Determining the Feasibility of Electrical Generation Projects

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Geothermal power development covers a range of resource technologies:

- A huge temperature range
- A host of alternative conversion technologies including:
  - Dry steam
  - Flash
  - Double flash
  - Binary
    - Organic Rankine cycle
    - Kalina cycle

The factors that must be considered when assessing the economic viability of a geothermal project vary from project to project and from conversion technology to conversion technology.

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.
- The transmission system and utility interconnections.
- The generation of revenue.
- Financing

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, or thermal energy, minus the cost of Operations and Maintenance (O&M) of the fuel supply and conversion facility, must be sufficient to meet or exceed the requirements of the financing package.

For many new projects, the largest operating cost per year is the cost of capital, i.e., debt service.

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 or coal.

The geothermal fuel is only available after extensive exploration, confirmation drilling, and detailed reservoir testing and engineering.

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, or even product sales.

- Developers must carefully evaluate how royalties will be calculated, due to the limited rewards that can be expected.

The second factor that will have an impact on overall project economics is obtaining all regulatory approvals.

- This includes completing all environmental assessments and securing all required permits and licenses.

- A complete environmental impact statement for any proposed development is now required by federal land management agencies in the U.S. Cost for preparation can exceed 1 million U.S. dollars!

- It is common to invest up to 40,000-60,000 person-hours in completing all necessary environmental documents and obtaining all required licenses and permits for a major electrical generation project.

- 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.

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, most of the time, before detailed exploration or drilling can begin, and with no clear indication that any of the cost can or will be recovered.

Exploration

Once access has been secured and all regulatory approvals have been obtained, the developer may begin the exploration program.

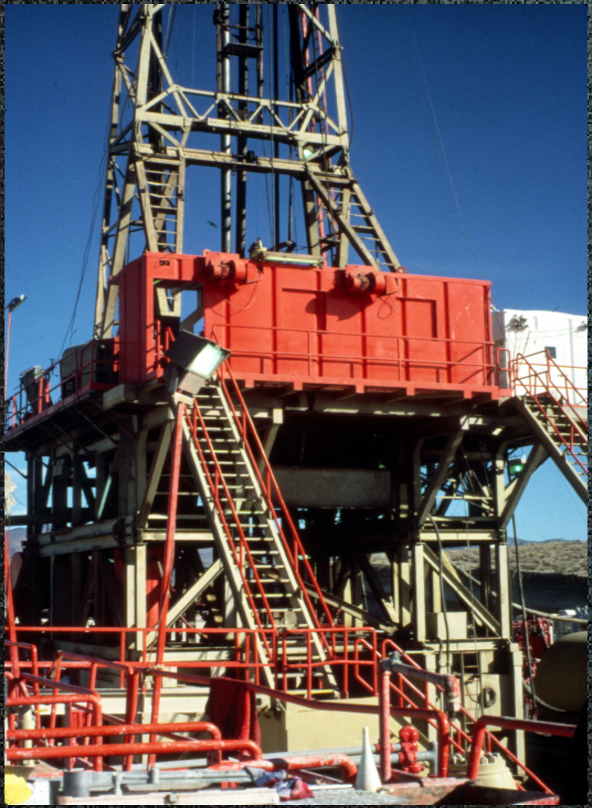
- This includes refining data gathered in the reconnaissance phase, and employing techniques that will lead to the drilling of one or more exploration wells.

- Hopefully these wells will be capable of sustaining a reservoir testing program, and possibly also serving as preliminary discovery and development wells.

Reconnaissance includes 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 for this can range from a low of a few thousand dollars to $100,000 or more.

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 hundreds of thousands of dollars to several million dollars per well for wells required to access high-temperature resources for electricity generation.

- Success ratios for exploration wells can be as low as 20%; and the risk of dry holes in the exploration phase remains high and can have a significant economic impact.
- Even one dry hole can cause a project to be seriously delayed or even abandoned.

- Even in developed fields, 10-20% or the wells drilled will be unsuccessful.
- If drilling is successful, the reservoir must then be tested to determine its magnitude, productivity, and expected longevity.

Well Field Development

- For an electricity generation project well field development can last from a few months to a number of years.
- At this stage it is critical to collect detailed data and to refine the information available on the reservoir. This includes both production and injection wells.
- Failure to do so can result in contract forfeiture or penalties related to milestone completion clauses in the contract.

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.

Even with proper O&M, 50% or more of wells will likely have to be replaced over the course of the project, adding considerable cost to the project.

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%.

The Power Plant

There are numerous power plant designs, including direct steam, flashed steam, double flashed steam, and binary cycle. Each are able to best meet the specific requirements of a particular reservoir.

- Selection of the most economically viable technology is only accomplished through a thorough evaluation of the differing strengths and weaknesses of various technologies relative to the characteristics of the resource and local circumstances, including environmental and regulatory requirements.

Terms of the power sales contract can also have a major influence on power plant design.

- Premiums paid for availability during certain times of the year or even times of the day.
- Advantages of operating in a load-following manner.
- Capacity payments

Steam Provision

- Is the steam field and the power plant under one ownership or is steam purchased from another party?
- If steam is paid for as a percentage of the selling price of electricity, there is little incentive to achieve high steam use efficiency and a strong incentive to minimize capital cost.
- If steam is purchased on the basis of dollars per kilogram delivered, achieving highest possible fuel use efficiency becomes extremely important.

In order to achieve maximum steam use efficiency, some developers have adopted equipment procurement evaluation criteria that penalize offerings for inefficient use of steam and/or electricity at a capitalized rate of X thousand dollars per kilogram of additional steam required and X thousand dollars per kilowatt of parasitic load.

Power Cycles

Direct Steam

- Direct steam will result in the lowest power plant cost.

Flash steam

- For high-temperature, liquid-dominated resources, a flash steam plant is the most economical choice.
- The brine can be used in another application, for example a bottoming cycle binary plan, or for space or industrial process heating and/or agriculture.

Double flash steam

- The advantage is increased overall cycle efficiency and better utilization of the geothermal resource but at an overall increase in cost.

- The decision as to whether or not a double flash plant is worth the extra cost and complexity can only be made after a thorough economic evaluation based on the cost of developing and maintaining the fuel supply, or cost of purchasing fuel from a resource company, plant costs, and the value of the electricity to be sold.

Binary

- Binary cycles can more economically recover power from a low-temperature (<175 °C) reservoir.
- May be more easily sited where environmental concerns are paramount and where either ga emissions or cooling tower plumes need to be avoided.

Other Design Considerations

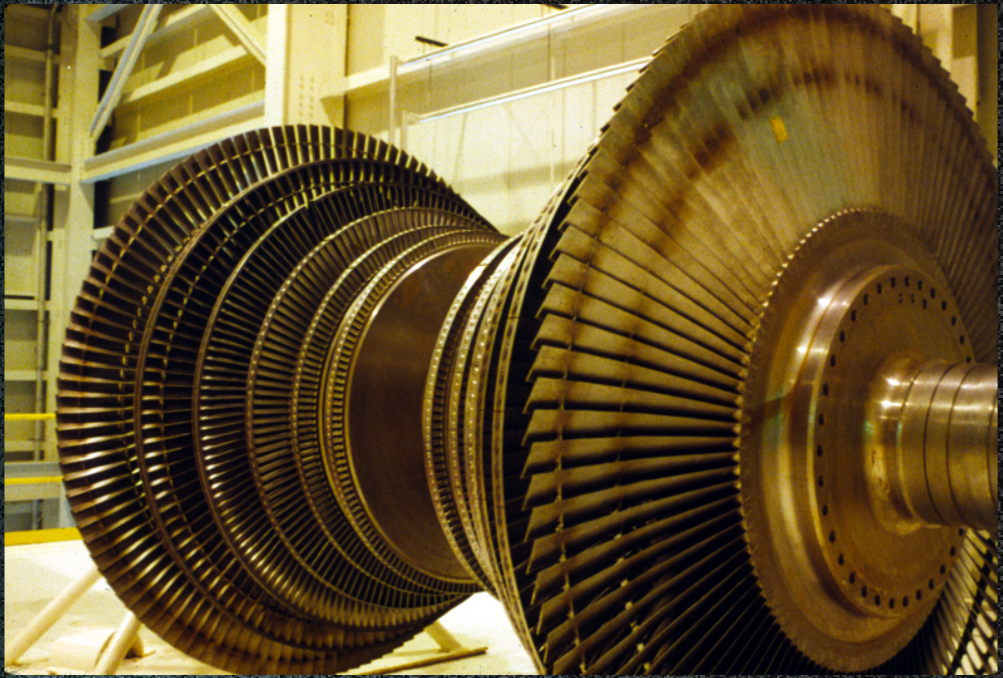
- Fluid chemistry is extremely important in cycle selection and power plant design.
- Many resources are highly aggressive brines, with high contents of dissolved solids (TDS).
- Design options include the use of a crystalizer reactor clarifier and pH modification technologies.
- The use of either technique can add considerably to capital costs as well as to plant O&M cost.

The terms of the power sales agreement may have a profound influence upon conversion cycle selection, cooling system design, and, eventually, plant operation.

Equipment Selection

The turbine generator set is the most expensive piece of equipment in a steam cycle power plant.

- Efficiency considerations include the number of turbine stages, blade length, and whether the plant will operate as a base load unit, will be used for load following, or must be dispatchable.



Two major categories of condensers are used with steam cycles: the surface condenser and the direct contact condenser.

- The advantage of the surface condenser is that contamination of the cooling water with constituents of the wellhead steam is avoided.
- The direct contact condenser, however, is less expensive and is less prone to maintenance problems.

The selection of direct contact or surface condenser will also have an impact on pumps and pumping requirements, i.e., parasitic power requirements.

Noncondensable Gases

Noncondensable gases must be removed from the condenser in order to reduce backpressure and optimize steam use efficiency. Noncondensable gas removal, however, results in a significant parasitic load either in terms of steam used in jet ejectors or electricity used to power compression or vacuum pumps.

A commonly used arrangement employs one or two steam jet ejectors in series followed by a liquid-ring vacuum pump, thus taking advantage of the low capital cost of the higher efficiency final stage.

If hydrogen sulfide removal is required, a number of options are available, including liquid reduction-oxidation using an iron chelate solution such as is employed in the Dow Sulferox process, and the Wheelabrator Lo-Cat process. Inclusion of hydrogen sulfide abatement can increase the capital cost of a power plant by 10% or more, and will also result in an ongoing increased cost for O&M.

Cooling Towers

The cooling tower design can also have a major impact on capital cost, O&M, and cycle efficiency. The most commonly used cooling tower designs include cross-flow, cross-flow with high efficiency fills, and counter-flow.

- Adding enhanced evaporation cooling to air condensers can improve summer efficiency by as much as 40+%, greatly improving the economics of such operations.

- The availability of cooling water is also an important consideration in plant design.

- A water-cooled cycle capable of approaching the wet bulb temperature presents a significant advantage, as far as overall power generation is concerned, in comparison to a dry cooled binary cycle that approaches the dry bulb instead of the wet bulb.

Binary cycle

Selection of the right working fluid is the most critical design decision in the development of a binary cycle power plant. The selection must achieve a good match between the heating curve of the working fluid and the cooling curve of the geothermal heat source. Working fluids used in binary plants fall into three broad categories: light hydrocarbons, freons, and ammonia.

Because the heat content of the geothermal resource is transferred in the binary cycle to the working fluid, the heat exchanger becomes an additional critical equipment component, and can account for a significant capital cost increase over that of a steam cycle plant.

Because of the heating curve, counter-current flow is desired and achieved by laying out the heat exchangers in series with single-pass flow on both shell-and-tube sides. The cost of the heat exchanger can

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is required.

Another major cost that is specific to the binary cycle is the number of pumps required and the significant parasitic load they place on the plant. Because brine from a liquid-dominated reservoir should be maintained as a single-phase flow through the heat exchanger, production well pumps are used.

Standard production pumps are multi-stage, vertical turbine pumps driven by a motor at the surface. Downhole pumps could be an attractive and economical alternative, and recent advances could soon result in commercially available downhole pumps.

The second major requirement for pumps stems from the need to pump the working fluid through the heat exchangers and to the turbine inlet. The pumps are usually multi-stage, vertical canned pumps.

Multiple stages are used to achieve the required turbine pressure.

In addition to the additional capital cost attributable to the need for production and/or working fluid circulating pumps, pumping requirements result in a parasitic load of 10 to 15% of the power that is generated, a significant reduction in the amount of power that is available for sale.

To date, a majority of binary cycle plants have employed air-cooled condensers. In the air-cooled condenser, the condensing working fluid is directed through the heat transfer tubes and air forced across the tubes to remove the heat.

The air-cooled condenser can be extremely large and expensive both to build and to operate.

The best of both systems may be the hybrid based on the use of air coolers but with injection of a water mist into the airflow of the air cooler or the spraying of water onto fibrous material used to enclose the walls of the cooling tower. This can significantly increase cycle efficiency and output during peak demand periods in a summer peaking area.

Power plant construction

A number of factors related to power plant construction can have a significant influence on project economics, including geologic conditions, terrain, accessibility, labor force, economies of scale, and site or factory assembly of major components.

Modular plants of approximately 25 MWe and less can often be on-line within one year of the start of construction with subsequent modular plants coming on-line at 6- to 12-month intervals.

The generation of considerable revenue during the construction period more than offsets any advantage that economy of scale may provide. In addition, the ability to bring units on-line sequentially often is a major benefit in being able to better track load

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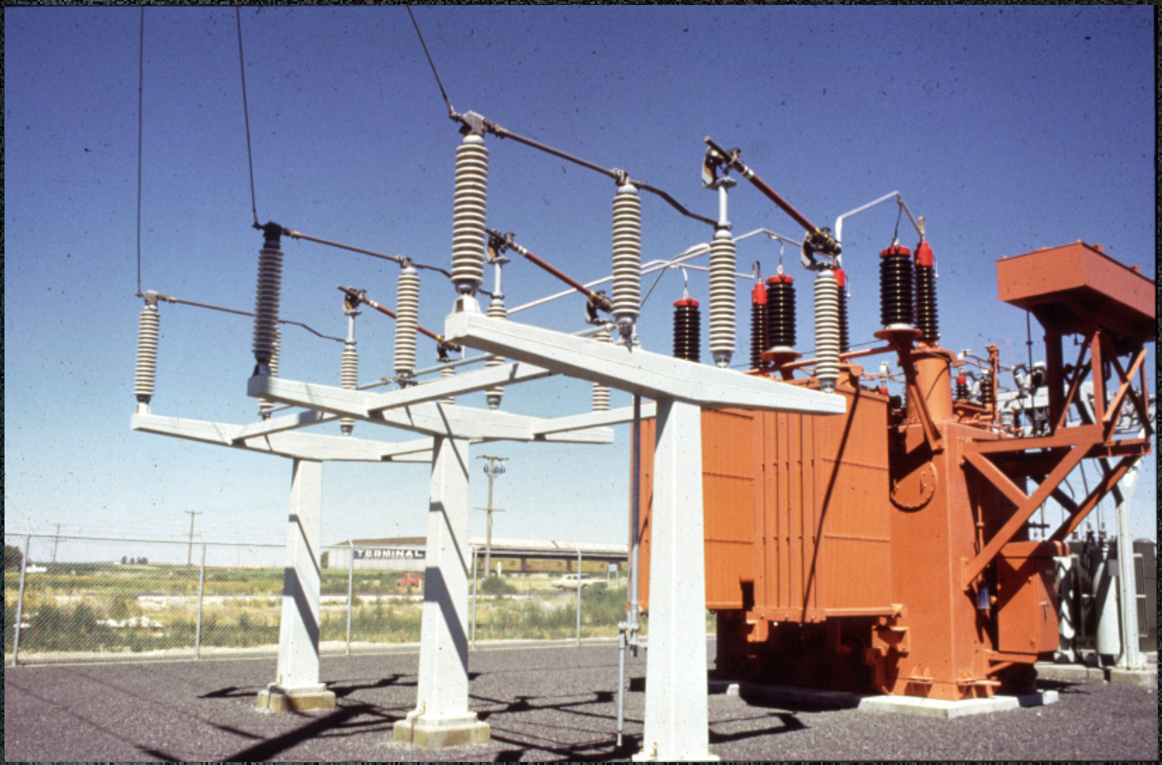
Revenue Generation

For power generation projects, the power sales contract establishes the legal framework for revenue generation.



Electrical generation

- The economic viability of a 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 what is required to purchase or maintain the fuel supply, including any royalties; to cover debt service related to capital purchases; and to cover operation and maintenance of the facility.

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.

Because most power sales contracts are output-based, and because geothermal generation costs are predominantly fixed as opposed to variable, the unit cost of geothermal power decreases rapidly as the capacity factor increases, i.e., maximum operation yields maximum return to the owne

For example, as the plant capacity factor increases from 50 to 90%, the levelized cost of producing electricity could be expected to decrease by nearly 50%.

A number of 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, noncondensable gas removal equipment, and the use of multiple turbine generation sets.

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 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 of the utility.

Co-Generation

Co-generation, or the simultaneous production of electricity 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 is to maximize the economics of the projects

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 power production, the removal of silica may allow additional geothermal energy extraction in bottoming cycles problems associated with scaling.

- Precipitated silica has a relatively high market value (1-10 U.S. dollars per kilogram) for such uses as waste and odor control, or as an additive in paper, paint and rubber
- Initial estimates from the Salton Sea geothermal field place the market value of extracted silica at 84 million U.S. 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.

Conclusion

The economic viability of the project will depend upon the capital cost of the well fluid and power plant, operation and maintenance costs, and the terms of the power purchase agreement as well as any revenue generation from supplemental sources.