) where ground temperature water from the primary well passes through a heat exchanger / heat pump system and the water at a slightly altered temperature (cooler if used as a heat source, warmer if used as a heat sink) is injected into the second well. The exact treatment requirements for potable well water will depend on local regulation, but UV sterilization should be considered over chlorination where possible due to carcinogenic disinfection byproducts.

Sprinklers inside residential units could be beneficial in addition to the planned external firefighting from a nearby water reservoir. If provided, the rate of water supply must be sufficient to provide for the sprinkler flow. Pressure (bladder) tanks can allow a smaller horsepower well pump to provide short-term demand and reduce the frequency of motor starts, which typically draw higher amps and wear motors. A variable frequency drive motor controller is beneficial to allow soft starts, reducing the initial amp draw.

7.0 SHARED UTILITIES TRENCHING

Utilidors that contain combined service conduits are common in permafrost region settlements where above-ground freeze protection is necessary. Multiple service providers such as electricity, potable water, sewers, natural gas, communications cabling, and sometimes thermal networks often install their equipment at different times in separate locations. With integrated utility planning, the colocation of these services offers many advantages and cost savings.

For the Rainbow Ridge site, the soil conditions and topography are well suited to trenching. By routing the trenches in loops between the central facilities building and each stage of development, the full potential is enabled without installing all infrastructure at once.

7.1 Trench Construction

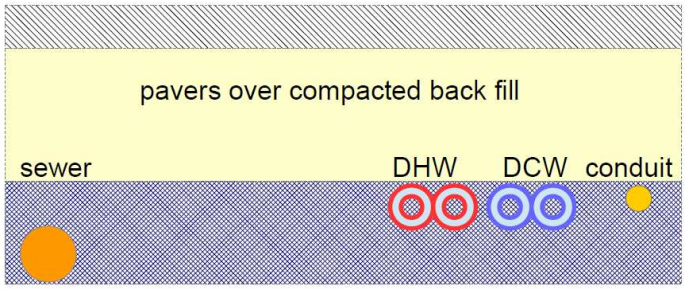
The sandy soil conditions on the property permit easy trenching. Elevations of the floor of the trench are based on gravity conveyance of wastewater to a treatment facility at a low point on the site proximate to the central facilities building. The width should be

approximately 1.2 m and the minimum depth 0.6 m to allow for required separations. Choice of conduits will affect permissible proximities. Sewage effluent forcemains that remain full of water between pump cycles would require frost protection (e.g. deeper burial, insulation, heat tracing).

Backfilling with lightweight aggregate (such as expanded shale) that cover pipes and conduits, provides an insulative layer for thermal circuits as well as wastewater. This may then be covered with polyethylene sheet then covered by excavated material and compacted. By this means, excavation and access for repairs, connections, etc. is expedited.

The location of the trenches correlates with direct pathways to and between housing units. Pavers, suitable for wheelchair and pedestrian use, cover the trenches. By this means, the trenches are marked for future access and to prevent unintended excavation such as for gardening or tree planting.

Figure 10 Utilidor concept [5]



UTILIDOR TRENCH UNDER SIDEWALK

7.2 Electrical Distribution

The default means of providing electrical services is to install poles between the utility distribution system and run overhead wires with disconnects at the utility pole and overhead connection to each housing unit. The Rainbow Ridge development is to have underground services, due to a nearby helicopter pad. Developments like Rainbow Ridge that are not proximate to BC Hydro utility infrastructure (e.g. within 30 m of a utility pole or immediately adjacent to an underground utility service box/transformer) will typically proceed through a bespoke “Design Connections” process, paying for the capital costs of the utility works, less a ~$2,500 contribution per customer, as a condition of connection. Customers are responsible for some civil works (e.g. digging trenches for underground services).

By having one service connection for the multi-housing development and buried cable to the housing units using a common trench, the cost of installing electrical services is reduced compared with overhead separate grid-connections.

Underground cabling has many advantages over above ground. The infrastructure is not seen, although path materials above would alert people not to dig and would make the trenches easier to access for future modifications. Above-ground distribution is subject to damage from fires, ice storms, wind, and tree fall, while power losses are lower for underground cabling. The primary downside is the higher cost of replacement.

7.3 Combined Potable and Hydronic Plumbing

The delivery of domestic hot and cold water requires supply and return lines with recirculation to maintain desired temperatures into the homes. The resulting 4-pipe system is then usable as a source of heating and cooling water for space conditioning. The result is fewer pipe runs, thus lower cost.

One advantage of recirculating potable water is that continuous UV disinfection is enabled, possibly reducing chlorination for periodic treatment of the distribution plumbing, but local practice and regulation needs to be consulted.

The 4-pipe hydronic system does not use reverse/return plumbing so relies on individual household recirculation pumps. The main loops have recirculation pumps with flow regulation based on return water temperature. ECM (electronically commutated motor) pumps operate with variable speed which will take advantage under conditions of frequent pump cycles and slow flow rates to achieve low pump power requirements.

Occasional draws on water will have no significant impact on availability of heating and cooling as these loads rely on longer periods of availability.

7.4 Sewers

Wastewater conveyance to treatment facilities is preferably by gravity and located lower and away from potable water piping which may be run in secondary containment insulation to ensure isolation from a sewage leak.

It is advantageous to not pump raw wastewater until after passage through a septic tank as a grinder pump is less efficient and requires more frequent maintenance and replacement compared to an effluent pump pumping clear effluent.

8.0 COMBINED THERMAL ENERGY AND POTABLE WATER SYSTEM

A key concept for improving energy efficiency while lowering capital costs lies with using shared heat pumps replacing individual ones and combining 4-pipe district heating and cooling with potable hot and cold water supply.

Hot water storage tanks reduce peak heating load and may be sized to enable heat pump operation to be shifted to off-peak hours that achieves reduction in utility costs by opting for time-of-use rates. From the utility standpoint, there are reductions in infrastructure investments as well as line losses.

8.1 Capacity Requirements

The peak space heating load for the houses is approximately 500 W for each of 24 households and 10 kW for the central building for a total of 22 kW. The peak 24-hour heating load is estimated at 350 kWh/d.

Although a water efficient figure of 30 L/d/p was stated in Section 4 (general assumptions) and in Section 6.2 (to model the energy available in the greenhouse), for the purpose of sizing equipment, the average daily hot water use could be conservatively estimated to be as high as 75 L per person, which requires 4 kWh of heat input. Assuming 75 inhabitants, 300 kWh/d is required.

BC Hydro offers a $50/MWh ($0.05 per kWh) rate reduction option between 11 PM and 7 AM. A hot water storage tank of about 5,000 L, sized to meet the daily load, yields utility cost savings. The heating rate for DHW would be 62.5 kW. The size of the thermal storage tank is based on raising water from 10 to 60°C and the DHW load occurring during the 8 daytime hours.

Most of the space heating occurs at night when outdoor temperatures and internal heat gains are lowest, so will benefit from the lower rates, if thermostat settings are not reduced during this period.

The total heating capacity required is the sum of nighttime DHW and peak space heating capacity which is about 85 kW. By supplying this load with 2 heat pumps, if one heat pump fails, the second heat pump should be capable of meeting the peak 24-hour load by operating continuously which requires 27 kW. This will also ensure upward deviations from average loads can still be met. With two 35 kW heat outputs, adequate capacity is assured relying on one unit and the second enables load shifting to nighttime rates for virtually all thermal loads.

The DHW tank supports microgrid operations. Electricity storage for a 24-hour outage, does not need to provide power for the heat pumps. For load shifting, PV with batteries can provide power to other loads during peak periods and top up battery storage including vehicles at nighttime rates. For lengthy outages, a back-up cogenerator, ideally using fuel derived from biomass, will obviate heat pump operation and utilize the thermal storage.

Cooling storage can also contribute to cost savings and resiliency. Active space cooling for the residences is a short-term load but occurs during the day. Heat extraction for DHW, provides cold water for free. The DCW circulation is used for delivering space cooling. If cold water usage for domestic purposes is insufficient to replenish cold water in the recirculating line, then the cold water from the storage tank would be injected.

Chilled water may be used to provide dehumidification in the greenhouse or a root cellar. If a community deep freezer is considered, it could be in the root cellar and benefit from lower cooling loss rate and more efficient refrigeration.

8.2 Hydronic System

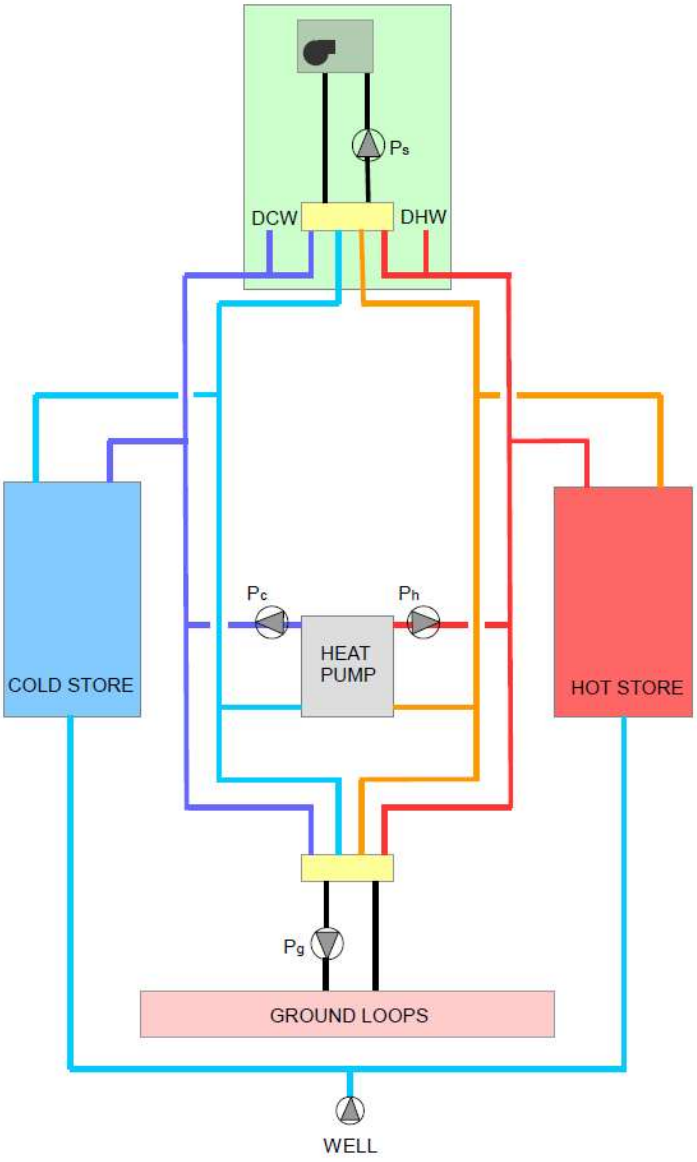
Pumping and circuit valving is simplified if freeze-protected liquids are not necessary, i.e. the heat source for the heat pump can be maintained safely above freezing. This is made possible by providing a steady supply of wastewater at room temperature over the geoexchange mat with the earth acting as diurnal storage.

The wastewater leaving the house is usually above room temperature with the heat that went into providing hot water along with cold water tempering it before draining. The available thermal energy is the heat that was added and the heat in the cold water supply. If the treatment vessel is insulated, the discharge temperature is above room temperature. When a heat pump extracts heat, it adds compressor heat to the supply. Since the dominant load is DHW, there will be surplus heat available above 7°C. When the greenhouse needs cooling, additional heat can be delivered to the geoexchange mat and stored in the surrounding soil.

A non-reversing heat pump between cold and hot storage that serve as the buffer tanks to moderate temperature excursions, keeps the heat pump circuits simple and at constant flow rate. The potable/thermal circuits have their flow rates set on return water temperatures. At each house and building, there is a 6-way valve that switches between cooling and heating circulation.

A schematic of the hydronic system layout is illustrated below.

Figure 11 Hydronic system layout



A heat pump that meets the properties is produced by Nordic, namely the 12 Ton non-reversing Commercial WH 150 series using R513a refrigerant. The effective COP can be over 4 based on Figure 12 for a heat source over 15°C (outdoor loop).

Figure 12 Specifications for Nordic 12 Ton heat pump [10]

	OUTDOOR LOOP *(Water)*						ELECTRICAL		INDOOR LOOP *(Water)*						
	ELT (°C)	Evap. Temp.	Flow (L/s)	LLT (°C)	Delta T (°C)	Heat Abs. (kW)	Compressor Current (A)†	Input Power (W)	EWT (°C)	Cond. Temp.	Flow (L/s)	LWT (°C)	Delta T (°C)	Heating (kW)	COP_H
HEATING	10.0	4.3	2.3	7.6	-2.4	22.9	13.4	8,286	45.6	52.0	2.3		3.3	**31.1**	**3.75**
	15.6	9.0	2.3	12.7	-2.9	27.8	13.8	8,604	45.1	52.2	2.3		3.8	**36.3**	**4.22**
	21.1	13.7	2.3	17.5	-3.6	33.5	14.3	8,946	44.4	52.3	2.3	49	4.5	**42.4**	**4.74**
	26.7	18.4	2.3	22.5	-4.2	40.2	14.8	9,320	43.7	52.5	2.3		5.2	**49.4**	**5.30**
	32.2	23.2	2.3	27.1	-5.1	47.8	15.4	9,731	42.8	52.7	2.3		6.1	**57.4**	**5.90**
	10.0	5.0	2.3	7.9	-2.1	20.0	15.0	9,993	56.8	62.9	2.3		3.2	**29.9**	**2.99**
	15.6	9.8	2.3	13.0	-2.6	24.2	15.5	10,315	56.3	63.1	2.3		3.7	**34.4**	**3.34**
	21.1	14.5	2.3	18.0	-3.1	29.0	15.9	10,649	55.8	63.2	2.3	60	4.2	**39.6**	**3.72**
	26.7	19.3	2.3	23.0	-3.7	34.6	16.5	11,026	55.2	63.4	2.3		4.8	**45.5**	**4.13**
	32.2	24.0	2.3	27.9	-4.3	40.9	17.0	11,423	54.4	63.5	2.3		5.6	**52.2**	**4.57**
	10.0	5.7	2.3	8.3	-1.7	16.5	16.9	11,836	68.1	74.2	2.3		3.0	**28.3**	**2.39**
	15.6	10.5	2.3	13.5	-2.1	20.1	17.4	12,194	67.7	74.3	2.3		3.4	**32.2**	**2.64**
	21.1	15.3	2.3	18.5	-2.6	24.1	18.0	12,591	67.2	74.6	2.3	71	3.9	**36.6**	**2.90**
	26.7	20.1	2.3	23.6	-3.1	28.7	18.5	13,001	66.7	74.7	2.3		4.4	**41.6**	**3.20**
	32.2	24.9	2.3	28.6	-3.6	33.9	19.1	13,447	66.1	74.9	2.3		5.1	**47.3**	**3.52**

9.0 MICROGRID SYSTEMS

The declining costs of distributed energy resources (DERs) such as solar PV, stationary batteries, electric vehicles (EVs) and "smart" load flexibility presents opportunities to create value for housing/neighbourhood developments like Rainbow Ridge. From the perspective of the Cortes Housing Society (CHS) and the residents, these DERs can:

- **Provide backup power in the event of grid outages.** The proposed design intent is to provide resilience through "island-able" systems with battery storage that can provide back-up power during grid outages for some duration (e.g. 24 hours).
- **Lower electricity costs by optimizing power consumption in response to dynamic utility rates.** Onsite battery storage, EV charging, and various "smart" programmable loads can take advantage of dynamic utility rates, such as BC Hydro's new optional "Time of Use" (TOU) Residential rate. These systems can concentrate energy use when costs are low, and curtail consumption when prices are high. Likewise, under BC Hydro's self-generation programs, customers can receive credit for net energy supplied back into the grid at TOU rates.

- **Provide services to the broader utility grid.** DERs could theoretically:
    - Respond to real-time wholesale power prices.
    - Provide capacity to defer distribution or transmission system upgrades.
    - Provide various ancillary services (e.g. voltage control; etc.)

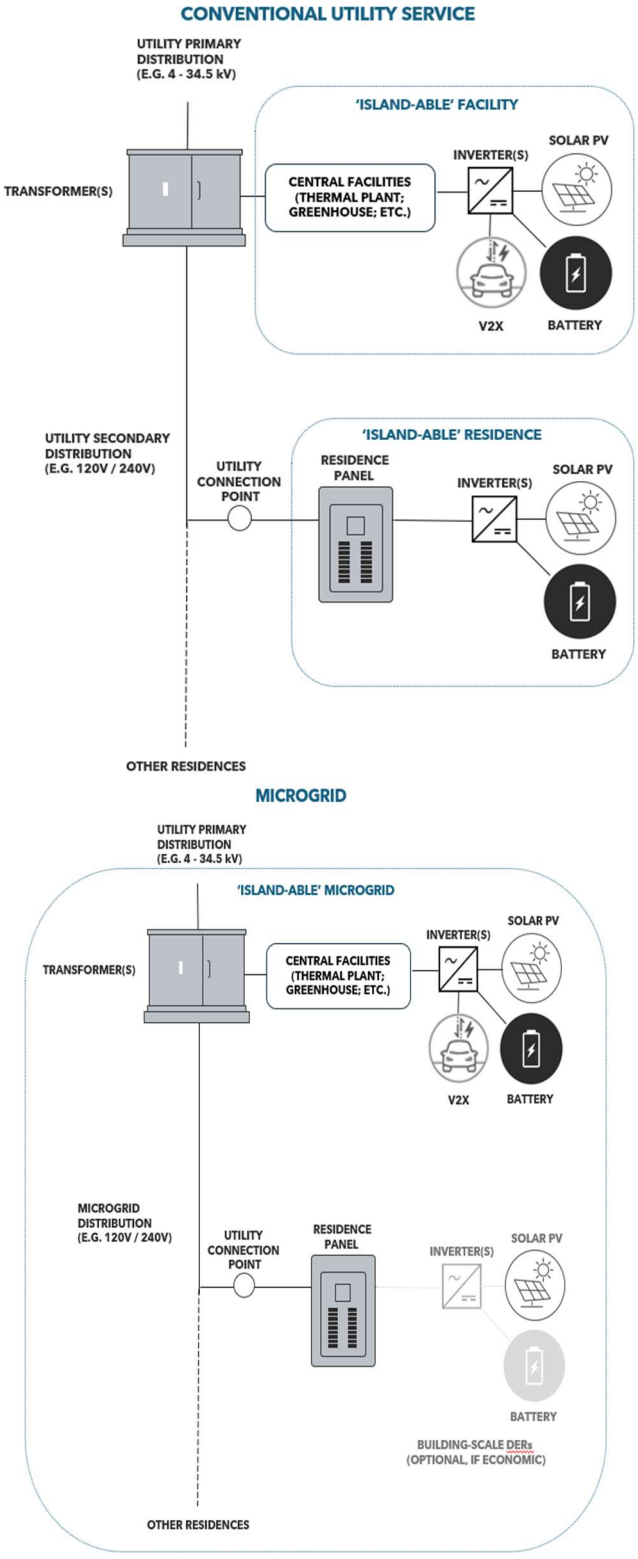
  Beyond response to dynamic utility rates and pre-existing programs, it may be possible to establish arrangements with local utilities to provide such additional grid services. The potential of DERs to provide some of these services (e.g. deferring distribution system upgrades) is often highly location dependent. The frameworks for DERs to provide these utility services are in relative infancy; fully capturing this potential value could be further explored with BC Hydro.

The specific opportunities to deploy such DERs is influenced by the ownership and governance of **electrical distribution systems** to residences and on-site facilities. Two broad frameworks were considered as part of this analysis:

1. **Conventional utility service arrangements.** The utility (e.g. BC Hydro) provides transformation from its primary distribution voltages (e.g. 4kV to 34.5kV) to secondary voltages (e.g. 120V/240V for residences), and a service to each building's utility connection point. The utility implements and manages metering and customer service for individual residences.
2. **Microgrid**. The site features an independently operated microgrid. The primary utility line is connected to a central service entrance and transformation. Onsite power distribution infrastructure is implemented by CHS, with distribution cabling in the shared utility trench noted in Section 7.0 above. Various distributed energy resources (e.g. solar PV, stationary battery storage, vehicle-to-microgrid electric vehicle charging, etc.) can be integrated to the microgrid distribution system. CHS is ultimately responsible for operations and management of the microgrid; these functions could be contracted to firms provided microgrid operations services, such as Schneider Electric Global who provide Ecostruxure turnkey installations.

The schematic diagrams below illustrate these two options.

Figure 13 Conventional utility service and microgrid service



The table below compares the implications of microgrid versus conventional electrical distribution systems, noting potential sources of value as well as costs and risks.

Issue	Considerations
Total sizing & cost of batteries and solar PV to provide resilience to grid outages for residences	Under conventional utility service arrangements, island-able systems with battery storage would need to be provided for each building/facility with an individual utility connection point. Conversely, with microgrid systems, the entirety of the site's electrical systems could island collectively. A microgrid would require lower total installed capacity of batteries and solar PV to achieve a given duration of back-up power (e.g. 24 hours). This lower total capacity stems from the inherent electrical diversity of combined loads; the averaged load of all residences and other facilities will be lower than the design electrical profile for individual buildings. This would reduce CAPEX (capital expense) by requiring less battery and solar PV capacity. Likewise, batteries and/or PV could be (predominantly) deployed in a single central array; building-scale solar PV could also be deployed to other residences' rooftops, if necessary to provide sufficient PV capacity. Central systems would require significantly fewer inverters and other balance of plant systems compared to distributed storage at each residence, again resulting in lower CAPEX.
Integration of "Vehicle to Everything" (V2X), biomass co-generation and other resources	As described further in Section 9.1, V2X provides an additional means to incorporate significant battery storage capacity. V2X could theoretically be integrated at individual buildings/facilities as part of conventional utility arrangements. However, in this conventional arrangement, a vehicle could only serve each utility service (e.g. building). Furthermore, at Rainbow Ridge, parking is not adjacent to each individual residence; running cabling from each residence to shared parking area could be costly. A microgrid system could better integrate with a central V2X system that can provide backup power, energy arbitrage, and/or grid services on behalf of the broader site. A single vehicle could potentially provide much of the sites' power needs in backup contexts, at lower CAPEX than each building. Similar, biomass co-generation would more readily integrated with microgrid systems.

Issue	Considerations
Ability to respond to time varying utility rates	Both the microgrid and conventional utility service paradigms are theoretically compatible to responding to time-varying utility rates (e.g. TOU rates) and self-generation programs. BC Hydro does not currently offer a General Service rate with real-time pricing. Were a microgrid deemed a General Service account, a time-varying rate may not be available in the near-term. However, BC Hydro may be in the process of providing more time-varying rates to a wider range of customer classes, to better reflect their time-varying cost to provide power. Conversely, with conventional utility service and metering, a Residential TOU rate is currently available. This would enable residences with onsite battery storage, and/or other flexible loads, to concentrate consumption during low overnight rates, reducing costs approximately 60% compared to on-peak.
Metering configurations	In the conventional approach, each unit is presumed to be metered by BC Hydro. For the microgrid, it is assumed there would be a single utility meter for the entire facility. Residential units could potentially be submetered. However, appliance, lighting, and plug loads are quite small compared to the DHW and space conditioning loads handled by the central thermal plant. With site-produced power, load shifting with batteries, and time-of-use rates, the costs are very low, and metering might be inconsequential to behaviour. It is likely that rents may be appropriately set as “utilities included”.
Management & operations of distribution systems	In the conventional approach, the utility is responsible for managing distribution infrastructure (e.g. transformers; secondary distribution systems) up to the utility connection point. In a microgrid, any repairs, maintenance, etc. would be the ultimate responsibility of CHS. Microgrid management services are available. Damage to systems would hopefully be unlikely, but would be high-consequence. BC Hydro has substantial repairs and grid-management capabilities; meeting their standards for e.g. response time could be challenging for a housing society.

9.1 Vehicle-to-Everything Systems

V2X refers to a broad set of technologies and applications that enable charging electric vehicle (EV) batteries from external power sources (e.g. the electrical grid) and later sending electricity stored in the EV's battery back to the grid, 'islanded' buildings, or other systems. There are several different applications of bidirectional charging, including:

- Vehicle-to-Grid (V2G)
- Vehicle-to-Home/Building (V2H/V2B)
- Vehicle-to-Microgrid (V2M)

Using V2X can reduce the size of stationary battery deployments necessary to provide lengthy back-up power because the amount of energy storage capacity available in EVs' batteries is large compared to most stationary storage applications. For example, a Ford F-150 Lightning EV has a battery size of 98-131 kWh (depending on model) with 9.6kW maximum power export capacity; likewise, many e-buses have batteries of 150kWh+ and 25kW+ export capacity. For point of comparison, peak heating season load for the site total site load is approximately 22 kW and with approximately 350 kWh/d. Thus, a reliable V2X could contribute meaningfully to back up power for site loads at Rainbow Ridge, reducing the need to deploy as much stationary battery storage capacity.

Because the battery is paid for primarily as a transportation device, V2X could reduce costs while providing considerably longer-term energy storage in the face of power outages and/or long periods of relatively high electricity prices.

A shared V2X-capable EV(s) administered by the property owner (e.g. a car-share; mini-bus; etc.) could provide the greatest assurance that the vehicle would be available for regular energy arbitrage and during outages. Alternately, it is possible to compensate residents for use of their vehicles.

Exporting power from a vehicle for use by AC grid (or micro-grid) requires an inverter to convert DC to AC. V2X can use an electrical inverter either built into the vehicle itself or into the electrical vehicle supply equipment (EVSE) :

- V2X-DC involves the vehicle exporting DC power. The inverter is in the EVSE.
- V2X-AC involves the vehicle exporting AC power. The vehicle's onboard charger serves as the inverter when exporting AC power. Level 1 or Level 2 EVSE can be used, without the need for an EVSE with an integrated inverter.

In V2X applications to date, V2X-DC is the most prevalent and should be anticipated in near-term deployments. Of vehicles that are compatible with V2X available today or announced by OEMs for the future, all are premised on V2X-DC. Because the inverter is integrated into an EVSE that is permanently installed in a fixed location, systems to certify the inverter for interconnection are analogous to those used for solar PV or stationary battery systems. Accordingly, the ecosystem of industry standards to support V2X-DC is relatively well established and it is easier for utility grid operators to administer interconnection and certification of V2X-DC systems. However, in the longer-term, V2X-AC may prove most cost-effective.

Unlike for solar and stationary storage, BC Hydro has yet to establish standard interconnection processes for V2X. Thus, utility permissions would need to be determined for deployment either as part of a microgrid system or in conventional utility services.

V2X systems are still relatively nascent. Careful design and commissioning of systems would be required. There is no pre-existing vehicle-to-grid power export program from BC Hydro; BC Hydro would need to be engaged to explore deployment on a pilot basis.

9.2 AC vs DC Power Distribution

The question of whether the distribution lines should be AC or DC requires more detailed study. With PV and batteries being DC and a growing amount of load operating on DC, the future may favour primarily DC systems with conversion to AC for vestigial loads. DC distribution systems would reduce DC/AC power conversion losses; AES Engineering estimates that in residential applications savings average on the order of 3-4% of total energy consumption and have empirically measured as high as 8%;[1] greater savings manifest the more loads are converted to DC.

However, DC microgrids for residential applications are in their infancy. There is an ongoing need for greater standardization and product development for a variety of essential DC microgrid components (e.g. power conversion equipment, protective devices, controllers) and DC equipment that comprise the largest loads (e.g. heat pumps, water heating, residential DC charging, etc.).

[1] AES Engineering. 2024. Automated Demand Response and Efficiency in DC Power Systems for Buildings. Prepared for CSA Group.

10.0 ENERGY ESTIMATES

The design goal for housing is to achieve a Passive House level of thermal envelope that results in a peak demand of 10 W/m^2. The domestic hot water usage is based on typical per capita consumption. Electricity for lighting and appliances per dwelling is assumed to be 3 MWh/yr.

10.1 Space Heating

An average of 3,000 degree-days is assumed. Internal and solar gains for a typical household in winter are estimated at 15 kWh/d. An average size for a 2-bedroom unit is 65 m^2 with a peak demand of 650 W for an outdoor temperature of -5°C. The internal gains for the day assuming 3 people, lighting, and appliances is about 20 kWh, and the losses are about 16 kWh, which implies there is no heating required on the coldest day. However, if there will be periods when lower occupancy occurs, they may require heating capability. Since the cost of space heating is negligible, metering costs to instill conservation will not likely be cost effective.

10.2 Domestic Water Heating

To calculate savings, we will use the water efficient household assumption of 30 L/d/p DHW. Assuming a supply water temperature of 10°C, a household of 3 will require 4.2 kWh/d of thermal energy input. For a total of 25 buildings, the water heating load estimate is 210 kWh/d. If the heating takes place over the 8 nighttime hours, the heating rate is 26 kW. With a COP of 4, the heat pumps' electricity demand is 6.5 kW. The daily electricity required is 52.5 kWh, for an annual total of 19 MWh/yr. The total annual cost of DHW would be $950 and about $40 per household.

By comparison, the baseline DHW heat pump annual load is 30.5 MWh at $100/MWh for $3,050/yr or $120 for an average household. The DHW system saves $80/yr per home.

10.3 Lighting and Appliances

With LED lighting, shared high-efficiency clothes washers, heat pump dryers, induction cooking, high efficiency refrigeration, and shared freezer, the annual electricity demand is estimated to be about 3 MWh per household and 75 MWh for the community, or 205 kWh/d. The HRV uses high efficiency fans, and the circulation pump is a very small load. Most of this demand occurs during the grid's peak period.

By storing electricity and avoiding on-peak utility consumption, the central battery could reduce utility charges for these loads at flat rates of $7,500/yr to about $4,500 by opting for BC Hydro's time-of-use rates. This translates into $120/yr savings per household.

10.4 Greenhouse

With improved efficiency glazing and natural ventilation, the greenhouse could be passively maintained between 5 and 30°C; however, the geoexchange mat enables heat to be stored during sunny periods and extracted directly or with the heat pumps to maintain more optimum growing conditions. The heat recovery ventilators provide CO_2 and humidity management with only periodic fan power required. Supplemental lighting is dependent on the value of the crop, so the energy use is discretionary. Artificial lighting reduces heating loads, so net energy impacts need to be analyzed.

Ceres Greenhouses has reviewed the proposed design and is prepared to undertake detailed energy modelling during a future design stage. A stand-in estimate of auxiliary lighting, fans, and pumps is 15 MWh/yr.

The annual electrical generation of the PV glazing is about 15 MWh. On a peak solar day, the output is about 100 kWh or about ½ household energy use. In an off-grid operation, it is appropriate to size the PV capacity so that not much more than the peak day generation equals the daily energy demand unless more than 24 hours of battery storage is installed.

The greenhouse contributes to lowering the thermal energy demand of the community. The heat pumps draw from stored heat in the ground beneath the greenhouse, raising the COP to 4 compared to 3 with open-loop groundwater. This difference in COP is based on the heat source under the greenhouse being approximately 10°C warmer than the well water used in an open-loop system.

10.5 Microgrid

The total annual electricity demand for the development is estimated at 130 MWh/yr. This does not include vehicle charging. An estimated average daily demand of 360 kWh may be used for sizing generation and storage.

On a full sunshine day, a total PV capacity of 60 kW will provide enough electricity for a day. During a 24-hour power outage, about half of the demand can be met directly from PV generation. 180 kWh of battery storage will enable full operation for 24 hours on a full sunshine day. An electric van may provide 100 kWh with the rest as 80 kWh of stationary battery capacity.

If the outage is longer and there is insufficient PV input, a back-up generator with a capacity of about 15 kW would be required and operated continuously in conjunction with battery storage. For the baseline, individual home generators, about 5 kW each would be necessary.

In off-grid applications, a microgrid could be operated with the same PV and battery capacities with biomass cogeneration added. The fuel could be produced from wood waste, such as a wood chip gasifier.

11.0 COST/BENEFIT ASSESSMENT

Detailed costing would require engineered specifications of the base case and proposed integrated solutions. However, approximate unit costs from on-line sources and technology providers are used to compare capital costs of baseline vs proposed and the assets. Some aspects of the integrated utility approach are optional and some are fundamental. The following assessment of the various features identifies whether there are cost savings or premiums and any added values.

11.1 Central Thermal Plant

The generation of heat with a central heat pump is at a commercial application scale with lower capital costs per unit of heat delivery, lower peak demand so lower capacity sizing, higher quality with lower maintenance, and higher energy efficiency. The load is primarily DHW as space heating and cooling is relatively incidental. A large central tank has much lower heat loss compared to individual tanks and can be sized to meet a full day's usage. Its cost is substantially lower than tanks in each home. By employing 2 heat pumps at ½ the required capacity, so that, combined, the load can be met at nighttime rates, the inoperability of one enables hot water demand to be met by running longer. This redundancy and serviceability provides resilience for households.

The installed cost of the base case DHW heat pump and the split system heat pump for space conditioning equipment in 25 units is estimated at $500,000. The average COP is approximately 2.5 and the life expectancy is about 15 to 20 years. The outdoor unit generates noise. The DHW heat pump extracts heat from the house which may require additional costs to mitigate.

The central heat pumps are estimated to cost $100,000 installed and distribution and coils at $50,000. The greenhouse cost is estimated at $150,000 including the space for mechanical and electrical equipment for the central facilities. Total cost is $300,000. This represents a capital cost savings for DHW, space heating, and cooling of $200,000.

There are further cost savings due to reduced housing unit floor area requirements to accommodate the equipment. Alternatively, additional floor area is valuable to families.

11.2 Treated Wastewater Heat Pump

The heat pumps' source and sink are the mass of soil and water around the geoexchange mat that is kept close to room temperature by the treated wastewater used to irrigate greenhouse plants. This is similar to building wastewater heat pumps except there is no need for expensive methods of preventing fouling of a metal heat exchanger.

Treated wastewater requires dispersal areas. With the coarse sandy native soils of the subject site, the proposed greenhouse irrigation provides dispersal of effluent while providing treatment through nutrient take-up by the plants and soil microbes. Part of the climate control cost for the greenhouse is the central heat pumps. The greenhouse irrigation system cost is included in the greenhouse estimate and replaces some or all of the dispersal bed costs for the treated wastewater. If the smaller size of an indoor dispersal system proves sufficient, the capital cost savings of eliminating the normal dispersal system would offset much of the cost of the greenhouse.

Assessment of the value of greenhouse horticulture needs to be considered. Affordability and food security are supported by community-based year-round gardening. The proposed greenhouse provides other benefits including PV generation and low energy demand. Compared with a conventional stand-alone greenhouse, the shared irrigation, space conditioning, PV generation, and nutrients lower capital and operating costs. This implies that fresh produce will be much more affordable.

Planting and harvesting may be done communally or by employment, further enhancing affordability. Other potential benefits are health, social cohesion, and education. The net capital investment may be treated as a business case, a donation, and/or built into housing rents.

The greenhouse dimensions lead to a dispersal area that is not as long and thin as the typical dispersal bed design derived from a linear loading rate and does not match the overall area of multiple dispersal systems that includes individual narrow beds with separation [7] [11] [12], but it is likely that the greenhouse dispersal can replace at least 50% of the standard dispersal bed. Based on water efficient actual flow with flow balancing (peaks are stored in an appropriately sized pump tank and pumped out evenly over time) it could completely replace the dispersal bed. As a contingency, the site does have the area to site primary and reserve bed areas. The greenhouse dispersal approach could be installed and the mounding of effluent under the greenhouse monitored to see if any additional dispersal area is required. If the dispersal area is insufficient, excess effluent can be pumped to an additional dispersal area.

Construction can also be phased in that the dispersal is set back from the perimeter of the greenhouse, such that the dispersal could be installed first and the greenhouse installed at

a later date. Compaction of the dispersal area is to be avoided or minimized prior and during the installation of the dispersal and then during the installation of the greenhouse.

Rivercourt Engineering tracks installer quotes for on-site sewerage systems in southern Ontario. For sites with clay soils requiring imported specified sand for raised beds, the total cost of installations adjusted to 2025 is about $24 per L/d (septic tanks, connecting piping, treatment technology to 10 mg/L CBOD5 and TSS, and raised bed in clay soils). For tight soil, the cost of the dispersal bed with imported soil is about half the total cost or $12 per L/d. For in-ground dispersal beds, which would be the case for Rainbow Ridge, it is estimated that the bed is half this cost or $6 per L/d. For a peak day design flow of 20,250 L/d, the estimated cost of dispersal bed(s) is 20,250 L/d x $6 per L/d = $121,500.

Based on the greenhouse replacing 50-100% of the dispersal beds, the cost savings are $60,750 to $121,500 or an average of $91,000. Some of this capital cost is still required to install the effluent dosing pipes, but the excavation cost is shared with the installation of horizontal ground source tubing for the heat pump. If the cost of just installing the effluent dosing piping was 25% of the $91,000 bed average figure, or $23,000, the savings of not constructing all of a separate conventional dispersal system could be on the order of $68,000 where the cost of excavating for the ground source tubing is already included in the Ceres-type greenhouse cost. The cost savings on the dispersal bed system of $68,000 is 45% of the estimated cost of the greenhouse of $150,000.

11.3 Combined Potable and Thermal Water Supply

Potable water supply from a shared well and continual recirculation and UV disinfection provides cost savings for both operating and capital expenditures. The supply/return piping enables work on the distribution to proceed without shutting off supply as the water is routed in two directions with a loop formation. This also provides cold water circulation for cooling loads, at much lower costs than the baseline heat pumps in each dwelling.

Similarly, the DHW and space heating is delivered as a loop and provides the same advantages. The DHW is kept at the required temperature for the user. The capital cost of hot and cold recirculation is more than offset by the savings for eliminating baseline individual heat pumps.

11.4 Microgrid

The proposed microgrid provides continuous back-up power, renewable energy supply that reduces grid electricity usage, shifts demand to periods with the lowest utility rates and utilizes vehicle battery storage through the charging station. The baseline for equivalent services would include individual gas-powered generators, individual PV installations with inverters connected to the grid, and on-demand vehicle charging stations.

For the 15 kW for the greenhouse glazing integrated PV, the installed cost is less than roof or ground mounted by about half, as the installation and support structure is part of the greenhouse construction cost. According to the supplier, utility PV incentives may fully pay for the panels. BC Hydro currently offers incentives for PV installations in the range of $1,000 up to 50% of the installed cost subject to the category of customer. The remaining 25 kW of PV could be on the housing rooftops or as a canopy for various purposes. Generally, larger arrays which provide an auxiliary service will be most economic.

Battery storage serves multiple purposes. If sized as back-up power during 24-hour outages, it enables PV output to be stored, extending off-grid supply. When grid electricity is available, the batteries may be charged at nighttime at low rates, and supply to loads at peak period rates.

Back-up electricity supply in the baseline costs in the range of $15,000 for each building for a total of $375,000 whereas the central generator with battery will be in the range of $25,000 for the generator, $75,000 for an EV minivan, and $50,000 for the battery set for total cost of $150,000. The utility cost savings for load shifting is estimated at $9,000/yr. Given that there are large capital cost savings, the other advantages of the microgrid make the case for adoption.

11.5 Optional Heating Plant

In the case that the greenhouse/wastewater project not proceeding, the open loop central heat pump may utilize the potable water supply and add an injection well or wells. The cost for well drilling and casing is estimated at $10,000 per well. For the heat pump to provide the required DHW temperature, 2-stage heat pumps are required which will result in somewhat higher energy use and capital cost but considerably better energy and cost performance than the baseline.

12.0 CONCLUSIONS

This study set out to assess the technical feasibility and benefits of an integrated utility for a small community encompassing potable water supply, wastewater treatment, heating, cooling, domestic hot water, microgrid electricity, a horticultural greenhouse, shared electric vehicle, and communal facilities. Some aspects are like apartment building servicing but applied to a cluster of semi-detached units. Others are novel and may have potential in a broader range of applications.

The following outcomes may be realized.

12.1 Energy Security

The high energy efficiency of electrical and thermal loads combined with energy storage and site renewables achieves very low utility costs, independence from fossil fuels, asset value to the grid, and the ability to operate over extended power outages or independent of the grid.

12.2 Water Security

Advanced treatment of wastewater helps to ensure the aquifer is protected from contamination. Dual wells and microgrid ensure a continuous supply. Disinfection is sustained with UV sterilization and recirculation.

12.3 Food Security

The greenhouse enables a continuous supply of fresh produce. A community garden, food processing kitchen, freezer and root cellar storage, and local farms provide sufficient food independent of supply disruptions.

12.4 Shelter Security

With very low utility costs, rent or mortgage charges are more manageable on seasonal incomes, pensions, and social securities.

12.5 Transportation Security

A community-owned electric minivan provides an option for those who can’t afford or are unable to operate a personal vehicle. It may also provide an income for the driver.

References

[1] "https://ceresgs.com/introducing-the-ecoloop/," [Online]. [Accessed 23 May 2025].

[2] BC Ministry of Environment , "Reclaimed Water Guideline," 2013.

[3] Orenco Systems Inc., "Advantex Performance Summary #1 and #2," 2012.

[4] "https://www.aqua-tt.com/," [Online]. [Accessed 23 May 2025].

[5] Rivercourt Engineering Inc..

[6] Orenco Systems Inc. , "https://www.affordableseptics.com/html/intermittant_sf.html," [Online]. [Accessed 23 May 2025].

[7] Ron McMurtrie and Associates, Consulting Engineers, "Proposed Rezoning for Phase 1 (On-Site Sewerage Report - Rainbow Ridge)," October 19, 2019.

[8] Heliene, "https://heliene.com/gipv-solar-glass/," [Online]. [Accessed May 2024].

[9] LiteZone Glass Inc., "https://www.litezone.ca/," [Online]. [Accessed May 2024].

[10] Nordic, "Application, Installation, & Service Manual, Commercial Water to Water Heat Pumps / Chillers, Performance Tables Metric Page 98," [Online]. Available: https://www.nordicghp.com/wp-content/uploads/2025/05/002746MAN-01-ISSUE-03-Commercial-W-R454b-WH-R513a-150-1000.pdf.

[11] Health Protection Branch, Ministry of Health, "Sewerage System Standard Practice Manual," 2014.

[12] Engineers and GeoScientists, British Columbia, "Onsite Sewerage Systems," 2018.

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