SCHEDULE E

Form of Completion Report for Studies

Please do not hesitate to contact your project officer to receive an electronic copy of the template of the Completion Report for Studies.

Upon completion of the Feasibility Study, a copy of the Final Study must be submitted along with this Completion Report for Studies.

FCM will post your report on the Green Municipal Fund™ (GMF) website.[1] This is because one of FCM's mandates is to help municipal governments share their knowledge and expertise regarding municipal environmental projects, plans and studies. Before you submit a report to FCM, make sure you hold the copyright for the report (you own all the rights to the content and can decide who is allowed to reproduce and distribute the report) and that it does not contain any confidential information.

If the report contains confidential information, you need to submit two versions: one containing confidential information, to be read by FCM staff, and one that does not contain confidential information, which can be posted on the GMF website. Please contact FCM if you have any questions about copyright and confidentiality.

How to complete the Completion Report for Studies

The purpose of the Completion Report for Studies is simple: to share the story of your community's experience in undertaking a Feasibility Study with others seeking to address similar issues in their own communities.

Please write the report in plain language that can be understood by people who are not specialists on the subject. A Completion Report for Studies is typically in the range of 5–10 pages, but may be longer or shorter, depending on the complexity of the Feasibility Study.

GMF grant recipients must enclose **final** copies of the Completion Report for Studies and the Final Study, both in electronic format, with their final Request for Contribution. The reports, including all attachments and appendices, must be submitted in PDF format with searchable text functionality. Reports that are not clearly identifiable as final reports, such as those displaying headers, footers, titles or watermarks containing terms like "draft" or "for internal use only," will not be accepted by GMF. Additionally, reports must be dated. If you have questions about completing this report, please consult GMF staff.

[1] http://www.fcm.ca/home/programs/green-municipal-fund.htm

Completion Report for Studies

GMF number	15061
Name of lead applicant (municipality or other partner)	City of Richmond
Name, title, full address, phone, fax and e-mail address of lead technical contact for this study	Nicholas Heap, Sustainability Project Manager, Sustainability and District Energy, Engineering and Public Works City of Richmond Phone: (604) 276-4267 Fax: (604) 276-4222 nheap@richmond.ca
Date of the report	August 20, 2019

1. Introduction

a. ***Who was involved in doing the Feasibility Study, and what are their affiliations? Please include name, title and contact information. Those involved could include municipal staff, engineers and other consultants, a representative from a non-governmental organization, and others.***

The *Micro-Sewer Heat Recovery District Energy Utility Heat Recovery Study (mSHR)* involved the participation of staff from the Engineering Planning and the Sustainability and District Energy groups within the City's Engineering department:

City of Richmond, Sustainability and District Energy
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City of Richmond, Engineering Planning
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Kelly Talmey, Project Manager (604-247-4658, KTalmey@richmond.ca)

Modelling, analysis, engineering design work and costing was carried out by a team of consultants, as follows:

Kerr Wood Leidal Consulting Engineers
Mike Homenuke, P.Eng., Municipal Wastewater Sector Leader (604-293-3242, MHomenuke@kwl.ca) Ayman Fahmy, P.Eng, Team Lead, District Energy (604-293-3243, AFahmy@kwl.ca)
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Rob Stephenson, Chief Technical Officer (604-940-9125, dr.rob.stephenson@gmail.com)

2. The Feasibility Study

a. Describe the process that you undertook to make this feasibility study a reality, from concept, to council approval, to RFP, to final deliverable.

The City has been aware of potential of sewer heat recovery for many years. Metro Vancouver had already studied the potential for sewer heat recovery from the large Gilbert trunk sewer owned by the regional district as well as other forcemains it operates in Richmond. This large collector pipe was assessed to have a heat resource sufficient to meet 70% of the projected thermal energy demand within the high-density neighbourhood-sized Oval Village District Energy Utility (OVDEU) service area. The City planned to access this heat resource once overall building energy loads connected to OVDEU were sufficient to support the capital investment.

By early 2016 the City had two separate District Energy systems in operation (Alexandra District Energy Utility [ADEU] and the Oval Village District Energy Utility [OVDEU]), with a third system (the City Centre North District Energy Utility [CCNDEU]) in the planning stage, all of which were located within the boundaries of the City Centre planning area. The City approved development of these DEU projects because of the potential of these projects to deliver heating and cooling services at a price competitive with other heating technologies (e.g. individual buildings heated by natural gas and/or electric baseboards).

The City owns and maintains an extensive network for municipal sanitary sewers that feed into this regional collector. Because the municipal wastewater system extends throughout the City's urban area, staff were interested in determining the feasibility for cost-effective sewer heat recovery using municipal sanitary sewer infrastructure to displace conventional energy use by new developments.

The City had also some gained some experience with operating and assessing smaller-scale sewer heat recovery projects. The City-owned Gateway Theatre (sited at a pump station) had a SHARC unit installed in 2013 to displace natural gas use. The City had also investigated the use of sewer heat recovery with regard to a new building at Kwantlen Polytechnic University (KPU). Both of these locations were situated outside of existing DEU service areas.

The sewer heat energy that is available within the City's own sewer pipe network was unknown, however. The City believed there was value in assessing the potential for smaller scale projects – described by the City as "micro-sewer heat recovery" or "mSHR" projects. In contrast to the large-scale sewer heat recovery project at the Gilbert trunk sewer planned for the high-density OVDEU service area, mSHR projects were anticipated to have lower capital costs, with output capacities suitable for a single development and/or a smaller development cluster.

The City anticipated that some locations within the City's pump stations and force mains would have sufficient capacity to provide cost-competitive heating and cooling services for smaller-scale stand-alone developments. In such cases, the mSHR project would most likely proceed in conjunction with the new development it was to serve. Alternately, an mSHR facility sited near the existing DEU service areas could serve as an ancillary energy input to an existing DEU. In these cases, development of the sewer heat recovery project might proceed independently of other redevelopment projects.

To offset costs, staff initiated an application for the Federation of Canadian Municipalities' Green Municipal Fund, which could provide up to 50% of eligible costs to a maximum contribution of $175,000 for feasibility studies.

On February 22, 2016, Richmond City Council approved a scope of work and budget for a Micro-Sewer Heat Recovery Study, and endorsed an application to the Federation of Canadian Municipalities (FCM) requesting funding of up to 50 percent of eligible costs for this study.

In light of the failure of a sanitary sewer forcemain due to the build-up of fats, oil and grease (FOG), which necessitated $1.5 million in emergency work, identifying effective means to prevent similar events in future became a priority for staff in the spring of 2016. In particular, staff were interested to assess whether a FOG buildup might be effectively addressed by building facilities to remove FOG from the sanitary sewer system rather than relying solely on a source control strategy (which seeks to minimize the amount of FOG entering the sanitary sewer system). Beyond this, staff considered that there might be substantial cost synergies in combining a FOG extraction facility and a sewer heat recovery installation into a single integrated facility. As a result, the overall scope of the mSHR project was expanded beyond FCM co-funded component to consider FOG extraction technologies, and to estimate the costs of building an integrated sewer heat recovery and FOG extraction facility, with the City. The City provided 100% of the funding for this additional component of the expanded mSHR scope of work.

The City's grant application was successful, and a funding agreement with FCM for the scope of work outlined above ssupporting the micro-Sewer Heat Recovery component of the feasibility study was finalized on July 16, 2016. All elements of the study pertaining to grease extraction were entirely funded by the City, and this was reflected in project budgeting and invoicing.

An RFP "to engage the services of a qualified Consultant with the necessary expertise to assess opportunities for micro sewer energy recovery facilities within the City relative to new development opportunities, to assess potential synergies with sewer grease extraction, and to conduct a feasibility study with regard to the top-ranked opportunities identified" was issued on August 24, 2016, with bids to be received by September 21, 2016. The RFP stated that the City had budgeted up to $135,000.00 in Canadian funds to complete this work, not including any work pertaining to sewer grease recovery, and all applicable taxes.

The City received three bids to complete this work. In November 2016, the City of Richmond (City) retained Kerr Wood Leidal Associates Ltd. (KWL) to conduct a feasibility study to assess extractable heat resources within the City's municipal sewer infrastructure, and to investigate whether it was cost effective to integrate 'micro' sewer heat recovery (mSHR) with the extraction of fat, oil, and grease (FOG) from municipal sewer systems.

The consultant began work in December 2016.

In January and February 2017, in response to an infrastructure funding opportunity under the federal government's Western Diversification Program, staff contracted KWL to do additional work (outside of the project funding detailed here) to help put together a funding proposal for an integrated micro Sewer Heat Recovery and FOG extraction facility.

KWL submitted a draft Phase 1 report in March 2017. Following revisions, the Phase 1 report was finalized in May 2017. This report included:

- An assessment of the current sewer heat resource throughout Richmond and that projected with a build-out of Richmond's OCP in 2041.

- An assessment of potential heat energy demand within the City Centre area and neighbourhood service centres designated in the OCP, as well as the City's district energy utility (DEU) service areas.

- A review of available sewer heat recovery technologies and available products, and recommended technologies to incorporate in Phase 2 cost assessments.

- A review of FOG issues with the municipal sewer system, and results of search of available FOG extraction technologies (none were identified)

The Phase 1 report did not recommend the use of any "in-line" sewer heat recovery technologies, in which a section of existing sewer pipe is replaced with a modified pipe incorporating a heat exchanger. The Phase 1 report did recommend the use of the locally-manufactured "off-line" SHARC technology, in which a stream of wastewater is diverted from a pump station wet well to a facility enclosure nearby, screened, passed through a heat exchanger and then returned to the wet well.

In identifying locations for the five business cases, priority was placed on optimizing the potential for both heat recovery and FOG extraction potential, and selecting locations suitable for development of a pilot project integrating sewer heat recovery and grease extraction within the short term.

The need to coordinate extended pilot project assessment and development timelines with that of the development being supplied with heat and/or cooling was expected to add complexity to this process. As a result, staff decided to expedite assessments of two sites connected with the City's existing DEU systems; when a sewer heat recovery facility is added as an additional node to an existing system, project timing constraints are removed, and implementation of a cost-effective project can be expedited.

As a result, the following two sites were chosen in June 2017:

1. Odlin West / ADEU: This would be a combined FOG-extraction and 800 kW sewer heat recovery facility, located adjacent to the Alexandra DEU Energy Centre. The facility would draw wastewater from the nearby West Odlin and/or Odlin pump stations. A location for the proposed facility was identified on City-owned lands. Two different plant configurations identified for costing.

2. Carrera: This would be a combined FOG-extraction and 700 kW or 1000 kW sewer heat recovery facility. The facility would be connected to a small existing natural-gas-powered district energy plant which is to be connected to the expanding Oval Village DEU system in the medium to long-term future. The existing district energy plant currently serves a single development, but might also serve a second development within a few years. The proposed FOG-recovery and sewer heat recovery facility would draw wastewater from a new pump station installed on the nearby Richmond Centre forcemain. Two different plant configurations were identified for costing, including one in which the FOG extraction took place at a separate pump station, upstream of the sewer heat extraction facility.

In September 2017, staff became aware of a potential future funding opportunity for a micro Sewer Heat Recovery facility through the federal government's Low Carbon Economy Fund.

On October 5, 2017, KWL provided staff with a technical memo on the initial design and estimated costs for the two business cases noted above.

During October and November, staff conducted a number of internal discussions to identify the remaining three business cases. Results in the October 2017 technical memo on the first two business cases, as well as discussions with the consultants, indicated that there were large additional infrastructure costs associated with a FOG extraction function, that limited wastewater retention times (driven by limited wet well capacities) would result in less than 50% of the total potentially extractable amount of FOG being captured, and that there were limited cost and process synergies achieved with an integrated FOG extraction and sewer heat recovery facility.

On November 23, 2017 staff decided to proceed with an SHR-only design for the last three business cases:

3. Skyline: A 700 kW SHR-only facility serving a proposed new development located within the City Centre area that would be "district energy ready" but would initially function as a stand-alone system. The proposed development is located very close to an existing pump station scheduled for redevelopment, and the business case assumed that the mSHR facility could be located within the mechanical room of the proposed development.

4. Richmond Centre South: A 1.2 MW SHR-only facility serving a very large proposed new development located within the City Centre area. This multi-building development would be "district energy ready" but would initially function as its own stand-alone system. The proposed FOG-recovery and sewer heat recovery facility would draw wastewater from a new pump station installed on the nearby Richmond Centre forcemain (the same forcemain that would be used in the Carrera business case option). The business case assumed that the mSHR facility could be located in a mechanical room within the proposed development. Note that the size of this facility exceeded the 1 MW limit originally used to scope this study.

5. East Cambie: This business case looked at the installation of a 300kW or 500kW SHR-only facility, drawing wastewater from a new pump station, that would serve the East Cambie neighbourhood service centre if it was to be redeveloped at an FAR of 1.5. This case was deliberately selected to expand the range of project sizes selected, and to investigate options outside of the Richmond City Centre area.

In early December 2017, KWL provided draft business case findings for the Odlin West / ADEU and Carrera business cases. The results confirmed the provisional conclusions noted above regarding the cost-effectiveness of these facilities when designed as integrated FOG-extraction and sewer heat recovery facilities. Staff decided in January 2018 not to proceed with an integrated FOG-extraction and sewer heat recovery facility at either of these two sites.

During 2017-18, the City's Parks Department developed plans to landscape parklands adjacent to the ADEU Energy Centre. While the business case results in fall 2017 indicated that sewer heat recovery was a cost effective option to meet new supply at ADEU, the optimal time to expand ADEU's geoexchange field below the park lands was prior to the park's redevelopment rather than after, and overall energy demand at ADEU was forecast to increase to the point where this additional (low-GHG) geoexchange capacity would be needed. As a result of the decision to proceed with an expanded geoexchange field, there was no longer a short-term need to implement a sewer heat recovery project feeding into ADEU.

KWL provided a draft Phase 2 report in April 2018, reporting results for all five business cases, including the Skyline, Richmond Centre and East Cambie sites. Staff provided comments and requests for clarifications, and a second draft of the Phase 2 report was provided to the City in August 2018. Several additional drafts were required to address unclear writing and resolve inconsistencies in some of the data included in the reports.

KWL provided a draft Summary report in January 2019. Several additional drafts were required to address unclear writing and include key elements of the Phase 1 report within the summary report. Internal staff changes resulted in delays to final sign-off on the Summary Report, which occurred at the end of June 2019.

As of this writing, the key takeaways of the mSHR study are that:

- Richmond has a large and extensive low-carbon sewer heat resource that can be accessed by means of its many pump stations, with most pump stations having an extractable heat resource greater than 1MW (i.e. the maximum project capacity assessed by the project); and that

- The cost-effectiveness of sewer heat recovery facilities is strongly influenced by the capacity of the facility, the amount of new civic infrastructure needed, the distance between the pump station and the load, and the availability of adequate space for the heat exchanger and heating/cooling mechanical systems.

b. What were the objectives of the Feasibility Study (what was it seeking to determine)?

The study was intended to assess the potential for sewer heat recovery (SHR) as a low-carbon heating/cooling option for new development within the City of Richmond. SHR projects might be developed either as isolated district energy nodes that would later connect to a DEU as the City's DEU service areas expanded, or they might be single-building systems or isolated district energy nodes located in other regions of the City that would never be expected to a larger DEU network.

More specifically, the project was intended to produce a city-wide assessment of the heat extraction resource within the municipal sanitary sewer network, as opposed to the central trunk line owned and operated by the regional district (already identified as the resource to be utilized for the Oval Village DEU.

This resource assessment would then be compared against energy loads expected from redevelopment throughout the city. Having assessed potential SHR energy supply, and projected energy demand from redevelopment, five potential SHR projects would be assessed for their cost-effectiveness. The study was scoped to look at SHR projects of up to 1 MW in capacity.[2]

The other principal set of objectives for the study focused on the buildup of fats, oils and grease (FOG) within the municipal sanitary sewer system, whether FOG build-up might be effectively addressed by building facilities to extract this material from points within the sewer system, and whether there might be cost synergies in combining a FOG extraction facility and a sewer heat recovery installation into a single integrated facility. The City provided 100% of the funding for the FOG extraction component of the study.

c. What approach (or methodology) was used in the Feasibility Study to meet these objectives?

Phase 1 of the study finalized in May 2017. This report included:

- An assessment of the current sewer heat resource throughout Richmond and that projected with a build-out of Richmond's OCP in 2041;
- The second phase of the study involved the selection of five business cases by municipal staff.

[2] In Phase 2 of the project, the Richmond Centre case study would assess a project with 1.5 MW of capacity.

- Priority was placed on optimizing the potential for both heat recovery and FOG extraction, and selecting locations suitable for development of a pilot project integrating sewer heat recovery and grease extraction within the short term. For these reasons staff decided to expedite assessments of two sites that would connect with the City's existing DEU systems.

- An assessment of potential heat energy demand within the City Centre area and neighbourhood service centres designated in the OCP, as well as the City's district energy utility (DEU) service areas;

- A review of available sewer heat recovery technologies and available products, and recommended technologies to incorporate in Phase 2 cost assessments; and

- A review of FOG issues within Richmond's municipal sewer system, and the results of a search for FOG extraction technologies (No commercially-available technologies were found).

The Phase 1 report recommended against the use of "in-line" sewer heat recovery technologies, in which a section of existing sewer pipe is replaced with a modified pipe incorporating a heat exchanger. Instead, the Phase 1 report recommended the use of the locally-manufactured SHARC technology, in which a stream of wastewater diverted from a pump station wet well to a facility enclosure nearby, screened, passed through a heat exchanger and then returned to the wet well.

Table 4-2: mSHR Case Definition

Case ID	Case Name	Description
Site 1 – Odlin West/ADEU		
R1a	Ref – BAU	'Business as Usual'. No additional renewables install remaining 7.5 MW of boilers and 2.6 MW of cooling towers. Includes piping extensions.
R1b	Ref – Add'l GHX	Install new 'South Greenway' geoexchange field (300 kW heating/800 kW cooling) in addition to boilers and cooling towers.
1	mSHR – 800 kW	Install 800 kW mSHR system in addition to boilers and cooling towers. No heat pumps.
Site 2 – Carrera/OVDEU		
R2	Ref – Additional 1,500 kW boiler	Install additional 1,500 kW boiler in Interim Energy Centre to provide sufficient N+1 capacity.
2a	mSHR – 700 kW	700 kW mSHR system w/heat pumps in standalone energy plant. No additional boilers.
2b	mSHR – 1,000 kW	1,000 kW mSHR system w/heat pumps in standalone energy plant. No additional boilers.
Site 3 – Skyline/Yuanheng Seaside		
R3	Ref – Gas Boilers	3,200 kW condensing boiler plant
3	mSHR – 700 kW	700 kW mSHR system w/heat pumps + 2,400 kW peaking boiler plant
Site 4 – Richmond Centre		
R4a	Ref – Gas Boilers Phase 1	3,600 kW condensing boiler plant
4a	mSHR – Phase 1 (1,000 kW)	1,000 kW mSHR system w/heat pumps + 2,700 kW peaking boilers
R4b	Ref – Gas Boilers Phase 1 + 2	6,300 kW condensing boiler plant
4b	mSHR – Phase 1 + 2 (1,500 kW)	1,500 kW mSHR system w/heat pumps + 4,500 kW peaking boilers
Site 5 – East Cambie		
R5	Ref – Gas Boilers	1,500 kW condensing boiler plant
5a	mSHR – 300 kW	300 kW mSHR system w/heat pumps + 1,000 kW peaking boilers
5b	mSHR – 500 kW	500 kW mSHR system w/heat pumps + 1,000 kW peaking boilers
Note: Site 1 cases included heating and cooling, while Sites 2 to 5 are heating-only.		

While the consultant concentrated efforts on the first two business cases, staff considered options for the remaining three business cases. When interim results on the first two business cases indicated that integrating FOG extraction with SHR would be costly, and have few cost and process benefits, staff decided to proceed with an SHR-only design for the last three business cases. These three cases consisted of a single-building SHR facility that would later connect to a DEU, a larger multi-building DEU node that would later connect to a main DEU network, and a small stand-alone DEU node outside of the city centre area.

The study produced an overall assessment of sewer heat energy resources within the city, as well as cost assessments for SHR (or integrated SHR and FOG-extraction) facilities in five different locations. While there was interest in moving forward quickly on an integrated SHR and FOG-extraction facility, the results of the study did not support further development of such a project. Costing results were positive for an SHR-only facility connected to ADEU, but a decision to proceed with expanding geoexchange (rather than lose the potential to do in the future), removed the short term need to add heating and cooling capacity at ADEU.

Please refer to the response to question A above for more details.

d. ***Please describe any public consultations conducted as part of the Feasibility Study and their impact on the Study.***

As an overall resource assessment and initial costing study of potential project options which were not approved for further development at the current time, there were no public consultations conducted as part of this study.

3. Feasibility Study Findings and Recommendations

a. What were the environmental findings related to the options explored in the Feasibility Study? Please provide quantitative results and summary tables of these results (or the page numbers from the Feasibility Study report).

Assessed Sewer Heat Resource:

Phase 1 of the study provided an assessment of the sewer heat resource available within Richmond's municipal sanitary sewer system in 2017 and that projected with a build-out of Richmond's OCP in 2041. The estimate of the available heat resource was based on modelling calibrated with actual temperature data from six pump stations, and the City's hydraulic model.

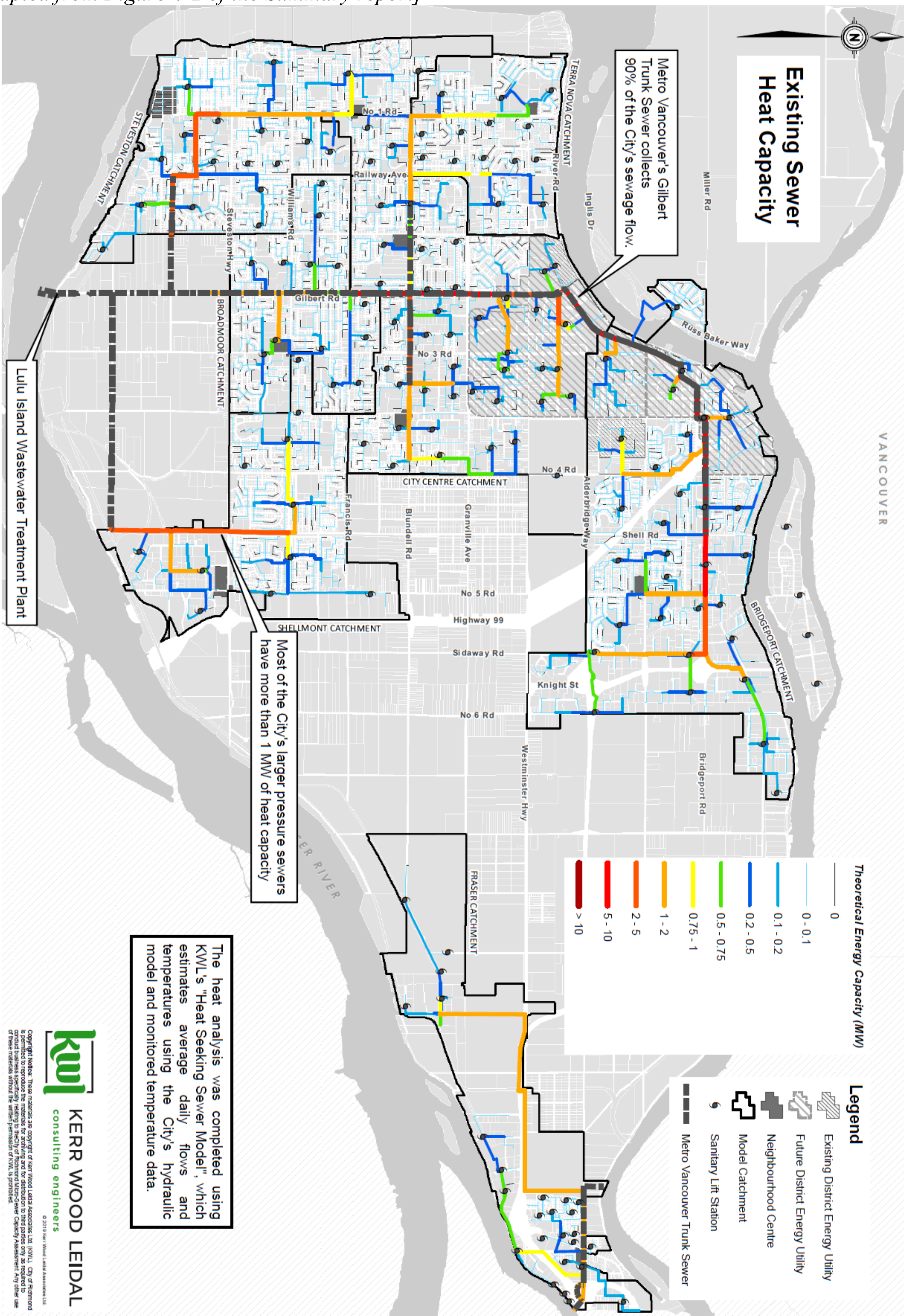
[from p.4-9 of the Phase 1 report]

Table 4-5: Sewage Heat Available to District Energy Areas

Pump Station	Area	Existing Flow (L/s)	OCP Flow (L/s)	Existing Heat Capacity (kW)	OCP Heat Capacity (kW)
ODLIN WEST	**ADEU**	**25**	**40**	**795**	**1,109**
BRIGHOUSE	BRIGHOUSE	32	63	1,009	1,981
BUSWELL	BRIGHOUSE	15	22	472	677
ECKERSLEY A	BRIGHOUSE	8	12	257	375
ECKERSLEY B	BRIGHOUSE	6	19	180	592
RICHMOND CENTRE	BRIGHOUSE	13	45	393	1,428
Subtotal - Brighouse		**74**	**161**	**2,311**	**5,053**
ACKROYD	CCN	4	21	113	648
BRIDGEPORT	CCN	211	257	6,613	8,066
CAPSTAN	CCN	19	1	610	36
SKYLINE	CCN	40	40	1,263	1,243
VAN HORNE	CCN	24	57	749	1,777
Subtotal - City Centre North		**298**	**375**	**9,348**	**11,770**
ALDERBRIDGE	LANSDOWNE	13	35	409	1,103
ALDERBRIDGE WEST	LANSDOWNE	6	15	200	469
ARCADIA	LANSDOWNE	15	16	480	487
LANSDOWNE	LANSDOWNE	6	6	174	196
LESLIE	ABERDEEN	20	104	626	3,263
Subtotal - Lansdowne / Aberdeen		**60**	**176**	**1,889**	**5,518**
ELMBRIDGE	OVDEU	10	38	327	1,207
MINORU	OVDEU	38	70	1,202	2,190
OVAL	OVDEU	4	14	126	453
Subtotal - OVDEU		**53**	**123**	**1,654**	**3,850**
TOTAL		**510**	**874**	**15,997**	**27,447**

Notes:
(1) Capstan Pump Station previously serviced a larger area, which is now serviced by gravity sewers draining to Skyline Pump Station.
(2) Heat capacity is based on a 5 ºC sewage delta T plus the compression heat from heat pumps at a COP of 3.
(3) OCP flows are based on the high-range scenario.

[adapted from Figure 4-2 of the Summary report]



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[from p.4-8 of the Phase 1 report]

Table 4-4: Sewage Heat Available to Neighbourhood Nodes

Node	Existing ADWF	OCP ADWF	Existing Heat Capacity[1]	OCP Heat Capacity[1]	Peak Heating	Existing Supply / Demand Ratio	OCP Supply / Demand Ratio
	L/s	L/s	kW	kW	kW		
Blundell	26.7	43.8	837	1376	1,939	43%	**71%**
Broadmoor	30.7	42.9	964	1346	865	**111%**	**156%**
East Cambie	33.3	33.5	1047	1052	1,558	**67%**	**68%**
Garden City	47.7	67.0	1497	2102	1,646	**91%**	**128%**
Hamilton	65.9	66.8	2070	2097	1,713	**121%**	**122%**
Ironwood	19.4	34.6	609	1088	3,013	20%	36%
Seafair	34.0	36.4	1067	1142	1,084	**98%**	**105%**
Steveston	16.2	99.3	509	3117	2,919	17%	**107%**
Terra Nova	23.3	29.2	731	917	798	**92%**	**115%**
Total			**9331**	**14239**	**14,528**	**64%**	**98%**

Note: (1) Assumes a heat pump COP of 3.0, which results in 1.5 times the output of the in-pipe sewage heat capacity.

<u>Findings with regard to Sewer Heat Recovery:</u>

[From p.5-6 to 5-7 of the Summary Report]

Greenhouse gas emissions were calculated from the gas and electricity use in each [of the five business cases assessed]. The GHG emissions factors used were 180 kg/MWh for natural gas and 10 kg/MWh for BC Hydro grid electricity, as per the 2016 BC Best Practices Methodology for Estimating Greenhouse Gas Emissions. The following graphs show the total emissions and emissions intensities for the reference and mSHR cases.

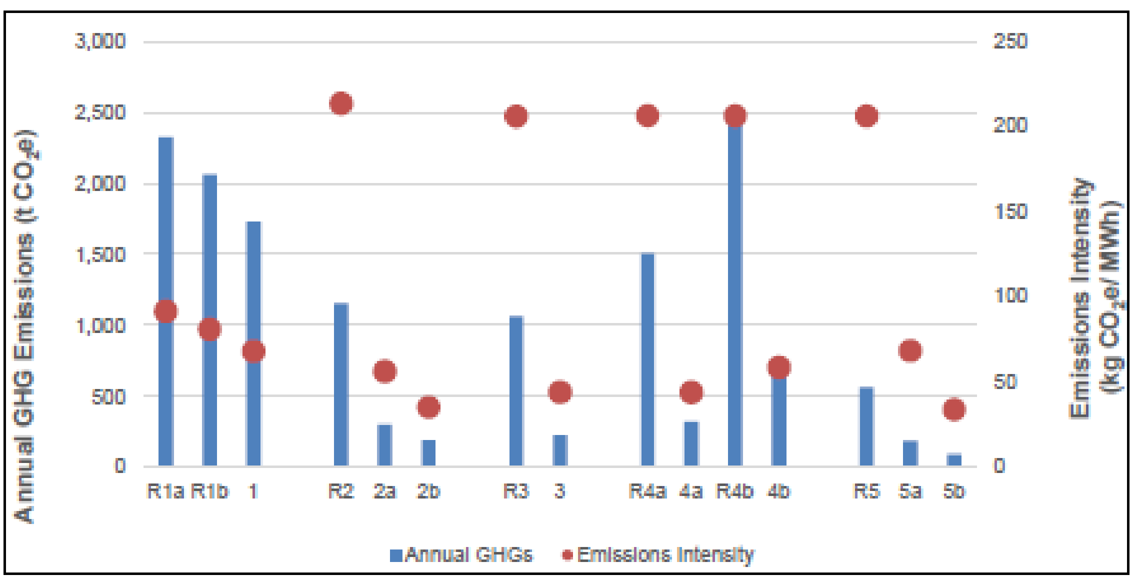

Figure 5-3: Annual GHG Emissions and Intensities

As would be expected the reference cases [relying on natural gas heating] have significantly higher GHG emissions than the mSHR cases. Most of the mSHR cases have emissions intensities below 50 kg CO2e/MWh. [In the reference cases for the ADEU site - "R1a" and "R1b" – most of the energy consumed is already provided by a low-GHG geoexchange system].

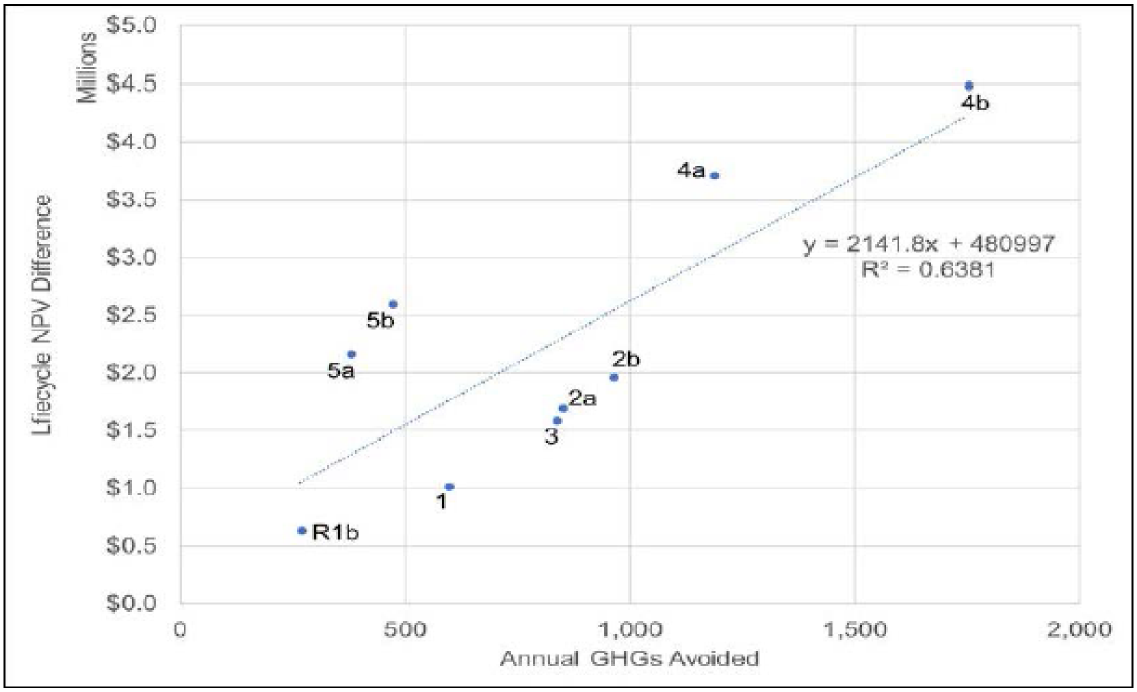

Figure 5-5: GHGs Avoided versus Lifecycle NPV Premium

The avoided cost of GHG emissions was calculated as the ratio of the difference in net present value between the comparable reference cases and mSHR cases. There was not a strong correlation between the magnitude of GHGs avoided and the marginal cost as shown in the following graph, which suggests that the individual site conditions play a strong role in determining the efficacy of using mSHR as a low-carbon energy source.

b. What were the financial findings related to the options explored in the Feasibility Study (for example, results of a cost-benefit analysis, financial savings identified, and so on)? Please provide quantitative results and summary tables of these results (or the page numbers from the Feasibility Study report).

Findings with regard to Sewer Heat Recovery:
[From p.5-2 to 5-8 of the Summary Report]

The following table summarizes the estimated capital costs for each case example. The mSHR cases have higher capital costs than the Reference Cases, which is to be expected.

The capital costs of the mSHR systems vary from about $2,400/kW to $6,500/kW. Unit cost allowances for peaking boilers are similar across all options. The mSHR unit costs are mostly affected by the distance from the source sewers and economy of scale. This is illustrated in the following graph. Site 1 [ADEU] is not included in the trendline as it does not provide the same level of service as the other projects, but otherwise has the lowest unit cost of all the mSHR projects.

The overall business case for any given site can generally be described in terms of its unit cost of energy over the project lifecycle, risk profile and cost effectiveness at reducing GHGs. Case 1 [Odlin West / ADEU] has similar unit energy costs as its reference cases. Sites 2 [Carrera], 3 [Skyline], and 4 [Richmond Centre] have similar lifecycle unit energy costs, as shown in the following graph. They are all higher than using gas boilers with natural gas. Cases 5a and 5b [Cambie East, with the smallest heat exchanger capacities studied] are considerably higher than all the other cases.

Table 5-1: Capital Cost Summary for mSHR Projects

Case	Mechanical/ Electrical/ Equipment	Buildings and Civil	Total
R1a	$1,810,000	$1,360,000	$3,170,000
R1b	$1,810,000	$2,720,000	$4,530,000
1	$3,480,000	$1,630,000	$5,110,000
R2	$400,000	$0	$400,000
2a	$2,510,000	$900,000	$3,410,000
2b	$2,830,000	$900,000	$3,730,000
R3	$910,000	$0	$910,000
3	$2,750,000	$120,000	$2,870,000
R4a	$1,110,000	$0	$1,110,000
4a	$3,700,000	$1,520,000	$5,220,000
R4b	$1,810,000	$0	$1,810,000
4b	$5,470,000	$1,520,000	$6,990,000
R5	$420,000	$0	$420,000
5a	$1,870,000	$210,000	$2,080,000
5b	$2,330,000	$210,000	$2,540,000

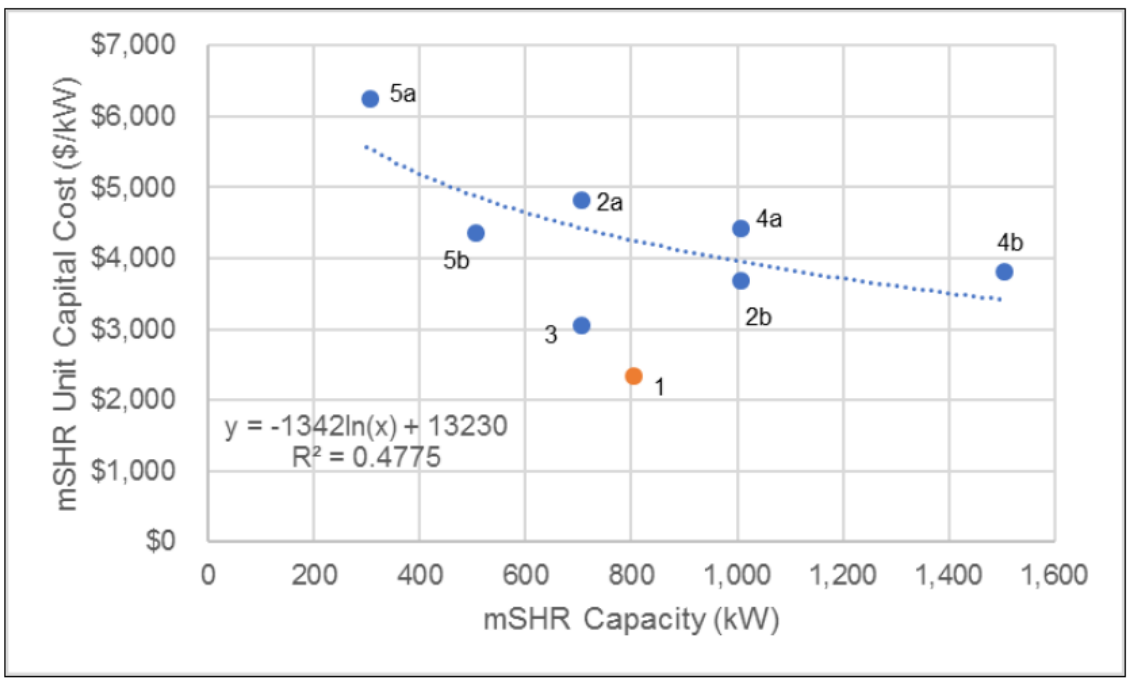

Figure 5-1: Unit Cost of mSHR Facilities vs mSHR Capacity

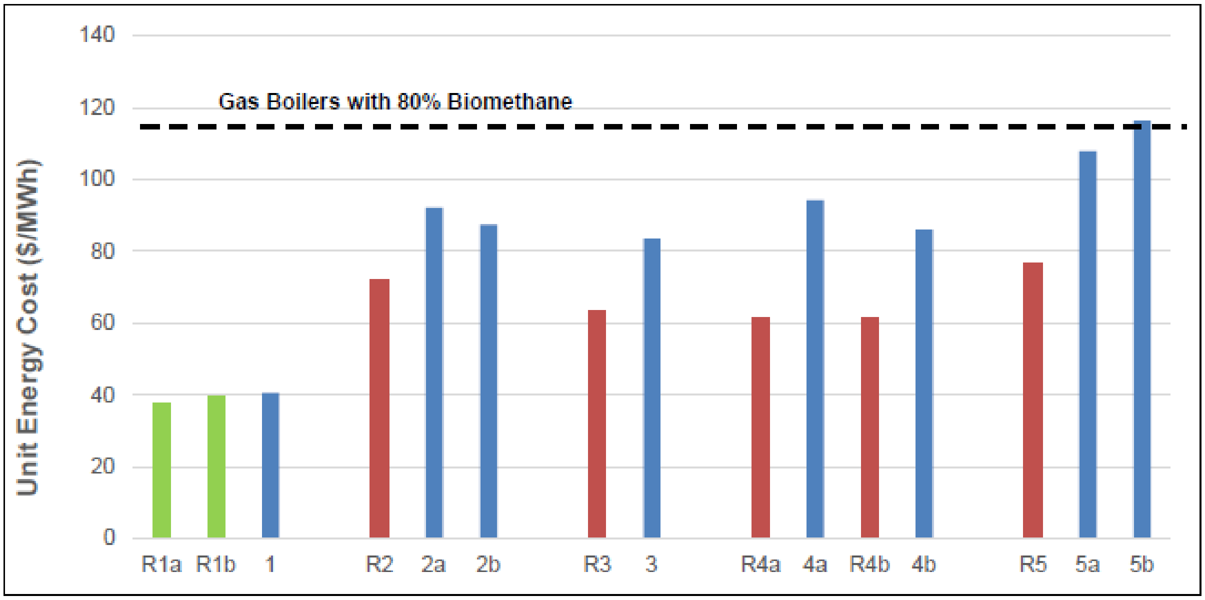

Figure 5-4: Lifecycle Unit Energy Costs

From this analysis, Site 3 (Skyline) is shown to have the lowest unit capital cost of mSHR projects that include heat pumps[3] for the following reasons:

1. This project is conceived as being executed simultaneously with the replacement of Skyline PS, so the project can be purpose-built to accommodate mSHR;

2. The distance from the sewage source to the mSHR plant is minimal; and

3. The sewage source is a pump station, which allows the simplest configuration for diverting sewage for heat recovery.

[However, the Skyline development was already well-advanced at the time of the study. Integrating sewer heat recovery into the project design would have resulted in design changes and significant process delays, and this option was not pursued.]

Sites 2 and 4 (Carrera/Richmond Centre) have relatively high civil costs compared to the other sites. This is because the mechanical plants are located about 200 m from the forcemains, and Site 4 requires an underground pump station.

The most expensive options on a dollar per kilowatt basis are for Site 5 (East Cambie), since this case has the smallest installed capacity.

The case study projects indicate a minimum lower-bound cost for any mSHR project may be approximately $2 million.

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[3] Site 1 (Odlin West / ADEU) does not require heat pumps

Table 5-4: Lifecycle Analysis Results for mSHR Projects

Case ID	Capital Cost	Annual O&M Cost (2018 $)	25-year Lifecycle NPV	Annual Avoided GHG Emissions (t CO_2e)	Marginal Cost of Avoided GHGs ($/t CO_2e)	Average Unit Cost of Energy ($/MWh)
Site 1 – Odlin West/ADEU						
R1a	$3,200,000	$520,000	14,000,000			38
R1b	$4,500,000	$520,000	14,600,000	267	90	40
1	$5,110,000	$470,000	15,000,000	594	67	41
Site 2 – Carrera						
R2	$400,000	$380,000	$6,100,000			72
2a	$3,410,000	$283,000	$7,800,000	848	80	92
2b	$3,730,000	$279,000	$8,000,000	962	82	87
Site 3 – Skyline						
R3	$910,000	$274,000	$5,100,000			64
3	$2,880,000	$248,000	$6,700,000	834	77	83
Site 4 – Richmond Centre South						
R4a	$1,110,000	$403,000	$7,000,000			62
4a	$5,220,000	$355,000	$10,800,000	1185	126	94
R4b	$1,810,000	$678,000	$11,400,000			62
4b	$6,990,000	$570,000	$15,900,000	1750	103	86
Site 5 – East Cambie						
R5	$420,000	$190,000	$3,300,000			76
5a	$2,080,000	$184,000	$5,400,000	376	231	108
5b	$2,540,000	$186,000	$5,900,000	471	221	116

Note: Case 1 capital costs include all long-term upgrades to ADEU, equal to the capital cost of R1a. Other cases only include sewage supply and energy centre costs. Case 2 capital costs do not include any components for FOG removal.

Findings with regard to Sewer Heat Recovery:
[From p.5-9 to 5-10 of the Summary Report]

The total net present cost of ownership and operation of the [FOG extraction] facilities is expected to range from roughly $1.6 million to $5 million over 25 years. This translates to an average annual cost of $60,000 to $200,000 per facility. In terms of overall cost impacts to ratepayers [of Richmond's freshwater supply utility], adding a FOG removal facility would roughly amount to a $10 to 20 annual fee increase per housing unit, a 5% to 10% over current rates [assuming costs would be recovered on the basis of fresh water consumed.]

This initial estimate of ongoing costs for a FOG removal facility provides a useful point of comparison with the cost of source control and education measures. The comparable 'business-as-usual' approach is assumed to have zero additional costs; therefore, all of the above costs are considered additive.

Table 5-5: Lifecycle Cost Results for FOG Removal Facilities

Net Present Value	Site 1 – Integrated	Site 2 – Integrated	Site 2 – Non-Integrated
FOG Concentration (mg/L)	**40**	**60**	**60**
FOG Removal (%)	**50%**	**50%**	**70%**
Capital Cost	$1,900,000	$2,400,000	$700,000
Fixed O&M Cost	$460,000	$980,000	$130,000
Variable O&M Cost	$880,000	$1,730,000	$760,000
Total – NPV	**$3,240,000**	**$5,110,000**	**$1,590,000**
Average Annual Cost (NPV)	**$129,600**	**$204,400**	**$63,600**
Equivalent Population Upstream (PE)	15,000	16,000	11,000
FOG Removed (Avg. Annual kg)	26,000	41,000	26,000
Wastewater Treated (avg. Annual m^3)	1,200,000	1,300,000	900,000
Cost/Population Equivalent	**$8.4**	**$10.6**	**$5.6**
Cost/kg FOG Removed	**$4.9**	**$4.1**	**$1.6**
Cost/m^3 Treated	**$0.10**	**$0.12**	**$0.07**

c. ***Based on the environmental and financial findings above, what does the Feasibility Study recommend?***

[From p.6-2 of the Summary Report]

For Sites 1 [Odlin West / ADEU], 2 [Carrera], and 3 [Skyline], the business case analysis showed promising outlooks for introducing mSHR. Further due diligence is required prior to proceeding with implementation, so in the meantime sewer flow and temperature data should be collected at these locations. The case for mSHR at Site 4 (Richmond Centre South) was not as good as Site 2, but it may be possible to connect the Carrera and Richmond Centre South developments to a common DES in order to improve cost-effectiveness. Site 5 [Cambie East] has no current plans for development but would be representative of other Neighbourhood Centres when redevelopment takes place at one of these sites.

The study found few potential benefits by integrating FOG and mSHR systems. Other similar mSHR systems in North America and Europe did not identify FOG build-up as a maintenance issue, and the preferred SHARC mSHR system was found to be not capable of screening FOG.

In the cases where integrated mSHR/ FOG sites were considered (Site 1 – Alexandra DEU and Site 2 – Carrera), the lifecycle cost of FOG removal was significantly higher than for non-integrated FOG removal upstream of a pump station. The capital costs of the mSHR facilities were not significantly reduced by integrating FOG removal systems with the designs.

Further risk assessment and FOG data should be collected before considering adding a FOG removal system, and the business case re-assessed at any potential future locations. FOG removal value and effectiveness relative to other FOG management options (e.g., source control, public outreach) should be considered prior to implementing a FOG removal system.

Overall, while none of the business cases analyzed in the report have yet proceeded, and some have been ruled out due to development timing (i.e., too late to integrate micro sewer heat recovery as a solution), the findings of this study showed that a positive NPV business case could be achieved at all sites. In three of the cases, the $ / MWh thermal rate figures are very good, along with significant amounts of GHGs avoided at relatively low cost.

4. Lead Applicant's Next Steps

a. ***Taking the Feasibility Study's recommendations into account, what next steps do you as the municipality plan to take? What potential benefits or internal municipal improvements would result from these next steps?***

Staff are pursuing opportunities to secure funding for development of a ~1MW sewer heat recovery facility at Carrera (Business Case #2) – a potential project that was initially identified through this study. As a result of the analysis conducted by this study, the City is currently assessing an SHR-only facility, (i.e. without any integration of FOG extraction technologies). As shown in the study results above, adding an SHR facility to this isolated DEU node would greatly reduce GHG emissions produced by the DEU plant, while significantly expanding its overall heating capacity.

Staff are continuing to move forward with plans to implement a large-capacity sewer heat exchange facility accessing the regionally-operated Gilbert sanitary sewer line, which can provide a considerable fraction of total heating and cooling demand of the Oval Village District Energy Utility. Even if the City proceeds with development of a large SHR facility on the Gilbert sewer, staff expect there will still be many locations suitable for the development of smaller SHR projects within Richmond.

Since major work on this study has been completed, Council has directed staff to "to gain feedback from residents and stakeholders regarding the recommended revised greenhouse gas (GHG) reduction target and revised climate action strategies and measures consistent with and in response to the UN's Intergovernmental Panel on Climate Change report." Staff are now assessing a range of options to dramatically reduce GHG emissions across the City, including increased use of low-GHG energy sources, and increased opportunities for compact, complete communities, and intend to present Council with recommendations in early 2020. Staff are mindful of the findings of this report, which show a large and extensive sewer heat resource throughout the City that could provide a low-GHG option for heating and cooling, especially within larger-scale developments, where the technology's efficiencies of scale may prove to be very cost-effective.

Since major work on this study has been completed, staff have also begun assessing potential options to encourage an increased intensity of land use with industrially zoned areas of the city. Given the higher wastewater temperatures associated with industrial land uses and the large building floorplates of industrial-zone buildings, staff believe that sewer heat recovery could be a promising option for redevelopment projects within industrial areas, particularly given the City's focus on achieving significant GHG reductions while fostering economic development.

Based on the findings of this report and lessons learned (see below), future assessments of potential sewer heat recovery projects may include consideration of intermediate-scale facilities and "in-line" SHR technologies, as this appears likely to yield an increased range of opportunities in which SHR might be a preferred solution.

5. Lessons Learned

In answering the questions in this section, please consider all aspects of undertaking the Study — from the initial planning through each essential task until the Final Study was prepared.

a. ***What would you recommend to other municipalities interested in doing a similar Feasibility Study? What would you do differently if you were to do this again?***

Perhaps the biggest takeaway of this study is that there appears to be a very significant sewer heat resource available at locations throughout the urban developed area of Richmond. That said, there appear to be three critical determinants for the cost-effectiveness of a SHR project:

- It needs to be close to a sewer heat resource;
- It needs to have sufficient energy demand to achieve economies of scale;
- There needs to be sufficient time to assess, and design the SHR project, so that this component does not threaten to impact overall development project timelines.

In different ways, methodology choices inadvertently reduced the extent of "close-by" sewer heat resources that could be considered, and prevented SHR resources with better efficiencies of scale from being considered.

Less avoidably, the normal time limitations involved with a study like this also likely had an effect in limiting the range of business case studies that could be considered. Of the five business cases studied, the two most likely to proceed were connected to an existing City-operated DEU, precisely because these projects were the ones that were most flexible in terms of project timing. There is much more flexibility for starting and completing a SHR facility when it links into an existing DEU system; it is crucial that an SHR facility supplying a single building or an isolated DEU node be completed prior to the development it is intended to serve.

The maximum project capacity should be limited only by available resource or project demand:
When the project was originally scoped, the intent was to study the potential heat resource within the smaller municipal sewers that flow into the main regional trunk rather than the main sewer itself (which had previously been studied). Setting a 1 MW upper limit on the capacity of systems to be assessed may have done to highlight this focus on "smaller" resources. However, there are strong economies of scale with larger capacity projects, and the modelled assessment of Richmond's sewer heat resources indicated that many of the tributary sewers within Richmond have an extractable heat resource well in excess of 1 MW. Maintaining the 1 MW limit on opportunities for consideration may have limited range of project opportunities that could have been investigated, and may steered the analysis towards smaller, less cost-effective projects. In the end, one of the five business cases (Richmond Centre) business case was costed out assuming an SHR capacity of 1.2 MW – but other larger-scale opportunities may well have overlooked as a result.

The analysis should cost projects using both off-line and in-line SHR technology options:
The modelled sewer heat resource map for Richmond indicates that there is a two dimensional "tree" of heat resources stretched across much of the City, with many larger forcemains located along arterial roads which could potentially be zoned for higher-density developments. Unfortunately, staff concurred with the consultant's recommendation that only one SHR technology be considered when developing business cases – a locally-produced "off-line" technology that can only be installed at pump stations. While Richmond has an unusually large number of pump stations, this decision meant that the heat resource available for case studies was reduced to a scatter of points within the city, greatly reducing the chance that a specific location would be located in close proximity to a heat resource. The impact of this decision was not appreciated by anyone involved in the study at the time, but it is striking that of the five business cases assessed, four involved the construction of a new, otherwise redundant pump station, generally located at the located at the closest point on an existing forcemain to the proposed development served by the SHR facility. Doing this had a significant impact of capital costs of these projects, and it is not surprising that the project with the best cost-productivity ratio was the one business case that utilized an existing pump station. The technology review in the study noted that no in-line SHR technologies are manufactured in North America, and that there are considerable cost and operations issues in digging up and switching out a length of operating sanitary sewer forcemain. What remains unclear is whether these costs would have exceeded the alternative of constructing a new pump station instead.

Put more priority on resource assessment and model calibration:
One of the strengths of the consultant leading this study was their in-house sewer heat resource model, which had been developed as a result of similar studies in the past. This model enabled the consultant to generate a City-wide model of sewer heat resources very quickly, which was very impressive. The study design also dedicated resources to gathering actual temperature data from a number of pump stations within Richmond's sanitary sewer system expressly so that the model could be calibrated. Unfortunately, the relatively aggressive pace of the study during its first phase meant that the calibration of the model was done on the basis of only three months of data, even though the monitors continued to collect data after this time. By the time the final three business cases were selected, these monitors would have collected a full year of data, which might have been used to further calibrate the model and increase confidence in its outputs. The outputs provided by the model were also notable for stressing seasonal variations; warmer and smaller flows in summer, versus larger and colder flows during the rainy winter months, driven both by ambient temperatures and inflows of groundwater into the sanitary system (via leaks and/or combined stormwater/sanitary overflow structures within the pipe network). What appeared seemed to be somewhat overlooked were daily variations in flow: there is not a lot of domestic water consumption in the middle of the night. While demand for heating during nighttime minimums appears to coincide with the low nighttime sanitary sewer flows, it is unclear to what extent these daily variations were factored into the overall heat resource assessment: the final summary report simply notes that
"Operating risks include insufficient sewage flow for heat recovery, (such as during night-time minimum flow periods)…" As a result, a similar study might want to consider scheduling extended low-intensity first phase in which extensive data is gathered in order to better calibrate a resource model. One of the few other tivities that might be carried out at this time would be to inform planning development staff of study, and the expected location of significant sewer heat resources (i.e. along larger-diameter sewer collector lines, and at pump stations associated with these larger pipes), with a view to having planning staff inform project proponents of the potential for this kind of low-carbon heating solution as soon as the project proponents inform staff of new development plans.

It takes a significant amount of time to develop an SHR project from scratch; the private sector (rather than the City itself) initiates most development projects; project designs for larger developments can be fairly advanced before a project proponent even begins to engage with City, and project proponents seek to avoid any delays during permitting processes. As a result, if a private development were to incorporate SHR, it would be necessary to engage the developer on this possibility very soon after they first approach the City with their development proposal. Starting a new SHR project with an extended information gathering phase might help identify potential project opportunities at an early enough stage to coordinate the study and development project timelines more effectively.

b. ***What barriers or challenges (if any) did you encounter in doing this Feasibility Study? How did you overcome them?***

6. Knowledge Sharing

a. ***Is there a website where more information about the Feasibility Study can be found? If so, please provide the relevant URL.***

This report is not currently available on the City's website. Results of the study will be communicated to Council later this year.

b. ***In addition to the Feasibility Study results, has your Feasibility Study led to other activities that could be of interest to another municipality (for example, a new policy for sustainable community development, a series of model by-laws, the design of a new operating practice, a***

manual on public consultation or a measurement tool to assess progress in moving toward greater sustainability)? If so, please list these outcomes, and include copies of the relevant documents (or website links).

As noted above, staff are continuing to seek co-funding for the proposed SHR-only project at Carrera (Business Case #2), as well as the large SHR facility utilizing the very large sewer heat resource in the regionally-operated Gilbert trunk sewer, which would offset heating and cooling demand by the large existing Oval Village DEU system.

There are extensive reports to Council, bylaw and other documents produced by the Lulu Island Energy Company (LIEC) that would be of potential use to other municipalities with a district energy utility, or with plans to develop one. Visit the LIEC website at: http://www.luluislandenergy.ca/

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