REPORT 2016-07 (Section B)

CONTRACT 2015-22

Roadmap

Direct-Use Geothermal Resources in British Columbia

Fairmont Hot Springs

TUYA TERRA GEO CORP. &
GEOTHERMAL MANAGEMENT COMPANY INC.

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REPORT 2016-07

SECTION B

ROADMAP FOR DEVELOPMENT OF GEOTHERMAL DIRECT-USE PROJECTS IN BRITISH COLUMBIA, CANADA

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Table of Contents

NOTE: A conversion rate of US$1.00 = CAD 1.33 (November 27, 2015 banking exchange rate) was used, however costs may vary considerably in many of the Canadian remote villages due to additional transportation and labor costs.

COVER: View looking east at the Fairmont Hot Springs' pools (site visit Lund, 2003).

List of Figures

List of Tables

Abbreviations

ASHRAE	American Society of Heat Refrigeration and Air-Conditioning Engineers
Btu	British thermal unit (= 1054 Joules = 252.0 gram calories)
^oC	Degree Centigrade (= 1.8 degrees Fahrenheit)
Ca	Calcium (chemical element)
CAD	Canadian Dollar
cal	Gram calorie (= 4.184 Joules = 0.003968 Btu)
cm	Centimeter (= 1/100 meter)
CO_2	Carbon dioxide (gas)
CPVC	Chlorinated polyvinyl chloride (plastic pipe)
DHE	Downhole heat exchanger
EA	Environmental Assessment (study/document)
EIS	Environmental Impact Study (U.S. document)
^oF	Degree Fahrenheit (= 5/9 degree Centigrade)
ft.	Feet (= 0.3048 meters = 30.48 cm)
gal.	Gallon (U.S. = 3.785 liters; Canada (Imperial) = 4.546 liters)
ha	Hectare (= 10,000 m^2)
H_2S	Hydrogen sulfide (gas that smells like rotten eggs)
In.	Inch (U.S.) (= 2.54 cm)
J	Joule (= 0.000948 Btus = 0.239 gram-calories)
K	Potassium (chemical element)
kcal	Kilocalorie (= 1,000 calories)
kg	Kilogram (= 1,000 grams)
kJ	Kilo Joule (= 1,000 Joules)
km	Kilometer (= 1,000 meters = 0.540 mile)
km^2	Square kilometer (= 1 million square meters = 100 hectares)
kWt	Kilowatt thermal
L/s	Liters per second (sometimes used as: l/s)
m	Meter (= 3.281 feet)
m^2	Square meter
m^3	Cubic meter
m/s	Meters per second
mi.	Mile (= 1.609 kilometer = 1,609 meters)
Mg	Mega gram (= 1,000,000 grams = 1,000 kilograms)
MJ	Mega Joule (= 1,000,000 Joules = 10^6 Joules)
MWe	Megawatts electric
MWt	Megawatts thermal
Na	Sodium (chemical element)
NOAA	U.S. National Oceanic and Atmospheric Administration
PEX	Cross-linked polyethylene (plastic pipe)
Si	Silicon (chemical element)
SiO_2	Silica (chemical compound)
PVC	Polyvinyl chloride (plastic pipe)
TJ	Tera Joule (= 10^{12} Joules)
ton	U.S. ton (= 2,000 pounds (lbs) = 907 kg)
tonne	Metric ton (= 1,000 kg = 2,205 U.S. pounds (lbs))
US$	United States Dollar
ΔT	"delta-T" (= change in temperature)

A ROADMAP FOR DEVELOPMENT OF GEOTHERMAL DIRECT-USE PROJECTS IN BRITISH COLUMBIA, CANADA

This document is Section B of Geoscience BC's Report 2016-07, "Direct-use Geothermal Resources in British Columbia" and was completed in conjunction with Section A of the Report.

A.1. The Nature of Geothermal Energy

Geothermal energy is heat that is naturally generated within the Earth's crust. In order for this heat to be useful to mankind, three conditions must exist:

1. There must be a relatively shallow heat source. This can comprise heated rocks, at depths of several kilometers beneath the surface, or rocks containing elements that radioactively decay and release heat.
2. There must be subsurface rocks that are porous, permeable to fluids, or which have been fractured enough that fluids can circulate through them. These are called geothermal reservoir rocks and can be of any type, though granular sediments, soluble carbonates (limestones or dolomites), and certain volcanic deposits such as ash flows, rubble zones, cinders are common.
3. Finally, there must be a way to circulate rain waters and snow melt to depths of several thousand meters where they can absorb heat from the reservoir rocks. These pathways can be thought of as a "plumbing system" and are faults and fractures that should, ideally, be close together and internally interconnected for optimum dispersal of the geothermal heat. Figure 1 illustrates the features cited above.

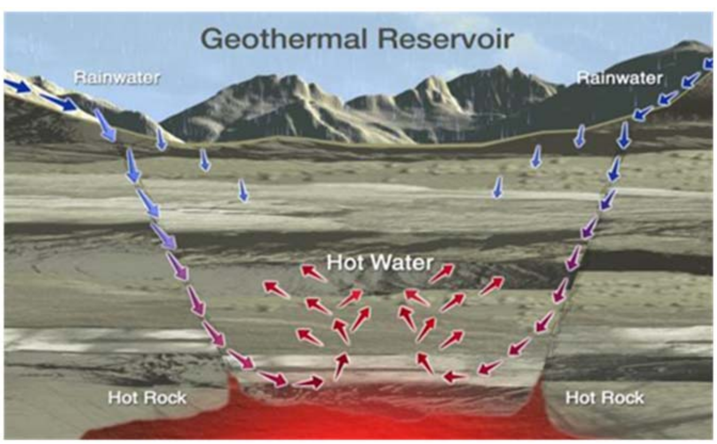

Figure 1. Schematic Geothermal System (GEO, 2015a).

When the thermal waters rise to the ground surface they can manifest themselves in the following ways. From coolest to hottest, these can include:

1. Areas where plants do not grow, waters that do not freeze, snow-free areas where snow cover would otherwise be typical and steaming ground. In most of these cases, the thermal waters are spread across relatively large areas (a few tens of meters) and individual flow rates are small.
2. Warm or hot springs that seep or flow out of cracks in rock outcrops or that bubble up through sands and gravels that cover the bedrock. Flow rates can vary widely from a few liters per second (L/s) to many hundreds of L/s.
3. Places where the thermal waters saturate fine-grained materials near the surface. If hot enough the waters can create mud pots or mounds known as mud-volcanoes. These features commonly have low-flow rates and just "burp" or bubble gently.
4. The most spectacular thermal manifestations are those that can spout above the land surface as "geysers". This can occur if the right internal pathways exist within the fracture network, and if temperatures are high enough. These emanations can range in height from a few centimeters to tens of meters (as at Yellowstone Park in the USA) and can involve large amounts of water and steam with each eruption.

Important thermal water topics, with regard to Direct-use include: temperature, flow/pumped production rate, chemistry, re-injection, and the potential for interference with existing users.

- Currently, the lowest thermal water temperature economically usable for power generation is about 74^{o}C, however at this temperature, very large amounts of water are required and the cooling waters for Binary condensers must be very near 0^{o}C, such as being utilized at Chena Hot Springs Resort in Alaska, USA. However, in most cases, waters at temperatures below 80^{o}C should be available for Direct-use applications. Figure 2 illustrates many of the possible Direct-uses and the ranges of temperatures required for each technology.
- The product of the flow rate or pumped rate (in liters per unit time) and the intake temperature (in ^{o}C) minus the discharge temperature (in ^{o}C) times a conversion factor (15,040 kJ x s/(hr x ^{o}C x liters)) equals the number of thermal units in kilojoules (kJ) available per unit time for a Direct-use project. As an example: 5 liters/second x (80^{o}C – 40^{o}C) x 15,040 = 3,008,000 kJ/hr.

  It is quite possible that the natural flow of a thermal manifestation will not be adequate for use in a commercially viable Direct-use project. In this situation, consideration should be given to drilling into a geothermal reservoir and/or its "plumbing system" of fractures so as to be able to obtain more (and maybe hotter) waters. The topics of exploration and drilling will be discussed later in this document.

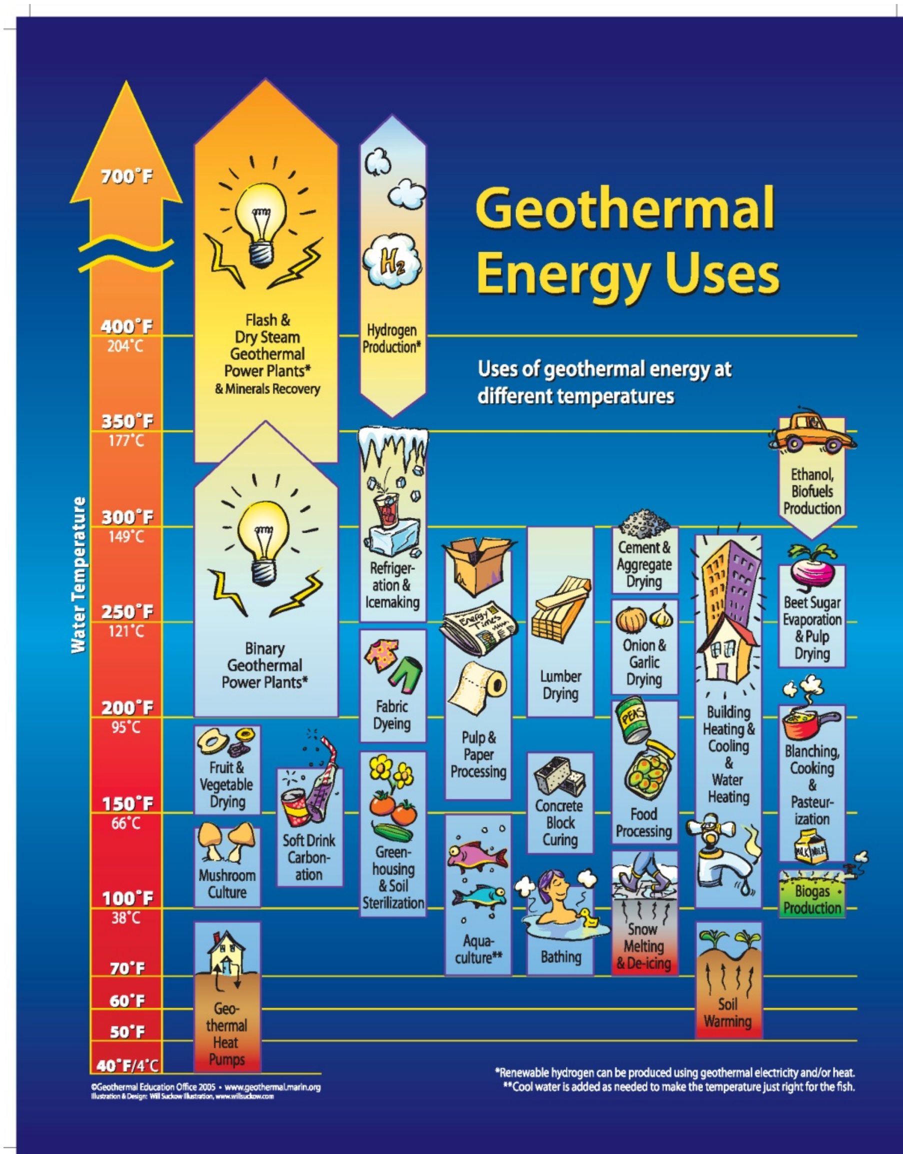

Figure 2. Geothermal Energy Uses (Used with permission: M. Nemzer, GEO, 2015b). In British Columbia, developments utilizing fluids at or greater than 80°C are regulated under the Geothermal Resources Act. Please refer to Section C.10 for additional information.

- Rarely are natural waters totally pure. This is especially true in the case of thermal waters that have a stronger tendency to leach (remove) many elements from reservoir host rocks than do non-thermal waters. When thermal waters are saturated with silica, calcium carbonate, chlorides, or some sulfur compounds and then cooled as they are exposed to ambient air temperatures and pressures, these dissolved minerals can impact the pipes and other elements of the development. Pipes used to transport the thermal water can be corroded (by acids) or plugged with calcium-based or silica scale as these mineral precipitate out of the cooling fluid. These undesirable situations can be mitigated, but at a cost that may negatively affect the project economics.

Thermal waters sometimes contain dissolved elements like arsenic, selenium, and boron that can rule out their direct application in agriculture or aquaculture. The presence of these types of elements can also be mitigated with the use of heat exchangers so they are not normally fatal flaws for a Direct-use project.

- The economics of most Direct-use projects are predicated on a life span of at least 25 years. Subsurface thermal waters are not unlimited and could be depleted with over-use in that time. In order to avoid this and extend the useable lifetime of a thermal feature, the waters produced must be re-injected into the reservoir so as to maintain pressure and available volume. Care must be taken not to re-inject used, cooled waters too close to the production conduits (fracture systems or wells) lest resource temperatures be undesirably lowered. As a rule of thumb, horizontal separation of about 300 meters is considered adequate with re-injection deeper than production (in the case of wells). However, this separation will vary depending on the permeability of the formation and other factors.
- As a word of caution, it is important to note that initiation of a new use of thermal waters at a site where there already exists a thermal water-using facility (such as a spa or swimming pool) may result in the lessening or cooling of the waters available to the first user. This inevitably causes disharmony, friction, and the possibility of legal actions. Accordingly, all efforts must be taken to assure that such interference does not happen or that mitigation methods have been planned and agreed upon by all stakeholders.

A.2. Definition and Capabilities of Geothermal Direct-use Projects

Geothermal Direct-use is the utilization of thermal waters, whose temperatures (less than ~80^{o}C) and/or flow rates are too low to fuel economically viable electric power generation, to supply heat for projects including, but not limited to, space conditioning, industrial processes, aquaculture, green-housing, crop drying, snow-melting, and spas/balneology (Figure 2). Note that in most cases, temperatures less than 65^{o}C are appropriate, however some Direct-uses may require temperatures up to 80^{o}C. These low temperature waters have the following capabilities:

- They can provide thermal energy (heat, kJs) to end-user(s) facilities that can either be built near the thermal manifestation or that are already in existence less than about 8 kilometers from the outflow area (or drilled wells) depending on the heat load. The hot waters, if chemically benign enough, can be used without chemical or mechanical modification. If their chemistry is aggressive (corrosive, scale-producing, or potentially harmful), then the use of a heat exchanger may be mandated to transfer the heat to the user prior to re-injection.

- The heat supplied by the thermal waters can substitute for thermal energy currently derived from fossil fuels or electricity. Once the initial costs of tapping the resource, transporting it to the end-use site, and re-injecting it have been incurred, there will never be any more fuel costs charged. There will be some operation and maintenance expenses to keep the system working properly, but otherwise, there will be many years of low-cost, environmentally beneficial operation realized.
- The decreased costs to the end-user(s) will hopefully translate into increased profits. These profits, when invested back into the community have the potential to, lead to improved quality of life. The profits may also lead to increased local employment so that the quality-of-life benefits may extend to larger parts of a community.

A.3. Limitations of Direct-use

- Though thermal waters have been successfully transported about 60 kilometers in Iceland, the cost of the piping was great and could only be justified because a) there was an enormous market for District Heating, b) the nation has no fossil fuels of its own and must import them at a great cost to the national economy, and c) a low-cost, above-ground, uninsulated piping system was used. For Direct-use projects of modest size as envisioned in British Columbia, thermal waters cannot be piped too far; 8 kilometers is considered to be a reasonable upper limit, depending on the heat load, water flow rate, its temperature, and the ruggedness of the terrain to be crossed by a pipeline.
- As previously stated, it is critically important that the temperatures and flow rates of a thermal feature to supply a Direct-use project remain steady for about 25 years. If natural recharge together with reinjection of used fluids cannot make this happen, then the monetary returns of some projects could fail to meet lender requirements, with unpleasant results for all stakeholders.
- In situations where there exists an entity that is already using waters from a thermal feature, a potential new user must reach agreements with the first party and must then make all possible efforts to prevent any adverse effects on the first users operations. These efforts could include the use of down-hole heat exchangers that take some heat from the thermal waters, but do not extract fluids from the resource as described later in this report.

Unfortunately, there is a limit to how much thermal water can be removed from a source and if that limit is exceeded, both temperatures and flow rates could be diminished. Accordingly, baseline data should be obtained by a potential new resource user so that claims of damages can be refuted or acknowledged as may be the case.

- Direct-use projects must be planned to be technically and economically viable without the use of thermal fluids. Geothermal waters should always be considered to be a bonus to a project that will enhance the returns on investment, not an indispensable ingredient the limitation of which will doom the project.

A.4. Selected Direct-use Project Background Information

There are some guiding principles that underlie the planning and design of any Direct-use project. Some of these have been mentioned in previous sections of this Roadmap. Regardless, they are presented below as a prelude to the Project Initiation Overview.

- The primary objectives of any geothermal Direct-use project are to use the natural heat of the Earth to replace fossil-fuel-generated heat sources such as oil, gas, coal, propane, or electricity. This substitution will save money in the long run, be environmentally beneficial, and help improve quality-of-lives in the project vicinity.
- In order for a geothermal Direct-use project to be successful, the capabilities of the resource (temperature, flow-rate, chemistry, longevity) should be matched with the project requirements. In some cases, if the match is not perfect, various types of hybrid installations can be considered. For instance, if flow rates and temperatures are not ideal, flows can be augmented with non-thermal waters and the temperature of the mixture boosted by limited use of a solar system, a wind-powered electric system, a bio-fueled boiler or a small fossil-fueled boiler to achieve peak project performance.
- Assuming that one major objective of any geothermal Direct-use project is to be profitable, the market demand for planned products must be identified and confirmed together with the costs of building the facility, plus annual operating and maintenance expenses. The net returns on investment to the developer should be acceptable without the benefits of lowered fuel costs due to the use of thermal fluids. If this is not the case, and the use of geothermal energy is critical to the success of a venture, then probably, the project should be modified significantly so that it can stand alone.

- There are a few “hard-and-fast” rules of thumb that apply to geothermal Direct-use projects. Each project is unique, however experience gleaned from other, similar projects is valuable, can help avoid repetition of mistakes, and should be taken into consideration as new projects are planned.
- Over the years, it has become evident that every new geothermal Direct-use project needs: a) the full support of the community and b) a “champion” or strong leader to guide the project through the planning, permitting, financing, construction, and finally, the operating stages. The “it will get done”, “they will do it” mentality just will not work. One person (or a small, workable group) must take charge and see the project to its conclusion.

B. DIRECT-USE PROJECT INITIATION OVERVIEW

In order to successfully develop a geothermal Direct-use project, the following steps, at a minimum, should be carefully undertaken and fully completed. Failure to do so could result in costly delays and decreased returns on investments.

1. Once a community has been made aware that there is a geothermal manifestation nearby, heat from which could be used beneficially, the community should be inventoried to identify all activities that require thermal energy (heat). These could include, but not be limited to: space heating, green-housing, crop-drying, concrete-curing, aquaculture, and spas.
2. Next, a determination should be made to learn whether anyone in the community has aspirations to develop a new facility that would benefit from use of the geothermal heat. If so, details of the idea should be obtained, and exposed to the community via printed and/or electronic means together with single purpose public meetings once the intellectual property rights of the proponent had been safeguarded if necessary
3. The purpose of this exposure is to obtain the consent of local citizens, non-native community leaders, First Nation leaders, and all of their respective constituents to the proposed geothermal development. It is likely that approval will not be unanimous, but objections should be heard and mitigated whenever possible. A spokesperson (or small, willing, communicative group of project protagonists) should be identified to take the lead as the project moves through the many development stages.
4. The next step will be to accurately quantify the amount of heat (in kJ/hr) that will be required by the geothermal Direct-use facility. This will require the services of an engineer who can determine the likely heat losses of all planned uses (buildings, ponds, green-houses, etc.) using

weather-related information including temperature ranges throughout the year, wind velocities and directions, relative humidities, etc. as well as thermal properties of planned construction materials. This information must then be supplemented by determination of the amount of heat to be needed by the planned Direct-use operations. This can be calculated by taking the desired input temperature and flow rate of thermal waters and subtracting the output temperatures and flow rates. The difference being the amount of heat used.

The formula used is: kJ/hr = (liters/sec)(Ti –To)(15,040)

Where: Ti is input temperature in ^{o}C; To is output temperature in ^{o}C, and 15,040 is a conversion figure described on page 2.

5. If the Direct-use project under consideration is already functioning and retro-fitting is proposed, the actual cost of the heat currently being used (gas, oil, coal, wood, propane or other) should be determined and converted to kJ/hr. If the Direct-use project is to be a new one, then the same cost estimate for non-geothermal fuel use should be made *conservatively*.
6. For an in-community project, determine whether thermal fluids can be logistically and cost-effectively piped from the thermal manifestation to the community. The distance, ruggedness of the topography, land ownership, need for and cost of re-grading old roads or building new roads, and winter maintenance should all be considered.
7. If the distance from the thermal feature is too great or if other costs of piping are too high, consideration should be given to constructing a Direct-use project at or very near the thermal feature. The piping and associated costs listed above will not be incurred, but the expenses of grading existing roads and the land on which the facility will be built, winter maintenance, worker transportation and/or living costs plus the installation of electric power should be accurately determined.
8. Once the resource has been determined to be adequate for use in the project based on its temperature flow rate, chemistry and predicted longevity, the sizes and types of materials needed for pipelines, heat exchangers, valves, and pumps should be identified and their availability times and costs confirmed. During the materials and equipment selection process, the stresses and strains of handling, moving and laying the pipes should be considered, as should be the need for relief valves and pressure tanks, plus the ease or difficulty of maintenance under inclement weather and road conditions.
9. As previously mentioned in this document, it will be important to properly dispose of used, cooled thermal fluids. Surface disposal, into rivers or onto the ground is not normally permitted

by regulatory authorities and lack of injection can lead to degradation of the resource. Reinjection is an important factor in maintaining the reservoir pressure in order to continue to utilize the resource. To appropriately dispose of the produced waters, a reinjection well should be drilled to a depth just greater than that of the geothermal reservoir. The waste fluids should then be flowed or pumped (if necessary) downhole. This will help maintain the reservoir pressure and also re-supply the source of the thermal waters. It will be important to re-inject far enough from the thermal fluid source (about 300 meters, depending on the permeability) and deep enough, to preclude or minimize any cooling effect or "thermal breakthrough".

10. When conducting the activities required to develop a geothermal Direct-use project, it is strongly recommended that qualified local labour be employed. This enhances the project image within the community, provides increased income that can be spent locally, and minimizes the distances that must be traveled by project workers. There will be tasks that must be done by geothermal experts and other professionals who may not live and work nearby. In these cases, such outside help must be employed, but if possible, internships for locals can be requested so as to develop the local expertise.
11. Before spending significant sums on the planned project a sound economic model needs to be built and tested. The financial inputs into this model needs to be once again reviewed including all anticipated costs of permits, legal assistance, insurance, land control acquisition, materials and equipment, licenses, consultants, royalties (if any), lender fees, interest on loans, and any others. Revenues must be conservatively estimated so that short-falls that commonly occur in the early project stages will not doom the plan immediately. Returns on the investment must satisfy the lender(s) as well as the developer and must exceed the returns that could be realized from interest accrued in banks, should the money not have been invested in the project. Note that if a Direct-use project is entirely sponsored by a community, the rate of return on the investment may be less important than achievement of greater employment for some citizens and improved economic well-being for the entire community.

C. PROCESS TO FOLLOW IN ORDER TO COST-EFFECTIVLY DEVELOP A GEOTHERMAL DIRECT-USE PROJECT

If the results of all the tasks listed above in section B suggest that utilization of some or all of the thermal energy believed to be available from the nearest thermal manifestation might be possible and profitable, the next steps are to *confirm and quantify the characteristics, capabilities, and limitations of the geothermal resource*.

C.1. Resource Confirmation and Quantification

Many of the surface geothermal manifestations in British Columbia have been cursorily examined, waters have been sampled, basic chemical analyses conducted, geo-thermometric temperatures calculated, flow-rates estimated or roughly measured, and shallow water temperatures recorded. At a few sites, there has been preliminary regional and local geologic mapping done, and in a very few cases, some thermal gradient holes have been drilled. Full scale geothermal exploration including the drilling of deep, production-scale wells has been conducted only at Meager Mountain.

Given that most, if not all, favourable project areas will be located on provincial Crown land, appropriate permitting guidelines will need to be followed in order to obtain access to the Crown land (please refer to Section C.10). In addition, it is important to assess if any other individuals or proponents have water rights in the area, so the process of obtaining the necessary water rights is begun at this early stage.

An essential step in any development in BC is to consult with First Nations communities. BC is legally obligated to consult and accommodate First Nations, where required, on land and resource decisions that could impact Aboriginal interests. While the Province is responsible for ensuring adequate and appropriate consultation and accommodation, it may involve the proponent in the procedural aspects of consultation. Thus, proponents are encouraged to engage with First Nations as early as possible in the planning stages to build relationships and for information sharing purposes.

Presented below are the steps that need to be taken in order to accurately characterize the thermal fluid parameters, understand the structure and stratigraphy in the vicinity of the thermal feature, propose potential reservoir rocks, identify significant faults and fractures and generally obtain all the resource-related information needed to develop a commercially and technically viable Direct-use project.

1. Carefully re-measure static and flowing temperatures and accurately quantify flow-rates from all surface orifices. Temperatures should be taken at multiple points and as deep as possible with long-stemmed thermometers, thermistors, or thermocouples. Flow-rate determination may require the digging of channels through which to focus distributed flows and the use of techniques more sophisticated than a calibrated container and a stop-watch i.e. weirs of an appropriate type.

2. Sample all of the thermal waters and, at least, the gasses H_2S and CO_2. A qualified, experienced geothermal geochemist should be employed to do this due to the toxic nature of H2S and because some important elements deteriorate or change structure if not captured and preserved properly. Note that gas sampling and shipment requires specialized training (WHMIS – Workplace Hazardous Materials Information System) and equipment. The samples should then be sent to a geothermally experienced laboratory for complete analyses and calculation of the SiO_2, Na-K-Ca, and Na-K-Ca-Mg geo-thermometric equilibration temperatures and to determine the potential for scaling or corrosion.
3. Employ an experienced geothermal geologist to obtain and study existing regional geologic and geophysical maps. The purpose is to gain an understanding of the structure (fault and fracture patterns) and the stratigraphy (rock types and ages) around, and near the thermal feature(s) of interest. Learning this will enable the creation of a preliminary model of the geothermal system, including the postulated heat source, the likely geothermal reservoir host rocks, and the fracture network(s) that can act as conduits for thermal fluid up-flows and recharge water down-flows.
4. Once this regional geologic and geophysical study has been done, more detailed geoscientific information should be obtained by mapping on a scale of about 1:2,500 or the area within a radius of about 1 kilometer from the thermal spring(s). Emphasis should be on the identification of all geothermal indicia, faults, fractures, joint patterns, local lithology, hydrothermal alteration zones (including metallic mineralization), and any topographic anomalies such as sinter or tufa mounds.
5. If initial measurements of the aggregate surface flows of thermal fluids suggest that they will not be adequate to fuel a geothermal Direct-use project, then consideration should be given to the drilling of one or more wells with which to try to obtain greater flows, from depth, by pumping. The first step towards this objective is to identify the best place to drill a deep well. This can best be accomplished by analyzing the local geologic map and using the data to select sites for two or three shallow (~200 meter) thermal gradient holes. The sites should be about equally spaced and situated where access for a small, truck-mounted drill rig is possible, hopefully without any new road-building. A nearby non-thermal water source would also be a plus and minimize or even eliminate the need to transport drilling water by tank-truck.
6. Consultation with the local communities, First Nations, and Provincial regulatory authorities should be ongoing throughout the entire process of planning and development. Up until this point, conduct of the activities recommended above would only require a Temporary License

under the Land Act's Industrial General Program in order to have surface rights to access the Crown land (please refer to Section C.10 for more information). Once drilling is proposed (either gradient wells or larger deeper production wells), a Lease (a longer term tenure under the Land Act), or an application for a Lease, is required from the Province in order to obtain a water license to drill the well. Time will be saved if, simultaneously, the permitting process can be initiated for future geophysical surveys, slim-hole (reduced diameter) drilling, and eventually production and injection well drilling. The payment of fees will be required for the permits, but the biggest obstacle may be the time the process takes, especially if there is no precedent for such a geothermally-related request. A very useful URL regarding the acquisition is http://www.frontcounterbc.gov.bc.ca/. This site is meant to be a "one-stop-shop" where all required permits can be obtained. To improve personal contacts, there are local Front Counter offices located in several, scattered, medium-sized towns throughout the Province the contact information for which can be obtained at the above link.

7. Following the completion of the thermal gradient drilling, if results are ambiguous, some consideration might be given to the conduct of an electrical resistivity survey to improve the identification of a drilling target for deeper well(s). This might comprise a dipole-dipole style or a small magneto-telluric (MT) type survey. The former will be less expensive, but the latter would probably yield more information about formation types, clay alteration zones, as well as the distribution of targeted low-resistivity zones. Neither of these geophysical surveys involves ground disturbance, only surface rights to the land.
8. It is possible that the preliminary geothermal system model based on results of the geologic mapping, the geo-thermometric equilibrium temperature calculations, the thermal gradient drilling and/or the electrical surveys strongly indicate the existence of a geothermal reservoir or a fault system near and beneath the surface thermal feature. If so, the next step in resource development should be the drilling of an exploratory slim-hole to the depth indicated by this model.

   When the water license application for thermal gradient drilling was submitted, any variations required for the purpose of drilling an exploratory slim-hole should have been included. If water flows are encountered during drilling or testing, an acceptable way to dispose of such waters will have to be identified. The drilling of a slim-hole is about 25% less expensive than the drilling of a full-scale production well, so it is likely that financing will have to be obtained. Though the amount of resource testing that can be done using a slim-hole is somewhat limited by its diameter, it is important to note that the slim hole can probably be used for water disposal if and when a full-scale production well is drilled (and before a dedicated injection well has been completed).

9. Hopefully, the slim-hole will transect either the reservoir or a nice open fracture system carrying lots of hot water. If so, then the drilling of a production well can probably be justified. To do this, the services of an experienced geothermal drilling engineer should be obtained in order to design the well, locate a reputable driller, and do the many things that are required to drill, test, and complete a well that will be serviceable for many years at a more or less “reasonable” cost. These days (2016), production wells can cost about $US 3,000/meter when all aspects of the project are included!

   Accordingly, well *before the drilling of thermal gradient holes, slim-holes or a production well is considered, the over-all economics of the venture must be reviewed and vetted or vetoed by an experienced geothermal financial specialist*. Seeking the advice of a financial analyst to ensure the financial model is sound is a wise decision.
10. If the project economics have been carefully reviewed and do make sense, then the production well and an associated injection well should be designed, permitted, financed, drilled, and tested using experienced engineers and contractors. Again, as much qualified local labour as possible should be employed. If all goes well, within about 60-90 days, the two wells should be finished and the geothermal reservoir ready to deliver thermal energy to the Direct-use proponent.

C.2. Surface-Structure Development Procedure

Once the resource temperature, flow/pumped rate, chemistry, and likely decline rate (from well-testing) have been accurately quantified, the number of kJ/hr available for a geothermal Direct-use project can be calculated. This will allow determinations as to the adequacy of the match between the heat available and the needs of the planned development. If such adequacy is confirmed, the following next steps should be followed:

1. The assumption is made that the community nearest the thermal features, and/or an independent investor, have an interest in development of a geothermal Direct-use project. Accordingly, funds have been expended to confirm that the resource is capable of providing most, if not all the thermal energy needed by such a project. Therefore, it is time to discover whether the community or the investor has the required technical and administrative expertise as well as the finances needed to move forward with expensive project phases or whether outside experts and funding will be needed.

2. It is now also important to determine the size and training level of the local labour force as well as to decide if training can be implemented to bolster the numbers and expertise of local workers. In addition to manual labour, employees will be needed for drilling operations, pipe installations, pumping and plumbing activities, and electrical system design and implementation.
3. Of critical importance is the availability of a local market for the products that are made, modified, or grown in the Direct-use facility. If not, then a study should be made to identify the best routes to get the product to a viable market and the costs incurred to do so. Obviously, all-weather, year-round market access will be mandatory in order to keep revenues coming in and all project obligations paid timely.
4. During the early planning stages of a geothermal Direct-use project, there should have been meetings held by the project proponents for the local citizens in order to ascertain the level of interest in the project. As an outcome from these meetings, a sense of the economic and social impacts of the project should have been obtained. Objections should have been addressed and appropriate plans made to mitigate, minimize, or eliminate objectionable project consequences.
5. Though it is not normally required for relatively small projects, there is a possibility that a BC Environmental Assessment (EA), or a Canadian Environmental Assessment, might be required in order to obtain the required approvals from local, First Nations, Provincial, or Federal agencies and to satisfy lenders and/or investors. EAs can be costly and take time to complete. These additional costs and impact on the development time-line must be taken into account if an EA is necessary.

   If an EA is not necessary, conducting a feasibility study should be considered. This is especially appropriate in the case of broad-scope projects like District Heating. The results of these technical and economic investigations, if encouraging, typically allay the concerns of most lenders and investors.
6. Finally, early on, during the project conceptualization stages, plans should be made to undertake the Direct-use project in distinct phases. Progress evaluations should be made, by independent third parties if possible, following completion of community surveys, market evaluations, geoscientific and road-access studies, thermal gradient hole drilling, and slim-hole drilling. As each project aspect is deemed satisfactory, the next phase is begun. Should the results of any phase be strongly negative or contain a “fatal flaw”, the project development should be reconsidered, appropriately modified, or abandoned so that no further funds are expended.

C.2.1. Producing heat from the well(s)

There are two ways to obtain heat from a geothermal well: (1) pumping hot water from the well and then transferring its heat to the application, either directly or through a heat exchanger, and (2) extracting only heat from the well using a closed loop of pipe called a downhole heat exchanger (DHE) and then using a secondary fluid to transfer the heat to the application (i.e.to a green-house, aquaculture pond, snow melting system, or an industrial process) (Figure 3).

C.2.2. Pumping the fluid.

Pumping is often necessary in order to bring geothermal fluids to the surface (Figure 4). For Direct-use applications, there are primarily two types of production well pumps: (1) line-shaft turbine pumps, and (2) submersible pumps – the difference being the location of the driver. In a line-shaft pump, the driver, usually a vertical shaft electric motor is mounted above the well head and drives the pump which may be located as much as 600 m below the ground surface, by means of a line-shaft. This driver style is limited to relatively straight wells (Figure 4). In a submersible pump, the driver (a long, small diameter electric motor) is usually located below the pump itself, in the geothermal fluid, and drives the pump through a relatively short shaft with a seal section to protect the motor from the well fluid (Figure 4). The former system is probably economically limited to setting of less than 250 m in Direct-use applications, whereas the latter system can have a setting depth of up to several 1,000 meters. In some installations, selection of pump type will be dictated by depth to water, the drawdown characteristics of the well, well diameter, well deviation, and/or temperature.

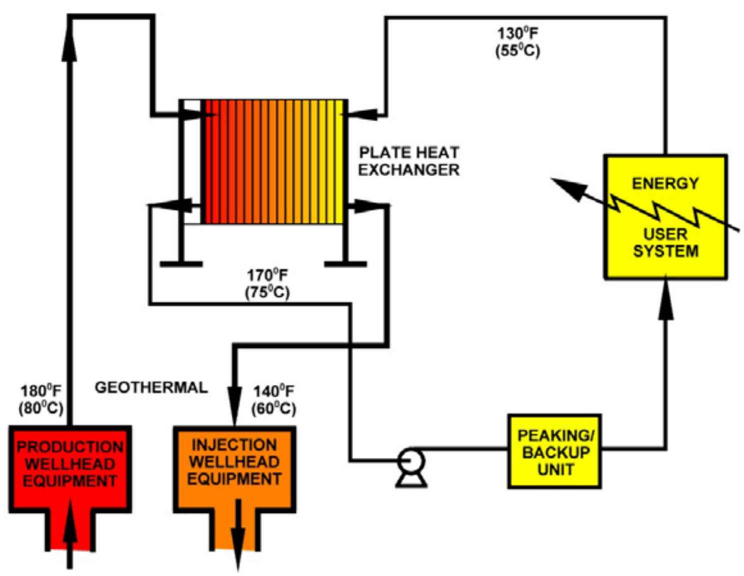

Figure 3. Direct-use heating schematic. Temperature drops shown are for example purposes and are typical for a system using 80°C water (Geo-Heat Center, 1998).

C.2.3. Downhole heat exchanger (DHE)

If disposal of well fluids is a problem due to potential interference with an existing thermal water user, disposal site limitations, or to save the cost of drilling an injection well, the use of a downhole heat exchanger may be justified. With this system only heat is taken from the well. The exchanger comprises several pipes or tubes suspended in the well through which "clean" non-thermal secondary water is pumped or allowed to circulate by natural convection so as to gain heat by conduction. This system offers substantial economic savings over surface heat exchangers in situations where a single-well system is adequate, typically less than 0.8 MWt, with well depths up to about 150 m. They may be economical, under certain conditions, at well depths up to 500 m. Several designs have proven successful, but the most popular are a simple hairpin loop or multiple loops of iron pipe (similar to the tubes in a U-tube and shell exchanger) which extend nearly to the bottom of the well (Figure 5).

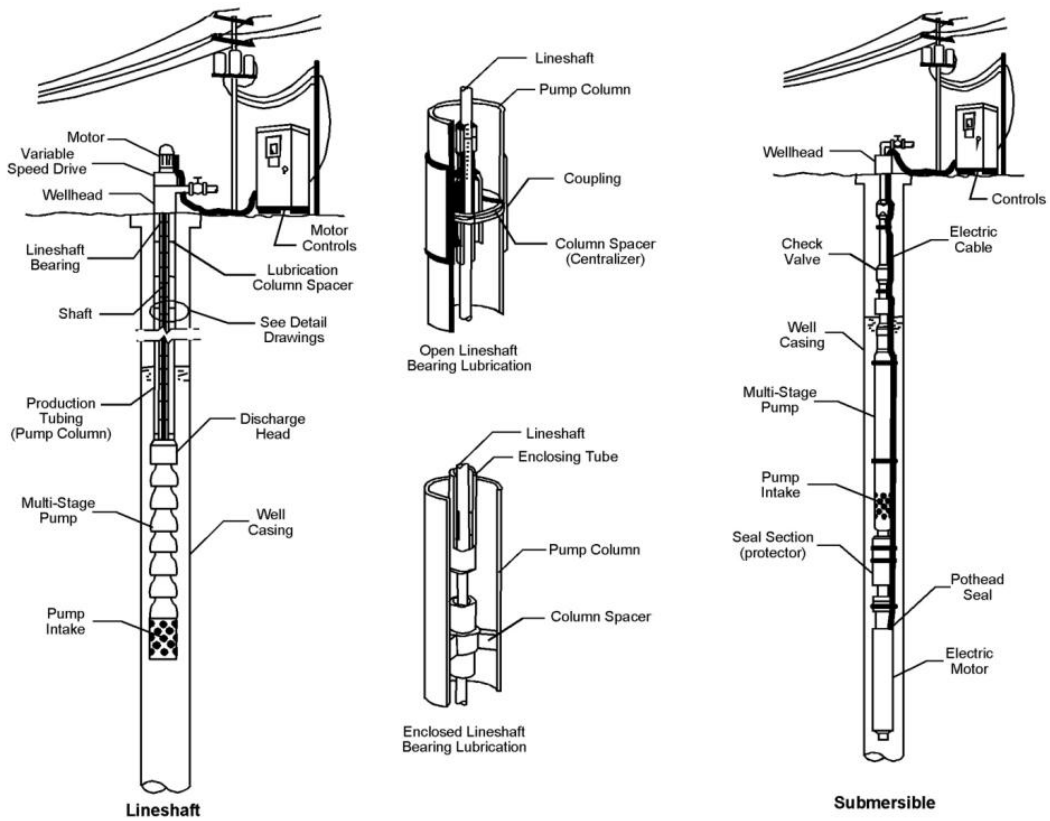

Figure 4. Lineshaft and Submersible Pump Diagrams (Culver and Rafferty, 1998).

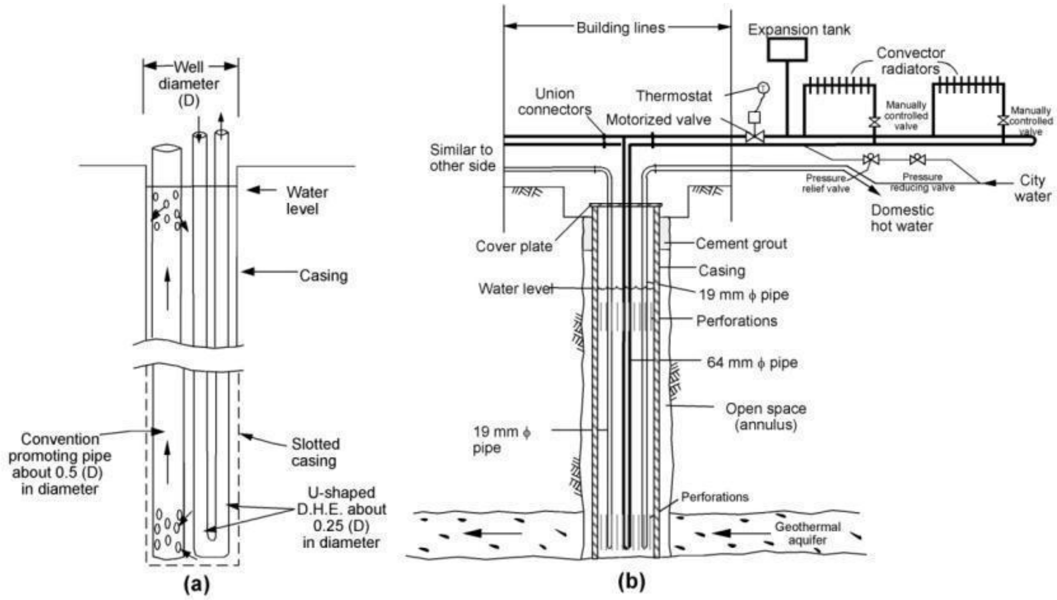

Figure 5. Downhole Heat Exchanger Designs a) with promoter pipe and b) with heating and domestic hot water loops (Rafferty and Culver, 1998).

In order to obtain maximum thermal output, the well must be designed to have an open annulus between the wellbore and casing, and perforations above and below the heat exchange surface, as shown in Figure 5b. Natural convection circulates the cooler water down inside the casing, out through the lower perforations, up in the annulus where it is warmed, and back inside the casing through the upper perforations. DHE outputs have been as high as 1.0 MWt in Klamath Falls, Oregon and a well producing 6 MWt has been reported in use in Turkey. A typical DHE well is 25 to 30 cm in diameter with a 20-cm diameter casing installed. The casing is torch perforated or pre-slotted in the live water area at the bottom and just below the lowest static water level. The space heating DHE is usually black iron pipe, 4 to 8-cm in diameter, with a return U bend at the bottom. A second domestic hot water loop can also be installed and is typically a 2 to 3-cm diameter black iron pipe. The heating loop is a closed (recirculating) system and the domestic hot water loop is an open system. Based on experience, one meter of heating loop can provide about 1.4 kWt. Normally, the heating loop operates as a "thermo-syphon" to circulate the hot water, but sometimes small circulation pumps (up to 100 W) are used to increase the flow rate and thus improve the heat transfer.

C.2.4. Promoter pipe.

A promoter pipe is simply a pipe that is open at both ends and placed in a well with a downhole heat exchanger (Figure 5a). These have been used extensively in Rotorua, New Zealand. The promoter pipe sets up a convection cell that is necessary to increase the temperature of the water over the length of the DHE. It is used when the well casing has not been perforated just below the low water line and in the live water flow at the bottom of the well, thus preventing the hot water flow from mixing sufficiently along the entire well-bore length. The DHE can be installed either in the convector or outside the convector, the latter being more economical since a smaller convector can be used. Typically the diameter of the promoter pipe is twice the diameter of the DHE pipe.

C.3. SWIMMING, BATHING AND BALNEOLOGICAL USES OF GEOTHERMAL WATERS

C.3.1. Background (Lund, 2001)

People have used geothermal waters and mineral waters for bathing and for improving their health for many thousands of years. Balneology, the practice of using natural mineral water for treatment and cure of disease, also has a long history. Based on archeological finds in Asia, mineral water has been used for bathing since the Bronze Age, about 5,000 years ago. Many hot springs have been used in connection with religious rites in Egypt and by the Jews of the Middle East. The Greeks, Ottomans, and Romans were also famous for their spas developed and used from Persia to England. The word “spa” traces its origin to a town near Liège in southern Belgium near the Germany border where a spring of iron-bearing water was used by an iron master in 1326 to cure his ailments. He founded a health resort called Espa at the spring (meaning fountain in the Walloon language) (Figure 6). Espa became so popular that the word known in English as spa became the common designation for similar health resorts around the world (Lund, 1996b).

Figure 6. The Peter the Great Pouhon building (1908)(Lund, 2000a).

A spa originates at a location mainly due to the availability of special waters from a spring or well. The water, with certain mineral constituents and often warm, give the spa its reputation as a special attraction (DeVierville, 1998). Associated with most spas are the uses of muds (peloids) which are either found at the site or imported. As an example, at Pieštany in Slovakia, there is a special laboratory that test muds or clays for their mineral content and their therapeutic benefits (Figure 7). The muds are stored in tanks and “cured” or “aged” for maximum benefits. The spas at Calistoga, California, use a mixture of volcanic ash and peat moss for their “muds” (Figure 8).

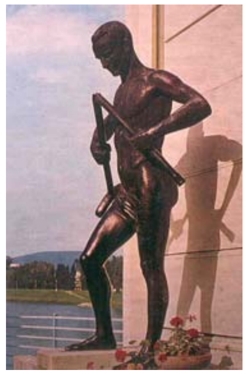

Figure 7. Pieštany, Slovakia (Lund, 2000b).

Figure 8. Calistoga, CA (volcanic ash and peat moss soak)(Lund, 1979).

C.3.2. Early North American Developments

In Canada and the United States, the use of natural springs, especially geothermal ones, have gone through three stages of development: (1) use by First Nations and Indigenous peoples as sacred places, (2) development by the early European settlers to emulate the spas of Europe, and (3) as places to relax and increase fitness.

The Indigenous peoples of the Americas consider hot springs as sacred places and believe in the healing powers of the heat and mineral waters. To recuperate from his strenuous duties, Montezuma, the great Aztec leader, spent time at spa Aqua Hedionda, which was later developed into a fashionable spa by the

Spaniards (Salgado-Pareja, 1988). Every major hot spring in the U.S. and Canada has some record of use by Aboriginals and First Nations people, some for over 10,000 years. These springs were also known as neutral ground, to which warriors could travel and rest unmolested by other tribes. Here they would recuperate from battle. In many cases, they jealously guarded the spring and kept its existence secrete from the arriving European for as long as possible. Battles were fought between Aboriginals and settlers to preserve these rights. The early Spanish explorers such as Ponce de Leon and Hernando De Soto where looking for the "Fountain of Youth," which may have been an exaggerated story of the healing properties of one of the hot springs.

The early European settlers in the 1700 and 1800s found and used these natural hot springs, and later, realizing their commercial value, developed many into spas after the tradition in Europe. Many individual developments were successful such as springs in Banff National Park, Alberta, and Harrison Hot Springs (called the Baden Baden of America), British Columbia in Canada, and Saratoga Springs, New York; White Sulfur Springs, West Virginia; Hot Springs, Arkansas; Hot Springs, Virginia; Hot Springs State Park, Wyoming; and Warm Springs, Georgia, all in the United States.

In Canada, First Nations people have made extensive use of hot springs. For example, on the west coast of British Columbia, the Nuu-chah-nulth used hot springs for treating chronic diseases such as arthritis (Woodsworth and Woodsworth, 2014). John Fannin, in an 1873 report on the Fraser Valley, wrote (Woodsworth and Woodsworth, 2014):

> "The Indians have, for a long time, been in the habit of using [hot spring water] in certain cases of sickness, and the plan they adopt is this: A piece of cedar bark is placed on the ground at the edge of the springs from where the steam is rising, and the invalid, covered with a blanket sits in a crouched position on this bark for hours at a time: and if they are to be believed, many cures have been effected."

The first recorded visit by Europeans to hot springs in Canada was in 1841 at Radium Hot Springs. Early European visitors to Banff found the waters useful for treatment of rheumatism, syphilis, and gunshot wounds. Workers of the Canadian Pacific Railways discovered the Cave and Basin Hot Springs of Alberta in 1882, which lead to the creation of Banff National Park in 1885, the first national park in Canada to commercialize the hot springs, and the construction of a hotel in 1886 (Raymond, et al., 2015). An early advertisement for St. Alice Hotel (now Harrison Hot Springs) even claimed the waters to be a sure cure for many ailments, including alcoholism, and to be excellent for the complexion. Springs high in lithium were said to be particularly beneficial for the kidneys and digestion (Woodsworth and Woodsworth, 2014).

C.3.3. Current Spa Development in the Americas

By 1940s, the interest in spas languished in Canada and the United States, and most of the majestic resorts went into decline and closed. However, more recently the health and fitness industry has been stimulated by increased consumer interest worldwide, resulting in high growth in revenue and profits. The most traditional type of health spa is the geothermal spa, featuring baths and pools of natural mineral hot water.

Today, there are approximately 210 spas in the U.S. with 4.5 million persons attending a spa in commercial pools heated by geothermal water for bathing purposes, along with thousands of hot springs (1,800 reported by NOAA, 1980). In western Canada, more than 150 thermal springs are known to exist, but only 48 have sufficient data for in-depth characterization and 13 have been developed into commercial hot spring resorts and spas (Thompson, et al., 2015, Raymond, et al., 2015). These commercial pools are mainly located in British Columbia (9) and Alberta (2), with one each in Saskatchewan and Yukon Territory (Table 1 and Figure 9). The commercial bathing facilities in Canada have an approximate total capacity of 8.8 MWt and an annual energy use of 277 TJ (equivalent to peak heating for approximately 220 homes in central BC).

> Note that: 1) the "Total Capacity" is the size of the equipment needed to produce the energy necessary to operate the facility, 2) "Energy Use" is the amount of energy for which the user will be charged in joules/second, Btu/hr., or ft.-lbs./hr., and 3) MWt is thermal megawatts which is the amount of heat available from a geothermal source. This differs from MWe or megawatts electric which is the amount of electric power that can be generated using a given amount of MWt. The difference between the two numbers is due to the efficiency of the referenced facility.

Table 1. Hot springs and thermal water commercially exploited in Canada (Raymond, et al., 2015).

Name	Province	Flow rate (L/s)	Spring temperature (°C)	Pool outlet temperature (°C)	Capacity (kWt)
Banff Upper	AB	14.9	47	38	563
Miette	AB	15.3	54	37	1,092
Ainsworth	BC	6.9	47	32	435
Fairmont	BC	20.9	46	44	176
Halcyon	BC	3.5	54	32	323
Harrison	BC	26.1	40	28	1,315
Liard	BC	30.0	52	30*	2,772
Nakusp	BC	1.2	57	30	136
Mount Layton (Lakelse)	BC	9.9	41	30	457
Radium	BC	28	40	32	941

Skookumchuck (St. Agnes)	BC	3.2	35	30	67
Takhini	YT	5.7	40	35	120
Temple Gardens Mineral Spa	SK	5.7	46	30	383
				Total capacity (kWt) Energy use (TJ/yr)	8,780 277

Abbreviations: AB = Alberta, BC = British Columbia, SK = Saskatchewan, YT = Yukon

*Assumed temperature as water flows in swamps.

Flow rates and temperatures range from 1 to 30 L/s and 35 to 57°C. Of the hot springs documented and described in Canada (Woodsworth and Woodsworth, 2014) 87 are from 87 to 32°C, 21 are from 31 to 20°C and 4 are from 19 to 10°C. Native Americans in the U.S. have developed warm springs for bathing at Warm Springs Reservation, Kah-Nee-Ta Resort, Oregon (Figure 10). The spring from the Warm Springs River at 60°C is cooled to a pleasant 35°C for the pool (Lund, 2004).

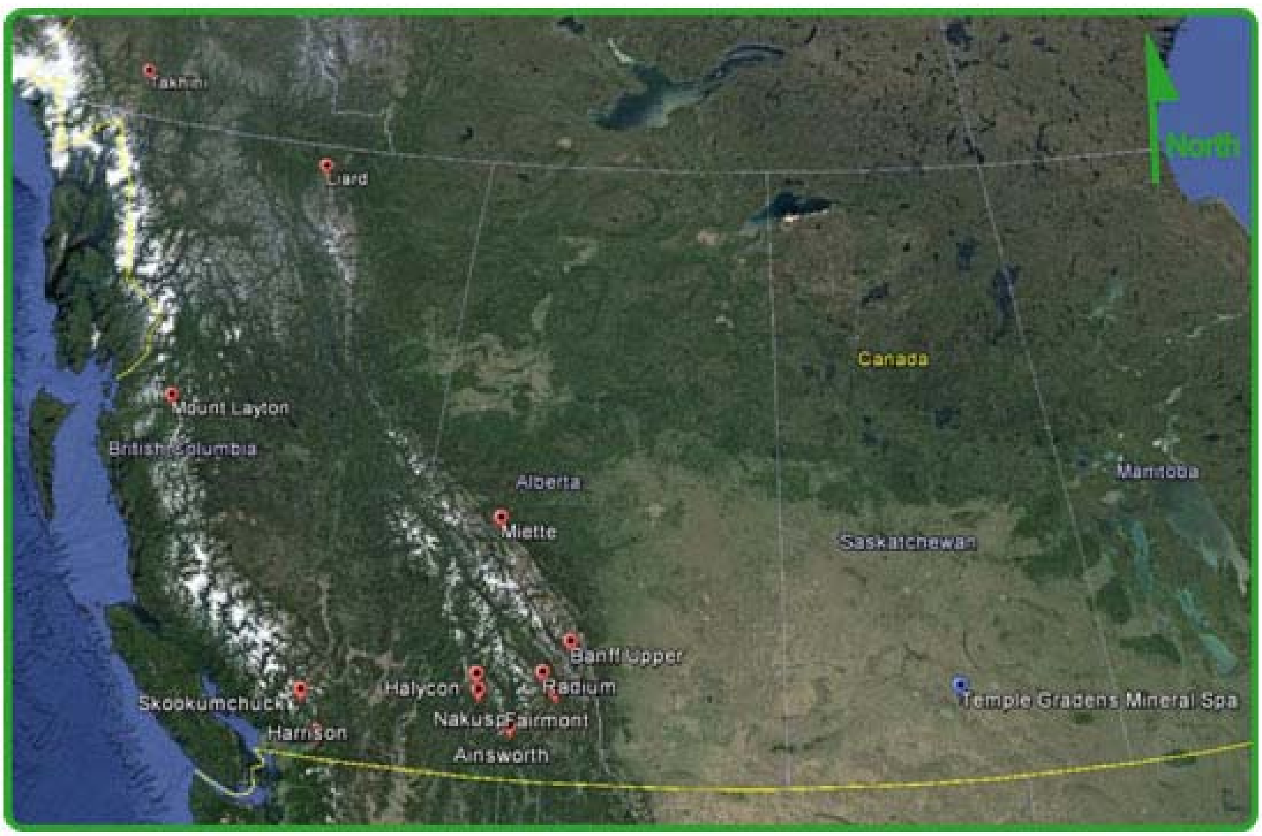

Figure 9. Google Earth image showing the location of the commercially exploited hot springs (red dots) and thermal water (undeveloped, blue dot) in Canada (from Raymond et al., 2015).

Figure 10. Geothermal pool at Warm Springs Indian reservation, Oregon (Lund, 2004).

Table 2. Hot Spring Water Chemistry from selected Canadian sites (Swisher, 2016). Units are mg/L.

Chemistry	Radium	Banff Upper	Miette	Ainsworth	Harrison	Fairmont
Sulfate	302	572	1,130	1,290	668	971
Calcium	135	205	307	340		483
Bicarbonate	100.8	134	124	680	66.6	771
Silica	31.8			117		60
Magnesium	31.6	42	56	248		100
Sodium		6.6	10.5	374		37
Potassium					24.6	
Lithium				46		

C.3.4. Soaking, Relaxing and Fitness

This recent interest in hot springs soaking and physical fitness has renewed the development of spas in the Canada and the United States. This natural way of healing and the "back to nature" movement has in many ways rejected formalized spa medical treatment as developed in Europe. In fact, the average American knows little of spa therapy and its advantages as many of the medical claims have been denied by legal authorities and many of the natural waters have been required to have chlorination or other chemical treatment. The main reasons people in the U.S. and Canada go to geothermal spas are to improve their health and appearance, to get away from stresses, and to refresh and revitalize their body and mind. Unlike European spas where medical cures of specific ailments are more important, North American spas give more importance to exercise, reducing stress, lifting depression and losing weight. A recent interest is the development of "health conservancies" to preserve natural areas for health and fitness activities.

The use of mineral and geothermal waters has developed along three lines in the U.S. and Canada: (1) relatively plush hot springs resorts with hotel-type services and accommodations; (2) commercial plunges or spring pools and soaking tubs with perhaps a snack bar or camping facilities; and (3) the primitive, undeveloped springs without any services (Sunset Magazine, 1983). Many resorts and natural hot springs have an informal dress code while soaking, including nude bathing. They have typically satisfied health department requirements for chemical treatment by allowing the water to continuously flow through without treatment.

C.3.5. Typical Spa Design

There are many designs for spas, depending upon the local culture, the unique character of the location, and what the developers are trying to achieve in terms of atmosphere, service, and type of clientele. Two basic types, with an emphasis on the use of geothermal water, are presented below.

The first (Figure 11) is one originally proposed for Hawaii (Woodruff and Takahashi, 1990) and is similar to ones in Calistoga, California. This design which includes living quarters surrounding the various bathing and soaking pool, lends itself to feature native plants and material in the landscaping and construction. Also, food and drink can be provided along with small shops and a fitness room for a health and fitness program. The enclosed pool area would provide privacy, but also allow access to and from the living area.

The second design (Figure 12) was also proposed for Hawaii (Woodruff and Takahasi, 1990). This design emphasizes private, semi-private and public bathing and soaking facilities. This is also typical of the design for the Polynesian Pools in Rotorua, New Zealand (Figure 13). This design does not include living quarters, but these could be added at a separate location and could be individual cottages. The semi-private and private pools could then be used by a single family and rented on an hourly basis. This would also be appropriate in cultures where bathing in public is less accepted.

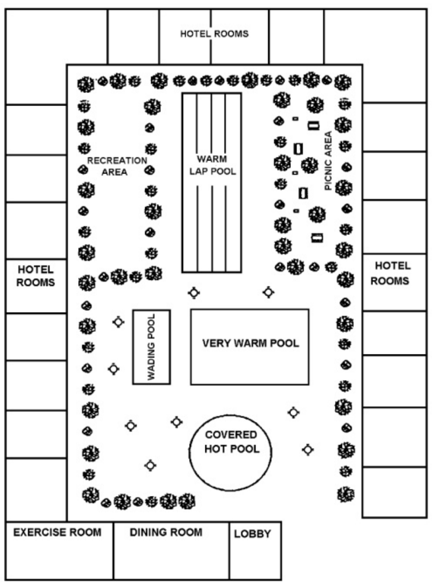

Figure 11. Typical spa design with hotel rooms (Woodruff and Takahasi, 1990).

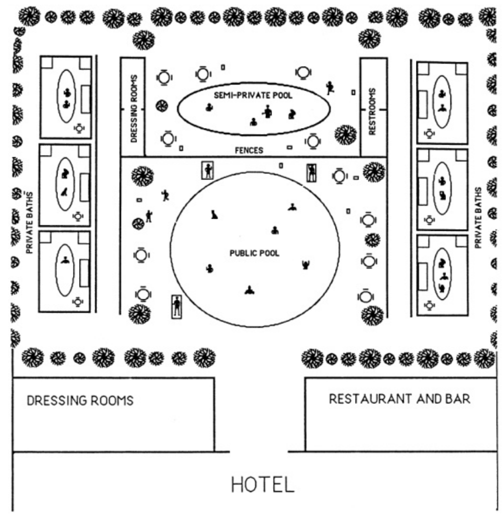

Figure 12. Typical spa design with individual private soaking tubs (Woodruff and Takahasi, 1990).

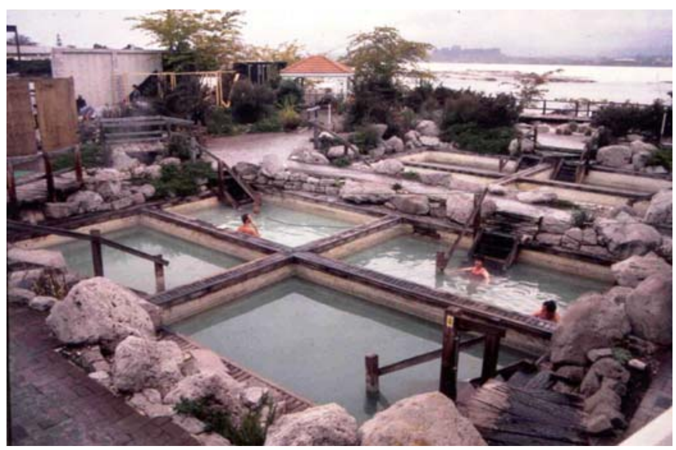

Figure 13. Polynesian Spa, Rotorua, New Zealand (Anderson, 1998)

Both of the above designs could be uncovered, completely enclosed or each individual pool covered with a temporary roof for use in inclement weather. Uncovered pools are extremely popular in the evening under a star-lit sky.

C.3.6. Design Considerations for Pools and Spas (Natatoriums) (Lund, 2001)

According to ASHRAE (1999a), the desirable temperature for swimming pools is 27°C; however, this will vary from culture to culture by as much as 5°C. If the geothermal water is hotter than is commonly tolerable, then some sort of mixing or cooling, such as by aeration or in a holding pond may be required to lower the temperature. If the geothermal water is used directly in the pool, then a flow-through process is necessary to replace the “used” water on a regular basis. Some cultures, such as the Japanese and “back to nature” groups, want to use the geothermal water directly without treatment. However, in many cases, the pool’s water is required to be treated with chlorine or ozone, thus, it is more economical to use a closed loop for the treated water and have the geothermal water provide heat through a heat exchanger. The water heating system in this case, is installed on the return line to the pool. Acceptable circulation rates vary from six to eight hours for a complete change of water. Heat exchangers must be designed to resist the corrosive effects of the chlorine in the pool water and scaling or corrosion from the geothermal water. This often requires, in the case of plate heat exchangers, the use of titanium plates.

Sizing of the system for temperature and flow rates depends on four considerations (ASHRAE, 1999a), as described below:

1. Conduction through the pool walls,
2. Convection from the pool surface,
3. Radiation from the pool surface, and
4. Evaporation from the pool surface.

Of these, conduction is generally the least significant, unless the pool is above ground or in contact with cold groundwater. Convection losses depend on the temperature difference between the pool water and the surrounding air, and the wind speed across the surface. This is substantially reduced for indoor pools and ones with wind breaks. Radiation losses are greater at night, again especially for outdoor pools; however, during the daytime there will be solar gains which may offset each other. A floating pool cover can reduce both radiation and evaporation losses. Evaporation losses constitute the greatest heat loss from pools amounting to 50 to 60% in most cases (ASHRAE, 1999a). The rate at which evaporation occurs is a function of air velocity across the pond surface and the pressure difference between the pool water and the water vapor in the air (vapor pressure difference). As the temperature of the pool water is increased or the relative humidity of the air is decreased, the evaporation rates increased. An enclosure can reduce this loss substantially, and a floating pool cover can practically eliminate the loss. Swimming and other pool uses causing waves and splashing will increase the surface areas and thus the evaporation rate.

An example of energy loss from a small pool is as follows (Table 3). The detailed calculations can be found in (Lund, 2001).

Assumptions:

- Pool surface areas: 5 m x 10 m = 50 m^2
- Outside design temperature: -10^{o}C
- Wind velocity: 2.5 m/s
- Desired pool water temperature: 25^{o}C
- Pool depth: 1.5 m
- Pool Volume: 75 m^3

Table 3. Summary of heat losses.

Heat loss components	Loss (kJ/h)	% of Total
Evaporation	67,900	47
Convection	39,600	28
Radiation	30,000	21
Conduction	5,500	4
Total	**143,000**	**100**

This is the peak loss, and the annual loss, assuming a load factor of 60%, (Note: the load factor is the equivalent number of full-load operating hours per year, i.e. a load factor of 0.60 = 8760 x 0.60 = 5256 hrs/yr) would be:

143,000 kJ/hr x 8760 hr/yr x 0.60 = 752 MJ/yr.

Assuming a geothermal resource temperature of 40^{o}C, then the flow required flow rate would be:

143,000 kJ/hr /[15,040 kJ x s x ^{o}F /(L x hr)] (40 – 25)^{o}F] = 0.634 L/s

where kJ = kilojoules (1 kJ = 1000 joules = 948 BTUs); L = liters, and; s = seconds.

If an enclosure were to be used it would reduce the air velocity across the surface and increase the humidity, the total heat loss would be reduced to about 78,400 kJ/hr or 55% of the uncovered pool.

C.3.7. Spas (Natatoriums)

Spas or natatoriums require year-round humidity levels between 40 and 60% for comfort, energy consumption, and building protection (see information below from ASHRAE, 1999b). Any design must consider all of the following variables: humidity control, ventilation requirements for air quality (outdoor and exhaust air), air distribution, duct design, pool water chemistry, and evaporation rates. According to ASHRAE (1999b):

"Humans are very sensitive to relative humidity. Fluctuations in relative humidity outside of the 40 to 60% range can increase the level of bacteria, viruses, fungi and other factors that reduce air quality. For swimmers, 50 to 60% relative humidity is most comfortable. High relative humidity levels are destructive to building components. Mold and mildew can attack wall, floor, and ceiling coverings; and condensation can degrade many building materials. In the worst case, the roof could collapse due to corrosion from water condensing on the structure."

Heat load sources for a spa include building heat gains and losses from outdoor air, lighting, walls, roof, and glass, and internal latent heat loads that generally come from people and evaporation. The evaporation loads are large compared to other factors and are dependent on the pool characteristics such as the surface area of the pool, wet decks, water temperature and activity level in the pool (Figure 14).

Figure 14. Evan's Plunge, Hot Springs, South Dakota (Lund, 1997).

It is important to apply an activity factor to the pool design for the estimation of the water evaporation rate. For example, the difference in peak evaporation rates between private pools (residential) and active public pools of the same size may be more than 100%. The following activity factors (Table 4) should be applied to the area of specific features such as diving area and water slides, and not to the entire wetted area when calculating the evaporation rate (ASHRAE, 1999b). For example, the table indicates that the evaporation rate for a whirlpool is twice that of a residential pool in kg/s.

Table 4. Activity Factors for Various Types of Pool (ASHRAE, 1999b).

Type of Pool	Typical Activity Factor
Residential pool	0.5
Condominium	0.65
Therapy	0.65
Hotel	0.8
Public, schools	1.0
Whirlpools, spas	1.0
Wavepools, water slides	1.5 (minimum)

ASHRAE (1999b) recommends operating temperatures and relative humidity conditions for design, and suggests that higher operating temperatures are preferred by the elderly. Air temperatures in public and institutional pools should be maintained 1 to 2°C above the water temperature (but not above the comfort threshold of 30°C) to reduce the evaporation rate and avoid chill effects on swimmers. The maximum water temperature that can be tolerated by the human body (for short periods of time) is 43°C. The ASHRAE recommendations are as shown in Table 5.

Table 5. Typical Natatorium Design Conditions (ASHRAE, 1999b).

Type of Pool	Air Temperature °C	Water Temperature °C	Relative Humidity %
Recreational	24 to 29	24 to 29	50 to 60
Therapeutic	27 to 29	29 to 35	50 to 60
Competition	26 to 29	24 to 28	50 to 60
Diving	27 to 29	27 to 32	50 to 60
Whirlpool/spa	27 to 29	30 to 40	50 to 60

Relative humidities should not be maintained below recommended levels because of the evaporation cooling effect on a person emerging from the pool and because of the increased evaporation from the pool, which increases the heating requirements. Humidities higher than recommended encourage corrosion and condensation problems as well as occupant discomfort. Air velocities should not exceed 0.13 m/s at a point 2.4 m above the walking deck of the pool (ASHRAE, 1995).

Ventilation is important, especially if chlorine is used to treat the pool water. Ventilation is also used to prevent temperature stratification in areas with high ceilings. Since exhaust air will contain chloramine from the chlorine treatment and also have high moisture contents, care must be exercised to vent this air outside and not into changing rooms, toilets and showers. In addition, pool areas should have a slight negative pressure and automatic door closers to prevent the contaminated air (laden with moisture and chloramine) from migrating into adjacent areas of the building. ASHRAE (1999b) states that most codes require a minimum of six air changes per hour, except where mechanical cooling is used. With mechanical cooling, the recommended rate is four to six air changes per hour for therapeutic pools.

Natatoriums can be a major energy burden on a facility, thus energy conservation should also be considered. This includes evaluation of the primary heating and cooling systems, fan motors, pumps, and backup water heaters (in the case of geothermal energy use). Natatoriums with fixed outdoor air ventilation rates, without dehumidification, generally have seasonally fluctuating space temperature and humidity levels. Since these systems usually cannot maintain constant humidity conditions, they may facilitate mold and mildew growth and poor indoor air quality. In addition, varying activity levels will also cause the humidity level to vary and thus change the demand on ventilation air.

C.3.8. Conclusions

Geothermal water has been used extensively for hot pools and baths, but not for heating or cooling the interior of structures of these spas. Space heating has been attempted in the past at many resorts; however, with mixed-to-poor results. Pipes would corrode or plug with deposits and require frequent repairs, replacement and cleaning. The expense was high and thus, "natural" space heating was usually replaced with conventional fossil fuel systems. Today, geothermal experts understand and solve these problems on a routine basis. The costs of installing the proper equipment and safeguards are more than offset by the savings in annual heating costs incurred with the use of fossil fuels.

The benefits for the spa visitor with regard to improvement of their mental and physical health include:

1. Living up to your potential both physically and mentally,
2. Minimizing the effects of aging,
3. Establishment of new eating habits,
4. Feeling healthier,
5. Feeling happier,
6. Toning up,
7. Reducing weight,
8. Quitting smoking,
9. Quitting drinking,
10. Looking more attractive,
11. Increasing athletic skills,
12. Preventing diseases,
13. Helping cure common ailments,
14. Treatment of specific male or female problems,
15. Stretching your body,
16. "Stretching" your mind,
17. Elimination or reduction of stress,
18. Having fun,
19. Meeting people (in person or "plugging in" socially),
20. Achieving a better body and more balanced personality,

21. Being pampered,
22. Promotion of family togetherness,
23. Facilitation of individual activity,
24. Solitude, and
25. Relaxation

Figure 15. Family Hot Tub, Columbia River Gorge Spa, Washington (photo by Yoshida, 1996).

C.3.9. For More Information

Several spa books have been written on the subject, documenting various facilities and their use: (Van Itallie, and Hadley, 1988; Sarnoff, 1989; Barish, 2009, Hotta and Ishiguaro, 1986).

Barish, E., 2009. Best Spas USA: The Guidebook to Luxury Resort and Destination Spas of the United States, BestUSA Publishing, Scottsdale, AZ, 237 p.

Geo-Heat Center Quarterly Bulletin, 1993. Nine articles on hot springs, spas and balneology in the U.S., Vol. 14, No. 4, Geo-Heat Center, Klamaath Falls, OR, 32 p.

Hotta, A. and Y. Ishiguaro, 1986. A Guide to Japanese Hot Springs, Kodansha International Ltd., Tokyo, Japan, New York and London, 284 p. (160 of the best hot springs in Japan from rock-lined river pools to luxurious resorts).

Stories from a Heated Earth – Our Geothermal Heritage, 1999. Edited by R. Cataldi, S. F. Hodgson, and J. W. Lund, Geothermal Resources Council, Davis, CA, 568 p. (34 papers on early uses of geothermal energy).

Van Itallie, T. B., and L. Hadley, 1988. The Best Spas, Perennial Library, Harper & Row, New York, NY, 431 p.

Figure 16. City Swimming Pool Reykjavik, Iceland (used year-round due to being heated with geothermal energy)(site visit Lund, 1997).

Figure 17. Blue Lagoon near Reykjavik, Iceland (geothermal power plant in background)(site visit Lund, September 2003).

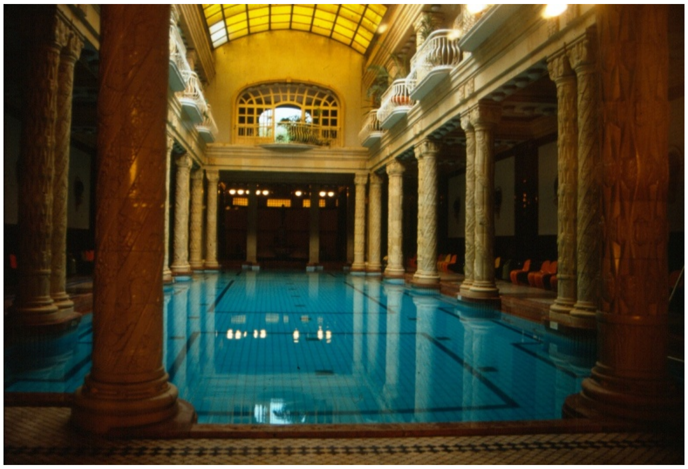

Figure 18. Gillerete Hotel, Budapest, Hungary (site visit Lund, April 2001).

Figure 19. Glenwood Springs, Colorado (largest geothermal pool in the U.S.)(site visit Lund, April 2009).

Figure 20. Radium Hot Springs, BC, (Lund, 2003).

Figure 21. Banff Upper Hot Springs (Lund, 2003).

Figure 22. Using "therapeutic" muds in Mexico (site visit Lund, July 1998).

C.4. Aquaculture

Aquaculture involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The use of geothermal fluids can control the temperature much better than if reliance is placed on solar heating.

There are now numerous commercial geothermal aquaculture facilities in operation world-wide. They nurture and grow species including, but not limited to: catfish, shrimp, prawns, exotic fish, tilapia, trout, sturgeon, and alligators.

A few important facts regarding this industry are presented below:

1. The use of geothermal waters, either directly or via heat exchangers, allows better temperature control with consequent enhanced production rates and less disease than does reliance on solar heat.
2. Temperature control is extremely important as aquatic species are far more temperature sensitive than are terrestrial animals. When the water temperature is below the optimum range, the fish lose their ability to feed because the basic body metabolism is affected (Table 6 and Figure 23). Note in Figure 23 that common domestic animals do not have the critical temperature controls for growth that aquatic species have.
3. Construction costs for professionally designed, lined ponds/tanks are CAD 120,000 to CAD 240,000 per hectare (ha) plus the cost of the geothermal system comprising wells, pipes, heat exchangers, filters, and pumps (Boyd and Rafferty, 1998).

4. Water quality is critical as some elements entrained in geothermal waters can be toxic to various species. If they are not toxic to the animals, their presence in the meat of the species grown and sold may preclude their sale for human consumption. Accordingly, the use of heat exchangers and local, clean, non-thermal waters may be required and should be budgeted during project planning.

Table 6. Temperature Requirements and Growth Periods for Selected Aquaculture Species (Rafferty, 1998c)

Species	Tolerable Extremes ^oC	Optimum Growth ^oC	Growth Period of Market Size (months)
Oysters	0 - 36	24 - 26	24
Lobsters	0 - 31	22 - 24	24
Penaeid Shrimp			
Kuruma	4 - ?	25 - 31	6 - 8 typically
Pink	11 - 40	22 - 29	6 - 8
Salmon (Pacific)	4 - 25	15	6 - 12
Freshwater Prawns	24 - 32	28 - 31	6 - 12
Catfish	17 - 35	28 - 31	6
Eels	0 - 36	23 - 30	12 - 24
Tilapia	8 - 41	22 - 30	-
Carp	4 - 38	20 - 32	-
Trout	0 - 32	17	6 - 8
Yellow Perch	0 - 30	22 - 28	10
Striped Bass	? - 30	16 - 19	6 - 8

General aquaculture design considerations include:

- Geothermally heated aquaculture uses low temperature water (<50^{o}C pond water) that range from 15^{o}C for trout and salmon, to 30^{o}C for shrimp and prawns.
- The growth periods are 30 to 50% shorter with constant and optimum temperature of the water
- Growth periods range from 2 to 3 months for tropical fish to 6 to 9 months for prawns (see Table 6 for more details).

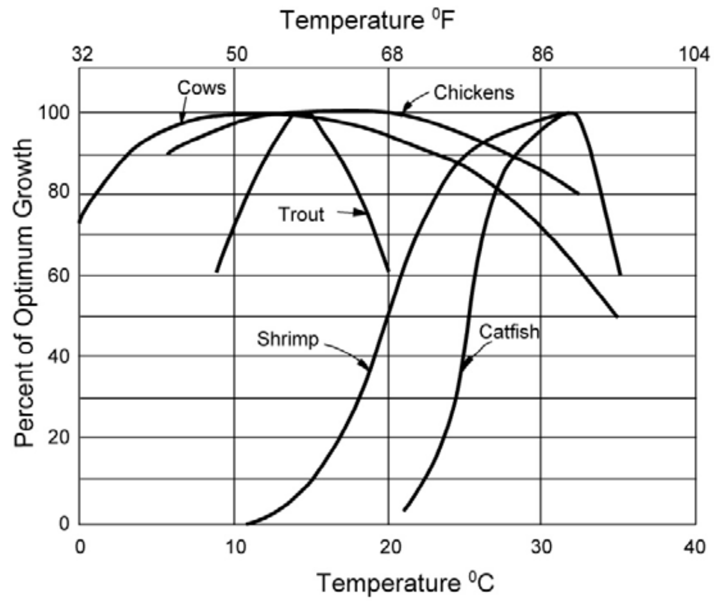

Figure 23. Growth rates of various land and aquatic species (Rafferty, 1998c).

Pond-specific design considerations for several aquatic species include:

- The ability to accommodate stocking densities of 80 to 160 kg/m^3 for catfish, 0.25 to 0.33 kg/m^3 for prawns, and 40 kg/m^3 for tropical fish.
- The (current) selling prices of CAD 4.80 to CAD 7.20/kg for catfish and CAD 27.25 to CAD 43.25 for prawns. (based on a conversion rate of US$1.00 = CAD 1.33 as of November 27, 2015 prices)
- Ideal pond sizes that range from 0.1 to 0.2 ha up to 0.4 ha
- Optimum pond dimensions for growing and harvesting that are 15 m by 60 m and 1.0 to 1.5 m deep.
- The option to use plastic or metal circular tanks 10 to 40 m in diameter
- The fact that a minimum size commercial operation should comprise 3 to 4 ha with 20 to 30 ponds or tanks, and
- That the typical pond water requirements are that the temperature range is 40 to 65^{o}C with a flow rate of about 5 L/s per 0.1 ha pond – uncovered, under cold climate conditions such as those in central and northern Canada.

Some geothermal aquaculture pond construction guidelines include:

- Building the long axis perpendicular to the wind to minimize wave action and temperature loss
- Use of earthen berms with clay or plastic liners to prevent water loss through seepage.
- Pond coverage with a plastic bubble in order to minimize evaporation losses.

- A typical geothermal pond design is shown in Figure 24. This design was used on the Oregon Institute of Technology in Klamath Falls, Oregon with the following design conditions:
    - Raising prawns (Macrobrachium Rosenbergii)
    - Minimum outside temperature of -21°C
    - Pond temperature of 27 to 30°C
    - Prawn growth of 2 cm/month
    - 900 cm^2 surface area/prawn = 21,000 prawns/pond (maximum density)
    - Pond depth was 1.2 meters.
    - Geothermal water was used directly with a peak flow rate of 22.8 L/min. at an outside temperature of -21°C.

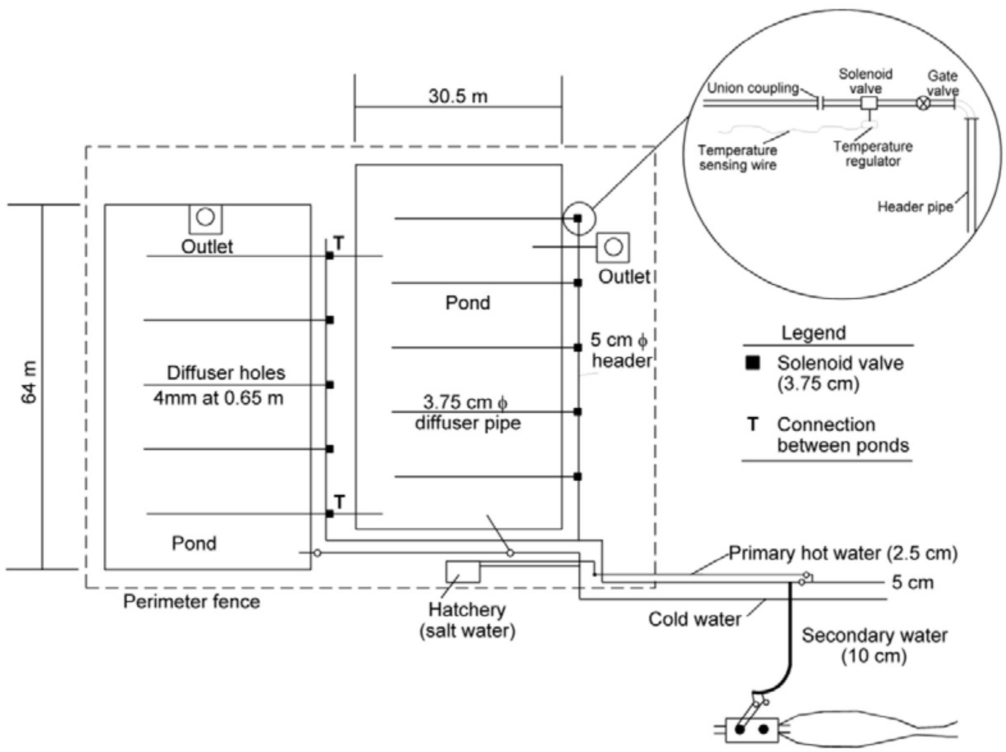

Figure 24. Sample aquaculture pond configuration for raising prawns (Based on an Oregon Institute of Technology Research Project 1975-1988)(Smith, 1981).

Some more detailed geothermal aquaculture pond design parameters include:

- The fact that uncovered ponds exposed to the atmosphere lose heat by four mechanisms:
    - Evaporation which can account for 50 to 60% of the heat loss
    - Convection which is the 2nd largest heat loss
    - Radiation which is the 3rd largest heat loss, and
    - Conduction to the surrounding pond materials

- The sum of the above losses is the total heat loss (the peak loss).
- The typical capacity factor for outdoor ponds is 0.65 (5,694 equivalent full load hours/year)
- The annual heating requirement is then: kJ/yr. = 0.65 x 8760 hour/yr. x peak loss (kJ/hr.)
- For enclosed ponds the heat loss is about 50% of uncovered ponds and is estimated at 1,200 $kJ/hr/m^2$ for most of British Columbia.

Reduction of the heating requirements can be accomplished by:

- Use of a floating mat, which may present an aeration problem, can reduce peak heating requirements by about 11%. Limitation of the use of a floating mat to one corner of the pond may provide a refuge for the ponds species at night and thus, not restrict the aeration of the pond surface, however the heat-loss reduction will not be optimized.
- Pond enclosure (mentioned above) which may be expensive, though sometimes an abandoned greenhouse can be found and used.
- Thermal mass as explained below.

The thermal mass of the pond water itself is an excellent heat storage medium. The pond is allowed to cool at night which may only be appropriate during the summer, late springs and early fall months and then brought up to the ideal temperature the next day using a combination of geothermal water and solar heating. In this way, only 70 to 80% of peak heat requirements may need to be met. *It is important to note that some species such as prawns may be too sensitive to temperature change to allow this system to be used even though in large ponds the temperature loss at night may be only 1 to 2°C.*

In summary:

- Surface evaporation of the pond water can be a major component of the heat loss, especially with outdoor uncovered ponds in cold climates.
- Covering ponds can reduce heat requirements. The use of an abandoned greenhouse structure might be considered in order to save money.
- The cleanliness and chemically benign quality of the water are both extremely important.
- Temperature control is also very important as slight variations will affect growth rates.
- A long term, reliable, accessible market for the products is critically important.

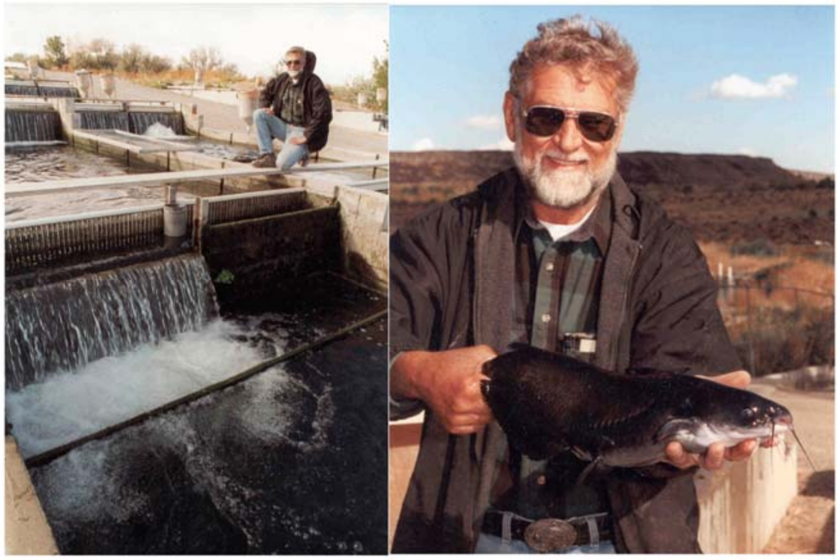

Figure 25. Leo Ray with catfish raised in geothermal flowing water (Idaho) (Clutter, 2002a).

Figure 26. Alligators raised in geothermal water (Idaho) (Clutter, 2002a).

Figure 27. Fish farming tropical African cichlids (Oregon)(Clutter, 2002b).

Figure 28. "Gone Fishing" tropical fish (African Cichlids) geothermal ponds (Oregon)(Clutter, 2002b).

Figure 29. Wairakei, New Zealand, commercial Malaysian prawn raising facility, using waste water from a geothermal power plant (Lund and Klein, 1995).

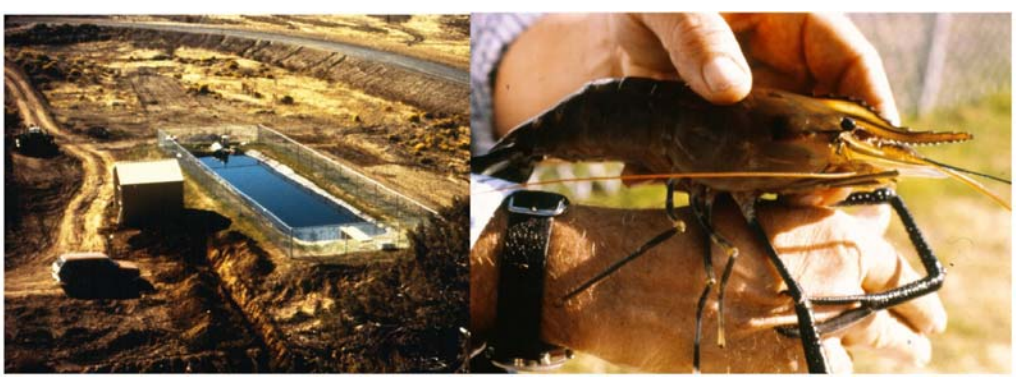

Figure 30. Small Malaysian prawn geothermal pond and grown species (Oregon)(Johnson and Smith, 1981).

C.5. Heated Greenhouses

The use of geothermal fluids in greenhouses is common and very practical. In Iceland, with its perennially cool climate, the town of Hveragerdi is almost entirely dedicated to greenhouses in which much of the country's vegetable crop is grown. Accordingly, green-housing appears to be a "natural" application for British Columbia with its similar temperature regime. Some advantages are listed below:

1. Optimizing growth by reducing time to plant maturity for almost all species.
2. Up to 25% reduction in operating costs as compared to fossil-fueled facilities. This is, of course, after the geothermal piping, wells, and pumps have been installed and commissioned.
3. The cost of fossil fuels to heat green-houses during winters is often high enough to spoil the economics of an otherwise profitable venture. The use of geothermal fluids for thermal energy typically allows economical operations in cold conditions. This would apply to much of British Columbia.
4. Experiences in green-houses world-wide have shown that thermal water temperatures as low as 25°C are useable and beneficial both technically and economically.
5. When thermal waters are piped through growing troughs to warm the contained soil, the lower humidity, as compared with spray-on systems, fosters improved disease control.
6. Because greenhouses can utilize such low temperature waters, they can easily be part of cascaded systems in which they can accept cooled waste waters from processes that initially required hotter fluids such as industrial applications or district heating.
7. If necessary, the geothermal energy system in a greenhouse can be combined with a fossil fueled boiler for peak heating. This can reduce overall costs by lowering the number of geothermal wells required.

The relationship between temperature and growth rate is shown in Figure 31. Note that the temperature control is very critical for optimum growth of these products.

Greenhouse construction can comprise a variety of materials and several different heating systems. Following is a list of some of the possibilities:

- The most efficient commercial greenhouse configuration consists of 0.2 to 0.4 ha connected, individual structures with a total of up to 6 ha of growing area.
- Some designs include a hot water storage tank that is used to meet peak demand, thus reducing the required number of wells and/or the peak pumping rate. See Figure 32.

- Typical greenhouse dimensions are 36 by 110 meters for fiberglass units (0.40 ha) or 10 by 30 to 45 meters for plastic film type units (0.030 to 0.045 ha). See a configuration example in Figure 32.
- Heating is commonly provided by a combination of 1) fan coil units blowing heated air into plastic tubing that is hung near the ceiling peak and 2) horizontal, finned tubed pipes installed along the walls and under the benches. In some cases, where plants are located on the floor of a greenhouse, heating tubes can be buried in the floor as shown in Figure 33.

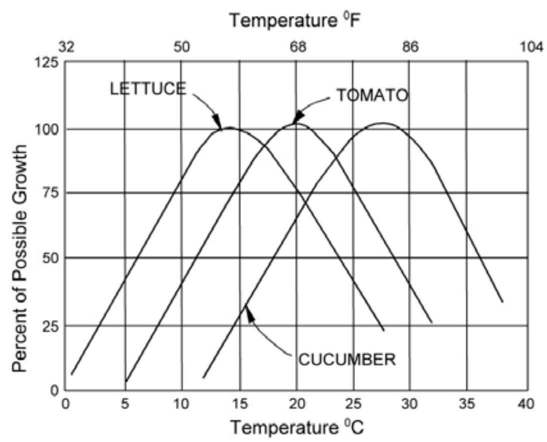

Figure 31. The relationship between temperature and percentage growth for certain vegetables (Rafferty, 1998b).

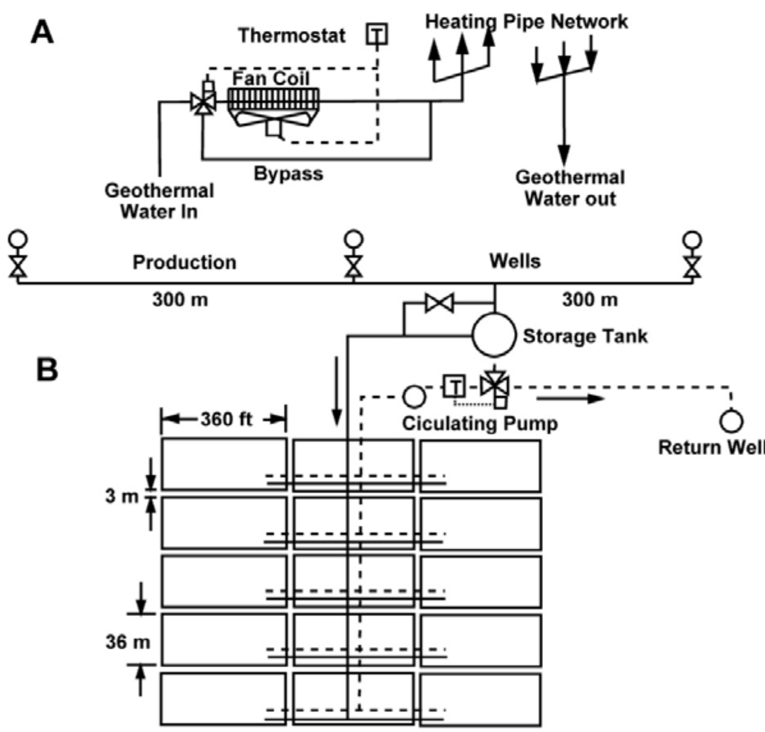

Figure 32. Typical large commercial greenhouse layout (6 hectares) (Lund, 2010).

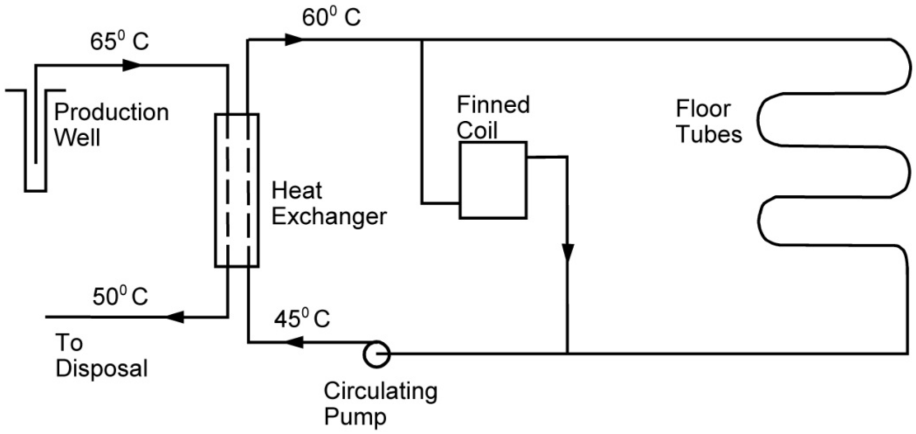

Figure 33. Heat exchangers schematic (Rafferty, 1998b).

- Approximately 6 liters/s of 60 to 80°C water are needed for peak heating of 0.2 ha or 2,000 m^2. This equates to 1,200 kJ/hr/m^2.
- The average capacity factor for geothermally heated greenhouses is 0.45 or 3,942 equivalent full load operating hours per year.
- Fortunately, most crops need lower nighttime than daytime temperatures, thus saving energy.

Greenhouses can be constructed using several different materials and in various shapes as shown in Figure 34. Some details regarding the construction materials are as follows:

- Common construction materials:
    - Glass
    - Plastic film
    - Fiberglass or similar rigid plastic
    - Combinations of film and fibreglass

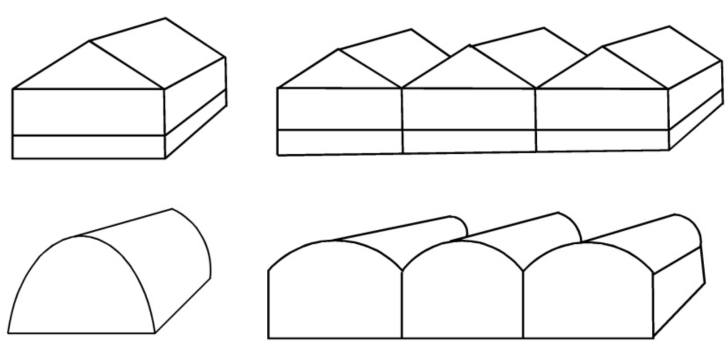

Figure 34. Greenhouse shapes showing arched and peaked roof designs (Lund, 2010).

- The building framework can utilize steel or aluminum. Wood was used in the past but no longer used due to adverse weathering, rotting and subsequent air leakage.

- Glass greenhouses are the most expensive to construct, however, glass is used where superior light transmission is required. It has the disadvantages of having the poorest energy efficiency and the highest outside air infiltration rate.
- Plastic film is typically used to cover greenhouses having arched roofs. It is commonly replaced at least every 3-years. The use of double layers of polyethylene plastic film provides better insulation but is more expensive.
- Fiberglass usually covers houses having peaked roofs and requires less structural support than glass sheathed structures. Heat loss is about the same with both materials.
- Construction of the buildings and installation of the heating systems will cost CAD 80.40 to CAD 160.80 per m^2, plus the costs of the geothermal well(s), the pipe supply system, and the primary heat exchanger (Boyd, 2008).

Heating systems for greenhouses using one or more warming techniques can be accomplished by:

- Passage of air over finned-coil heat exchangers through which thermal water is circulated. The warmed air is then piped through perforated plastic tubes running the length of the greenhouse ceiling so as to maintain uniform heat distribution.
- Another system can feature hot water circulating through pipes or ducts located in (or on) the greenhouse floor.
- Alternatively, the hot air or hot water can be circulated through finned tubes located along the walls and under benches. Bare pipe can be run along the walls, as in Iceland where 2.0 m of pipe is installed for every 1.0 m^2 of floor area.
- Combinations of the above styles are typical.

The peak heating requirement needs to be determined for the greenhouse structure(s). This requirement has two components:

1. Loss of heat via transmission through the walls and roof, and
2. Infiltration and ventilation losses due to the need to heat cold outside air. This is based on the number of air changes per hour required.

The <u>total peak heating</u> requirements is the sum of these two. The <u>annual heating requirement</u> is a product of the total peak heating requirement, the load factor (typically 0.45) and the time (usually 8760 hr/yr).

Additional important greenhouse facts:

- A greenhouse heating system usually has more than one style. The actual systems chosen depend on the types of crops and the amounts of work space needed.
- Artificial lighting is now becoming more commonly used – even during the daytime.
- The cost of labor can be very significant, as most crops require extensive hands-on care.
- As previously stated in this document, marketing is critical because without long-term, reliable markets for the greenhouse products, the enterprise will not last long.
- The use of carbon dioxide (CO_2) can enhance growth, and this gas can often be economically extracted from some geothermal fluids.

Some photos of typical geothermally heated greenhouse scenes follow:

Figure 35. Six hectares of commercial greenhouses in New Mexico, USA (Witcher and Lund, 2002).

Figure 36. Typical glass houses (Italy) (site visit Lund, 1995).

Figure 37. Greenhouses with steep roofs used in areas of heavy snowfall (New Mexico, USA) (Witcher et al., 2002a).

Figure 38. Simple plastic tunnels with crops planted on the ground (Hungary) (Lund, 1990).

Figure 39. Typical fiberglass greenhouses (Bruneau, Idaho), (Street, 1985).

Figure 40. Arched greenhouses with cover for solar reduction (New Mexico, USA) (Witcher and Lund, 2002).

Figure 41. Forced air heating system with overhead plastic tubing perforated along the bottom for the air flow (Witcher et al., 2002)(site visit Lund, 1977).

Figure 42. Finned tube heat pipes along the greenhouse outer wall (site visit Lund, 2003).

Figure 43. Bench top plastic tube heating system (site visit Lund, 2002).

Figure 44. IFA Greenhouses in Klamath Falls, Oregon, USA, growing tree seedlings. Note overhead sprinklers. Heating system is under bench forced air (Geo-Heat Center site visit, 2002).

C.6. District Heating

District heating is defined as the heating of two or more structures from a central source. Heat may be provided in the form of either steam or hot water which may be utilized to meet both space heating and domestic hot water requirements, as well as being cascaded for greenhouses, aquaculture and/or pavement snow melting,. A marginal geothermal district heating system (in terms of cost, resource temperature, or resource volume) can be made economically viable by peaking with fossil fuel or geothermal heat pumps (described on page 55). The cost of installing a peaking plant has to be weighed against the cost of drilling more wells, using larger diameter pipes, and the additional pumping requirements.

The use of geothermal fluids for District Heating is a common Direct-use objective, with or without heat exchangers or supplemental boilers. The use of heat exchangers is commonly recommended in order to decrease the chances of damage to the heating system by corrosive or scale-producing thermal water constituents. To be economically viable, the local winters should be long and cold (which maximizes the heat demand and improves the economics of the investment in the system) with more than 2,200 degree-days Centigrade per year, the service area should have closely spaced buildings with an overall heat-load density in excess of 50 MW per square kilometer, and the source of thermal waters should be less than 8 kilometers from the area to be served. See Table 7.

The advantages of a geothermal district heating/cooling are:

1. Reduced fossil fuel consumption (carbon reduction)
    - 72.2 tonnes/TJ of coal
    - 13.7 tonnes/TJ of natural gas
2. Reduced heating costs
    - Increased efficiency
    - Lower cost; 50 to 70% of conventional fuel
3. Improved air quality
    - Less gases
    - Less particulates
4. Reduced fire hazard in buildings
5. Co-generation using a resource >100^{o}C can also produce electric power
6. Benefits to society
    - Use of local resource
    - Keeps money in the local economy
    - Community pride
    - Catalyst for economic growth
    - Integration into community planning

Table 7. District Heating Thermal Load Requirements by Building Type (Bloomquist et al., 1987).

Type of Area	Thermal Load Density MW/km^2	Thermal Load kJ/hr·ha	Desirability for District Heating
Downtown High rises	>70	>2.52	Very favorable
Downtown Multi-Storied	50-70	1.82 - 2.52	Favorable
City Core Commercial Buildings and Multi Family Buildings	20-50	0.73-1.82	Possible
Apartment Buildings Residential:			
Two-family houses	12-20	0.44 - 0.73	Questionable
Single-family	<12	<0.44	Not Possible

Space heating for individual buildings can be provided by using the geothermal water directly or indirectly using downhole heat exchangers or via geothermal heat pump systems (described on page 55. The type of heating system depends upon the temperature of the resource. For example, marginal temperatures between 40 and 50°C can be used effectively in radiant floor heating systems or in large baseboard finned tube radiators. Forced air heating systems require temperatures in the 60°C range and above.

District heating is generally feasible when buildings are heated with baseboard hot water, in-floor radiant, or radial coil forced air systems (Table 8). In these cases, retrofit for use with geothermal fluids is relatively easy. If buildings are heated by electricity or wood, then the retrofit may not be economical, especially if the buildings are old. In any case, the heating requirements of any candidate building must be determined. This will require the services of an architect or engineer trained in this discipline. The design of the supply and return piping from the thermal water source to the district and of distribution pipes to each building within the district will also require specialized engineering. If the thermal water temperature is "marginal" and their chemistry is "aggressive", the use of one large, or multiple small heat exchangers and clean, local non-thermal waters may be indicated together with a fossil-fueled boiler to increase the fluid temperature during peak demand periods.

Geothermal energy is transferred from a production field to a group of buildings in a district heating system as shown below in Figure 45. The services provided can include:

- Space heating
- Space cooling; normally geothermal water greater 80°C
- Domestic hot water heating
- Industrial process heat

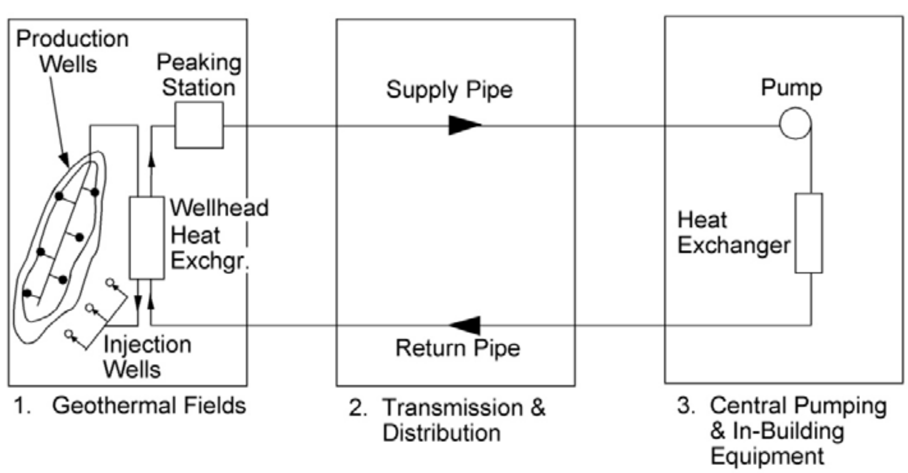

Figure 45. Major components of a district heating system (Lund and Lienau, 2005).

Table 8. Retrofit Suitability Values of Selected Heating Systems (Rafferty, 1998a).

Air Systems	Retrofit Suitability (a,b)	
	Single Air Handler	Multiple Air Handler
Low temperature hot water (<65°C)		
Single zone, multi-zone, dual duct	10	8
Terminal reheat, variable volume, induction	8	6
Standard hot water (80-95°C)		
Single zone, multi-zone, dual duct	8	7
Terminal reheat, variable volume, induction	7	6
Steam		
Single zone, multi-zone, dual duct	6	6
Terminal reheat, variable volume, induction	5	4
Electric resistance forced air	6	5
Air-to-air split system heat pump	4	3
Fossil fuel fired furnace	5	4
Roof top packaged equipment	4	3
Fossil fuel fired unit heaters	4	3
Water Systems		
Loop heat pump	10	
Radiant panel	10	
Fan coil/unit ventilator		
2 Pipe	9	
4 Pipe single coil	9	
4 Pipe	7	
Unit heaters	7	
Finned tube/convector	6	
Steam Systems		
Finned tube radiation	3	
Unit ventilator	3	
Two pipe cast iron radiator	2	
One pipe cast iron radiator	1	
Perimeter Electric Systems		
Electric resistance baseboard	2	
Through-the-wall units	1	

a) Suitability values shown above are average. Site specific conditions frequently influence suitability in positive or negative ways. The table addresses only the mechanical considerations of the retrofit. The relative energy efficiency of the existing system also heavily influences retrofit suitability.
b) A value of 10 is best, 1 is worst.

The system could also be a hybrid system augmented by (Figure 46):

- Heat pump to boost temperature
- Conventional boiler for peaking

Hybrid systems avoid the need for:

- Deep wells

- Expensive and large diameter transmission piping
- Large production pumps

Hybrid system benefits:

- Low temperature resources, often below 60°C
- Reduced investment costs

The major components (Figure 45) of a geothermal district heating system include:

1. Heat production – well field(s)
    - Production wells
    - Injection wells
    - Peaking station
2. Transmission/distribution system
    - Delivery to consumer
3. Central pumping station, and in-building equipment
    - Meters
    - Heat exchanger for domestic hot water

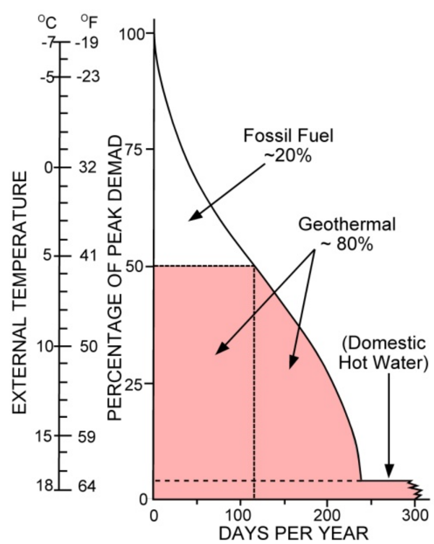

Figure 46. Peaking a geothermal heating system with fossil fuel (Modified from Anderson and Lund, 1997).

The use of the geothermal resource for space heating in existing buildings, for snow melting, and for a new development would require a building survey to determine the possibility and cost of retrofitting individual heating systems. Baseboard, forced air, and radiant floor heating systems using gas or fuel oil are much easier and less costly to retrofit than electric heating systems. New construction obviously lends itself to be designed for the geothermal system in advance and, thus is the best option. Depending on the outside design temperature, the heating load can be determined for buildings. See graph in Figure 47.

Presented below is a list of basic tasks to be accomplished when contemplating development of a geothermal District Heating project. Note that some of these have been discussed earlier in this document as they are essential for any type of Direct-use project.

1. Quantify the geothermal energy available and the anticipated thermal load to determine the degree to which they are matched. Both of these objectives have been previously reviewed.

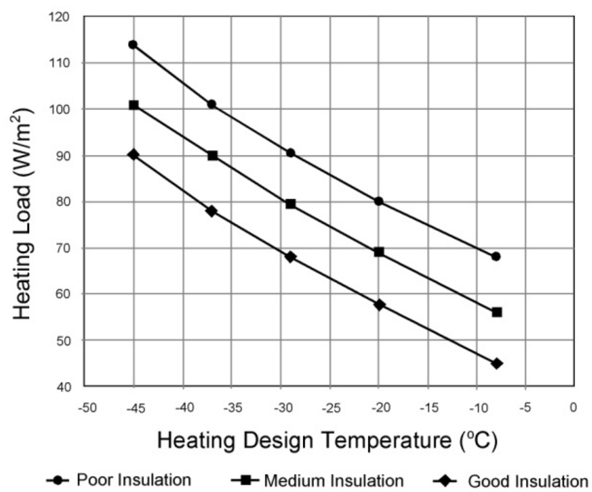

Figure 47. Heat loads for various outside design temperatures (Community Energy Technologies, 1997).

2. Identify the most likely areas within a community where a District Heating project will be accepted and be technically and economically viable if properly designed and implemented.
3. Determine the technical and economic feasibilities for the following scenarios:
   - Space and domestic water heating only
   - Space cooling; would need temperatures >80°C
   - Industrial process thermal loads that might be addressed.

   Note that these three potential uses can materially increase the number of equivalent full-load operating hours per year or the "load factor", the maximization of which should be a project objective.

4. Employ a qualified, experienced geothermal engineer to design and estimate closely the costs of implementing a heating network for the proposed District.

a) Determine, for each building, whether the existing heating system will lend itself to retrofit or whether entirely new construction will be required.

b) Carefully select and specify only the most appropriate, proven, reliable piping, valves, heat exchangers, pressure tanks, pumps, and controls for the system. The invested time and cost to do this will be more than justified by the minimization of future maintenance expenditures.

5. Using the information gleaned in the steps above, carefully and conservatively analyze the economic aspects of the proposed District Heating systems and revise the financial model. Allow for unforeseen delays and problems when doing this and remember that returns on their investments will be required by the lenders and/or investors together with significant cost savings to the building owners. If the economic pro-formas created do not provide for these returns, the project should be re-considered, modified, or abandoned.

Geothermal district heating systems can have a variety of configurations including:

- Both open and closed distribution systems whose design options are shown in Figure 48
- Approximately 50% have a central plant with heat exchangers, circulating pumps, expansion tanks and controls
- Volume and energy meters, or fixed rate for billing
- Disposal of fluid on the surface or to injection well(s) and/or soaking ponds.

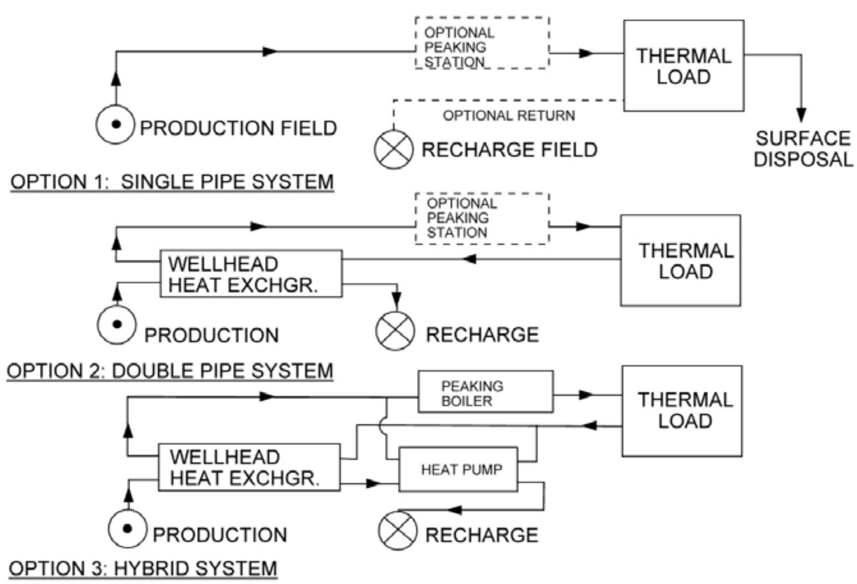

Figure 48. District heating design options (Lund and Lienau, 2005).

Other practical District Heating possibilities to consider are institutional settings such as:

- Single ownership neighborhoods
- Municipal or other government buildings
- Colleges and university campuses
- Military bases
- Correctional facilities
- School complexes
- Office park
- Industrial parks

Another option to consider, especially when resource temperatures are low (say below 40^{o}C) are geothermal (ground-source) heat pumps (GHP). They have the advantage of being useable anywhere in the area, as they only require ground or ground water temperatures between 5 and 30^{o}C. In addition they can supply both heating and cooling, which lend themselves especially to commercial, public and governmental buildings, as the cooling load required from lights and occupants can be just as much as the heating load, even in Canada. GHPs do, however, require electrical energy input into the compressor, usually about 20 to 25% of the energy output. Two main systems are used with GHP – open loop systems using well or surface water, and closed loop using the earth as the heat source or sink in either a vertical mode or horizontal mode. GHPs can be considered on an individual building basis and on a commercial scale for District Heating.

Indications of retrofit costs for various types of buildings are shown in Table 9.

Table 9. Representative Retrofit Costs for Various Building Types in a Geothermal District Heating System (Lund, et al., 2009).

Building Type	Retrofit Cost
Medium-density residential	US$ 18.00/m^2; CAD 24.00/m^2
High-density residential	US$ 10.00/m^2; CAD 11.50/m^2
Commercial/industrial/institutional (small buildings)	US$ 20.00/m^2; CAD 22.50/m^2
Commercial/industrial/institutional (large buildings)	US$ 12.00/m^2; CAD 16.00/m^2

Practical considerations to evaluate in planning a geothermal District Heating system include:

- Marketing is one of the most difficult tasks facing developers of modern district heating systems. The marketing must begin early in the planning stages and continue throughout all phases of development.

- District heating requires major adjustments in traditional attitudes toward energy planning, energy resources and production, delivery mechanisms, and energy consumption equipment and utilization.
- Who will own the system: public vs private.
- Funding and financing options (i.e. for profit or as a public service/not-for-profit)
- How will energy metering and billing be handled? kJ consumed, flow rate, or fixed billing.
- Provider and customer responsibilities, dispute resolution, etc. must be spelled out in the service contract(s) between the supplier of heat and the end users

In summary, geothermal district heating has been successful in several domestic locations and internationally. The oldest district, in Chaude Aigues Cantal in France, distributed geothermal water as early as the 14th century through wooden pipes. The most famous district in the US (Boise, Idaho) was started in 1892 and provided geothermal heat to 450 large residences. It is still operating today providing heat to about 250 residences. The largest system in the world is in Reykjavik, Iceland. It began in 1930 and now supplies 99% of the space heating requirement for the city of over 200,000 people living in 58,000 homes. Other notable geothermal district heating systems are in Paris, France, Elko, Nevada, USA, and Klamath Falls, Oregon, USA. The latter provides heat to 24 buildings, and snow melt system in the downtown area, is used in the beer brewing process, and is piped to about two hectares of greenhouses which are used for raising tree seedlings for the commercial market.

C.7. Pavement and Sidewalk Snow-Melting

Geothermal pavement and sidewalk snow and ice-melting installations have proven popular, safe, and relatively affordable when climatic conditions are challenging, snow storage space is at a premium, and budgets for snow removal are a concern.

The conveniences of a geothermal snow and ice melting system are:

- Safety (i.e. less accidents because surfaces dry faster)
- Reduced maintenance (reduced or no shoveling, plowing, sanding and salting)
- Increased pavement life (freeze and thaw cycles are reduced or eliminated, less or no damage to adjacent grass and sod, and building carpets are not exposed to snow and salt)
- Energy savings and pollution mitigation as compared with using boiler water from fossil fueled heating systems

Presented below are some salient facts concerning this use of thermal waters for snow and ice melting:

1. The heat requirements depend on the snowfall rate, the air temperature, the relative humidity, and the wind velocity.
2. Typically, historically, pipes were either metal or plastic, however, due to corrosion and brittleness problems of these materials, the use of cross-linked polyethylene pipe is now increasingly popular.
3. Common installation sites include sidewalks, driveways, roads, bridges, and airport traffic areas.
4. The in-ground fluid temperatures range from 24°C to 62°C when the snowfall rate is from 0.64 to 2.46 cm/hr. in various Canadian climate zones (Table 10). This temperature range is based on the requirements at flow rates of 0.43 to 0.76 L/s in a 2.0 and 2.5 cm diameter pipe.
5. In a geothermal system, the heat transfer medium can be hot water, steam or an ethylene glycol solution (antifreeze) warmed using a heat exchanger.
6. Geothermal energy can be supplied to target areas through the use of heat pipes, directly from circulating pipes, through heat exchangers, or by allowing warm water to flow directly over the pavement.
7. Geothermal melting systems cost about CAD 530 per square meter plus the charges for well(s), pumps, and the bridge deck material (where appropriate).

Table 10. Design Heat Requirements and Circulating Fluid Temperature for Melting Snow from Pavements in Six Canadian Cities (Williams, 1974).

City	Design snowfall cm/hr.	Average exposure MJ/hr/m^2 (°C)	Sheltered MJ/hr/m^2 (°C)	Extremely Exposed MJ/hr/m^2 (°C)
Toronto	1.67	1.16 (29)	0.96 (24)	1.43 (36)
Halifax	2.46	1.54 (38)	1.16 (28)	1.86 (46)
Quebec City/Ottawa	1.32/1.02	1.75 (43)	1.35 (34)	2.13 (53)
Winnipeg/Edmonton	1.12/0.64	2.13 (53)	1.54 (38)	2.52 (62)

The snow melting system must first melt the snow and then evaporate the resulting water film. The rate of snowfall determines the heat required to warm the snow to 0°C and to melt it.

The heat needed to melt snow is a large part of the total heat requirement. If completely bare pavement is required, the system must be designed to melt the maximum hourly rate of snowfall anticipated at a site. Tables 10 and 11 provide some estimates of such requirements. Because a large amount of heat is needed to maintain a pavement completely free of snow during periods of heavy snowfall, melting systems are seldom designed to melt all of the snow as it falls. Even larger amounts of heat are needed for areas subject to drifting snow because the rate at which it can drift into a site can be several times the average rate of snowfall during a storm. It is important to provided adequate drainage for snow melting systems so that pavements can dry quickly, thus reducing substantial heat loss by evaporation. As surface heat loss is directly proportional to wind speed, the heat loss at sheltered sites will be substantially less than that at exposed sites.

Table 11. Heat Required to Melt Snow (Williams, 1974).

Average rate of snowfall during storm (cm/hr)	Estimated maximum hourly rate of snowfall (cm/hr)	Heat required to melt maximum hourly rate MJ/hr/m^2 (Watts/m^2)
0.64	1.3-2.3	0.464-0.774 (129-215)
1.27	2.8-4.6	0.929-1.548 (258-430)
2.54	5.6-9.1	1.858-3.100 (516-861)

Piping material options for pavement snow melting systems are described below along with their advantages and limitation.

- Steel, iron, and copper pipes have been used extensively in the past; however, corrosion can be a problem as the metal degradation tendency doubles with each 10^{o}C in temperature rise. The corrosion is usually external and is caused by de-icing salts, ground water, or materials in the pavement.
- Present practice is to use plastic circulation pipe with an iron or copper header pipe (Figure 42). Typical material is cross-linked polyethylene (PEX) which can tolerate temperatures up to 82^{o}C at pressures up to 6.9 bar (kg/cm^2) and 93^{o}C at 5.5 bar (kg/cm^2). PVC and CPVC pipes are limited by lower temperature and pressure tolerances and can become brittle and subject to fracturing.
- Other advantages of PEX pipe include its flexibility (30 cm diameter bends), and the fact that it is shipped in long coils thus minimizing the need for couplings.

Figure 49. Details of the header pipe with PEX pipe for a pavement snow melting system (Boyd, 2003).

Snow-melting system piping can be installed in a variety of pavement types and locations within the pavement system.

- Portland Cement Concrete (PCC) and Asphalt Cement (AC) pavements have had snow melting pipes built into or under them mainly in the United States and Iceland.
- The thermal conductivities of pavement materials are different, thus, pipe spacings are also different – i.e. AC pavements have lower thermal conductivity, thus closer spacing of the pipes is necessary in order to provide the same heat to the road surface as for PCC pavements.
- AC is placed hot and compacted (usually above 100^{o}C), thus, the pipes can be damaged. However, to minimize this damage, cold water can be circulated through the pipes while the AC is poured, as is common practice in Iceland.
- In PCC pavements the pipes can be attached to the reinforcing steel, however; the pipes need at least 5 cm of cover above and below the pipe.
- Normally the pipes are placed below the pavement in a sandy or slurry cement bedding so that the pavement above can be cut for repairs.
- Pipes should not cross expansion or contraction joints in pavement.
- Pavements should also be protected from frost heaving, especially where the heating pipes are connected to the header pipe.

The details of a bridge deck with PEX pipe details of Uponor pipe installed under concrete and under asphalt are shown in Figure 50 and 51 respectively.

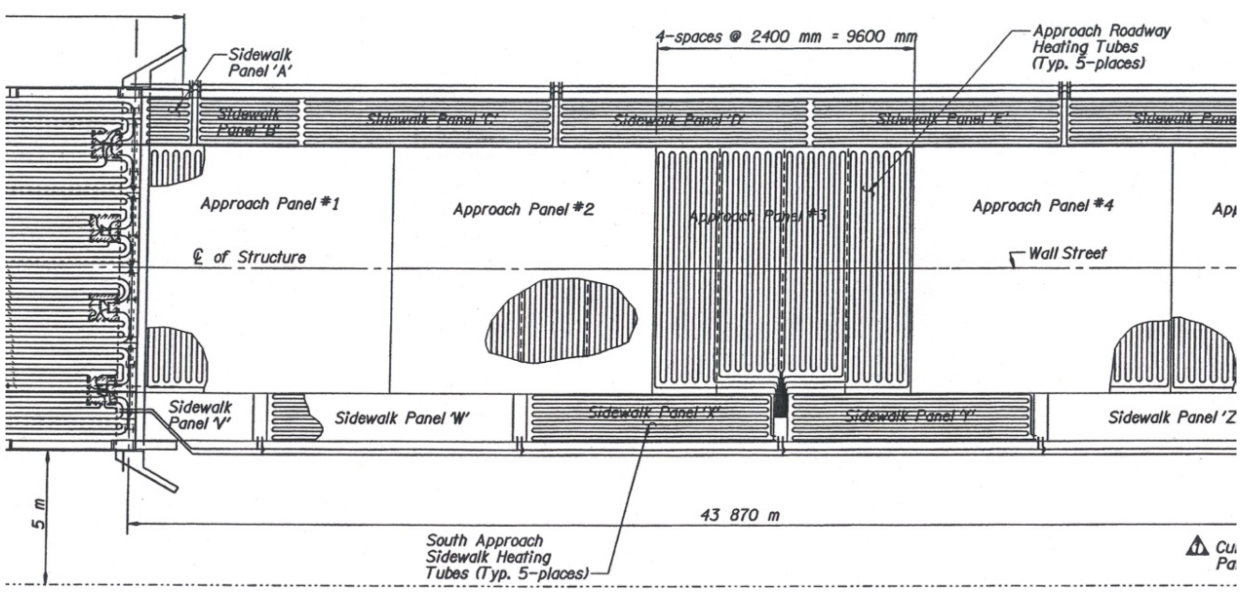

Figure 50. Details of the PEX piping system for a highway PCC pavement and bridge deck in Klamath Falls, Oregon, USA (Boyd, 2003).

Internationally there are multiple examples of the different ways in which the geothermal heat can be supplied to the surface to be heated. These include:

- Heat pipes (New Jersey, Colorado and Wyoming, USA)
- Pavement sprinkling (Japan)
- Geothermal steam in pipes (Argentina)
- Geothermal hot water in pipes (Iceland, Japan and the United States)

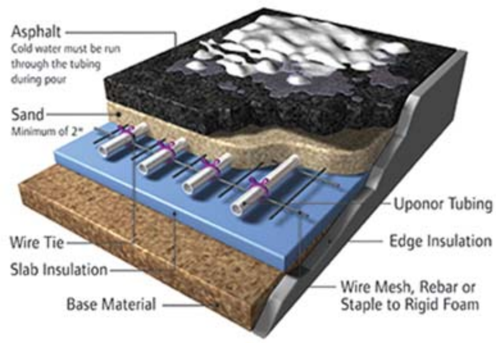

Figure 51. Snow melting system beneath asphalt concrete pavement (Uponor, 2010).

Some salient characteristics of heat pipe systems are as follows:

- They are gravity-operated and use ammonia and Freon (Figure 52 and 53).
- The lower end of the pipe is the evaporator and the upper end the condenser.
- When the evaporator is warmer than the condenser, a portion of the liquid vaporizes and travels to the condenser where the latent heat of vaporization is released upon condensing, thus melting the snow on the surface.
- Large amounts of heat are then transferred by pressure difference and gravity with a small temperature change (ΔT).
- 177 heat pipes were used to warm about 1,000 m^2 of bridge deck in Wyoming, each pipe is 30 m long and, with ground temperature of 12^{o}C, the system raised the bridge surface temperature up to 27^{o}C.

Pavement sprinkling is used in Fukui City in Northern Japan. There, thermal ground water at 16^{o}C flows through heat exchanger ducts buried in the sidewalk where the temperature is reduced to 7^{o}C. After melting the snow on the sidewalk the water is sprinkled directly on the adjacent roadway to melt the snow. Sensors detect if snow has fallen and is remaining on the surface to automatically start the system.

A geothermal steam pavement snow melting system is located in the resort region of Copahue-Caviahue located on the slopes of the Andes in west-central Argentina. In that area, temperatures reach -12°C with winds velocities up to 160 km/hr. The steam is produced from a 1,400-m deep geothermal well at a rate of 30 tonnes/hour. The steam is transported from the well through a 2.6-km long pipeline to the resort. The geothermal steam is then used for heating the street and the access road to the ski resort and keeps the pavement temperature between 12 and 16°C. The heat is transferred through 2,400 m^2 of radiant panels installed under the road surface.

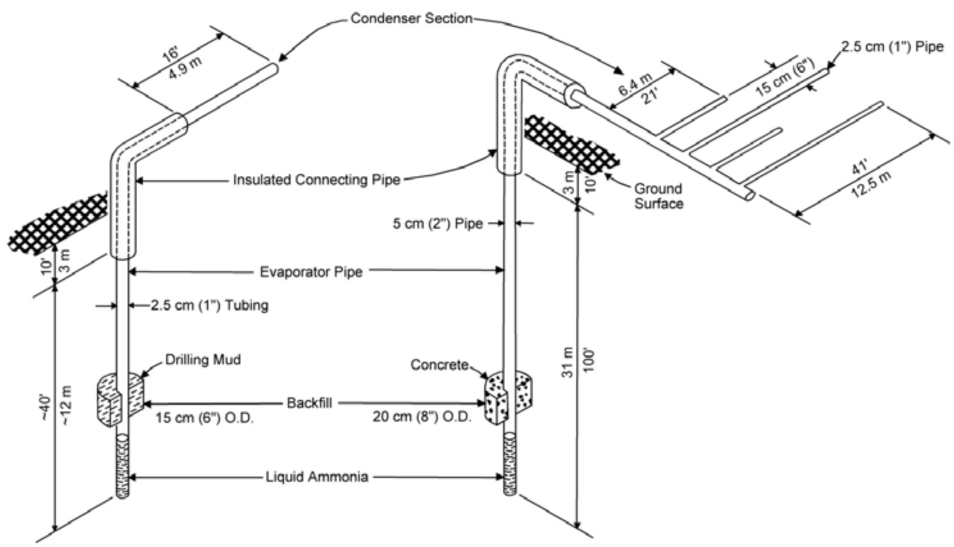

Figure 52. Wyoming heat pipe system, gravity-operated, using ammonia and Freon, with no mechanical moving parts (Lund, 2000c).

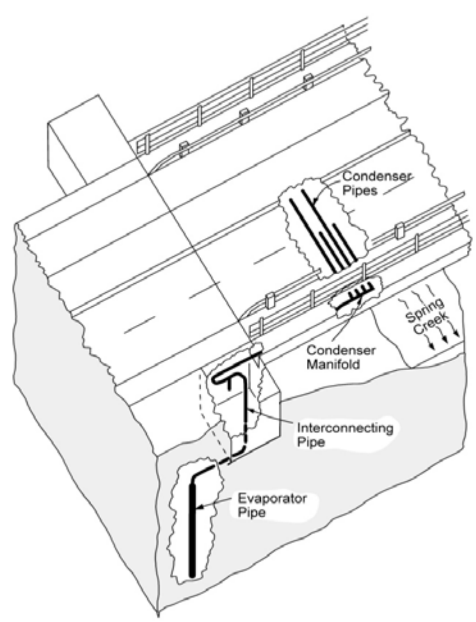

Figure 53. Details of the Spring Creek heat pipe system in Wyoming (Lund, 2000c).

There are no airport runways with geothermal snow-melting systems currently in place in the United States. However, computer simulations have indicated that a runway pavement heating system at Chicago's O'Hare airport, using low-grade water sources, could be technically and economically viable. A heating system with a conductance of 50 $W/m^2/^oC$ (180 $kJ/hr/m^2/^oC$) and a water source temperature of 10^oC was predicted to melt snow as rapidly as it falls approximately 40% of the time. Melting at the snow/pavement interface would occur 87% of the time that there was some snow cover. Therefore, only 13% of the time (when the runway was snow-covered), would the runway clearing operation be faced with the complicated situation of an icy surface.

Figure 54. Snow melting scenes in Klamath Falls, Oregon, USA. Notice the unheated areas (Lund, 1999; site visit Lund, 1995; Lund, 1999).

In summary, two main geothermal snow melting systems are utilized: 1) direct-use of geothermal water, and, 2) heat pipes. The latter is more common because geothermal fluids at temperatures >40^oC are not available everywhere. Heat pipes can be used with normal ground temperatures. The geothermal and heat pipe systems can be installed for CAD 400 to CAD 530/m^2 plus the pavement, water well, and pumping systems (Nydahl et al., 1984). Total cost for the deck or pavement and the heating system is approximately CAD 1,600 to CAD 2,660/m^2 (Boyd, 2003). These systems are best used for bridge decks (exposed to the elements from top and bottom), airport hard stands, refueling areas, baggage handling areas, and passing walkways. They are not economical for an entire road surface or runway.

Figures 55. Oregon Institute of Technology, Klamath Falls, Oregon, USA, snow melting applications (site visits Lund, 2011 and 1995).

The design of pavement snow melting systems is based on criteria established by ASHRAE (Handbook on Heating, Chapter 46, Snow Melting) in the United States and those established by the National Research Council of Canada, Institute for Research in Construction (CBD-160, Design Heat Requirements for Snow Melting Systems). Additional information can be found in Uponor ”Radiant Snow and Ice Melting Design and Installation Manual”.

C.8. Vegetable, Fruit and Fish Drying

Drying (dehydration) of fruit, vegetables and/or fish is one of the oldest forms of food preservation methods known to man. The process involves the slow removal of most of the water contained in the vegetable, fruit or fish so that the moisture content of the dried product is below 20% (Andritsos, et al., 2003). The traditional method of drying these products is by using the sun, a technique that has remained largely unchanged from ancient times. Today most drying, especially on the industrial scale, is done by using a continuous forced-air process. Drying of vegetables, fruit and fish generally requires higher temperatures than space heating, greenhouses and aquaculture project, usually in the 70 to 95^{o}C range (Figure 56). Some vegetables, fruit and fish products can be dried using geothermal energy. These include onions, garlic, carrots, pears, apples, dates, cod and other ocean fish. Commercially, these processes make more efficient use of the geothermal resources as they tend to have high load factors in the range of 0.4 to 0.7, which reduce the cost of energy.

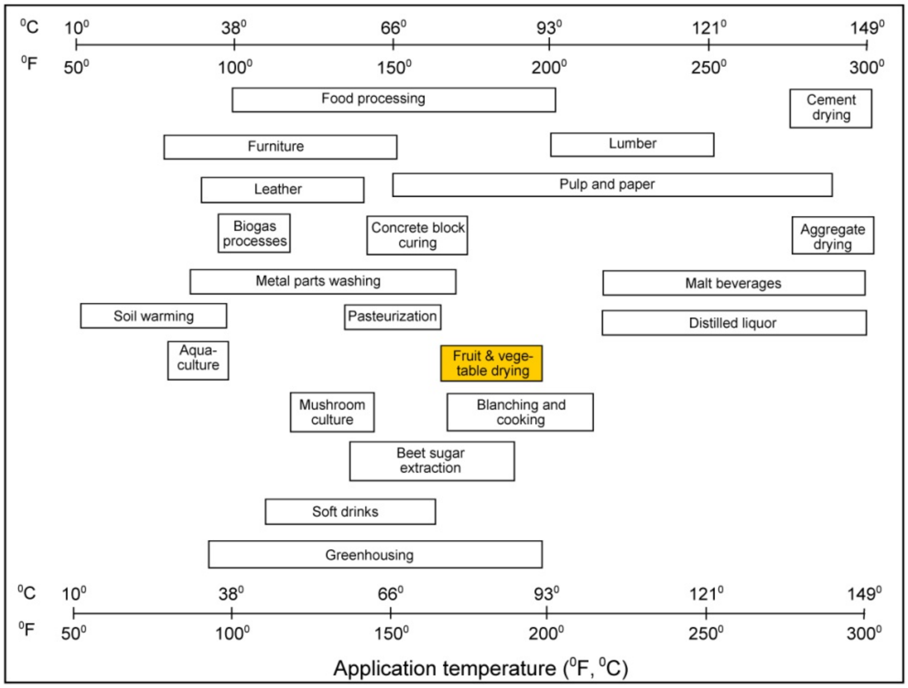

Figure 56. Examples of drying temperatures for various industrial applications (modified from Lienau and Lund, 1998).

The main purpose of drying is to prolong the useable life of the product by curtailing the deterioration of food caused by microorganisms or chemical processes. Both of these processes are slowed down by drying and finally stopped altogether, depending on how far the drying is carried out, with one exception, which is oxidation. The drying time is generally divided into two periods, one using a constant drying rate and another with falling drying rates. The air velocity, temperature and level of humidity control the drying rate. At the end, the drying process stops entirely and the moisture content of the product at that point reaches "equilibrium humidity". Equilibrium humidity is primarily dependent on the degree of humidity of the air and, to some extent on the air temperature (Arason, 2003).

C.8.1. Tunnel Dryers

Typically, vegetable, fruit and fish drying involves the use of a tunnel dryer, or a continuous conveyor dryer using warm or hot air circulated through or above the product. A tunnel dryer is an enclosed housing in which the products to be dried are placed upon tiers of trays or stacked in piles in the case of large object. Geothermal heat is provided by circulating the geothermal water through a finned-tube heat exchanger and passing air over it to provided heated air to the drying operation. A small tunnel dryer is shown in Figures 57-59.

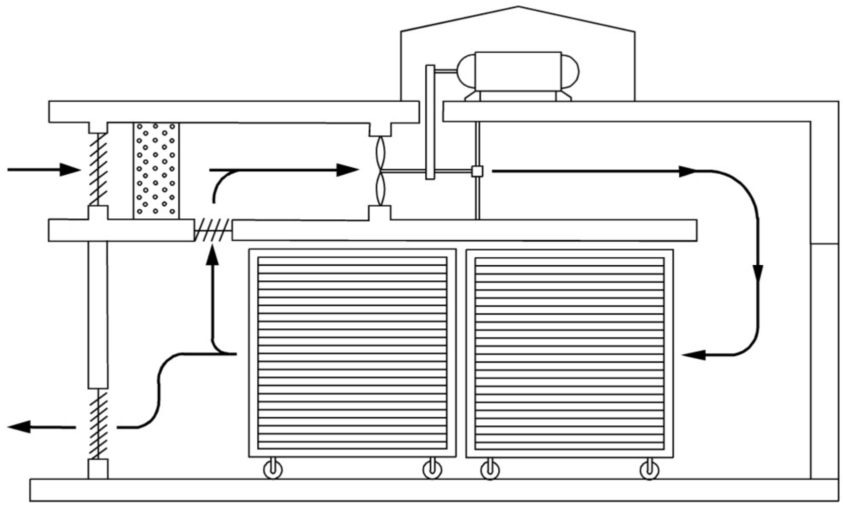

Figure 57. Small tunnel dryer using geothermal energy (Lund, 1996a).

This type of drier could be built for about CAD 10,000. The details of a small tunnel drier are summarized below. This facility was designed for use at a geothermal test site in the Philippines and at another one at Los Azufres, Mexico (Guillen, 1987; Lienau and Guillen, 1987; Lund, 1996a).

- Design (for pears, prunes, peaches):
    - Building 4.0 m x 1.35 m x 3.2 m high
    - Two trucks with 30 trays each
    - Each tray 1 m x 1 m x 5 cm high
    - Each tray will carry 15 kg of wet fruit
    - Approx. one tonne of fruit/cycle
    - Fruit dried from 80% to 20% moisture in 24 hrs
- Geothermal design:
    - Required air speed: 240 to 300 m/min = 240 to 300 m^3/min. in 50% of cross -section (with trays in place).
    - Air drying temperature 60 to 74^oC
    - Heat exchanger: 91 x 91 cm – 2 rows of 8 finned tubes
    - Geothermal fluid temperature : <100^oC
    - Majority of air recycled – 1.12 kW fan @ 61 cm diameter
    - Geothermal fluid flow rate - 0.03 L/s which keeps the dryer at 60^oC,

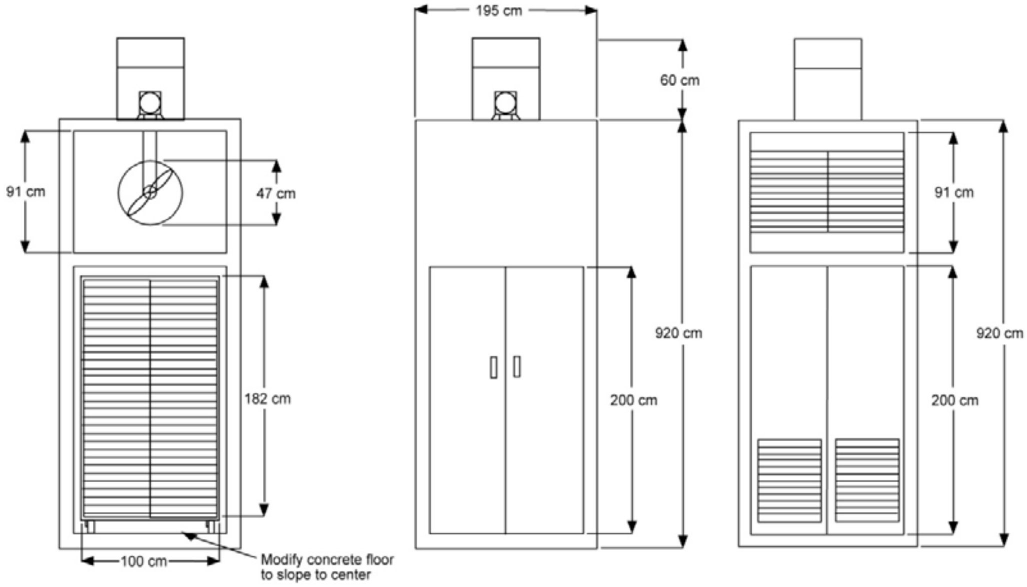

Figure 58. Details of the small tunnel dryer (Lund, 1996a).

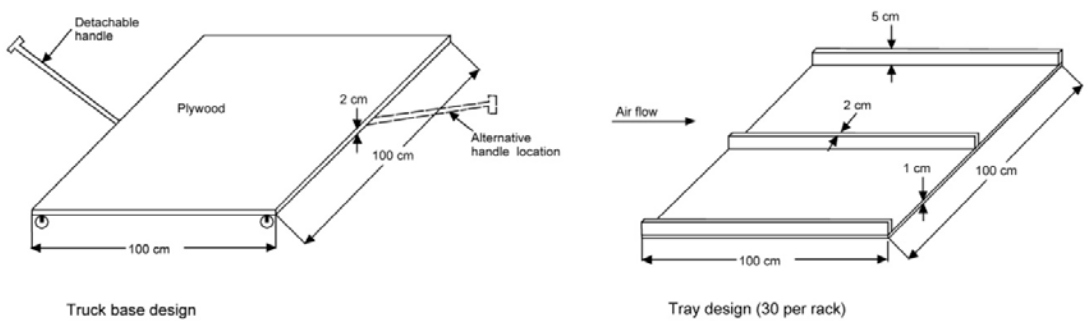

Figure 59. Details of the pallets used in the small tunnel dryer (Lund, 1996a).

C.8.2. Tomato Drying

Another example of a small tunnel dryer is one constructed in Greece to dry tomatoes (Figure 60). This system consists of a finned-tube air-water heat exchanger having a capacity of 1,255 MJ (300,000 kcal) with cold air entering at 20 to 35°C and leaving the heat exchanger at 55°C. The geothermal water heating the air enters the heat exchanger at 59°C and leaves at 51 to 53°C with a flow rate of 25,000 L/h (6.94 L/s). The fan units, which propel the heated air through the tunnel, comprise two fans with a total rated power of 7 kW. The drying tunnel is 14 meters long, 1 meter wide and 2 meters high. The tomato-loaded trays are placed in the entry to the tunnel and are then conveyed towards the point where the hot air enters the tunnel in a continuous manner. Approximately every 45 minutes, 25 trays with dried product are removed and 25 trays loaded with raw tomatoes are inserted at the entry to push the downstream trays towards the end (Figure 61 shows the trays in the rack). About 7 kg of raw tomatoes are placed on each tray. The raw tomatoes begin with a moisture content of 90 to 92% and end with a final moisture content of about 10% (Figure 62). Over a 30-hour residence time for the product in the drier, 4,200 kg of raw tomatoes can be introduced into the tunnel. They weigh about 400 kg at the end of the cycle. The details of the operation are shown in Figure 63. During the first year of operation about 4 tonnes of dried product was produced and packaged in glass jars of various sizes containing olive or sunflower, oil, wine vinegar, salt, garlic and various herbs. This particular tunnel dryer could also be used to desiccate figs, peppers and mushrooms (Andritsos, et al., 2003).

Figure 60. A small tunnel dryer used in Greece primarily for drying tomatoes (Andritsos, et al., 2003).

Figure 61. Drying racks used in the Greek tunnel drier (Andritsos, et al., 2003).

Figure 62. Dried tomatoes ready for packing (Andritsos, et al., 2003).

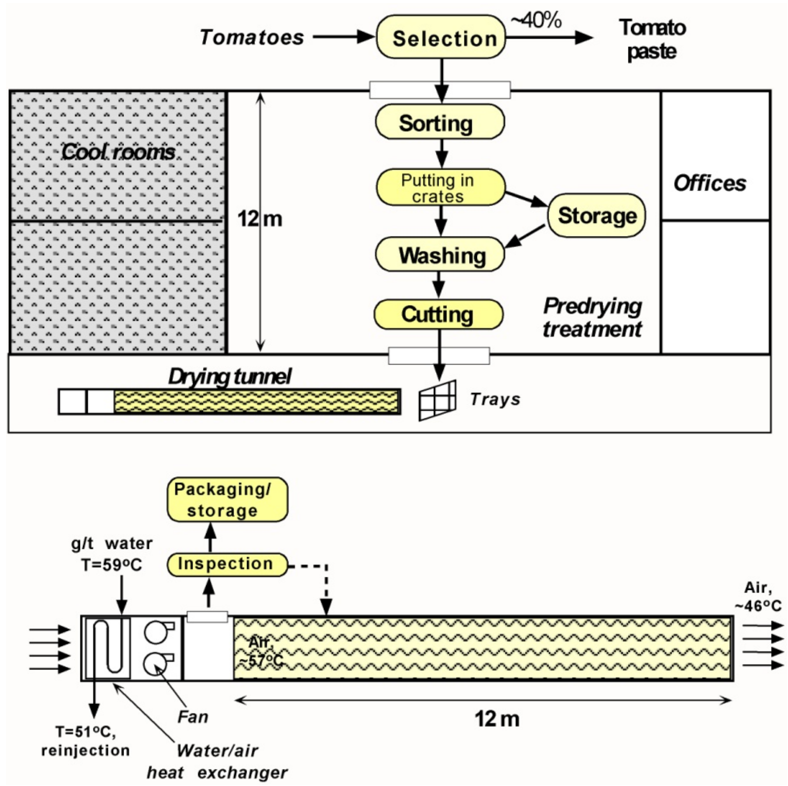

Figure 63. Details of a small geothermal tunnel drying operation for tomatoes used in Greece (Andritsos, et al., 2003).

C.8.3. Onion Drying (Dehydration)

Onion dehydration involves the use of a continuously moving belt conveyor using hot air at 38 to 104°C. Years ago, heat was generated steam coils, but now natural gas use is in favor. Recently, two onion dehydration plants were built in Nevada using geothermal energy (Lund, 1994; and Lund and Lienau, 1994). These plants are located about 160 km north and east of Reno, Nevada, USA in the San Emidio Desert. Today, only one plant is in operation, run by Gilroy Foods (ConAgra), near Fernley, Nevada.

All onions processed are grown from specific varieties that are well suited for dehydration. Specific strains of the Creole Onion, Southport Globe Onion, and the Hybrid Southport Globe Onion were developed by the dehydration industry (Figure 64). They are white and have a high solids content which yields a flavorful and pungent onion.

Figure 64. Photograph of the typical onions used in Nevada, USA drying plants. (site visit Lund, 1994).

Typical commercial processing plants will handle 4,500 kg of raw product per hours (single line) reducing the moisture content from around 83 percent to 4 percent producing and yield 680 to 820 kg of finished product. These plants produce 2.3 million kg of dry product per year, using from 3,500 to 4,600 kJ of geothermal energy per dry kg, or 9,300 kJ per kg of water evaporated. 630 kW of electrical energy is also utilized per dry kg.

A simplified diagram of how a one-stage, single-line plant operates is shown in Figure 65. An example of a large four-stage commercial plant equipment is a Proctor dehydrator similar to the ones utilized by the Nevada geothermal processing plants (Figure 66). This unit is a single-line 64.6 m long and 3.8 m wide, requiring 2,450 m^3 of air per minute and up to 42 million kJ of geothermal energy per hour. Due to the moisture removal, the air, in some cases, can only be used once, and is then exhausted. Special silica gel "Bryair desiccation units" are required in the final stage to remove the last amount of moisture. Approximately CAD 300,000 in geothermal energy are thus used in a single-line dryer in a year's operation of 180 days.

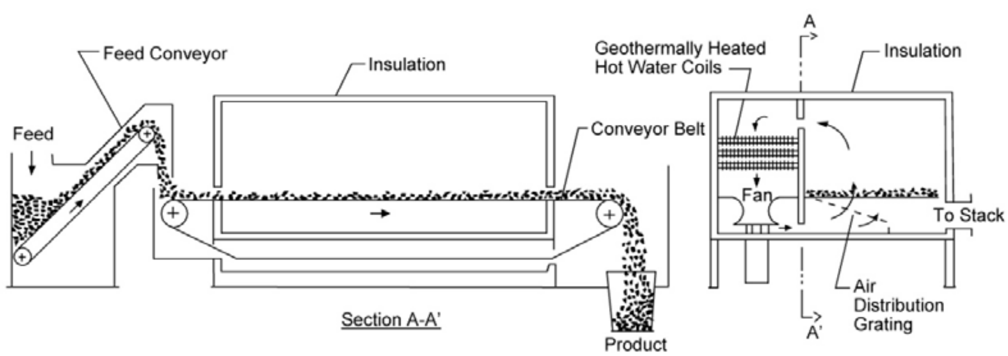

Figure 65. Example of a small onion/vegetable continuous belt drying plant (Popovska-Vasilevska, 2003).

In general, four stages (A through D) are preferred; however, if the ambient air humidity is below about 10 percent, stage D can be eliminated. Also, the temperature and number of compartments in each stage may vary. Figure 67 shows the typical energy requirements for a four-stage drier. The normal drying temperature for stage A is around 104°C; however, temperatures as low as 80°C can be used. The lower temperature will increase the processing time; however, the quality will improve. Figures 68 and 69 are photographs of the Nevada geothermal onion dryer. A summary of the various stages are shown in Table 12. Note: these numbers can vary depending on the quality of the onions and the ambient air temperature.

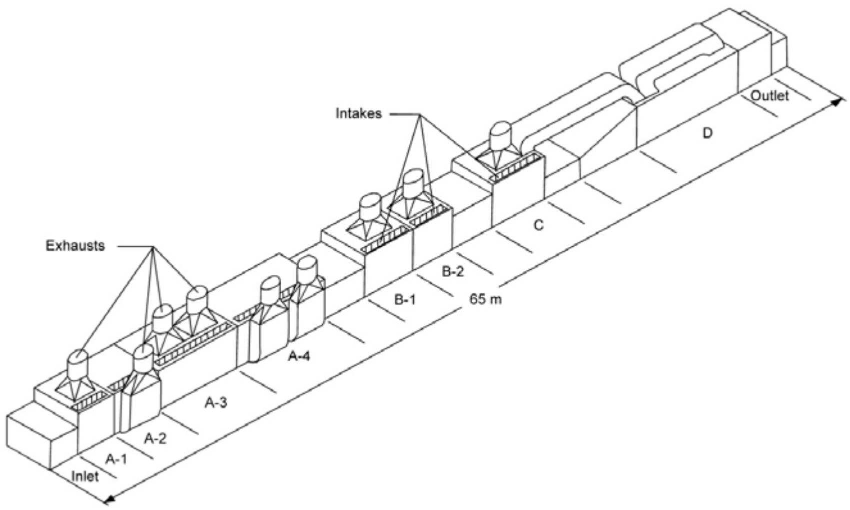

Figure 66. Overview of a large onion drying plant (Lund, 1994).

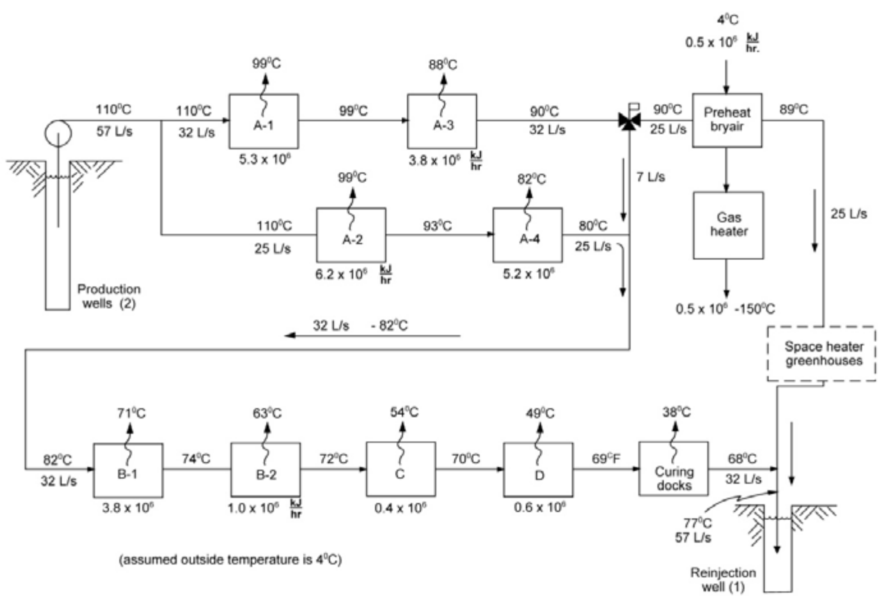

Figure 67. Energy and temperature requirements for a large geothermal onion drying plant (Lienau and Lund, 1998).

Table 12. Air temperatures in a large onion dryer (Lienau and Lund, 1998).

	Stage A	Stage B	Stage C	Stage D
Temperature (°C)	95 - 80	80-72	60	50
Bed loading (cm)**	5 - 10	30	75 - 100	180
Moisture content (%)	83 - 30	30 - 10	6	4

** i.e. the thickness or depth of the onion layer on the belt (site visit Lund, 1994).

Figure 68. Photographs of the sides of a large onion drying plant in Nevada, USA (site visit Lund, 1994).

Figure 69. Photograph of the 3.8 m wide onion drying belt in Nevada, USA (site visit Lund, 1994).

C.8.4. Fruit Drying in Guatemala

Geothermal energy is utilized for two direct-use operations at the Amatitlan geothermal site in Guatemala (Merida, 1999). The first one is Bloteca, a construction block factory that uses geothermal steam in the curing process of concrete products. The other one is Agroindustrias La Laguna, a fruit dehydration plant that was setup as an experimental and demonstration project. While developing this second project the owners decided to bring a product, Eco-Fruit, to the local market using the plant. The product was so successful that it has been in all supermarket chains (Figure 70).

The fruit dehydration project uses a downhole heat exchanger that provides heat to a finned tube heat exchanger. The airstream across the heat exchanger dries the fruit. The fruit is set up in trays and tray-trucks inside a tunnel drier (Figure 71). The fruit stays in the tunnel drier until its water content is reduced to 4%. This is similar to the Mexican and Greek dehydration plants described earlier. The capacity of the plant varies depending on the fruit it handles and the way the fruit is shaped – either slices or cubes. Plant capacity averages are shown in Table 13:

Table 13. Products dried in the Guatemala geothermal operation (Merida, 1999).

Fruit	Capacity (kg)	Drying time (hrs)
Banana	816	22
Mango	726	16
Pineapple	816	18
Pear	680	12
Apple	680	12

Figure 70. Samples of Eco-Fruit (Merida, 1999).

Figure 71. Truck dryers with fruit trays (Merida, 1999).

C.8.5. Grain Drying

An example of grain drying is a rice-drying unit in Macedonia. The geothermal water used comes from a 75°C spring flowing at 2.86 L/min. The drying facility has a capacity of 10 tonnes/hr of rough or milled rice. The grain is fed into the top of the dryer and the heated air is blown in a direction perpendicular to the direction of the grain movement (Figure 72). The geothermal water has a heating capacity of 1,360 kW and exits the unit at 50°C. The air temperature is kept below 40°C to prevent cracking of the rice. The rice enters at 40% moisture and exits at 14%. The grains are cooled at the end of the process to prevent rapid absorption of moisture. One of the advantages of the unit is that it requires heat energy in a period of the year (summer) when heat is not required for greenhouses (Popovska-Vasilevska, 2003).

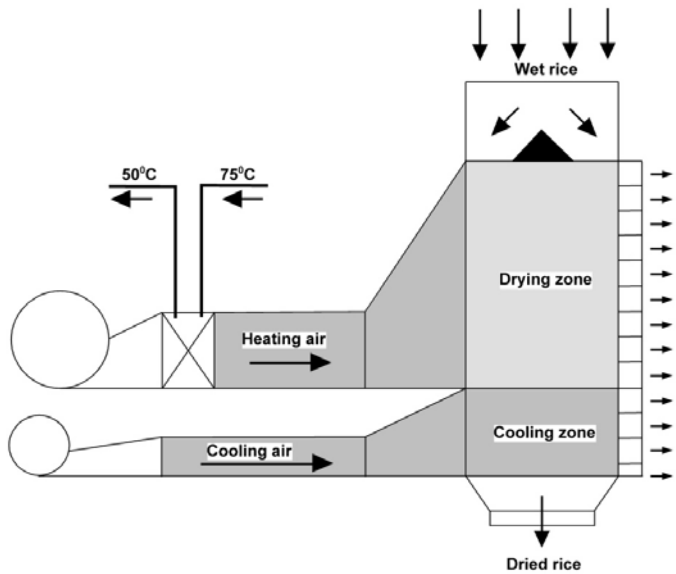

Figure 72. Geothermal rice dryer in Macedonia (Lienau and Lund, 1998).

C.8.6. Fish Drying with Geothermal Energy

Weather conditions put limits on outdoor drying in many climates (Figure 73). Indoor drying of fish is done in such a way that hot air is blown over the fish and the moisture from the raw material is thus removed. It is a great advantage to be able to dry fresh raw material all year around and not be dependent on the weather conditions. Furthermore, drying indoors takes much less time, from several weeks outdoors to a few days indoors. The main advantages of indoor drying are therefore (Arason, 2003):

- Shorter drying time,
- Drying all year around and regular export shipments,
- The product is more consistent in quality and water content,
- Flies and insects are prevented from contaminating the product, and
- Utilization of local energy (geothermal in this case).

Figure 73. Air drying of fish in Iceland (1977) (Arason, 2003).

A variety of fish can be dried, ranging from small pelagic (ocean) fish, to cod heads as is done in Iceland. Drying has been done successfully indoors in two stages, primary drying and secondary drying. Dried fish, such as cod heads, can be consumed locally or exported for human consumption. Cod heads are ground and exported to Africa for human consumption and can also be used in pet food.

Primary indoor drying can be done in a rack cabinet or a conveyor-belt cabinet. The rack cabinet is most common, consisting of two tunnels with a pyramid in the center (Figure 74). Primary drying in the case of cod heads (though, similar with other fish products), is done by arranging the heads in one layer on the rack with about 25 kg of heads per square meter (Figure 75). The optimal conditions for the drying air are: a temperature of 18 to 25^{o}C, relative humidity 20 to 50%, and air velocity about 3 m/s. The process duration is about 24-40 hours. The water content of the heads at the end of this stage is about 50 to 55%. Secondary drying of the semi-dried cod heads in conducted in drying containers of 1 to 2 m^3 volume with hot air blown through (Figure 76). The optimal conditions are: air temperature 22 to 26^{o}C, humidity 20 to 50% and air velocity in a full container is about 0.5 to 1.0 m/s. The water content of the cod-heads after full drying is about 15%, which is achieved after about three days of drying. Figure 77 shows a complete flow diagram for the drying of cod heads, including yield figures. The total drying time for split cod heads is about 120 hours and yield is 21.2% by weight.

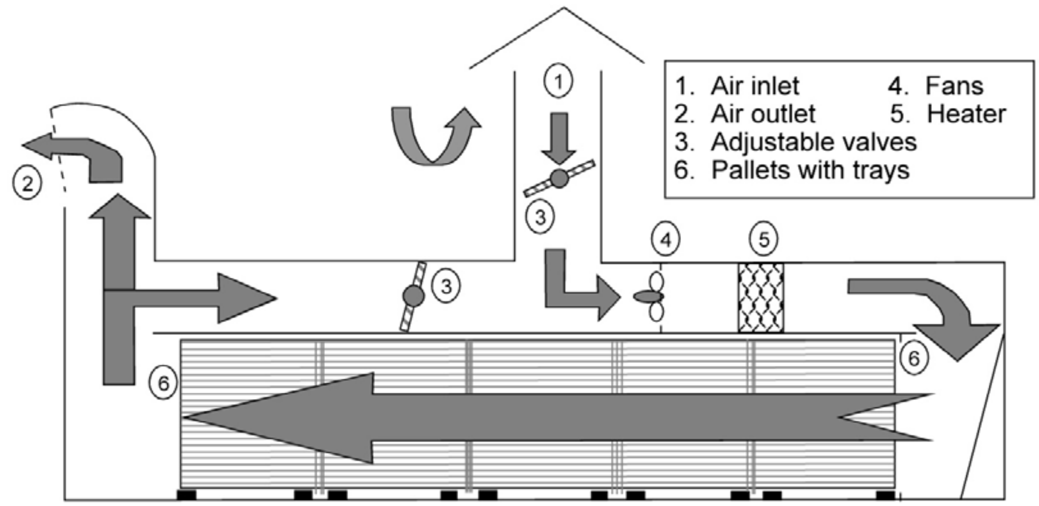

Figure 74. Construction of the rack drying cabinets, 1st stage (Arason, 2003).

Figure 75. Fish heads on rack cabinet (Iceland)(Arason, 2003).

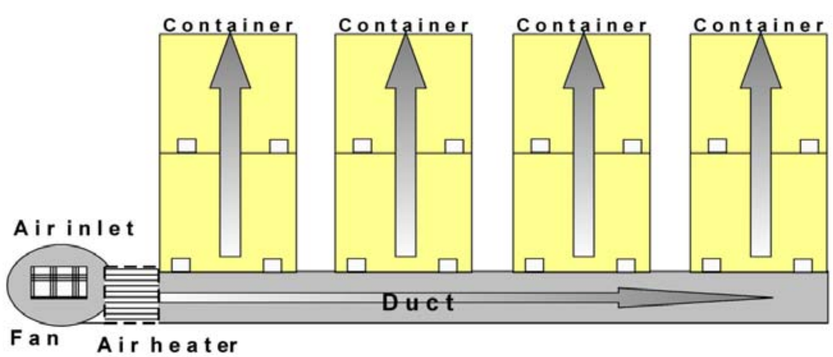

Figure 76. Secondary air drying unit (Arason, 2003).

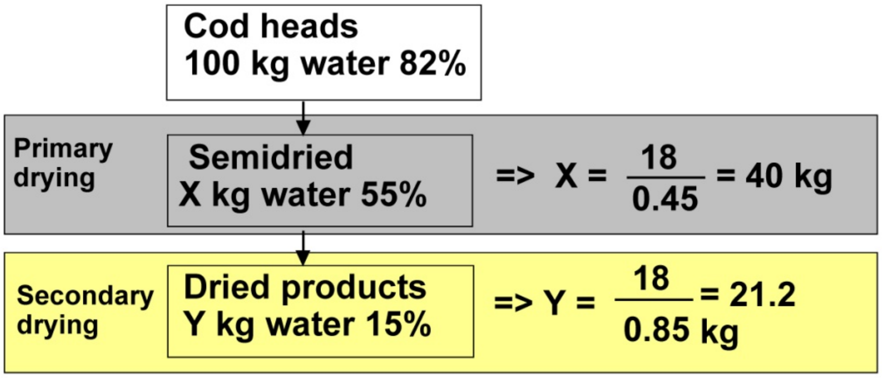

Figure 77. Flow diagram for the drying of cod heads (Arason, 2003).

C.8.7. Conclusions

The use of geothermal energy for drying is highly dependent on the price of crude oil and electricity and the marketing prices of the various vegetable, fruit and fish products. These drying facilities as described earlier in this section, due to their similarity in design, can be used for drying a variety of products depending on the current market. Fortunately, most of these processes use geothermal temperatures below 80^{o}C, certainly within the range found in British Columbia. Freeze drying of various products is an alternative that is being explored using geothermal energy; however, this process requires temperatures above 100^{o}C.

C.9. Lumber Drying

Wood drying (also called seasoning lumber or wood seasoning) reduces the moisture content of wood before its use. When the drying is done in a kiln, the product is known as kiln-dried timber or lumber, whereas air dying is the more traditional method.

There are two main reasons for drying wood:

- **Woodworking**: when wood is used as a construction material, whether as a structural support in a building or in woodworking objects, it will absorb or lose moisture until it is in equilibrium with its surroundings. Such equilibration (usually drying) causes unequal shrinkage in the wood, and can cause damage to the wood if equilibration occurs too rapidly. The equilibration must therefore be controlled to prevent damage such as warping and splitting.
- **Wood burning**: when wood is to be burned, it is usually best to dry it first. Damage from shrinkage is not a concern in this case, and the drying may proceed more rapidly than when the drying is for woodworking purposes. Moisture affects the burning process, with unburnt hydrocarbons going up the chimney. If a 50% wet log is burnt at high temperature, with good

heat extraction from the exhaust gas leading to a 100°C exhaust temperature, about 5% of the energy of the log is wasted through evaporating and heating the water vapor. With condensers, the efficiency can be further increased; but, for the normal stove, the key to burning wet wood is to burn it very hot, perhaps starting a fire with dry wood.

Kiln drying: In small lumber mills where drying kilns are heated by steam from conventional oil fired boilers, substitution of geothermal energy for the heating energy source can achieve substantial cost savings. In larger, well integrated mills, all energy for operations can be provided by burning sawdust and other wood waste products. If a market develops for the waste products or when the energy can be more economically applied elsewhere, the geothermal source may again become an economical solution, even in integrated plants. Drying lumber in batch kilns is standard practice for most upper grade lumber in the western U.S. and Canada.

The two basic purposes of drying lumber are to:

- Set the sap, and
- Prevent warping

The sap sets at 57 to 60^{o}C, and warping is prevented by establishing uniform moisture content throughout the thickness of the wood. If wood is left exposed to the sun (air drying), then the exterior of the wood loses moisture faster than the interior causing stresses that can result in warping.

Moisture within wood resides in cell cavities and in the cell walls. Most of the moisture is first lost from the cell cavities. This loss is not accompanied by changes in the size of the cell and does not cause warpage. Next, water is lost from the cell walls. When this happens however, the wall fibers do shrink and thus create the stresses that can cause warping. In the kiln drying process, the evaporation rate must be carefully controlled to prevent build-up of these stresses. The drying rate varies with the wood type and increases with thicker plank sizes.

The kiln drying process involves the following steps (Figure 78):

- One batch usually comprises 100 m^3 of wet wood
- Heat in the kiln is provided through finned tube or bare pipe heat exchangers.
- High velocity reversible fans are used for air circulation
- Exhaust fans are used to draw out the moist air
- The drying takes place in an insulated building to conserve the heat
- The lumber is stacked and separated by 2-5 cm wood strips called sticks for better air circulation (Figure 79).

- The stacks are typically 4 m high by 2 m wide by 4 m long and weighted on top to prevent warping. Commonly, 3 stacks make up one batch.
- Though steam is commonly used to supply heat, the drying rate is slow in order to prevent warping (Figure 80).
- The time for drying varies per batch depending on the wood type
- It is often necessary to re-moisturize the wood surface at the end of the drying process to reduce stresses in the outer, dryer surface.

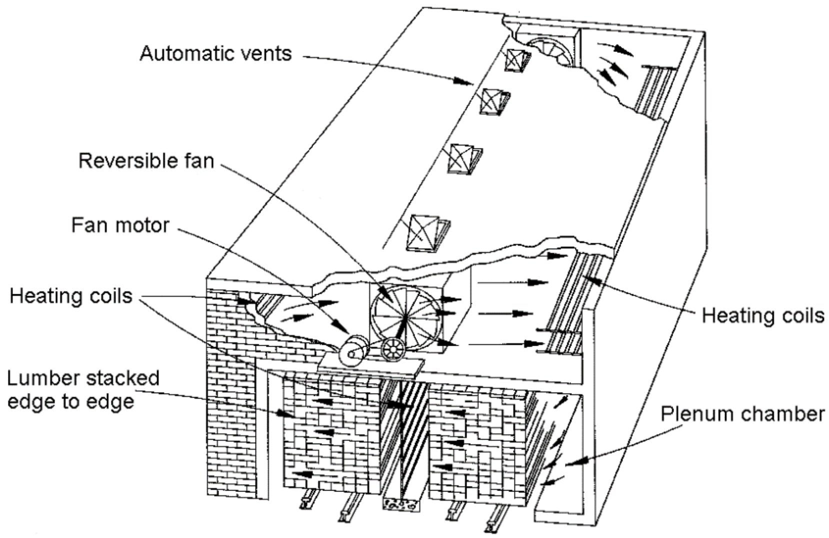

Figure 78. Long-shaft, double track, compartment kiln with fans (Lienau and Lund, 1998).

Figure 79. Lumber stacked prior to drying. Note the spaces between layers and the weights on top (Kawerau, New Zealand) (Scott and Lund, 1998).

Figure 80. Lumber being dried with geothermal steam in closed kiln (Kawerau, New Zealand). Note steam escape above the unit (Scott and Lund, 1998).

The drying schedules are specific for each species of lumber and for size/thickness. The larger the size or the thicker plank, the more tightly the moisture is held in the wood fiber, and the slower the drying process must be. Drying schedules range from less than 24 hours to several weeks per batch. An example of a drying schedule for Ponderosa pine is shown in Table 14.

Table 14. Drying Schedules for Ponderosa Pine (Lund, 1999b).

Dry bulb temperature	Wet bulb temperature	Time	Final % moisture
Ponderosa pine 4"/4" (10 x 10 cm)			
71°C	54°C	21 hrs	5.8%
Ponderosa pine 6"/4" (15 x 10 cm)			
71°C	60°C	24 hrs	7.9%
74°C	60°C	12 hrs	6.7%
77°C	60°C	24 hrs	5.7%
82°C	71°C	24 hrs	7.6%
82°C	78°C	20 hrs	12.2%
Ponderosa pine 12"/4" (30 x 10 cm) 22 days in 9 steps from 46 to 82°C			

Green wood contains large amounts of moisture. Ponderosa pine, for example, holds approximately 60% water. Because of the physical and chemical binding of the water molecules to the wood, it takes from 1.5 to 3 times the energy to evaporate moisture from the wood as it does to evaporate pure water. The drying energy required varies widely with the species and sizes processed as shown in Table 15.

Table 15. Energy Consumed to Dry Three Types of Lumber (Lund, 1999b).

Lumber	Energy Use (kJ/kg of H_2O)	MJ/dry m^3
Douglas Fir	4,600 – 7,000	700 – 1,050
S. Yellow Pine	3,700 – 5,100	2,060 – 2,820
Red Oak	7,000+	3,510+

Geothermal energy can be adapted to kiln drying by passing air over finned heat exchangers tubes carrying the hot water. A finned tube heat exchanger can be placed inside existing kilns so that the air recirculation route would include a pass over the heat exchanger as shown in Figure 81.

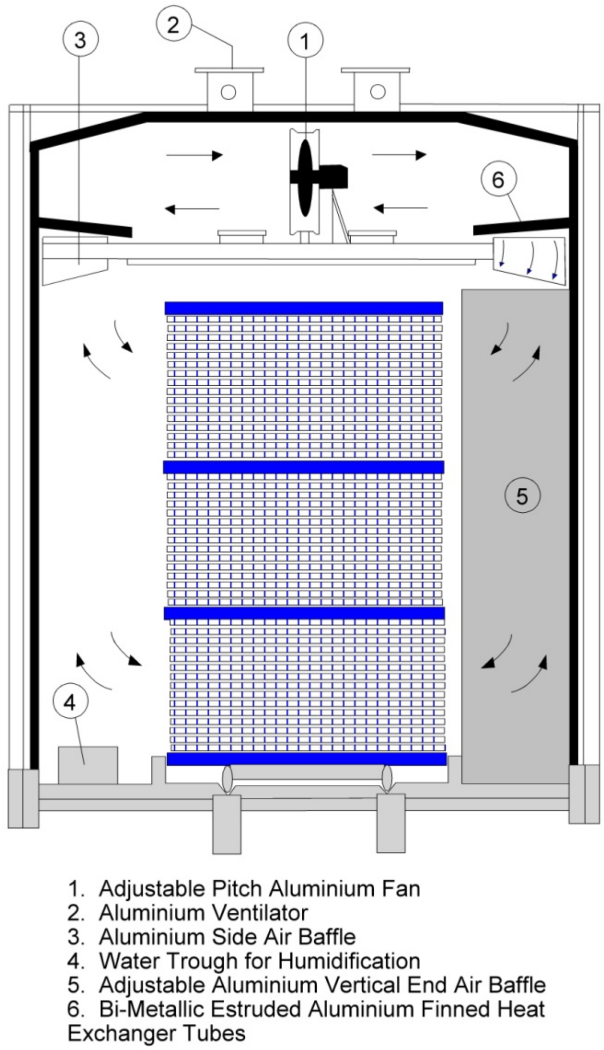

Figure 81. Kawerau, New Zealand lumber drying kiln using geothermal energy (Scott and Lund, 1998).

Geothermal kiln operation:

- Entering geothermal water temperature must be 10 to 20°C above the temperature required in the kiln. Thus, the entering water temperature must be in the range of 90 to 115°C.
- Only 10 to 15% of the heat available in the geothermal water is actually extracted, thus, the discharge water can be re-used (cascaded) for heating office buildings, greenhouses, etc.
- When the temperature of the available geothermal fluid is too low (<80°C) to use in a kiln drying operation, the geothermal energy can be supplemented by conventional heating systems during

the final high temperature portions of the drying schedule. Some fuel cost and pollution savings and mitigation will still be realized.

- Table 16 gives the minimum geothermal fluid temperature required to dry two sizes and several species of lumber.

The geothermal fluid discharged following its use for these drying applications would have temperatures ranging from 70 to 80°C and would be available for other purposes at the mill, for heating of office buildings, for creating log ponds, or other cascaded uses.

Table 16. Minimum Geothermal Fluid Temperature (°C) Required in Kiln Drying (Lund, 1999b).

Species	Lumber 4" x 4" (10 x 10 cm)	size 8" x 4" (20 x 10 cm)
Ponderosa pine	80	90
Sugar pine	80	80
Engleman spruce	80	-
Sitka spruce	90	90
Douglas fir	90	90
Incense cedar	85	-

An example of geothermal lumber drying is in Oradea, Romania where oak used in furniture manufacturing is dried. This facility dries 5,000 m^3/year of oak, at 150 m^3 per batch, in three bins. 0.5 to 1.0 L/s of 100°C geothermal water is used to produce a 50°C drying temperature. Drying the oak takes two weeks to one month per batch.

In summary, timber drying, like many industrial applications, can operate many hours during the year thus producing a high load factor. The high load factor reduces the cost of energy as shown in Figure 75.

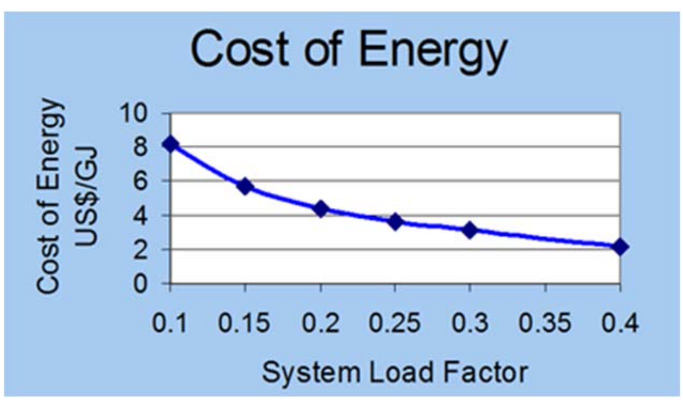

Figure 82. The load factor vs cost of energy (Rafferty, 2003).

Timber drying is certainly an optional use for geothermal energy in British Columbia, however it requires temperatures >80°C. In British Columbia, water temperatures higher than 80°C are considered to be “geothermal” and their exploration and development requires compliance with a much more rigorous, slower, and more expensive group of regulations than if a project simply seeks to use “non-geothermal” resources having temperatures of 80°C or less. Since lower temperature waters are the ones most easily characterized and developed in British Columbia, the temperatures of these cooler fluids would have to be increased with fossil fuels in order to make them suitable for use in kiln drying lumber. Economic analyses will have to be undertaken, on a case by case basis, to determine if this approach to partial geothermal use is economically feasible.

C.10. Permitting

As with oil and gas and mineral rights, the Province of British Columbia (BC) has jurisdiction over provincial Crown land, water and geothermal rights.

There are four broad types of land ownership in BC: private land, First Nations treaty settlement land, provincial Crown land, and federal Crown land. In BC, the majority of the land base is provincial Crown land at 94 percent of the land area (88.7 million hectares; Crown Land Indicators Statistics Report; http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/land-water-use/crown-land/crown_land_indicators__statistics_report.pdf). Crown land is land (or land covered by water like rivers or lakes) that is owned by the provincial government. The BC government operates within a framework of policies that govern the disposition, administration and management of Crown land. Permission to use Crown land is obtained by application under the *Land Act* (LA: http://www.bclaws.ca/civix/document/id/complete/statreg/96245_01), administered by the Ministry of Forests, Lands, and Natural Resources Operations. These policies establish principles on land use, allocation, tenure term, pricing and all other aspects associated with Crown land. Crown Land uses are broad and varied, including aquaculture, industrial uses, commercial uses, recreation, etc.

Ground and surface waters in BC are regulated under the *Water Sustainability Act* (WSA: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/laws-rules/2016_water_sustainability_regulation.pdf), which came into force on February 29, 2016. The *Water Sustainability Act*, administered by the Ministry of Environment, repeals and replaces BC`s *Water Act*. One of the significant changes introduced by the WSA is that you are now required to be authorized to use groundwater for anything other than household use. Regulating groundwater use allows surface water and groundwater to be managed and protected as one interconnected resource, and clarifies the rights of groundwater users.

BC is host to most of the nation's overt geothermal indicia found within and west of the Rocky Mountains and to date, is the only province that has enacted regulations to administer geothermal rights. BC's *Geothermal Resources Act* (GRA: http://www.bclaws.ca/civix/document/id/complete/statreg/96171_01), administered by the Ministry of Energy and Mines, has defined a geothermal resource as

> "the natural heat of the earth and all substances that derive an added value from it, including steam, water and water vapour heated by the natural heat of the earth and all substances dissolved in the steam, water or water vapour obtained from a well, but does not include water that has a temperature less than 80^{o}C at the point where it reaches the surface, or hydrocarbons".

The GRA only provides sub-surface rights to a geothermal resource. In order to obtain surface land and water rights (if water below 80^{o}C will be encountered/used), it will still be necessary to apply for the required permits/licenses under the *Land Act* and *Water Sustainability Act*.

An essential step in any development in BC is to consult with First Nations communities. BC is legally obligated to consult and accommodate First Nations, where required, on land and resource decisions that could impact Aboriginal interests. While the Province is responsible for ensuring adequate and appropriate consultation and accommodation, it may involve the proponent in the procedural aspects of consultation. Thus, proponents are encouraged to engage with First Nations as early as possible in the planning stages to build relationships and for information sharing purposes. More information and resources about First Nations consultations can be found at:

Link: http://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/consulting-with-first-nations.

For the purposes of this report, a community-based participatory approach with a strong First Nations emphasis was developed in order to engage as many communities as possible. This emphasis put on First Nations participation is essential, as many of the communities with direct-use potential in BC are First Nations or have significant First Nations representation. The community-based approach has in the past been successfully carried out with First Nation communities in BC and has the added advantage of building community-research capacity and resource-development awareness. This approach enhances relationship building, and will pave the way for future community engagement and development of identified resources.

Below, general permitting guidelines are outlined for various scenarios: permitting under the *Geothermal Resources Act* for the development of a geothermal resource; permitting for Direct-use projects using waters under 80^{o}C with a focus on Crown land use under the *Land Act*; and a discussion of water licensing under the new *Water Sustainability Act.*

C.10.1. Permitting under the Geothermal Resources Act

All geothermal resources encompassed by this definition are vested with the BC government. The Ministry of Energy and Mines issues and administers geothermal resource rights on behalf of the BC government and, with other provincial agencies, regulates exploration and drilling activities. There are two types of geothermal tenure:

1. Permit: A time-limited, exclusive right to explore a specific area, with set terms and conditions. Permits are for one year and may be renewed up to seven times.
2. Lease: Issued only after a permittee drills a geothermal well within a permit area and submits a satisfactory development plan for the location. Leases are issued for a 20-year term and may be renewed.

Tenure for permits under the GRA is typically issued through a sealed bid public competition. Prior to the disposition, a public notice is required to be published in the BC Gazette. The sales process is as follows:

1. Request Geothermal Exploration Permit: a company or individual can request an exploration permit for crown geothermal tenure land. The holder of the permit has exclusive right to explore for geothermal energy by drilling wells. More information about requesting geothermal exploration permits is available: http://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/renewable-energies/geothermal-energy/exploration-and-sales/request-geothermal-exploration-permit.
2. Pre-tenure Referral: prior to making a permit available, the Ministry will conduct a pre-tenure referral process with provincial agencies/ministries, local governments and First Nations to identify local values and overlapping land uses. The pre-tenure review process ensures that potential bidders are aware of environmental and land-use issues and allows them to plan their exploration activities with care. Examples of Geothermal Permit Referrals are provided: http://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/renewable-energies/geothermal-energy/exploration-and-sales/geothermal-permit-referrals.

3. Tenure Disposition (Sale): Geothermal exploration permits are issued through a sealed bid public competition. Prior to the sale, a public notice is published in the BC Gazette, outlining all the terms of the permit tenure disposition and specific tenure terms and caveats. The tenure terms and caveats may arise as a result of the pre-tenure referral process. Bids are opened on sale day and evaluated according to the criteria outlined in the public notice. The successful bidder's name is released shortly after the sale has concluded through a notice posted to this website. More information is provided: http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/geothermal/geothermal_bids_information_letter.pdf. Examples of Sales Notices and previous results are available: http:\www2.gov.bc.ca\gov\content\industry\electricity-alternative-energy\renewable-energies\geothermal-energy\exploration-and-sales\geothermal-permit-sales
4. Despite this approval process, the minister may also dispose of geothermal resources on terms approved by the Lieutenant Governor in Council (Section 3 of the GRA).
5. Once a project proponent receives the geothermal exploration permit for the tenure location, they have the rights for subsurface exploration under the GRA.

Because the GRA only authorizes subsurface exploration rights, surface land use and water rights must still be acquired by the proponent. It is recommended that the geothermal (subsurface rights), land use (surface rights), and water rights applications are completed concurrently to avoid legal conflicts over rights ownership under the various regulations. Surface land rights and water rights regulations will generally follow the same guidelines as development of a low-temperature Direct-use project and will be covered in detail below.

C.10.2. Permitting for Direct-use Projects using waters under 80°C

Because most of the geothermal indicia identified and sampled to date in BC have surface temperatures less than 80°C, their capture for Direct-use purposes will not require a GRA exploration permit from the Province. Accordingly, it is advisable to focus on the features with temperatures below the 80°C threshold, or if drilling is needed to acquire increased thermal water flow rates, then the well(s) should be bottomed at a depth where 80°C is not exceeded.

The general process for acquiring the necessary land use and water licenses/permits is described below. These steps will also be required in order to obtain surface and water rights for the development of a geothermal resource under the GRA.

1. In order to access a site of interest for initial investigations of a Direct-use project it will first be necessary to determine the legal status of the land on which the project is located. Most projects, if not all, would likely fall on provincial Crown land, requiring an application for a land use permit under the *Land Act*. An easy to use tool, referred to as "GATOR" (Government Access Tool for On-line Retrieval: http://a100.gov.bc.ca/pub/pls/gator/gator$queryforms.menu), allows registered users to use the Internet to interactively view, extract and print information from the Crown Land Registry. The Crown Land Registry is a database of Crown land records for the province of British Columbia. In addition to surface land rights, it is important to assess if any other individuals or proponents have water rights in the area.
2. Depending on the intended use, the services and access available, and the required tenure term, an application for surface rights to access provincial Crown land can be made through FrontCounter BC (http://www.frontcounterbc.gov.bc.ca/) for a land use license under the *Land Act*. Land use permits are available by intended use, in this case being industrial development. The land use permit would fall under the Industrial General Program (http://www2.gov.bc.ca/gov/content/industry/natural-resource-use/land-use/crown-land/crown-land-uses/industrial-uses/industrial-purposes). There are three types of tenures under the Industrial General Program and each has different purposes and fees:
    a. A Temporary License can be issued for up to 2 years to authorize a temporary use. A temporary license may also be issued to allow an applicant to conduct investigative work required to obtain a more substantial tenure. The Province allows for 140 business days (~7 months) for approval of a Temporary License.
    b. A License of Occupation is issued where the applicant does not require long-term certainty, does not wish to incur the cost of a legal survey and no significant land improvements are intended. A license is issued for a 10-year term.
    c. A Lease is issued where substantial improvements to the land are to be made, or where boundaries are necessary to avoid conflicts with neighbouring operators. A lease is normally issued for 30 years.
3. In particular, once the project is at the point of drilling a water well or using water for any purpose, a Lease (under the Industrial General Program of the Land Act) is required in order to obtain a water license.

Once more information is known on what type of projects a Direct-use resource can be developed for, more specific permits are required depending on intended use. For example:

Aquaculture: http://www2.gov.bc.ca/gov/content/industry/natural-resource-use/land-use/crown-land/crown-land-uses/aquaculture; an example of an aquaculture land use permit is also available (http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/land-water-use/crown-land/freshwater_mapping_description_and_templates-sitemapsample.pdf).

Greenhouses: http://www2.gov.bc.ca/gov/content/industry/natural-resource-use/land-use/crown-land/crown-land-uses/agriculture/intensive-agriculture

C.10.3. Water Licensing in BC under the Water Sustainability Act

All water in British Columbia is owned by the Crown on behalf of the residents of the province. The Province has the proprietary right to ensure its protection and sustainable use. The *Water Protection Act* reconfirms that surface water and groundwater are, and always have been, vested in the Crown, except in so far as private rights have been established. Authority to divert and use surface water is obtained by a license or approval in accordance with the statutory requirements of the *Water Sustainability Act* (WSA), put in force February 29, 2016. In order to obtain approval for any type of water well drilling or surface water use, the necessary land tenure requirements must be fulfilled. It is recommended that water use and land use applications be submitted concurrently.

British Columbia applies the historic First-in-Time, First-in-Right (FITFIR) system, in which senior licensees (those with earliest priority dates) have precedence over junior licensees, regardless of the purpose for which the water is used.

Water licenses are regulated under the WSA and, if granted, permits the diversion, use or storage of surface water from a stream, and to construct works (http://www.frontcounterbc.gov.bc.ca/guides/water/new-water-licence/overview/). A water license specifies the water source, the water use purpose, the maximum quantity of water that may be used and the works associated with the water use as well as where the water can be used. It is possible to apply for more than one water use purpose. For short term water use, "use approvals" authorize holders to use water for a period of up to 24 months.

Qualified well drillers (certified under the WSA) or qualified professionals (registered with the Association of Professional Engineers and Geoscientists of BC with competency in hydrogeology or geotechnical engineering) must be employed to ensure an accurate pre-drilling assessment and that provincial regulatory requirements are followed (such as controlling or stopping artesian flow).

As of February 29th, 2016, all non-domestic groundwater users, both existing and new, are required to apply for a water license, and pay an application fee and annual water rentals. The BC government offers an online tool called the Water Rent Estimator (http://www.env.gov.bc.ca/wsd/water_rights

/water_rental_rates/calculator/index.html) that provides an estimate of provincial water rentals, which are annual payments for the diversion and use of water. Application fees can also be estimated. The tool was updated in 2016 to reflect changes that came into force with the WSA.

Going through the permitting guidelines, it is clear that the acquisitions of the necessary rights to a geothermal resource, land use, water use are intrinsically linked. It is essential at the early stages of a project that an investigation is completed on whether there may be any conflicts with neighbouring land use permittees or land owners.

D. SUMMARY OF RECOMMENDATIONS

All of the Direct-use applications reviewed in this *Roadmap* would be well-suited to BC, given appropriate due diligence, in-depth consultations with nearby First Nations and communities and detailed economic analyses on a case by case basis.

Listed below are the activities that should be conducted to go from "grass roots" to a completed project. Figure 83, at the end of this document, is a flow diagram that graphically illustrates the processes involved in the development of a Direct-use project.

- Confirm that there is an accessible geothermal manifestation (mud pot, altered ground area, warm spring, hot spring) within about 8 kilometers from the community.
- Identify the owner of the land on which the thermal feature exists and determine the possibility of leasing or otherwise obtaining rights to develop all or part of the resource.
- Acquire the legal rights to conduct non-invasive surface exploratory activities, follow-up thermal gradient drilling, and ultimately production and injection well drilling.
- Measure water temperature, flow rate, obtain samples for chemical analyses, and note odours, and formation of silica or calcium scale.
- After reviewing the Geothermal Energy Uses Diagram (Figure 2), make a preliminary list of Direct-use projects whose thermal energy needs that might be met the temperature and flow rates measured at the thermal feature. Prioritize the list.
- Hold a community meeting to discuss what has been discovered and what potential projects might be developed. Get the community members' reactions and have a preliminary list of projects available for ranking by the citizens.
- Identify potential local leaders to spearhead the project implementation.

- Determine whether the project is opposed by any groups, including First Nations or existing users of the thermal waters, on grounds that cannot be readily mitigated or compromised.
- Do a very preliminary estimate of the costs to: i) confirm the resource characteristics, ii) develop the resource to its full potential including acquisition of all required permits and licenses, iii) transport thermal waters to the community, iv) build the Direct-use facility, v) market the products, vi) initiate operations, and vii) operate and maintain the facility over the long term.
- Estimate the revenues from the project after deduction of all expenses and debts.
- Determine if, preliminarily, the project will provide an adequate return on investment to the lenders, the developers, and the owners. This assumes that the project proponent is not a Municipal, Provincial, or Federal entity.
- Identify all of the Federal, Provincial, and local permits that are likely to be required for the type of project contemplated and determine how long it will take to obtain them and their costs.
- Determine if employment of local community members can be planned and if so, find out how many qualified workers might be available and the range of their talents.
- Identify the type(s) of fluid disposal that may be permissible and the potential disposal sites. (This assumes that for some reason re-injection is not planned).
- Initiate studies to determine the environmental and social impacts of the proposed project. This work is commonly known as an Environmental Assessment and should include extensive interviews with all potential project stakeholders and the gathering of environmentally-related baseline data including, but not limited to: cultural use by First Nations, archeological or heritage interests, wildlife impacts, ambient noise levels, seismic activity history (if any), land subsidence or sliding, any local odours, existing "visual pollution", the statuses of flora and fauna in the project vicinity, and certainly, the current temperature ranges, flow-rate ranges, and chemical variations over time of the thermal feature.
- If the natural flow rate of the thermal feature is low and geologic/hydrologic experts opine that it could be increased by drilling and pumping wells, then a plan should be formulated to identify the best sites at which to drill. This plan should include conduct of moderately detailed geoscientific studies (geologic mapping, geochemical surveys, and limited geophysical surveys) followed by a modest thermal gradient hole-drilling program to be based on the information gleaned from the preceding work.
- Once the results of the thermal gradient hole drilling have been obtained and studied, a decision should be made whether to drill a reduced diameter exploratory well ("slim hole") or whether to

drill a full-scale production well. The former would be less expensive, but the latter would provide more information and might turn out to be of commercial quality.

- Once the drilling decisions have been made, tenders for the drilling of the well(s) should be generated and bids sought from qualified drillers. The well(s) should then be drilled and tested over a long enough period to allow the acquisition of substantial and significant hydrological information. This could mean that well tests of at least 10 days and preferably somewhat longer would be conducted.
- Once the well testing has been completed and analyzed, the temperature, flow (or pumped) rate, the chemistry, and the hydrologic characteristics of the geothermal resource will be known. This information should provide the planners and developers of the Direct-use project with the resource-related data that is needed to finalize the design and the cost estimates for the project.
- From this point onward, the Direct-use project can proceed like any other construction project. Permits will have to be acquired, road access built or improved, pipelines built, land leveled and/or excavated, utilities installed, and buildings erected.
- Do final design with assistance from a professional engineer/geologist
- Select equipment, construct the facility, test, and modify if necessary
- Hire qualified local work force, operate the facility, and market the product(s) for a profit that will benefit the developer and the community.

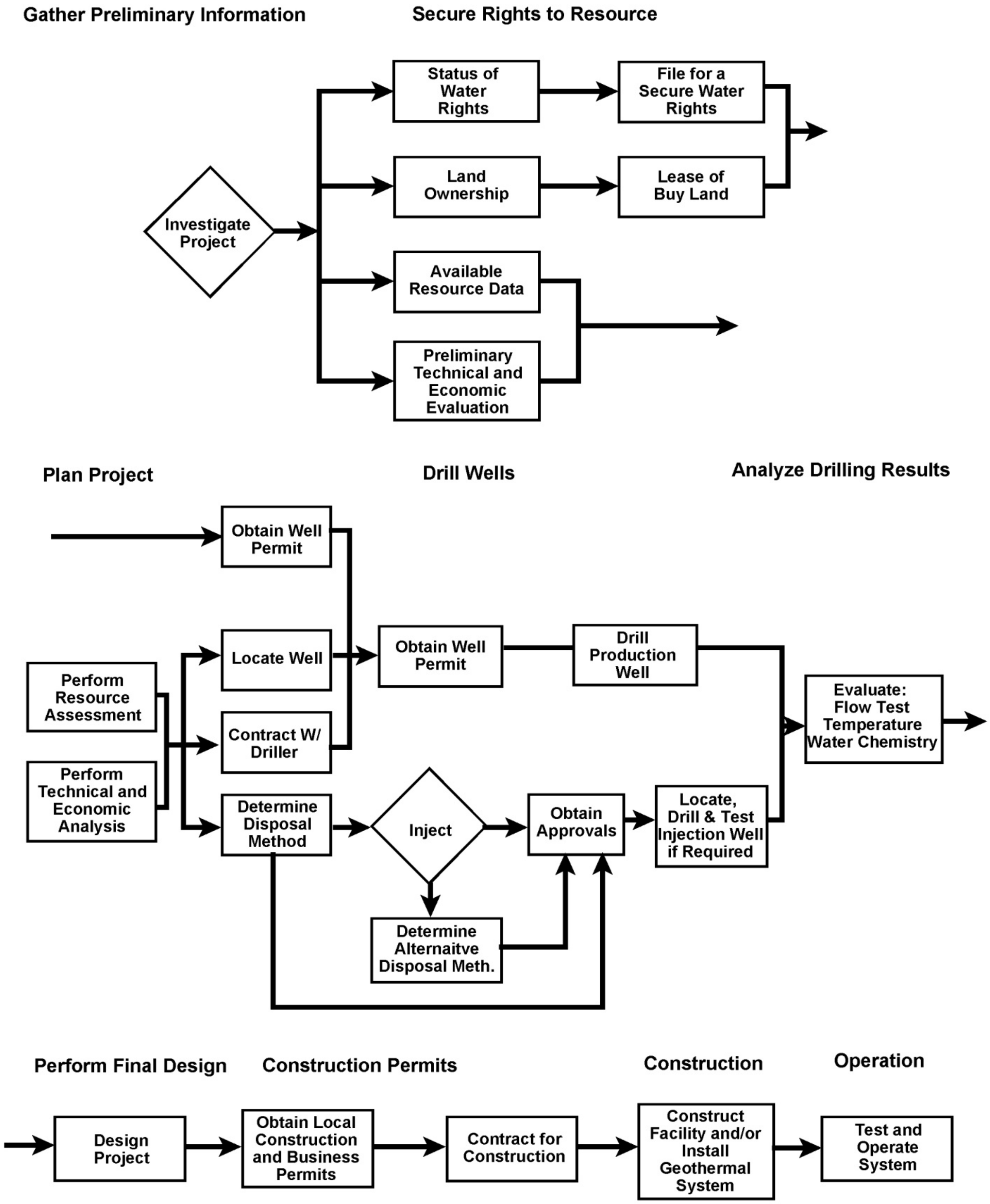

Figure 83. Direct-use development flow diagram (Lienau, 1998).

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