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# ECONOMIC FACTORS IMPACTING DIRECT USE GEOTHERMAL DEVELOPMENT VIABILITY

R. Gordon Bloomquist

Washington State University Energy Program, Olympia, U.S.A.

## INTRODUCTION

The factors that must be considered when assessing the economic viability of a geothermal project vary from project to project, from conversion technology to conversion technology, and especially from electrical generation to direct use. There are, however, a number of factors common to all projects, although actual cost and impact on project economics will be, to a large extent, dependent upon resource characteristics and national or even local political and economic circumstances. This paper will concentrate primarily on direct use economic factors; however, increasingly more and more projects are combined heat and power and thus economic factors related to electrical production must also be given at least some consideration, and economic viability may require a number of revenue streams from, for example, power sales or offset, sales of thermal energy or products produced, or even sales of byproducts such as minerals.

The economic factors that are common to all projects include: provision of fuel, i.e., the geothermal resource; design and construction of the conversion facility and related surface equipment, in the case of district heating the distribution system and customer connections; financing; and of course the generation of revenue. The cost of obtaining the required fuel supply, together with the capital cost of the conversion facility, will determine the amount that must be financed. Revenue generated through the sale of electricity, by-products, thermal energy, or product produced, e.g., vegetables, plants, or flowers from a greenhouse, minus the cost of O&M of the fuel supply and conversion facility, must be sufficient to meet or exceed the requirements of the financing package and expected rate of return on investment.

Because financing is such a critical factor in the economics of any project, an entire subchapter could be devoted to this subject with the express aims of describing the institutional prerequisites for successful financing and development of a geothermal energy project, summarizing the debt and equity structures for such a project, with emphasis on the broad range of structuring options and funding sources, and surveying the key issues in project agreements that should be addressed so that financing can take place. However, such a discussion is beyond the scope of this paper. The reader is, however, referred to *Geothermal Energy* (M.H. Dickson & M. Fanelli) for more information on this topic. It must be noted, however, that for many new projects, the largest annual operating cost is the cost of capital (Eliasson et al., 1990). In fact, the cost of capital can be as high as 75% of the annual operating expense for a new geothermal district energy project with O&M (15%) and ancillary energy provision (10%) making up the balance.

## 1. ECONOMIC CONSIDERATIONS

### *Provision of fuel*

For most projects that require a sustained and economically attractive fuel supply, the project sponsor must only contact a supplier and negotiate a long-term supply of natural gas, oil, propane, biomass, or coal. To help guarantee low and stable fuel supplies, more and more project sponsors are purchasing gas fields, or oil or coal reserves. For projects that depend upon biomass (wood), fuel can be contracted from a wood products mill or the mill may even become a partner in the project, providing an even more secure supply. Long-term availability of biomass can be determined from long-term timber holdings within a geographically defined area and/or plans for harvesting as defined by a state or federal land management agency. With municipal solid waste, fuel supply can be assured through local government action requiring that all material be controlled by one entity and delivered to a specific facility for a given time period.

In the case of geothermal resources, however, the fuel cannot be purchased on the open market, legislated into existence, bought from a local utility, or transported over long distances from a remote field.

Whether the steam or hot water is to be provided by the project sponsor, i.e., the geothermal field and conversion facility are under one ownership, or whether the steam or hot water is to be provided by a resource company, the geothermal fuel is only available after extensive exploration, confirmation drilling, and detailed reservoir testing and engineering. Once located, it must be used near the site and must be able to meet the fuel requirements of the project for the lifetime of the project. Even before exploration can begin, however, the project sponsor may incur significant cost, and a number of extremely important legal, institutional, regulatory, and environmental factors must be fully evaluated and their potential economic impacts considered.

### *Obtaining access and regulatory approval*

In order to obtain rights to explore for and develop geothermal resources, access must be obtained through lease or concession from the surface and subsurface owners. In many countries, the state claims rights to all land and to all mineral and water resources. In other countries, land and subsurface rights can be held in private ownership or the surface and subsurface estates may be separated. Unless the geothermal developer has clear title to both surface and subsurface estates, an agreement for access will have to be entered into with the titleholder of these estates. Such access will normally require a yearly lease fee and eventually royalties upon production. In areas where there is significant competitive interest, competitive bidding may be used to select the developer. Competitive bids can be in the form of cash bonuses or royalty percentages. Royalties can be assessed on energy extracted, electrical or thermal energy sales, gross sales, net profit, or even product sales. Whatever the system, it will have an impact upon project economics and should be carefully considered in terms of overall economic impact. In particular, developers of direct use projects, because of the limited economic rewards that can be expected, must carefully evaluate how royalties will be calculated. In a number of instances evaluated by the author, royalties, if assessed, would comprise up to 50% of annual operating cost, making projects un-economical to pursue.

The second factor that will have an impact on overall project economics is obtaining all regulatory approvals, including the completion of all environmental assessments and the securing of all required permits and licenses, including, if necessary, a water right. Increasing concern for the environment in nearly all countries of the world has resulted in sharply increased cost for preparing the necessary environmental documents and acquiring all necessary permits and authorities. A complete environmental assessment and possibly impact statement is now required by federal land management agencies for any proposed development in the United States, and cost for preparation can exceed one million dollars. It is not uncommon to invest up to 40,000 – 60,000 person-hours in completing all necessary environmental documents and obtaining required licenses and permits for a major electrical generation project. Although most direct-use projects will be somewhat simpler to permit, the cost and time required to fulfill all requirements can be substantial. Because so many environmental decisions are now contested, a contingency to cover the legal costs related to appeals must be included in any economic analysis; depending upon the issues and the financial and political power of those appealing a decision, the cost of obtaining necessary approvals can easily double. Because most direct-use projects are more limited in scale and, therefore, in environmental impact, these costs may be only a small fraction of the cost incurred by the proposal for a major power generation project. Even such a reduced cost can, however, be significant in relationship to the scale of the project, and the economic impact should not be underestimated. Unfortunately for the project sponsor, most of the cost related to obtaining access and environmental and regulatory approval must be incurred early in the project, and, in many instances, even before detailed exploration or drilling can begin, and with no clear indication that any of the costs will or can be recovered.

### *Exploration*

Once access has been secured and all necessary regulatory approvals have been obtained, the developer may initiate a detailed exploration program, refining whatever data was initially gathered in the reconnaissance or pre-lease phase of the development process and sequentially employing increasingly sophisticated techniques that will lead to the drilling of one or more exploration wells; hopefully these wells will be capable of sustaining a reservoir testing program, and possibly also serving as preliminary discovery and production wells. Reconnaissance, in all likelihood, included such activities as a literature search, temperature gradient measurements in any existing wells, spring and soil sampling and geochemical analysis, geologic reconnaissance mapping, air-photo interpretation, and, possibly, regional or even local geophysical studies. Costs incurred may range from a low of a few thousand dollars to $100,000 or more, dependent upon prior work in the area, geological complexity, and, of course, the scale of the proposed project and whether or not the intended use is electrical generation or direct application.

Once the area of principal interest has been selected, the exploration program can be more intensely focused, with the primary objective of siting deep exploration wells. Techniques likely to be employed include detailed geologic mapping, lineament analysis, detailed geochemical analysis, including soil surveys and geochemical analysis of all springs and wells, temperature gradient and/or core drilling, and geophysical surveys, including for example resistivity, magnetotellurics, gravity, and seismic. Costs increase with the complexity of the techniques and as the details of the surveys become more focused. For large, direct-use projects, costs of $100,000 or more can be incurred. For projects directed toward electrical generation or even major industrial process uses, the cost of this phase of the work can easily exceed several hundred thousand dollars, and may exceed several million dollars.

The final phase in any geothermal exploration program involves the siting, drilling, and testing of deep exploratory wells, and, subsequently, drilling production and injection wells.

### *Well Drilling*

Well cost can vary from a low of a few tens of thousands of dollars for small, direct-use projects to several million dollars per well for wells required to access high-temperature resources for electricity generation and in some cases large district energy or high temperature industrial process applications. Success ratios for production wells can be expected to exceed 60%; however, the risk of dry holes in the exploration phase remains high ($\approx$ 80%) and can have a significant economic impact. Even one dry hole can cause a project to be seriously delayed or even abandoned by a risk adverse or under-capitalized developer. Even in developed fields, 10 to 20% of the wells drilled will be unsuccessful (Baldi, 1990). Drilling cost is typically 30-50% of the total development cost for an electrical generation project and variations in well yield can influence total development cost by some 25%. (Steffanson, 1999.) For many direct-use projects, well costs comprise the largest single expenditure and might exceed 80% of the entire project cost. Prospective developers must anticipate and prepare for the eventuality that despite an investment ranging from a few hundred thousand dollars to several million dollars in lease fees, environmental studies, licenses and permits, and exploration and drilling activities, an economically viable geothermal reservoir may not be discovered.

If, however, drilling is successful, the reservoir must then be tested to determine its magnitude, productivity, and expected longevity. Only after such testing can a determination be made as to the eventual size and design of the generating facility or direct-use application, and financing for project construction be secured.

### *Well field development*

Well field development for an electricity generation project or in some cases large direct use projects can last from a few months to a number of years, depending upon the size and complexity of the project, the speed at which procurement contracts can be let (Koenig, 1995), and the availability of drill rigs. At this stage it also becomes of increasingly critical importance to collect detailed data and to refine the information available on the reservoir. Of course, for most projects this will include both production and injection wells. Many projects experience unnecessary difficulties and delays in obtaining financing or in milestone review because of either incomplete or inaccurate data collection, analysis, and/or interpretation (Koenig, 1995). Such difficulties and delays can seriously affect project economics and can have a catastrophic economic impact if delays result in contract forfeiture or if contracts contain a penalty clause tied to milestone completion. Coincidental with well field development will be the construction of well field surface facilities.

Costs associated with both drilling and the construction of well field surface facilities will be affected by the availability of skilled local labor and by geologic and terrain factors. Labor costs can be expected to increase by 8-12% in areas where most of the labor must be brought in or a construction camp erected to provide housing and meals. Terrain and geologic factors can add from 2-5% if special provisions must be made for work on unstable slopes or where extensive cut-and-fill is required for roads, well pads, sumps, etc.

Over half of the total production cost over the lifetime of most projects will in fact be expenses associated with the well field. Because of this, it is imperative that wells must be properly maintained and operated to ensure production longevity. But even with proper O&M, many wells will have to be periodically worked over and, for most power generation projects, 50% or more of the wells will likely have to be replaced over the course of the project, adding considerably to the initial well field cost and, of course, to the cost of generating power. For example, if 60% of the wells must be replaced over the economic life of the plant, it would have the effect of increasing the levelized cost of electricity by 15 to 20% (Parker et al., 1985).

For small to medium-sized direct-use projects requiring only one or two production and injection wells, costs will generally be much lower. Because the water chemistry of most geothermal resources that are developed for direct-use applications is of generally higher quality than that available for power production, well life can be expected to be much longer and few, if any, wells will have to be worked over or redrilled during the economic life of the project.

## 2. DIRECT USE DEVELOPMENT

A discussion of project design and facility construction relative to direct-use projects is more difficult than with power generation, because a direct use project may be supplying the needs of a greenhouse or aquaculture complex, an industrial facility, or a district energy system supplying multiple commercial, industrial, and even residential customers. (Note: Individual systems to heat and/or cool a single residence or greenhouse, or projects directed toward balneology, will not be considered.)

### *Design Considerations*

The three uses mentioned above, however, share a number of design considerations and even some equipment components, all having a bearing on the economics of the project. All are highly dependent upon resource characteristics, including temperature and flow, hydrostatic head, drawdown, and fluid chemistry. The characteristics of the resource will dictate not only the type of project that can be developed, but also the scale of the project and the metallurgy of the components selected. Direct use projects must be located near enough to the resource site to allow for economic transport of the geothermal fluids from the wells. However, for very large district energy systems and some industrial process applications, this distance may be several tens of kilometers. If the well(s) does not flow artesian, well pumps will be required, and at resource temperatures at which most direct use projects operate, either line shaft or downhole pumps may be used. Because of variations in flow requirements to meet seasonal loads, inclusion of variable speed drives is normally considered in order to minimize electrical costs.

Piping from the well(s) to the application site will be dependent upon temperature, pressure, and distance. Insulated pipe may or may not be required, and will depend on distance and whether or not some temperature loss is acceptable. The pipes may be constructed above ground, but local regulations or safety and/or security issues may require burial.

Another major design consideration is whether or not the heating system should be based on meeting the peak heat demand entirely with geothermal or whether the system should rely on a fossil fuel (oil, propane, natural gas, or even coal) boiler for peaking and/or backup. In many instances, a strategy where the geothermal system is designed for 'base load only' operation may be the most economical. For both greenhouse applications and district energy systems, designing the geothermal system to meet 50 - 70% of the peak heating load will still allow the geothermal system to meet 90 - 95% or more of the annual heating requirement in most climatic zones. This is because a system that is designed to meet peak-heating load operates only a few hours of the year under those conditions. For example, if a district energy system is to meet peak demand solely with geothermal, the number of wells will have to be doubled and the size of the distribution piping increased by approximately 30% to accommodate the requirement for increased flow. Another strong argument for meeting peak demand with a non-geothermal system is the need for back up for both greenhouse applications and for district energy systems. And although back up can be provided through the use of standby wells and back-up generators to run pumps, a fossil fuel system may be the most secure alternative and also the most cost effective. Whether or not to include fossil fuel peaking for an aquaculture or industrial application will depend upon the particular requirements of the application. However, because most industrial procesşses that use geothermal energy operate on a more or less continual basis, the geothermal system will generally be designed to meet the entire load. Back-up could, however, still be a consideration if any interruption in the process is unacceptable.

In addition to giving careful design consideration to the selection of the most appropriate and economical heating system, similar consideration should also be given to the provision of cooling. For most greenhouse operations, cooling can be provided through a combination of shading and the use of evaporative coolers. However, if a more sophisticated cooling system is required, or there is a need for refrigeration, absorption cooling may be an option worth evaluating. New advances in double and even triple-pass absorption equipment allow for a coefficient of performance (COP) significantly above 1 to be obtained, if temperatures are adequate for such applications, and even at geothermal resource temperatures as low as 80 - 100°C, absorption cooling may be the answer to meeting the needs of both greenhouse operators and providers of district energy service. Where refrigeration is a requirement, ammonia absorption or a binary driven turbine/refrigeration unit may be well worth considering.

### Equipment selection

Pumps are one of the most critical components and careful consideration should be given to their selection. Historically, line shaft pumps with variable speed drives have dominated the geothermal industry. However, recent advances in down-hole pumps with plug-in connections may well provide an economically attractive alternative that could significantly reduce maintenance cost while at the same time allow for pumping from greater depths and from deviated wells.

Most if not all systems will require the inclusion of a heat exchanger to separate the geothermal fluids from the in-building or process heat circulating loop because of the potential for corrosion and scaling associated with most geothermal fluids. Both plate-and-frame and shell-and-tube heat exchangers have been successfully employed in such applications. Despite higher cost, a number of factors tend to favor the plate-and-frame exchanger. Approach temperatures across the plate-and-frame exchanger are somewhat better at 3° to 6° C vs. 8° to 11° C for shell-and-tube. Another major consideration in the selection of a plate-and-frame heat exchanger is the ability to easily add plates in order to expand the heat exchanger capacity, and the fact that the exchanger can be easily opened for cleaning. (NOTE: This is not true for brazed plate-and-frame exchangers.) Materials include various grades of stainless steel and titanium. Although titanium is considerably more expensive, the added cost may be well justified on a life-cycle cost basis.

Selection of the piping material is especially important in applications that have extremely long pipe runs such as is common to nearly all district energy systems. If the geothermal fluid is to be circulated through the distribution-piping network, material selection and even carrier-pipe wall thickness become crucial decisions. For example, in the case where geothermal fluids are circulated, thin-walled, pre-insulated district heating pipe, so common to most district energy systems in Europe, may not be appropriate. If, however, the heat is transferred to a secondary fluid that is circulated in a closed loop, and where addition of inhibitors is practical, the thin-walled, pre-insulated pipe is probably a logical choice. Other points to consider include the choice between metallic and nonmetallic pipes and whether flexible pipes should be used. Studies by the International Energy Agency indicate that flexible piping can reduce the cost of pipe installation by as much as 60%. Flexible piping is only available in the smaller size ranges, but the decrease in cost associated with its installation may make providing heat to areas with relatively low heat load density economically viable. If nonmetallic piping is selected, care must be taken to ensure that it has an oxygen barrier or that areas served with nonmetallic pipes are separated by a heat exchanger from areas served with metallic pipes. If this is not done, severe corrosion problems may occur in the metallic pipe portions of the system due to oxygen infiltration.

Other system components and design considerations are very application-dependent and beyond the scope of this chapter. The reader is, however, referred to the Geothermal Direct-Use Engineering and Design Guidebook published by the Oregon Institute of Technology in Klamath Falls, Oregon (see listing at: htpp://geoheat.oit.edu).

### Project construction

For greenhouses, aquaculture projects and many industrial process applications, construction of the geothermal portion of the project is usually a very minor part of the entire project, and consists primarily of wells, pumps, heat exchangers, peaking and/or backup equipment, piping, and controls. However, with a district energy system, the thermal energy transmission and distribution piping system will comprise 60% or more of the total construction budget. District energy systems may include multiple heat exchange and peaking or back-up stations, thermal storage tanks, and extensive control systems. In the majority of district energy applications, the geothermal fluid is most often used to heat a secondary fluid that is circulated to meet customer needs. In some cases, however, the geothermal fluid is circulated directly to each customer, where the heat exchange takes place. The principal cost during construction is related to pipe lines and includes, in addition to the piping, excavation, traffic control, pipe-laying, back filling, and repaving, if necessary. The installation of the piping system can run from an equivalent of $300 US per meter to as high as $9000 US per meter in highly developed urban areas dependent of course upon pipe diameter and material selected. A major problem for most developers of district energy systems is that the transmission piping as well as some of the distribution piping must be sized to meet the needs of the system at full build-out although revenue will increase only slowly as the system expands and as the customer base increases. This dilemma is by far the most important economic consideration in determining the feasibility of introducing geothermal district energy service into an existing community or new development. The use of computer models for determining the economic viability of constructing a new district energy system or expanding an already existing system is now available. For one such model see HEATMAP©5GEO, at http://www.energy.wsu.edu/software/. In a new community or a new area of a community, much of the cost of constructing the distribution system may well be shared with the developers of other utility services, including sewer, water, and electricity, but will require good planning and close coordination.

Another major factor that is often given too little consideration is the cost of retrofitting existing facilities. Because most aquaculture, greenhouse and even industrial facilities will be designed from the ground up to use geothermal, retrofitting is seldom an issue. However, in the case of district energy, the technical capability and cost of retrofitting will be of critical importance in attracting customers to the system and thus the overall economics of system development. Connecting a geothermal district energy system to customers whose heat is provided through a central hydronic system or even a forced air system is by far the easiest. On the other hand, if the existing heating system is based on electric residence or an electric or fossil fuel fired unit heater, retrofitting to accept district energy service can be extremely difficult and expensive. A careful analysis of the payback for each potential customer must be undertaken in order to determine whether or not an acceptably high penetration rate in the service area can be achieved. With new construction, of course, the in-building system can be designed to be compatible with the geothermal district system and penetration could reach 100%.

## 3. REVENUE GENERATION

For power generation projects, the power sales contract establishes the legal framework for revenue generation. For direct use projects, however, the revenue stream to support the project may well come from the sale of a product, e.g., flowers, plants, or vegetables from a greenhouse project, fish or shellfish from an aquaculture project, value-added service, e.g., dehydration in an industrial process, or thermal energy sales for a district energy project. Considerable interest in so-called co-production is also increasing rapidly as a means of improving the economics of geothermal power generation as well as direct use projects by providing an additional revenue stream. Co-production involves the extraction of valuable by-products from the geothermal brine before reinjection. These by-products may include zinc, manganese, lithium and silica – all with relatively high market value.

### *Electrical generation*

Ultimately, the economic viability of a particular power generation project will depend upon its ability to generate revenue, and revenue can only be generated from power sales. Such sales must be equal to or exceed that required to purchase or maintain the fuel supply, including any royalties; to cover debt service related to capital purchases; to cover operation and maintenance of the facility; and to meet expected return on investment of investors. The output from the plant, and hence the source of revenue generated, will be highly dependent upon how well the plant is maintained, how it is operated, and the ability to take maximum advantage of incentives to produce at certain times or under certain conditions. For example, a plant selling into a summer peaking service area must be able to provide maximum possible output when a premium is being paid for output.

A number of innovative approaches have been adopted to ensure the highest possible capacity factor and thus maximum revenue to the plant owner. The most common of these is the use of redundant or back-up equipment, including spare wells, cooling water pumps, non-condensable gas removal equipment, and the use of multiple turbine generation sets. The presence of redundant equipment allows for routine or even forced maintenance to be accomplished without taking the plant off line or at least the entire facility off line. The use of multiple modular turbine generators is a prime example of a strategy to achieve maximum capacity factor. In many instances, the steam or brine can be routed from the downed unit to other operating units capable of operating at slightly over design, thus providing the possibility of covering the entire load of the unit that is out of service.

Revenue can also be affected by plant availability, dispatchability, and load-following capability. Many power purchase contracts provide incentive payments for: availability, i.e., the ability to generate at certain levels or during certain peak demand periods; dispatchability, i.e., the ability to go off-line or curtail production when the power is unneeded; or load-following capability, i.e., the ability to match power output to the need for power of the receiving utility. Availability, much like plant capacity factor, can be achieved through the highest possible flexibility and reliability in plant operation, and, as with capacity, is often achieved through the use of redundant equipment. However, possibly as important in terms of revenue generation is the ability of the plant to quickly come on-line after a forced outage, after being tripped off-line, or upon request of the utility to curtail production.

Other factors that can affect revenue generation include plant dispatchability and load-following ability. Although the commonly held philosophy is that geothermal power plants, because of the ratio of fixed to variable costs, must operate in a base load manner, utility requirements and/or reservoir concerns may require that the plant be operated in a load-following or dispatchable manner. Reservoir depletion at both The Geysers and Larderello has forced load following, and some utility contracts provide incentives for dispatchability that more than offset any loss of revenue while the plant is operated below design capacity.

The direct link between revenue generation, plant availability, and capacity also places greater emphasis on plant and well field O&M.

A vested interest in plant performance provides a motivating influence to the O&M provider. Such motivation, in turn, provides security to financiers. Incentives such as a bonus for good operation, tied with a penalty for not meeting minimum performance requirements, help ensure optimum performance, guarantees achieving output to match contractual requirements, and generate maximum revenue and profit. But good O&M goes beyond maximizing current profits, to an efficient use of the reservoir in order to prolong life and assure supply. Smart developers also know that a good performance record will be critical to obtaining both future power sales agreements and financing for future projects at attractive rates.

### *Co-Generation*

Co-generation, or the simultaneous production of electricity or mechanical energy and thermal energy, is becoming increasingly attractive to geothermal developers. Many geothermal power plants can be coupled to direct-use applications in a so-called cascaded use of the resource. The idea, of course, is to maximize the use of the energy that is pumped from the wells in order to enhance the economics of the projects. Depending upon the nature of the project, the electrical generation may either precede the direct-use applications (topping cycle), e.g. district energy, greenhousing or aquaculture, or generation may be based on the use of the "waste heat" from, for example, a geothermal industrial process that requires a high temperatures source, e.g. agriculture product dehydration (bottoming cycle).

### *Co-Production*

Co-production, i.e. the production of silica and other marketable products from geothermal brines, is rapidly becoming not only a very viable source of additional revenue for geothermal project developers, but a key technique for improving project economics by reducing operation and maintenance costs. In the case of, for example, power production, the removal of silica may allow additional geothermal energy extraction in bottoming cycles or, in the case of direct-use, additional uses of low-grade heat that are presently prohibited due to problems associated with scaling. In both cases the economics of the project can be substantially improved.

Precipitated silica has a relatively high market value (1-10 US dollars per kilogram) for such uses as waste and odor control, or as an additive in paper, paint and rubber (Borcier, 2002, *Personal Communication*, Borcier, et al., 2001). For example, initial estimates from the Salton Sea geothermal field place the potential market value of extracted silica at 84 million US dollars a year.

Silica removal also opens the door to the downstream extraction of, for example, zinc (Zn), manganese (Mn), and lithium (Li), all with relatively high market values. The first commercial facility for the recovery of zinc from geothermal brine was built in the Salton Sea geothermal area of southern California in 2000. The facility is designed to produce 30,000 metric tonnes of 99.99% pure zinc annually at a value of approximately 50 million US dollars (Clutter, 2000).

Silica removal has the additional benefit of helping to minimize reinjection problems and could allow use of the spent brine as the source of cooling water for use in enhanced evaporative cooling to improve summer power plant performance of air cooled plants. Initial studies indicate that power plant efficiency of an air-cooled binary plant could be increased by 25+% through the use of evaporative cooling (Sullivan 2001, *Personal Communication*). This would provide substantial additional revenue especially in summer peaking areas.

### *Direct Use*

Most large-scale direct use projects tend to fall into three broad categories: provision of district energy; industrial processes, including dehydration; and agriculture, including greenhouses and aquaculture. In all except the provision of district energy, revenue is generated from the sale of a product, such as potted plants from a greenhouse, or from a value-added service rendered, e.g., the drying of onions in a dehydration plant. Ultimately, in both cases, revenue generated and economic viability is totally dependent upon the value and marketability of the end product. Long-term contracts for sale of these products are almost never available. Geothermal may be the most economic form of energy for any given application, and may even provide certain other benefits such as fuel price stability or constant heat, but the economic viability of the project will seldom be driven by the cost of developing and/or operating and maintaining the geothermal source. The geothermal resource developer must therefore not only have a thorough appreciation of the costs involved in developing and operating a geothermal project in an economical manner, but must fully understand what factors ultimately determine the economic viability of the products produced.

With district energy, on the other hand, revenue is generated solely from the sale of thermal energy in the form of either hot water or chilled water. Long-term sales contracts to customers are the norm, and most contracts call for both capacity (fixed) payment and variable payment components.

The capacity or fixed portion of the payment is based upon the capital invested, including wells, heat exchangers, thermal storage units, back up or peaking boilers, and the transmission and distribution network. The variable portion of the amount charged relates to O&M, including personal cost, cost for fossil fuels used in the back up and/or peaking boilers, pumping and redrilling of wells. In most systems, charges are based on usage, metered either as flow or thermal demand, i.e., kW/hour. Some systems, however, use a fixed orifice and charges are based upon the orifice size.

Because weather conditions will, to a large extent, determine thermal energy usage by residential and commercial customers, it is extremely important that rates are structured in such a way as to ensure that revenue is always able to cover both fixed and variable costs. As was mentioned earlier, the cost effectiveness of connecting to the geothermal district energy system will determine the size of the customer base and ultimately the economic performance of the system. The higher the overall penetration rate, the more economic the system will become.

## *4.* SUMMARY

The economic factors that ultimately determine the economic viability of a geothermal project are extremely complex and highly variable. Each and every project must be evaluated based on reservoir characteristics, exploration and drilling costs, known and expected capital and O&M costs, and of course, potential for revenue generation. Seldom if ever can that evaluation be done prior to project initiation, and then left on the shelf until project completion. It should in fact be an interactive process with a new evaluation completed at each stage of the project as more and more information becomes available. The project proponent must be fully prepared to alter the scope on even the nature of the project as each phase is completed and even abandon the project if economic factors so dictate.

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For correspondence, contact:

Dr. R. Gordon Bloomquist
Geothermal, Hydrothermal & Integrated Energy Systems
925 Plum St. S.E., Bldg 4
P.O. Box 43165
Olympia, WA 98504-3165
USA

Phone: 001- 360-956-2016
Fax: 001 - 360- 956-2030
e-mail: bloomquistr@energy.wsu.edu