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Geothermal Heat Energy Potential for Small Communities in Alberta, Canada

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ABSTRACT

Here we examine the potential of sedimentary basin derived geothermal heat and power production for small communities (populations >3k - <10k), with specific focus on the Canadian province of Alberta, which is underlain by the Western Canada Sedimentary Basin (WCSB). The range of feasible net geothermal heat and geothermal power production was assessed by adjusting the specific heat capacity of low salinity brines (some 4200 J/kg K) down to much lower (3150 J/kg K) for the brines found in deep aquifers of the WCSB. For the deepest regions in the Alberta foreland basin (adjacent to the Rocky Mountains) geothermal energy power was assessed as up to 2.2 MWe (e - electrical), and 10 times that for thermal (MWt) for a doublet system. Heating represents more than 80% of energy use in small Alberta communities. Our results show 1 to >20 MWt is possible for a geothermal heat production system, capable of heating hundreds up to maximum of 4,000 households possible on a single doublet well system to meet these needs.

1. INTRODUCTION

In Canada, space heating is the dominant energy demand in single households, representing majority of energy usage. Statistics Canada (2018) states that the typical Alberta household energy use is about 7200 kWh of electricity and 130 GJ of natural gas per year. Natural gas furnaces are the dominant heating systems in Alberta. Yearly Alberta household natural gas use represents on average 7293 kg/year of CO_2 emissions. The 2016 census reported Alberta had a population of 4,067,175 living in 1,527,678 total dwellings. Since most heating comes from natural gas, we can estimate that this relatively clean energy resource (comparing to coal) still emits some 12 Mtonns of CO_2 annually. Majorowicz and Moore (2014) showed that installing geothermal heating systems might reduce a large proportion of CO_2 emissions annually and 1000 geothermal systems would save approximately 10MT - 30MT CO_2/year.

Previously we analyzed potential of geothermal heating for the 26 large communities in Alberta populations >10k, with a combined total population >2,500,000 (Majorowicz and Grasby, 2020). The most prospective formations studied in the past and compiled by Weides and Majorowicz (2014), as listed in Table 1. Here we further this work by assessing the potential associated with smaller communities, those with populations >3k - 10<k shown in Figure 2 and are listed in Table 2.

Where feasible, geothermal energy used in heat or power production could cut fossil energy emissions by communities, directly reducing community CO_2 emissions, and helping to support the transition to a green economy. The offset of fossil fuels by clean and renewable geothermal sources could be most significant in higher latitude regions, where cold winter climates create heating demands that exceed that of power, such as in much of Canada (Grasby et al., 2011; Majorowicz and Grasby, 2019). A crucial constraint for such geothermal development though is the proximity of the geothermal well systems to the load, given the high costs for piping and heat loss that occurs over larger distances (Horne, 1988, Agemar et al., 2015; Limberger et al., 2018;). Therefore, assessment of the geothermal potential of a region requires analyses of the potential near individual communities.

Temperature-depth conditions in Alberta have been extensively studied from corrected bottom hole temperature (BHT), Drill Stem Test (DST) temperatures and Annual Pool Pressure (APP) tests by Lam and Jones, 1984;1985;1986; Jones et al., 1985; Jones and Majorowicz, 1987; Majorowicz and Jessop, 1981; Jessop, 1990a,b; 2008; Majorowicz and Grasby, 2010; Grasby et al., 2011; Gray et al., 2012; Majorowicz and Moore, 2014; Weides and Majorowicz, 2014; Majorowicz and Weides, 2015; Majorowicz et al., 2014a,b; Nieuvenhuis et al., 2015; Majorowicz, 2016). Since BHTs and DST temperatures are recorded in wells in non-equilibrium thermal conditions several corrections for return to equilibrium were applied, like the Horner correction used by Lam and Jones (1984), Majorowicz and Jessop (1981), Nieuvenhuis et al. (2015), or a statistical correction like the Harrison – SMU" correction described by Blackwell and Richards (2004) and Crowell et al. (2012) used by Weides and Majorowicz (2014), Majorowicz and Weides (2015), and Nieuvenhuis et al. (2015). For comparison of uncorrected and corrected temperature records in Alberta see Majorowicz and Grasby (2019). In Alberta, there are very few equilibrium temperature (T) depth (z) continuous logs to constrain calculated equilibrium point T values over 2 km depth. Limited examples include the 2363 m deep AOC Granite-Hunt well, a well drilled into basement granitic rocks ~ 30 km west of Fort McMurray (Majorowicz et al., 2014b).

Previous work has shown that the highest temperature gradients are derived from APP T(z) data recorded after shut in well tests, as compared to gradients derived from DST and corrected BHTs (Majorowicz and Grasby, 2019;2020). After applying Harrison-Blackwell corrections the DST and BHTs gradients were more consistent with the APP T gradients.

With this contribution we hope to refocus the search for geothermal energy to where it is needed, as compared to where you can produce the most, given the large transmission losses. Producing these catalogues of basic feasibility for geothermal use for the 3-10k population communities throughout the Alberta part of the WCSB basin can aid this effort.

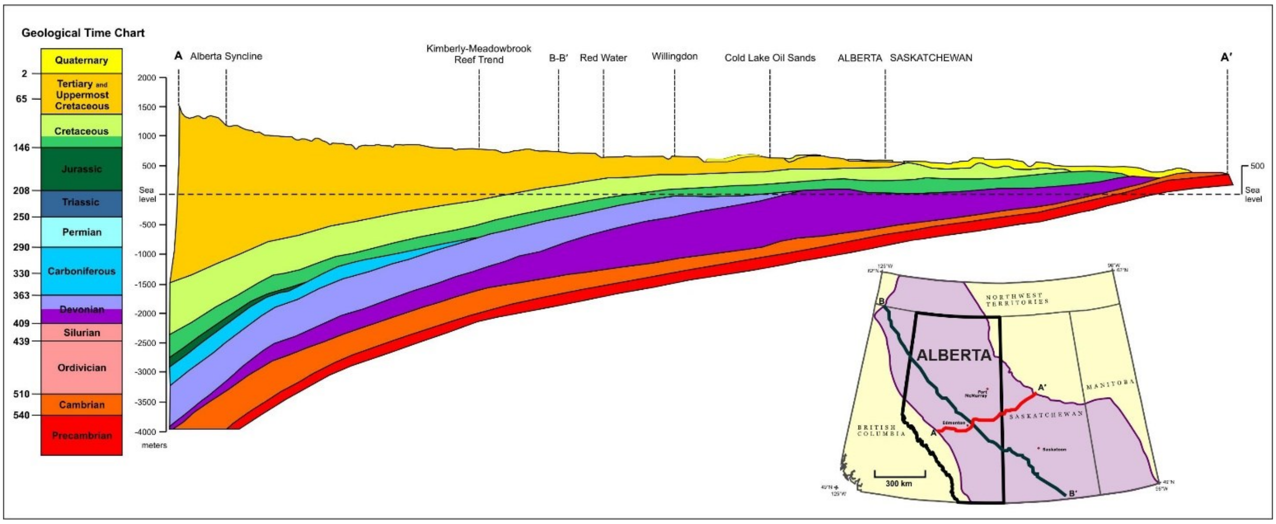

Fig. 1: Study area – 2D Geometry of the Western Canada Sedimentary basin's major geological units shown across Alberta and part of Saskatchewan Provinces, Canada and approximal geological time chart. Study area of Alberta is shown with thicken border line.

Table 1: List of formations and predominant lithology in Alberta

Period	Group	Formation	Lithology
Cretaceous	Mannville		sandstone
Cretaceous	Mannville	Cadomin	sandstone & congl.
Mississippian	Rundle		carbonates
Mississippian	-	Charles	carbonates
Mississippian	-	Banff	limestone
Devonian	Wabamun	Wabamun	dolomite
Devonian	Winterburn	Nisku	carbonates
Devonian	Woodbend	Grosmont	dolomite
Devonian	Woodbend	Leduc	dolomite
Devonian	Woodbend	Cooking Lake	reefal carbonates
Devonian	Beaverhill Lake	Slave Point	reefal carbonates
Devonian	Beaverhill Lake	Swan Hills	reef carbonates
Devonian	Elk Point	Pine Point	dolostone
Devonian	-	Granite Wash Unit	sandstone
Cambrian	Lynx	Deadwood Fm.	sandstone
Cambrian	-	Basal Sandstone Unit	sandstone

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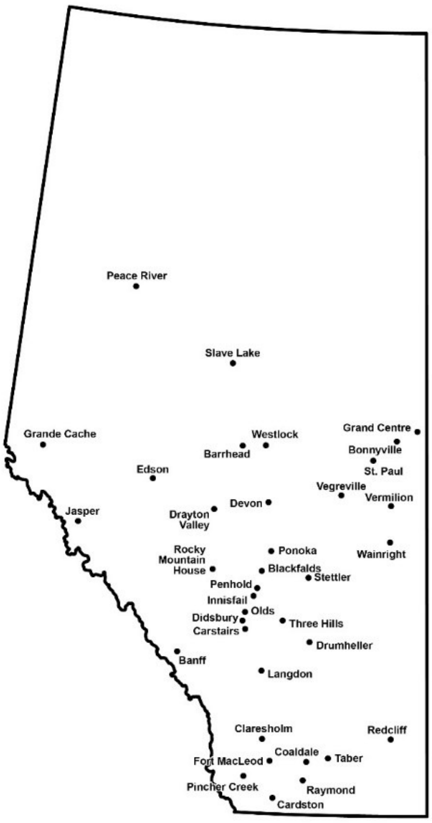

Fig. 2: The small Alberta centres with 3k to 10k populations analyzed for geothermal potential shown by black points.

Table 2. List of population centres 3-9 k in Alberta

Rank	Name		Population2016	Population 2011	Change
1	Olds	Small	8944	8025	0.115
2	Blackfalds	Small	8749	6123	0.429
3	Taber	Small	8199	7677	0.043
4	Coaldale	Small	8153	7239	0.126
5	Edson	Small	8148	8214	-0.008
6	Banff	Small	7851	7854	0.035
7	Grand Centre	Small	7256	6868	0.056
8	Innisfail	Small	6927	7208	-0.039
9	Ponoka	Small	6899	6505	0.061
10	Drayton Valley	Small	6867	6751	0.017
11	Cold Lake	Small	6678	6131	0.089
12	Devon	Small	6578	6515	0.01
13	Drumheller	Small	6439	6582	-0.022
14	Rocky Mountain House	Small	6429	6687	-0.039
15	Slave Lake	Small	6155	6517	-0.056
16	Wainwright	Small	6153	5803	0.06
17	Stettler	Small	5862	5397	0.086
18	St. Paul	Small	5728	5337	0.073
19	Redcliff	Small	5474	5546	-0.013
20	Vegreville	Small	5436	5440	-0.001
21	Didsbury	Small	5222	4905	0.065
22	Bonnyville	Small	5081	5860	-0.133
23	Langdon	Small	5060	4211	0.202
24	Westlock	Small	4678	4532	0.032
25	Barrhead	Small	4387	4158	0.055
26	Jasper	Small	3948	3489	0.132
27	Peace River	Small	3924	4078	-0.038
28	Vermilion	Small	3617	3531	0.024
29	Raymond	Small	3533	3594	-0.017
30	Pincher Creek	Small	3523	3572	-0.014
31	Claresholm	Small	3424	3378	0.014
32	Grande Cache	Small	3286	3839	-0.144
33	Cardston	Small	3258	3283	-0.008
34	Penhold	Small	3165	2328	0.361
35	Carstairs	Small	3080	2665	0.156
36	Three Hills	Small	3078	3018	0.02

2. METHODS

Use of lower temperature geothermal systems <120 °C for power production is not economically feasible based on the low efficiency. Of geothermal power plants for instance, the Organic Rankine Cycle (ORC) (typically some 10% efficiency), will result in some 90% loss of geothermal energy. For economic reasons >120 °C fluids with a high production rate (~ 80 kg/s) are required for geothermal power production. In practice, power production with ORC or Kalina power plants will typically only be economical with fluids > 150 °C (Tester et al., 2006; 2015). In contrast, for efficient geothermal heating systems temperatures of at least 60 °C are required (Jessop and Vigrass, 1984). Therefore, knowledge of the spatial distribution of temperatures, along with geologically promising formations for high fluid production rates, is crucial for determining which communities have sufficient geothermal conditions for development of geothermal heating or power.

The geothermal gradient map shown here (Fig.3) is derived from T measurements from the most recent data compilation done during the University of Alberta HAI (Helmholtz-Alberta) study (Nieuvenhuis et al., 2015). Temperature data used includes 243,842 APP temperatures, 58,693 DST temperatures, and 119,977 BHTs. The calculated variation in average geothermal gradient from these temperature data is given as Grad T= dT/dz, where T is temperature in °C and z is depth (km).

Heat and power production were estimated as follows: available heating energy in GJ per year was derived from the number of households possible to heat with geothermal systems at the Alberta average 130 GJ per year, for an average 0.7 yearly heating load; and power generation (MW electrical) @ 10% efficiency of ORC plants, and the enthalpy gain (KJ/kg) was calculated for the range of parameters assumed in Table 3. These calculations were conducted for prospective aquifers and for populations centres from >3k to <10k (Tables 4-8). We assumed conditions of 30-80 kg/s brine production rates based on compiled flow rates for aquifer units in Alberta and other parts of the WCSB (Lam and Jones, 1985, 1986; Ferguson, 2015, Ferguson and Ufondu, 2017; Vigrass and Jessop, 1984; Jessop and Vigrass, 1984; Jessop, 2008; DEEP, 2019; Banks and Harris, 2018) and in other analogous sedimentary basins (Tester et al., 2006; Blackwell et al., 2007; Agemar et al., 2014; Moeck, 2014).

Table 3: Assumed parameters

Production temperature of geothermal fluid	60-160	°C
Backflow temperature	50-60	°C
Specific heat capacity of produced geothermal brine	3150-3993	J/kg °C
Specific heat capacity of water	4186	J/kg °C
Flow rate	30-80	kg/s
Conversion thermal to power factor	10	%

A drop off temperature of 60 °C was assumed for geothermal heating systems based on the Paris Basin geothermal direct district heating system (Laplaige et al., 2005) and the 50-60 °C outflow temperature for ORC engines. It is possible to get drop off temperatures down to 40 °C if a cascade system is used. Heat capacity is the amount of heat energy required to heat a gram of material one Kelvin degree. The heat capacity of freshwater is 4182 J/(kg K) and the specific heat capacity of seawater (35 g/L salinity) is 3993 J/(kg K). At 100 g/L salinity specific heat capacity will be much lower, some 3700 J/(kg K) and at 150 g/L salinity the specific heat capacity will be 3150 J/(kg K). The salinity of fluids in the WCSB ranges from 20 g/L to over 300 g/L in the most prospective Devonian aquifers (Grasby and Chen, 2005). We calculated heat available using specific heat for the most common value for deep saline aquifers. Two different values were used. We have used the most common range of 3.15-3.99 kJ/kg K for saline brines. Additional details on feasible flow rates for the WCSB are in Majorowicz and Grasby (2019; 2020).

Electrical energy can be extracted in binary-cycle power plants from geothermal reservoirs with moderate temperatures between some 80 °C and 182 °C and flash steam plants above182 °C (USDOI and USDA, 2008). A drop off temperature of 50-60 °C was assumed for ORC power plants (Tester et al., 2006, Blackwell et al., 2007). Conversion of thermal energy to electrical power assumes average 10% efficiency (8-12%) according to Tester et al. (2006). Calculations do not consider power needed to run surface and submerged pumps to keep fluid circulation through the doublet geothermal wells system (one producing well-one reinjecting well) and power needed for pumping hot water into an infrastructure to redistribute heat, to heat exchanges and into district heating systems for the communities. For power production through geothermal power plants, like the Organic Rankine Cycle, power is needed for pumping the fluid through the system into heat exchangers and internally through Organic Rankine Cycle systems to produce electricity to be distributed by an electrical power grid. At the end of the equation for non-artesian large flow systems the result would be different if the power required to run pumps was considered. Power for pumps varies in a large range depending on the aquifer and typically is in the 0.1 -0.7 MW el. range. (Majorowicz and Grasby, 2019). The power to drive pumps could also be delivered by other green power energy systems like windmills to further reduce CO_2 emissions. In Tables 4 - 8 we calculate as a first approximation the energy estimate (J/s) of Alberta households to be heated by such systems based on the average of 130 GJ per household annual energy demand. We have also calculated Power (MW) electricity available for a range of most likely Alberta basin parameters.

3. GEOTHERMAL GRADIENT PATTERN

The mean Alberta geothermal gradient Grad T=31.3 °C/km is average compared to worldwide sedimentary basins (Majorowicz et al., 2014a,b; Majorowicz and Moore, 2014; Weides and Majorowicz, 2015), but this average value does not reflect large spatial variability in Grad T (Fig. 3). Grad T values range from 20 °C/km in the southern Alberta Rocky Mountain foothills to as high as 55 °C/km in NW Alberta, at the border with British Columbia. In general, for higher population density areas south of Penhold-Stettler the Grad T is < 30 °C/km and as low as 20 -25 °C/km in the southwestern Alberta deep foreland basin. In low population density areas of northwestern Alberta values range from 40-50 °C/km (Fig. 3).

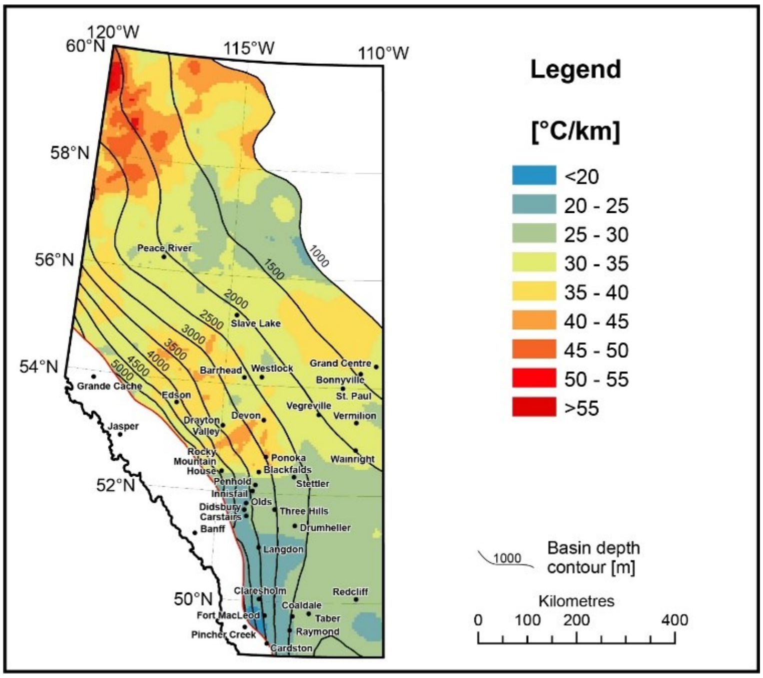

Fig. 3: The map of geothermal gradient for Alberta, Canada from ground surface to basin's base.

4. GEOTHERMAL ENERGY POTENTIAL FOR SMALL COMMUNITIES IN ALBERTA

The Alberta Basin has temperatures varying from a few tens' of °C in the eastern shallow <1.5 km part of the basin to >110-120 °C in the deeper >2.5 km thick part of the foreland basin, generally west of Panoka-Devon -Barrhead, (Fig. 4). For the mean geothermal gradients (Fig. 3) in the deep Alberta foreland basin, wells would need to be drilled >3.5 km to reach aquifers >120 °C, the recommended minimum temperature for power production (USDOI and USDA, 2008). The maximum feasible temperatures in Alberta are ~170 °C, west of the Edson area, and in the western 6 km deep basin along the margin of the Disturbed belt (see Fig. 4). In contrast, in the shallow northeastern part of the basin around Fort McMurray, temperatures are only 12 °C at the 0.5 km deep base of sediments (Majorowicz et al., 2014a, b). Formations at the deepest part of the basin, the Devonian Granite Wash and Middle Cambrian Basal Sandstone Unit, are of interest for geothermal energy potential. High temperatures in deep basin for the Upper Devonian (Figure 5) and the Woodbend Group's Grosmond karstic dolomites, Cooking Lake dolomites and of Beaverhill Lake Swan Hills, Slave Lake and Elk Point's Pine Point and Devonian Winterburn (Fig. 6) are prospective geothermal reservoirs (Table 1).

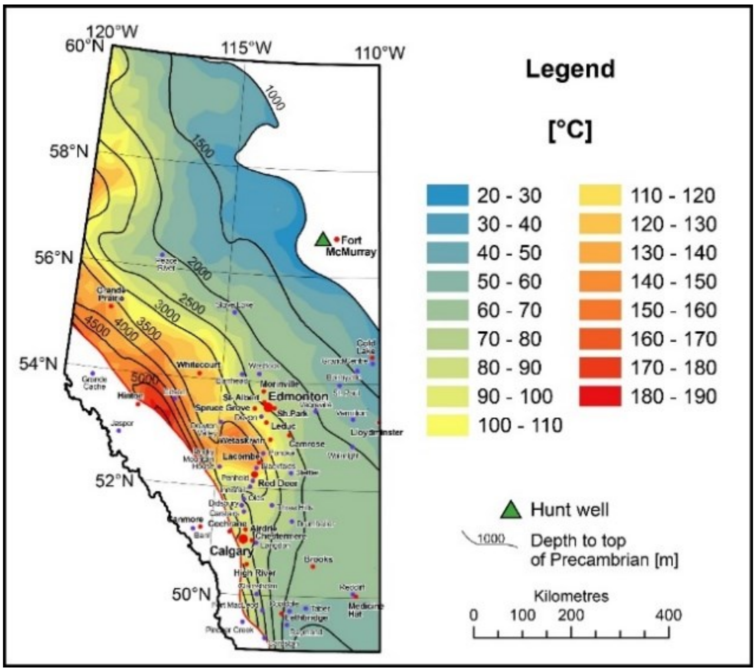

Figure 4: Small population centres >3k (blue dots) vs. map of maximum feasible temperatures at the base of Phanerozoic sedimentary succession. Large population centres >10k (red dots) - analyzed previously by Majorowicz and Grasby (2020).

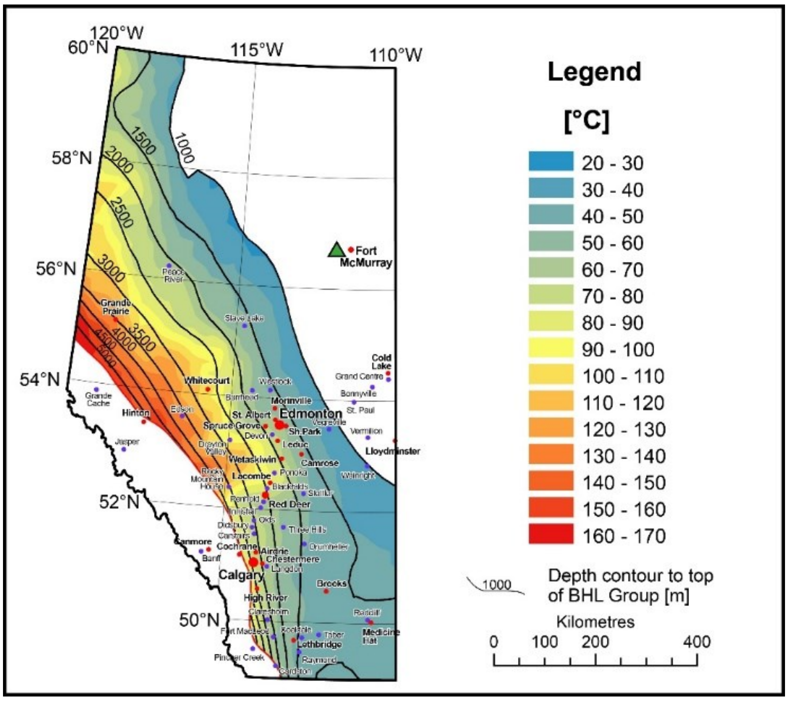

Figure 5: Population centres >3k vs. map of maximum feasible temperatures at Upper Devonian Beaverhill Lake group.

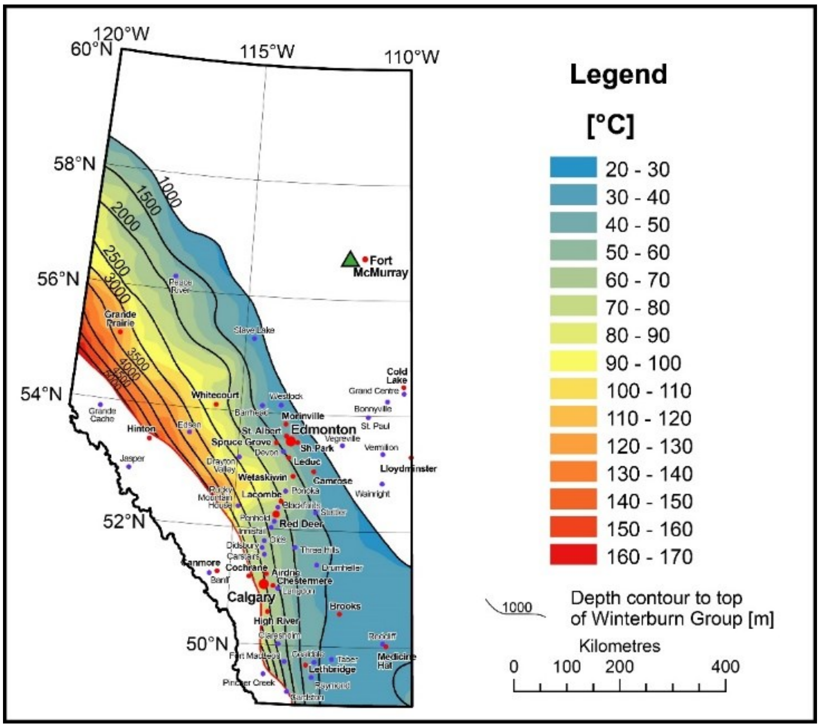

Figure 6: Population centres >3k population vs. map of maximum feasible temperatures in the Winterburn Group.

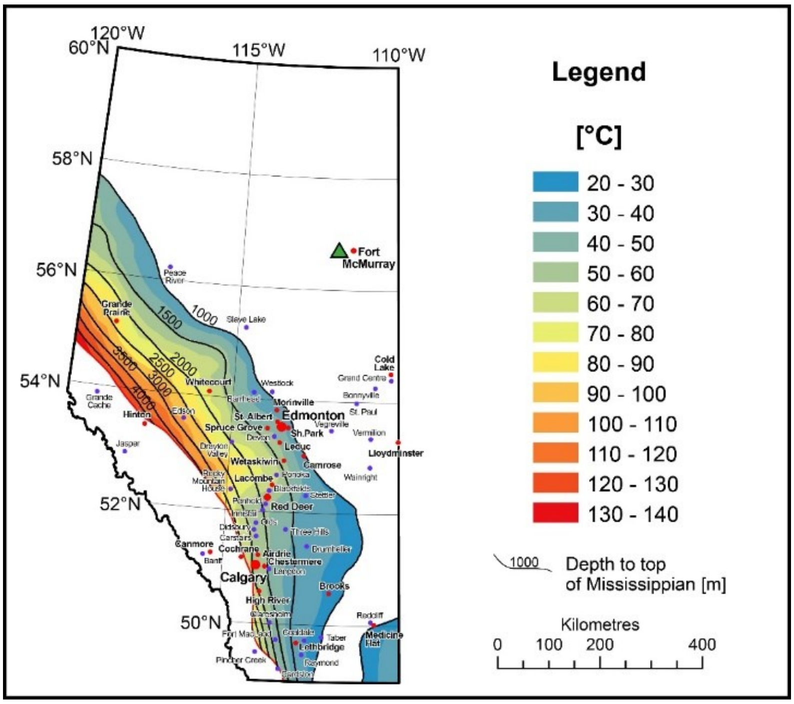

Figure 7: Population centres >3k vs. map of maximum feasible temperatures at Mississippian.

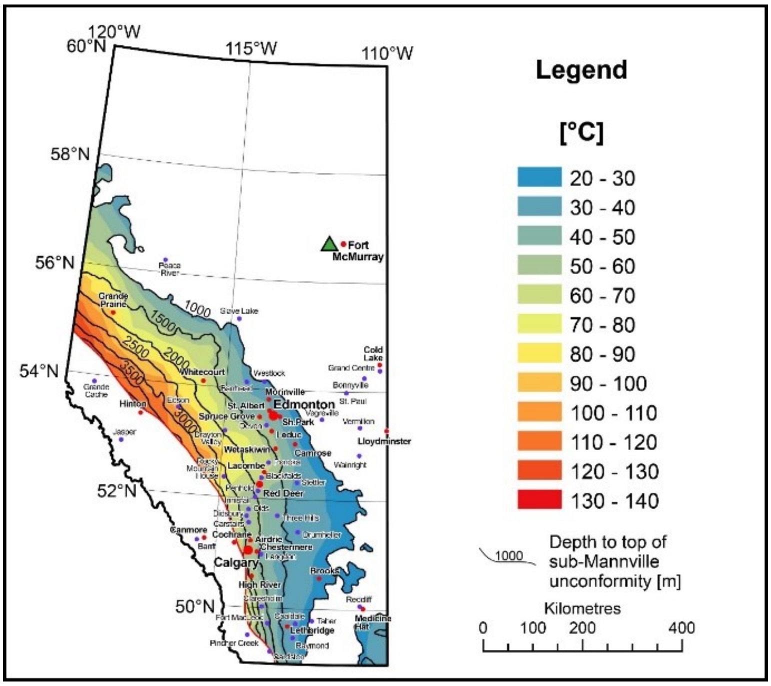

Figure 8: Population centres >3k vs. map of maximum feasible temperatures at Sub Manville unconformity (Lower Cretaceous).

For most of the study area, high temperature zones found in the basal Devonian Granite Wash and Middle Cambrian basal sandstone units are shown in Figure 4, the calculated range of geothermal energy production based on the range of assumed parameters for these formations is shown in Table 4. Results in Table 5 show that temperatures >80 °C can be found in the Upper Devonian Beaverhill Lake Group (Fig. 5). Other potential formations with geothermal feasibility include the Woodbend Group's Grossmond karstic dolomites, Cooking Lake dolomites, Beaverhill Lake's Swan Hill Formation, Slave Lake Formation and Elk Point's Pine Point Formations. The Winterburn Group, Wabamun and Nisku Formations geothermal prospects for heating and power are shown in Table 6. The Wabamun Group's partly porous dolomites (Weides et al., 2013), and Winterburn Group's Nisku Formation sandstones and limestones have good temperatures (Fig. 6) and geothermal energy prospects west of Edson and to the northwest towards Grande Cache (Weides and Majorowicz, 2014). The Mississippian Rundle Group's dolostones and limestones, Charles Formation dolostones and limestones and Banff Formation limestones are all in the >80 °C temperature zone in the deepest western part of Alberta (Fig. 7). The calculated energy, power and enthalpy gains for these units are shown in Table 7. Low to mid-enthalpy potential for geothermal hot saline fluids also exists for the Cretaceous Mannville sandstone and Cretaceous Mannville Group sediments and Cadomin Formation sandstone & conglomerates as found by Lam and Jones (1985) for the deepest parts of the Alberta Basin in the Edson –Hinton area. The sub-Manville unconformity temperature distribution in Figure 8 shows temperatures >70 °C that are useable for geothermal heating exist in the towns of Drayton Valley, Edson, and Rocky Mountain House (Table 8).

Tables 4-8 listed below show geothermal energy for a range of flow rates (well production rate), specific heat capacity of geothermal brine, the number of direct geothermal heated households feasible for small communities of >3k - <10k population at average energy use of 130 GJ/Year at 0.7 yearly uses, enthalpy and calculated formation temperature and depth required to drill to prospective geological formations at these calculated temperatures.

5. GEOTHERMAL ENERGY RANKING FOR SMALL COMMUNITIES IN ALBERTA

The geothermal prospect ranking (1-5) used by Majorowicz and Grasby (2020) for Alberta large communities is applied here to assessment of geothermal ranking for small communities. This follows also the ranking criteria developed based on Younger (2015) for the world resource classification.

1- Very low enthalpy prospects: Very low enthalpy gain <80 kJ/kg, aquifer heat to be used with heat pumps.

2- Low enthalpy prospects, (80-200) kJ/kg: Geothermal heat prospects with uplift of temperature by other means.

3- Medium enthalpy prospects (200- 320) kJ/kg: Direct deep aquifer source heating prospects.

4- High enthalpy (320- 520 kJ/kg): Direct heat prospects, marginal to good EGS geothermal power.

5- Very high enthalpy (>520 kJ/kg): Deepest hot aquifers, sometimes unexplored, unreached by deep drilling yet likely will be useful for good geothermal power production with ORC, Kalina or flash steam.

The best prospects of Alberta communities for 3-9K population varies spatially (Figs. 4-6, Tables 4-6) with highest temperatures in Cambrian-Upper Devonian aquifers. In the central-western part of the Alberta Basin, high enthalpy prospects (4-5) associated with deep aquifers occur. The highest ranked prospects (rank 5) are in the deep northern and western parts of the basin west of Edson, within deep aquifers predicted to be capable of producing heat and power with Rankine or Kalina cycles (Ranked 5) and limited to the town of Hinton. High enthalpy prospects (4) occur in central -western Alberta and for 3-10k population centres limited to towns of Blackfalds, Panoka, Rocky Mountain House, Penhold, Devon, and Drayton Valley. Medium enthalpy (Ranked 3) prospects for geothermal heating >70 °C and < 90 °C exist for towns of Barrhead, Westlock, Stettler, Innisfail, Olds, Didsbury, Castairs, Three Hills, Langdon, Claresholm and Fort MacLeod. However, going south in Alberta the GradT decreases (Fig. 3) and the Precambrian basement is deeper (Fig. 4) which means deeper drilling (>3.5 km) for Didsbury, Castairs, Claresholm, and Fort MacLeod.

The lowest ranked geothermal prospects occur in the shallow parts of the basin (low enthalpy, rank 2) for the communities in north-central eastern part of Alberta (Peace River) and in the southeastern part of the Alberta Basin in places like Grand Centre, Cold Lake, Bonnyville, St. Paul, Vegreville, Vermillion, Wainright and in the south of Alberta in Redcliff, Taber, Coaldale, and Raymond. In these locations lifting fluid temperature after a heat exchanger by use of heat pumps (see Agemar et al., 2016, for general design of the geothermal heating system) would be needed before direct heating of buildings (like lifting fluid temperature after heat exchanger phase from 40-50 °C water to at least 70 °C).

6. CONCLUSIONS

Analysis of geothermal feasibility for small cities and towns in Alberta shows that heating energy is available from several geological groups from deepest above the Precambrian basement through Devonian, Mississippian and up to Cretaceous Mannville.

Depending on T (°C) and production rate kg/s (Tables 4-8) the range of households that are feasible to be heated by direct deep aquifer sourced geothermal energy is in the 100s to 1000s (maximum 4k) for produced water >70 °C, which is available in most of Alberta deep foreland basin. Some 49 out of 73 population centers analyzed (small centres geothermal prospects analyzed in this report and previously analyzed large cities and towns by Majorowicz and Grasby (2020)) have geothermal direct heating potential. Shallow and ‘cold’ parts of the basin in eastern-northeastern Alberta have temperatures not suitable for direct geothermal. In those locations heat pump systems could be a more viable option.

Power production in Alberta cities and towns can be available at large flow rates preferably >80kg/s and for temperatures >120 °C. The range of the feasible power production with 10% efficient ORC geothermal power plants is between single decimals of MW electrical and up to 2.2 MW electrical in deep hot high production systems. Economics of the system will depend on efficiency of the geothermal power plants (usually low 10%), power required for pumping for production, reinjection of fluids, and getting it through surface piping and power plants, was assessed to vary between 0.1-0.7 MW electrical (Majorowicz and Grasby 2019) and the depth of geothermal resource required to drill a doublet well system. Cost will increase exponentially with depth and shallow hot resources are rare in the Alberta basin for the cities and towns analyzed.

The other concern will be the proximity of the geothermal resource to the potential market. The search for geothermal energy needs to be refocused to where it is needed, as compared to where you can produce the most, given the large transmission losses. Therefore, finding old wells or drilling new ones in the closest proximity to the population centres in Alberta is needed.

Table 4: Deepest Alberta basin above the crystalline basement - Energy, Enthalpy, Power, No. of direct geothermal heated households feasible for small communities >3k - <10k population.

City Location	Temperature	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy gain	Formation Group	Depth
		at C=3993	at C=3150	at C=3993	at C=3150	Minimum	Maximun	at C=3993	at C=3150	at C=3993		
		at 30kg/s	at 30kg/s	at 80kg/s	at 80kg/s	number	number	at 30kg/s	at 80kg/s			
Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Y	@ 130 GJ/Y	MW el.	MW el.	kJ/kg		km
Olds	90	66110	52153	176293	139074	401	1356	0.5	0.8	280	M.Cambrian Basal	3.6
Blackfalds	120.25	132770	104740	354054	279306	806	2723	0.8	1.5	400	M.Cambrian Basal	3.25
Taber	59.4									157	M.Cambrian Basal	2.2
Coaldale	62.5	5509	4346	14691	11589	33	113	0.1	0.1	170	M.Cambrian Basal	2.5
Edson	147	191718	151243	511248	403314	1163	3933	1.2	2.2	507	M.Cambrian Basal	4.2
Banff	?										Disturbed belt	?
Grand Centre	40.5									82	M.Cambrian Basal	1.35
Innisfail	87.5	60601	47807	161602	127484	368	1243	0.4	0.7	270	M.Cambrian Basal	3.5
Ponoka	123	138830	109521	370214	292055	842	2848	0.9	1.6	411	M.Cambrian Basal	3
Drayton Valley	119	130016	102567	346709	273512	789	2667	0.8	1.5	395	M.Cambrian Basal	3.4
Cold Lake	42									88	M.Cambrian Basal	1.2
Devon	99.9	87926	69363	234469	184968	534	1804	0.6	1.0	319	M.Cambrian Basal	2.7
Drumheller	72.9	28427	22426	75806	59802	173	583	0.3	0.3	211	M.Cambrian Basal	2.7
Rocky Mountain House	144	185107	146027	493619	389407	1123	3797	1.1	2.1	495	M.Cambrian Basal	4.8
Slave Lake	73.5	29749	23469	79332	62583	181	610	0.3	0.3	214	M.Cambrian Basal	2.1
Wainwright	64	8815	6954	23506	18543	53	181	0.2	0.1	176	M.Cambrian Basal	2
Stettler	78.3	40327	31813	107538	84835	245	827	0.3	0.5	233	M.Cambrian Basal	2.7
St. Paul	55.25									141	M.Cambrian Basal	1.7
Redcliff	60.5	1102	869	2938	2318	7	23	0.1	0.0	162	M.Cambrian Basal	2.2
Vegreville	64	8815	6954	23506	18543	53	181	0.2	0.1	176	M.Cambrian Basal	2
Didsbury	92.5	71619	56499	190984	150663	435	1469	0.5	0.8	289	M.Cambrian Basal	3.7
Bonnyville	49									116	M.Cambrian Basal	1.4
Langdon	80.5	45175	35638	120467	95034	274	927	0.4	0.5	242	M.Cambrian Basal	3.5
Westlock	73.6	29970	23643	79919	63047	182	615	0.3	0.3	214	M.Cambrian Basal	2.3
Barrhead	83.2	51125	40331	136333	107550	310	1049	0.4	0.6	252	M.Cambrian Basal	2.6
Jasper	?										Disturbed belt	?
Peace River	67.2	15866	12517	42310	33378	96	325	0.2	0.2	188	Devonian Granite	2.1
Vermilion	55.8									143	M.Cambrian Basal	1.8
Raymond	57.5									150	M.Cambrian Basal	2.5
Pincher Creek	89.3	64567	50936	172179	135829	392	1324	0.5	0.7	277	Disturbed belt fm	4.7
Claresholm	75.6	34377	27119	91672	72318	209	705	0.3	0.4	222	M.Cambrian Basal	3.6
Grande Cache	?										Disturbed belt fm	?
Cardston	70	22037	17384	58764	46358	134	452	0.2	0.3	200	Disturbed belt fm	3.5
Penhold	95.2	77569	61192	206850	163180	471	1591	0.5	0.9	300	M.Cambrian Basal	3.4
Carstairs	90	66110	52153	176293	139074	401	1356	0.5	0.8	280	M.Cambrian Basal	3.6
Three Hills	80.6	45395	35811	121054	95497	275	931	0.4	0.5	242	M.Cambrian Basal	3.1

Table 5: Upper Devonian Beaverhill Lake Group - Energy, Enthalpy, Power, No. of direct deep geothermal energy heated households feasible for small communities >3k - <10k population.

City Location	Tempera	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthal	Formation Group	Depth
		at C=3993	at C=3150	at C=3993	at C=3150	Minimum	Maximun	at C=3993	at C=3150	at C=3993		
		at 30kg/s	at 30kg/s	at 80kg/s	at 80kg/s	number	number	at 30kg/s	at 80kg/s			
Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Y	@ 130 GJ/Y	MW el.	MW el.	kJ/kg		km
Olds	76.3	35809	28249	95492	75332	217	735	0.3	0.4	225	Leduc F.	3.05
Blackfalds	85.0	55091	43461	146910	115895	334	1130	0.4	0.6	260	U. Devonian Beaverhill L.	2.5
Taber	45.9									103	U. Devonian Beaverhill L.	1.7
Coaldale	47.5									110	U. Devonian Beaverhill L.	1.9
Edson	126.0	145441	114736	387844	305962	883	2983	0.9	1.7	423	Beaverhill l. Group	3.6
Banff	?										Disturbed belt	?
Grand Centre											Shallow basin	
Innisfail	68.8	19282	15211	51419	40563	117	396	0.2	0.2	195	U. Devonian Beaverhill L.	2.75
Ponoka	88.0	61702	48676	164540	129802	374	1266	0.5	0.7	272	U. Devonian Beaverhill L.	2.2
Drayton Valle	86.8	59058	46590	157488	124239	358	1211	0.4	0.7	267	U. Devonian Beaverhill L.	2.8
Cold Lake											Shallow basin	
Devon	72.2	26885	21209	71692	56557	163	551	0.3	0.3	208	Cooking Lk F.	1.9
Drumheller	51.3									125	Leduc F.	1.9
Rocky Mounta	108.5	106877	84313	285006	224836	649	2192	0.7	1.2	353	U. Devonian Beaverhill L.	3.5
Slave Lake	54.4									137	U. Devonian Beaverhill L.	1.6
Wainwright	33.6									54	U. Devonian Beaverhill L.	1.05
Stettler	55.5									142	Leduc F.	1.85
St. Paul										-80	Shallow basin	
Redcliff	45.4									101	U. Devonian Beaverhill L.	1.65
Vegreville	35.2									61	U. Devonian Beaverhill L.	1.1
Didsbury	78.8	41319	32595	110183	86921	251	848	0.3	0.5	235	Leduc F.	3.15
Bonnyville											Shallow basin	
Langdon	69.6	21155	16689	56414	44504	128	434	0.2	0.2	198	Leduc F.	2.9
Westlock	51.2									125	U. Devonian Beaverhill L.	1.6
Barrhead	59.2									157	U. Devonian Beaverhill L.	1.85
Jasper											Disturbed belt	
Peace River	67.2	15866	12517	42310	33378	96	325	0.2	0.2	188	Leduc F.	2.1
Vermilion											Shallow basin	
Raymond										112	U. Devonian Beaverhill L.	2
Pincher Creek											Disturbed belt	
Claresholm	70.4	22808	17993	60821	47980	138	468	0.2	0.3	201	U. Devonian Beaverhill L.	3.35
Grande Cache											Disturbed belt	
Cardston	66.0	13222	10431	35259	27815	80	271	0.2	0.2	184	U. Devonian Beaverhill L.	3.3
Penhold	70.2	22477	17732	59939	47285	136	461	0.2	0.3	200	U. Devonian Beaverhill L.	2.6
Carstairs	75.6	34377	27119	91672	72318	209	705	0.3	0.4	222	Leduc F.	3.15
Three Hills	59.8									159	U. Devonian Beaverhill L.	2.3

Table 6: Winterburn/Wabamun Groups - Energy, Enthalpy, Power, No. of direct deep geothermal energy heated households feasible for small communities >3k - <10k population.

City Location	Tempera	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy gain	Formation Group
		at C=3993	at C=3150	at C=3993	at C=3150	Minimum	Maximun	at C=3993	at C=3150	at C=3993	top of Winterburn Group
		at 30kg/s	at 30kg/s	at 80kg/s	at 80kg/s	number	number	at 30kg/s	at 80kg/s		
Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Y	@ 130 GJ/Y	MW el.	MW el.	kJ/kg	
Olds	67.5	16527	13038	44073	34768	100	339	0.2	0.2	190	Dolomite Nisku
Blackfalds	73.1	28868	22773	76981	60729	175	592	0.3	0.3	212	Dolomite Nisku
Taber										71	top of Winterburn Group
Coaldale										80	top of Winterburn Group
Edson	112	114590	90398	305574	241061	695	2351	0.7	1.3	367	top of Winterburn Group
Banff										-	Disturbed belt
Grand Centre											Shallow basin
Innisfail											Shallow basin
Ponoka	72	26444	20861	70517	55630	160	542	0.3	0.3	208	Winterburn/Dolomite Nisku
Drayton Valley	72	26444	20861	70517	55630	160	542	0.3	0.3	208	Wabamum dolomite
Cold Lake											Shallow basin
Devon	57									148	Wabamum dolomite
Drumheller	45.9									103	Dolomite Nisku
Rocky Mounta	93	72721	57368	193922	152981	441	1492	0.5	0.8	291	Wabamum dolomite
Slave Lake	37.4									69	Dolomite Nisku
Wainwright	0										Shallow basin
Stettler	43.5									94	top of Winterburn Group
St. Paul											Shallow basin
Redcliff	34.375									57	top of Winterburn Group
Vegreville											Shallow basin
Didsbury	70	22037	17384	58764	46358	134	452	0.2	0.3	200	Dolomite Nisku
Bonnyville											Shallow basin
Langdon	62.4	5289	4172	14103	11126	32	108	0.1	0.1	169	Dolomite Nisku
Westlock	38.4									73	Wabamum dolomite
Barrhead	44.8									99	Wabamum dolomite
Jasper	0										Disturbed belt
Peace River	56									144	top of Winterburn Group
Vermilion	0										Shallow basin
Raymond	42									88	top of Winterburn Group
Pincher Creek											Disturbed belt
Claresholm	60.9	1983	1565	5289	4172	12	41	0.1	0.0	163	top of Winterburn Group
Grande Cache	0										Disturbed belt
Cardston	60									160	top of Winterburn Group
Penhold	62.1	4628	3651	12340	9735	28	95	0.1	0.1	168	top of Winterburn Group
Carstairs	68.4	18511	14603	49362	38941	112	380	0.2	0.2	193	Dolimite Nisku
Three Hills	50.7									123	Dolimite Nisku

Table 7: Mississippian Groups - Alberta - Energy, Enthalpy Power, No. of direct deep geothermal energy heated households feasible for small communities >3k - <10k population.

City Location	Tempera	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy gain	Formation Group	Depth
		at C=3993	at C=3150	at C=3993	at C=3150	Minimum	Maximun	at C=3993	at C=3150	at C=3993	top of Winterburn Group	
		at 30kg/s	at 30kg/s	at 80kg/s	at 80kg/s	number	number	at 30kg/s	at 80kg/s			
Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Y	@ 130 GJ/Y	MW el.	MW el.	kJ/kg		km
Olds	57.5							0.1		150	Mississippian	2.3
Blackfalds	59.5							0.1	0.0	158	Banff l.	1.75
Taber	27									28	Rundle l.	1
Coaldale	30									40	Rundle l.	1.25
Edson	96.25	79883	63018	213020	168047	485	1639	0.6	0.9	304	Rundle l.	2.75
Banff											Disturbed belt	
Grand Centre											shallow basin	
Innisfail	50									120	Banff l.	2
Ponoka	64	8815	6954	23506	18543	53	181	0.2	0.1	176	Mississippian	1.6
Drayton Valley	60							0.1		160	Banff l.	2
Cold Lake											shallow basin	
Devon	51.3							0.0		125	Mississippian	1.35
Drumheller	37.8									71	Mississippian	1.4
Rocky Mounta	81	46277	36507	123405	97352	281	949	0.4	0.5	244	Rundle l/Banff l.	2.7
Slave Lake											shallow basin	
Wainwright											shallow basin	
Stettler	37.7									71	Mississippian	1.3
St. Paul											shallow basin	
Redcliff											shallow basin	
Vegreville											shallow basin	
Didsbury	57.5							0.1		150	Banff l.	2.3
Bonnyville											shallow basin	
Langdon	46									104	Rundle d.	2
Westlock											shallow basin	
Barrhead	35.2									61	Mississippian	1.1
Jasper											Disturbed belt	
Peace River											shallow basin	
Vermilion											shallow basin	
Raymond	31.2									45	Rundle l.	1.3
Pincher Creek											Disturbed belt	
Claresholm	50.4									121	Banf/Rundle l.	2.4
Grande Cache											Disturbed belt	
Cardston	50									120	Banf/Rundle l.	2.5
Penhold	50.4									121	Banf l.	1.8
Carstairs	55.2									141	Banf l./Rundle d.	2.3
Three Hills+M	41.6									86	Rundle d.	1.6

Table 8: Lower Cretaceous - Energy, Enthalpy, Power, No. of direct deep geothermal heated households feasible for small communities >3k -<10k population.

City Location	Tempera	Energy 1	Energy 2	Energy 3	Energy 4	Househodls	Households	Power	Power	Enthalpy gain	Formation Group	Depth
		at C=3993	at C=3150	at C=3993	at C=3150	Minimum	Maximun	at C=3993	at C=3150	at C=3993	top of Winterburn Group	
		at 30kg/s	at 30kg/s	at 80kg/s	at 80kg/s	number	number	at 30kg/s	at 80kg/s			
Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Y	@ 130 GJ/Y	MW el.	MW el.	kJ/kg		km
Olds	57.5							0.1		150	Lower Mannville Group	2.3
Blackfalds	63	6611	5215	17629	13907	40	136	0.2	0.1	172	Lower Mannville Group	1.75
Taber											shallow	0
Coaldale	32.5									50	Lower Mannville Group	1.3
Edson	91	68313	53891	182169	143710	415	1401	0.5	0.8	284	Lower Mannville Group	2.6
Banff											Disturbed belt	
Grand Centre											shallow	
Innisfail	50									120	Lower Mannville Group	2
Ponoka	65.6	12340	9735	32908	25960	75	253	0.2	0.1	182	Lower Mannville Group	1.6
Drayton Valley	68.25	18180	14342	48480	38245	110	373	0.2	0.2	193	Lower Mannville Group	1.95
Cold Lake											shallow basin	
Devon	51.8									127	Lower Mannville Group	1.4
Drumheller	37.8									71	Lower Mannville Group	1.4
Rocky Mounta	78	39666	31292	105776	83444	241	814	0.3	0.5	232	Lower Mannville Group	2.6
Slave Lake											shallow basin	
Wainwright											shallow basin	
Stettler	40.6									82	Lower Mannville Group	1.4
St. Paul											shallow basin	
Redcliff											shallow basin	
Vegreville											shallow basin	
Didsbury	57.5							0.1		150	Lower Mannville Group	2.3
Bonnyville											shallow basin	
Langdon	43.7									95	Lower Mannville Group	1.9
Westlock	32									48	Lower Mannville Group	1
Barrhead	38.4									73	Lower Mannville Group	1.2
Jasper											Disturbed belt	
Peace River											shallow	
Vermilion											shallow	
Raymond										50	Lower Mannville Group	1.35
Pincher Creek											Disturbed belt	
Claresholm										121	Lower Mannville Group	2.4
Grande Cache											Disturbed belt	
Cardston											Disturbed belt	
Penhold										140	Lower Mannville Group	1.9
Carstairs										150	Lower Mannville Group	2.3
Three Hills										97	Lower Mannville Group	1.7

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