Cooperative Models for Engineering Geothermal Power Plants

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Abstract: Some Observations on Developing Geothermal Resources for Local Benefit

The idea of reliably generating electricity from indigenous hydrothermal resources – extremely hot water from wells – is economically, environmentally, and socially attractive, especially in places such as the Great Rift region of Africa or around the Pacific Ring of Fire. Geothermal plants offer their home countries and regions the potential to generate reliable electric power that can offset or displace electrical power generated at higher cost using imported energy sources such as oil, natural gas, and coal.

There are other hometown advantages to development of geothermal projects. Most geothermal plant projects are typically under 100 MW in capacity, not gargantuan efforts as conventional fossil-fired plants tend to be. Because of this more accessible scale and other factors inherent to the geothermal resource, these projects can offer additional opportunities for home-country financial, engineering, operational, and supply resource participation, despite the highly specialized equipment and folk wisdom required for certain aspects of their design and operation.

However, achieving this integration of larger numbers of locally based people and companies requires increasingly complex project management structures and thoughtful consideration in the beginning to maximize home-country participation. In this paper, we discuss strategies for geothermal project structure and execution to support effective inclusion of in-country resources in project engineering, procurement, construction and operation, with the aim of keeping these projects financially attractive, locally rewarding, and successful in the long-term. Illustrative examples – the good and the sobering – from projects in Africa, the Americas, Europe, and Asia are provided. Among other factors, we propose that geothermally appropriate and clear divisions of responsibilities between local and foreign parties, integration of local entities throughout all project phases, and specialized knowledge transfer are all shown to assist in project execution and maximize long term benefits to the project and community.

Some Things to Keep in Mind While Reading This Paper

- **Geothermal Plants Are Odd:** Geothermal projects, like the resources they use, are a little strange. Hardly any two geothermal plants or projects are truly alike. Geothermal resources may contain exotic constituents, and may change and evolve over time. If the resource causes problems, the owner is in no position to upgrade the fuel specification or order a better batch from the supplier.
- **A Zillion Parts:** Design and construction projects, even for comparatively small plants, are complicated. Each one has a zillion parts and problems inevitably arise during design and construction. Luckily, geothermal artists have a great capacity for providing solutions, so it is useful for projects to have access to a good, practical experience base to avoid serious disruption in the plant's ability to enter service and continue to serve its owners and power consumers.
- **Building Value at Home:** Geothermal power plants can be long-term partners for the communities that host them, and not just a distantly owned drive-by industrial facility that shuts down when the tax credits run out. A power plant is light, and life, for the people it serves. The aim of this paper is to highlight ways that a geothermal plant can be developed to conserve capital and knowledge within the plant's home region. Ownership and mastery of geothermal technology in the local setting is the best way to bring reliable geothermal power to more and more people who can benefit from it.

The Objectives of This Paper – The Peculiar Challenges of Geothermal Power Generation

This paper discusses the characteristic challenges posed by geothermal plant development. It draws on our history with geothermal projects in many places in the world, and on the experience of others involved in development as well.

Capable project management is an essential characteristic for successful completion and long-term harmony of a geothermal plant with the surrounding communities. This management can be an added challenge for geothermal plants, compared to other capital-intensive industrial or commercial projects, due to special characteristics of these remarkable plants. Preparing decision makers for these issues, and presenting strategies to overcome these to maximize project benefits to the region, is the goal of this paper.

In this photograph taken at Bouillante II in the West Indies, Tom McAuliffe holds a lump of mineral scale removed from plant equipment. The potential for scaling is one of the design challenges that set geothermal plants apart from more conventional plants.

What makes geothermal plants different from a conventional power project? First and foremost is some uncertainty in the extent of the available resource. Skilled geophysicists, geochemists, and other specialists must determine the physical characteristics of the reservoir to estimate the total energy to be produced over the life of a power plant. Reservoir models can improve with more input and history of observation, but are not infallible. Elements of uncertainty and other aspects [1] may make financing a challenge, or may result in requirements for rates of return higher than for conventional fossil units.

Technically, geothermal plants provide a different set of challenges. Geothermal plants use working fluids of lower temperature and pressure than fossil plants. As a result, fluid flows are, for a given MW capacity, more massive, resulting in larger piping and vessels, larger equipment, and higher initial capital costs. Corrosion/erosion issues may require the use of more costly materials such as high grade stainless steels. Steamfields can be sizeable, such as at the Miravalles field in Costa Rica, which extends over 21 square kilometers [2]. As the reservoir is better characterized or ages, modifications to the plant and steamfield equipment may be desirable. These factors result in initial and ongoing operations and maintenance (including labor and materials) costs per MW of installed capacity being higher than for fossil units. But these higher initial investment in a geothermal plant, which may have a high local content in value, can pay off handsomely throughout the project's life cycle in the form of avoided cost to purchase imported fuels for a comparable fossil power station. It's a conventional practice to see the initial capital cost of a geothermal plant as a way of buying all the "fuel" for the plant's entire life cycle up front.

Where there is no history of geothermal power plant utilization, regulators and financiers may have some learning to do about how these plants work and what their habits are. Therefore, unfamiliarity with the technology, noxious components of geothermal fluids, and land use issues may draw additional permitting scrutiny and requirements to geothermal projects. These concerns may well be warranted, but often require some orientation and education for local bureaucracies. Specialized materials, equipment, and fabrication techniques, if required, may be a learning opportunity for the local labor pool and equipment vendors.

For the reasons listed above and others, geothermal plants may present new challenges for decision-makers. However, some of these challenges also represent an opportunity for greater local participation and knowledge transfer than for conventional plants, and this paper will explore those possibilities. We will discuss these challenges throughout each of three phases of a project:

1. Project delivery methods and initial project bidding
2. Project execution
3. Project maintenance, and long term relationships with the community

Project Delivery Methods – EPC? D/B/B?

Project structure is a key cost driver. A popular method for constructing plants, especially recently, has been the Engineer, Procure and Construct (EPC) delivery method, where a single contractor is responsible for delivering a "turnkey" product to the owner in accordance with tender specifications [3]. This contractor assembles the requisite engineering and construction teams, which perform the detailed design, procurement, construction, and commissioning. The prime contractor provides a single interface with the owner. The contractor may assume liability in the form of liquidated damages for schedule, workmanship, and performance guarantees. This structure is attractive to financiers because a single fixed price is agreed upon and the number of interfaces between the owner and contractor is minimized.

Design-Bid-Build is a competing delivery method. In D/B/B, the owner retains the services of an engineer, who performs the detailed design and then provides tender documents to contractors; one or many. Since the owner and their engineer have performed the detailed design, they shoulder most of the performance risk, so long as the workmanship of the contractors is acceptable. The owner may in some cases place purchase orders for major equipment such as the turbine and condenser.

An advantage of the EPC approach is the fixed up-front price, which is a considerable incentive, especially under conditions of high volatility in commodities. A disadvantage to the owner may be higher total project costs from the contractor, to compensate for risk and markups on much of the equipment. The preparation of tender documents for an EPC bid can take some time, and the detailed design of a plant which repeats the features of the tender specification represents a redundant element. Thus the project timeline can be lengthier than for D/B/B. Since the EPC contractor is undertaking most of the detailed design, owner input to the process is less and thus control over design features, if desired, is weakened.

An advantage of the D/B/B approach, since the owner shoulders additional risk, is that the quoted cost from the contractor may be lower. Since there is only a single detailed design cycle, there may be a shorter schedule. Preliminary project estimates based on D/B/B may thus be apparently less expensive than for EPC, and in our experience subsequent estimates of EPC contractor profit margins and premiums for liquidated damages are often unduly optimistic. This may introduce a pitfall, if financiers insist on a later switch to EPC, thus the project delivery method and consequences of switching should be carefully considered very early. The D/B/B approach requires the owner to use a more sophisticated engineering firm, whereas for the EPC approach a smaller supervisory team may be sufficient for the owner.

One key hazard in a D/B/B approach we have encountered regards the splitting of the project to a large number of subcontractors. The Bouillante project in Guadeloupe, for example, was developed under a rather alarming D/B/B approach in which separate firms dealt with the civil, mechanical, structural, and controls engineering and supply aspects of the project, with no supervisory engineering entity overseeing the overall plant design until late in the project. In our view this was very difficult for the owner to manage, and resulted in prolongation of the project to a duration in excess of what a well-managed EPC project would have consumed, in which the contractor is more motivated to minimize their mobilization time.

Participation of local contractors in geothermal projects is desirable and attainable under either project delivery method. In the EPC method, the prime contractor, which may be a foreign firm, needs to assemble local consortiums to execute the work. Local contractors that are multidisciplinary, or that have successfully demonstrated good cooperation with firms of other disciplines within this consortium, will have a decided advantage (for example, structural and electrical construction firms with demonstrated past successful cooperation on substation construction). The more integrated front that local contractors can present to a prime contractor, the greater the opportunities for successful execution of the project.

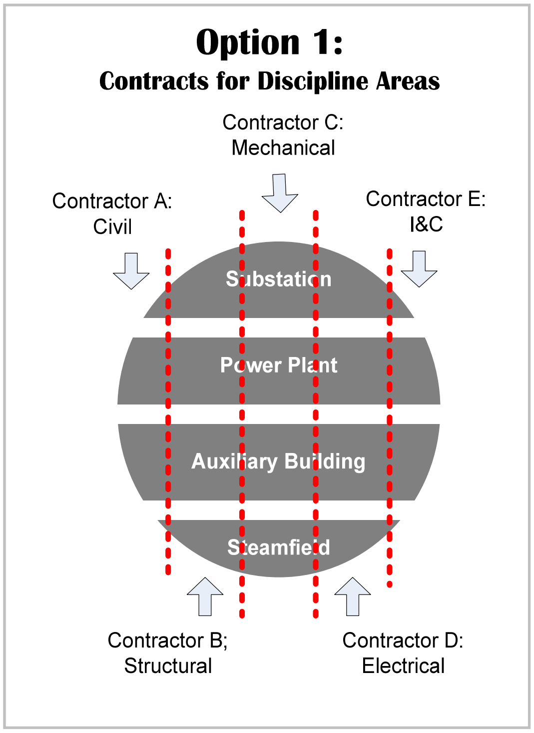
The initial stages of the EPC bid require considerable estimating skills on the part of the EPC as the EPC prepares its bid to the owner. Local firms with accurate knowledge of bulk material prices, labor rates and efficiencies, and other estimating tools have a decided advantage in winning projects, or at least in developing realistic bids. (Sometimes inaccurately low bids win projects, but the outcome is rarely good.)

Table 1: Summary of EPC and D/B/B Characteristics

	Engineer/Procure/Construct (EPC)	Design-Bid-Build (D/B/B)
Familiar style?	Recently very popular because of risk management concerns	The traditional project structure for utilities
Essentials?	Single contractor delivers “turnkey” project and guarantees performance.	Owner contracts with engineer for design, and then bids supply and construction.
Price and risk advantage?	EPC limits price risk, though the EPC entity charges more to cover risk.	D/B/B can deliver low price if the project goes predictably; if not, cost increases pass to owner.
Schedule performance	Can be slower than D/B/B due to EPC spec and wary contract development.	D/B/B can be quicker because of less internal contractual friction and only one major engineering activity.
Owner control of design and construction outcome	Limited; the EPC entity has principal control.	High.
Contracting simplicity for owner	Simple – one EPC entity to contract with.	Sometimes complex, with separate contracts for engineer, constructors, equipment, etc.
Overall contracting style	Potentially competitive, a zero-sum game between owner and EPC	Potentially more cooperative, without an EPC contract to separate and pit the interests of owner and contractors
Neocolonial complications?	EPC contracts tend to attract large firms confident enough to take on the schedule and performance risks. Such firms may not be highly sensitive to the appeal of local technology transfer and local involvement. However, such firms may also be relatively bankable by commercial lenders or NGOs.	A D/B/B project, typically with home-country ownership or direction, can potentially be managed by the developer or owner with a high interest in local involvement and technology transfer. Such an approach may not inspire bankers or NGOs with confidence, however.
Owner management style required	Hands off. What you get is what you get.	Demand for owner attention and management may be bottomless.

Speed is also useful in estimating. Bidding cycles are always compressed, and the speed to execute accurate estimates is highly valued, as the gap between project authorization and the execution of an EPC contract must be minimized to reduce vulnerability to commodity prices or other economic fluctuations. This is especially true for geothermal plants with large investments in copper and stainless steel, which have been particularly volatile of late [4].

The size of tasks may be a challenge for individual local firms. If splits in scope are made, they should be reviewed carefully in order to minimize the number of interfaces. Consider two options:



Option 1: Scope Sliced by Discipline

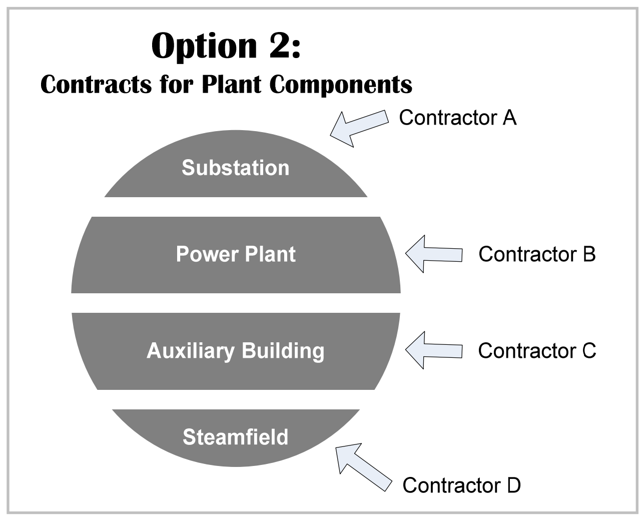
- Complete project civil design/construction by contractor A
- Complete project structural design/construction by contractor B
- Complete project mechanical design/construction by contractor C
- Complete project electrical design/construction by contractor D
- Complete project instrumentation and control design/construction by contractor E

Option 1 allows smaller firms to bid on more manageable work packages that may be better suited to their field of specialization. This was the approach generally used for the Bouillante and Olkaria II Unit 1 and 2 projects.

This may be perceived as more hospitable to participation by small local contractors, but in our opinion, this option can create management and construction challenges due to the extremely high number of interfaces between firms – for example, the coordination of hundreds of pipe supports with the design of structural steel.

Option 2: Scope Sliced by Project Component Area

- Substation design/construction by contractor A, handling civil, mechanical, electrical, and instrumentation/controls tasks
- Power Plant design/construction by contractor B, handling civil, mechanical, electrical, and instrumentation/controls tasks
- Auxiliary building design/construction by contractor C, handling civil, mechanical, electrical, and instrumentation/controls tasks
- Steamfield design/construction by contractor D, handling civil, mechanical, electrical, and instrumentation/controls tasks



Option 2 requires multidisciplinary firms, but it may still be possible to keep the work package scopes manageable by dividing the project into separate physical aspects. Separating steamfield and powerplant is one natural division, and perhaps other aspects such as auxiliary buildings or injection piping can be partitioned as well. Ideally, the minimum number of firms necessary participates in design and construction, but as needed to suit the size of available organizations, dividing packages by geography or physical layout areas rather than discipline allows far more efficient organization. This Option 2 approach to minimizing interfaces is more reflective of what was used for Olkaria II Unit 3.

These considerations need to be evaluated during the initial project estimation and selection of project delivery methods, since an EPC consortium made up of these firms will build their estimates according to these divisions of responsibility. Similarly, although the selection of contractors in the case of a D/B/B approach may be made later in the project than would be required in an EPC project, the detailed design performed by the owner should consider these factors to produce biddable work packages reflective of the capabilities of local firms.

Project Execution: Specialised Materials and Equipment are Areas Worthy of Attention

Assuming a wise choice of project delivery method and a motivated team of contractors, what are challenges and opportunities that a geothermal project may present for local participation during the execution phase? First, please note that these considerations are highly site-specific; they may or may not be applicable to a given project. The wide variety of countries and resource types where geothermal power may be utilized makes it difficult to offer standardized approaches.

Most geothermal sites generate power from naturally occurring fluids (steam, hot water or brine) that contain proportions of various solids such as silica, or non-condensible gases such as hydrogen sulfide. The interaction of these compounds often creates corrosive and erosive environments, requiring time-tested selections of materials for specialized components such as control valve internals, pump seals and bearings, and other wetted parts. The selection of proper materials is essential for providing a robust 20+ year plant design. This is not to say that materials selection for geothermal applications is arcane or mysterious, since conventional wisdom on materials is widely available among geothermal plant engineering specialists and many industry suppliers, but it is critical to plant well-being and productivity.

When the designer works with manufacturers to select the proper equipment, it is important to keep the local representatives aware of the need for specialized options. This can result in some tension if a local manufacturer´s representative, who is not familiar with geothermal projects, attempts to propose unsuitable equipment that is more locally common, say for mining industries. At times there can be a competition between the local representative and the home office of the manufacturer to decide who will handle the order and produce the documentation, as there often is a commission involved.

Any long-term successful project requires the solid support of the local equipment representatives for aftermarket support. However, during the design phase, the demands on the equipment supplier – to be familiar with geothermal applications and to produce very detailed CAD drawings of site-specific equipment that will be in use for the life of the plant – may be beyond the capabilities of the local representative. We suggest that this coordination between manufacturers and their local representatives be encouraged and clarified very early in the equipment bidding phase so that a quality product can be delivered, while also ensuring that the local representative is a good partner for long-term maintenance needs of the plant. Neither party should feel excluded.

We have often encountered significant delays in bidding, contract negotiation, and obtaining equipment design documents, for example on miscellaneous pump or control valve procurement, as various parties of the same manufacturer but located in Indonesia, Singapore, Europe, and Asia would vie for control of the contract.

Procurement of bulk materials such as carbon, galvanized, and stainless steel piping and structural members offers a good opportunity to maximize local content. What can be sourced in the home country? If not available locally, do local suppliers have a good relationship with adjacent (Gulf country?) distributor, and can they obtain these at globally competitive prices and within a tight schedule? Local firms with these logistical links in place have more reliable information for preparing the initial bid and permit smoother project execution.

For the Olkaria II project, much of the carbon steel piping and supports were able to be sourced through Kenyan firms, resulting in cost and schedule savings. Conversely, the fact that the appropriate grades of stainless steel, certain structural members, and pipe support specialty components were not locally available was identified early and allowed appropriate arrangements and lead times in the schedule for those to be procured overseas.

Skilled local contractors can serve an important role early in the project if their wisdom can be tapped during the design phase. For the Darajat III project, constructability reviews held between designers and contractors identified a potential improvement in the cooling tower. During work on the previous unit, the extensive labor involved with the cast in place concrete cooling tower contributed to significant costs and may have been a factor in a fatality during construction. The construction manager suggested that a precast design would be possible, which would allow less formwork and less labor activity required in the dangerous area high above grade.

The cooling tower manufacturer agreed to adjust their design to accommodate this, at a modest cost due to the early notice. The tower was constructed efficiently and safely using this new technique. Having local participants integrated into the design decisions via formally structured events like constructability reviews allows opportunities for material, labor, or safety improvements applicable to local conditions to be identified sufficiently early to be acted upon.

Geothermal projects often require significant permitting efforts due to land and water use concerns, air quality monitoring, wildlife and access issues, fire safety, and other aspects of interest to local administrators. A local engineering firm familiar with the process and able to smoothly coordinate with the prime contractor and local agencies is a valuable resource. For the Miravalles III project in Costa Rica, a local firm was contracted that was able to take the construction documents generated by the EPC contractor and transform those into the appropriate format and Spanish language for permitting packages. Firms with capabilities such as these are valued partners and should be identified early in the project.

Dividing Up the Project Duties – Some Views for your Consideration

A key tool to aid cooperation between contractors is to identify the division of responsibilities for all phases from project estimation, design, procurement, and construction. A matrix identifying these should be exhaustively detailed, and preparation of such a matrix (or numerous draft matrices) is a way of thinking in advance of ways that the best strengths of in-country participants can be best applied in project execution.

In our experience – which is happily extensive, but still not comprehensive or authoritative in all cases – certain kinds of project activities seem to fall most handily, productively and accountably onto the hands of particular kinds of project entities. The matrix below, and the following discussion, recounts some of our company's observations and experience with responsibility divisions from past geothermal projects.

Table 2: Some Observed Efficiencies in Dividing Responsibilities for Geothermal Projects

Components particularly suitable for the prime contractor	Components particularly suitable for local firms	The Grey Area: Components suitable for either local entities or the prime contractor, with cautions
▪ Design/supply of key power block components ▪ Powerhouse layout ▪ Specialized pipe supports ▪ Plant control systems ▪ Control valves and manual valves	▪ Field-fabricated tanks and vessels ▪ Procurement of carbon steel piping ▪ Powerhouse detail design ▪ Bulk items ▪ Piping shop fabrication and NDT ▪ Structural steel ▪ Site security	▪ Design and/or supply of HVAC systems ▪ Fire protection systems ▪ Electrical substations

Discussion of Efficiencies in Responsibilities

Prime Contractor Areas:

There are some components where it is generally efficient that the prime contractor retains responsibility for the design and procurement. These include:

- Design/supply of key power block components: turbine, large equipment foundations, circulating water system including condenser; cooling tower, large pumps, and switchgear. These products are often sourced internationally or from the prime contractor directly, if they happen to be an equipment supplier such as Mitsubishi Heavy Industries or Fuji. The specialized knowledge for interconnection based on past experience is essential and it may invite lengthier engineering than warranted, construction delays, or serious operational difficulties if this is outsourced.
- Powerhouse layout and conceptual design. Useful to be done by the prime contractor, since they will have a better recognition of space requirements for overhaul or maintenance.
- Specialty (engineered) pipe supports or items such as spring cans, snubbers, or expansion joints. These are often not available locally, or the relationships of stress analysis and the need for specific products instead of less expensive substitutes may not be appreciated by local firms.
- Plant control system. *A note to owners:* the geothermal development process consumes significant time for resource exploration, tender specification preparation, bidding negotiation and other phases. Commonly control system specifications are obsolete, through no fault of the owner, by the time the detailed design is performed. During the Olkaria II and Miravalles III projects we encountered this; in the first case for aspects of the steamfield controls, and in the second for the plant control system. In both cases constructive discussions between the owner and contractor regarding the latest state of the art equipment helped bridge the gap between the obsolete specification requirements and the currently available commercial solution [5]. This is a common occurrence and should be anticipated.
- Control valves and manual valves. Due to special materials which may be required, these may be unique to a country without previous geothermal projects. In such a case, it may be advisable for these to be sourced internationally by specialists experienced with the particular application.

Local Firm Areas

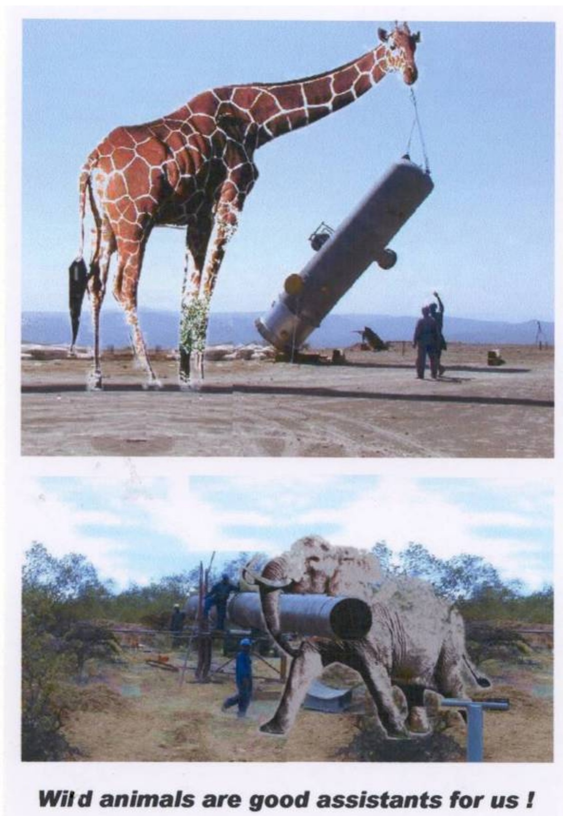
Conversely, there may be many opportunities where local firms can efficiently provide design and procurement services. These include:

- Field-fabricated tanks; sometimes vessels if shops are qualified to the ASME or PED certifications.
- Procurement of carbon steel steamfield and plant piping.
- Powerhouse detailed design such as cladding, architecture, and plumbing. Local firms often have a better grasp of local codes and standards, aesthetics, and materials, fixtures and fittings available locally and economically. They may be well suited to take a powerhouse conceptual layout and transform it into a detailed design. At the Germencik project in Turkey, local designers performed the complete conceptual and detailed design and procurement for admin and warehouse facilities.
- Bulk pipe supports, bolting, electrical bulks. These are good candidates for local sourcing, so long as the potentially corrosive aspects of the geothermal fluids and the needs for specialized coatings in some cases are taken into account. In many cases steel must be galvanized and copper wiring must be supplied tinned, for protection from atmospheric H_2S. At Olkaria II a significant local effort was used to galvanize fittings and steel used on the project. Identifying the availability of hot-dip galvanizing facilities in advance is helpful.
- Pipe fabrication and testing. It may be possible to shop-fabricate large-bore piping in-country. It is important at an early stage to identify between the designer and fabricator the level of detail required on design drawings and check that segregations of shop and field fabrication are appropriate.
- Structural steel. For the Germencik project, at the initial design stage the local contractor provided the designer with a detailed list of structural shapes available economically in the local market. The designer then based most selections from the list, minimizing use of difficult-to-obtain shapes.
- Security. A strong security presence at the site is essential for maintaining site safety and preventing losses of essential material or equipment that may take months to replace. At the Olkaria II project many of the site guards were hired from the surrounding Masai communities, and they proved to be excellent at strictly regulating access to the site.

The Grey Area

Several pieces of equipment fall into a grey area, where either the prime or local contractors may take responsibility for design and procurement, but some caution should be observed. These include:

- Heating, ventilation, and air conditioning systems (HVAC). Local contractors may have performed this type of design, and local materials may be available. However, all parties need to recognize that the HVAC systems are the principal line of defense against the introduction of H_2S into electrical and control equipment spaces, where it has the potential to swiftly corrode copper materials. Often HVAC equipment contains copper piping or components, and if not adequately protected with proven techniques, can degrade and break down. Design of these systems also requires strong coordination with the overall powerhouse and electrical building design to resolve interferences.
- Fire protection and substations. These systems may be commonly encountered at other industrial facilities. However, similar material concerns about the geothermal environment apply. Contractors unfamiliar with these should be prepared to closely evaluate their selections.



We received this cheery Christmas card, with some thoughts on efficient workscope divisions, from H Young, a Kenya project partner for the Olkaria II project.

Project Execution: Technology/Knowledge Transfer

Project execution provides valuable opportunities for knowledge transfer. Working shoulder to shoulder with geothermally skilled construction and commissioning managers provides continuous learning opportunities. Often future operators are involved; manipulating systems for testing under the supervision of the contractor´s commissioning manager. This provides valuable informal training.

At Olkaria II, a comprehensive formal training program was provided to operators and maintenance personnel by the contractor. Teaching materials for programs such as these can be retained and used for additional training of new operators by the owner throughout the life of the plant. Successful knowledge transfer to laborers, operators, and maintenance personnel should be well defined from the start of the project.

Long Term Relationships

Geothermal plants have closer relationships with adjacent communities compared to conventional power plants. The underground resource is never perfectly characterized, and will change over time as fluid is withdrawn and injected. It is possible that additional wells will be drilled or plants added as more data are gathered, resulting in additional jobs for the local workforce. Natural degradation of piping over time due to corrosive/erosive effects of geothermal fluid may result in more frequent small upgrade and maintenance projects than for conventional fossil plants. The changing nature of the resource may provide opportunities to change non-condensible gas extraction (such as at Miravalles, [6] or fluid injection strategies (such as at the Geysers, [7]). The dynamic nature of a geothermal field means there is value in the relationships between owners and local contractors continuing long after commissioning.

A positive relationship an owner can maintain with the local community may extend to the expansion of the plant into a “resource park” that provides other services, such as district heating, recreation, and health opportunities, exemplified at the Svartsengi plant [8]. Plant tours and energy education programs are a way to motivate technical aptitude in students and foster good relationships with the community.

Some of the most important keys to long-term success are local champions. These are something international prime contractors cannot build; as it is essential to have more than a figurehead several thousand kilometers away or a temporary foreign consultant. Project champions need to be national, local, and committed to the project success, armed with sufficient authority and resources.

Despite good technology, over time challenges inevitably develop, and without champions the best designed and constructed plants will suffer from the ravages of nature. Such project champions, which ideally have a solid technical background, can build on their education during the design, construction, and commissioning processes. Champions can gain additional expertise though opportunities such as Iceland´s remarkable United Nations University (UNU) Geothermal Programme, which offers specialized training in geothermal exploration, drilling, reservoir engineering, and utilization, tailored for the individual and country [9]. Similarly, Mexico offers sophisticated technical training in the form of the Geothermal Diploma Program at the Autonomous University of Baja California in Mexicali. The program is run by the University in conjunction with the national utility (CFE) and with the Institute of Electrical Studies and the National Council of Science and Technology. [10] Both the UNU and CFE have the considerable institutional luxury of having magnificent local assets such as the Cerro Prieto and Hellisheidi projects which can be used as laboratories for resource management, drilling and well development, plant design, and plant operation and maintenance. Attendees at these institutions should be prepared to help disseminate knowledge upon their return to their team and other new entrants to the geothermal field.

Conclusions

Geothermal projects offer many ways to build relationships between the plant and local communities, and specific strategies have been presented to structure and maintain these. It is possible to neglect these concepts and build a technically superior plant, but foregoing opportunities will result in lower long-term reliability and community benefits. Key strategic decisions are made very early in the plant development process. Essential considerations include project structures that offer avenues for greater local participation, discussions that result in comprehensive and achievable division of responsibilities reflecting the challenges of a geothermal project, continuous knowledge transfer, and the importance of local champions. Geothermal plants offer reliable renewable energy, with users secure in the knowledge that, unlike many other industrial facilities, it cannot be moved with economic winds of fate. A well executed geothermal project should be a source of pride, benefit, and responsibility for the community as a valued local asset.

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