

# Best Practices for Geothermal Power Risk Reduction Workshop Follow-Up Manual

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### *Compiled, Edited, and Prepared by*

*Benjamin Matek, Geothermal Energy Association*

*Cori Sue Morris, United States Department of State Bureau of Energy Resources*

### *Authored by*

*John Armstrong, Magnus Gehringer, John McKinsey, Ann Robertson-Tait, Doug Hollett, Patrick Dobson, Dr. James E Faulds, Bob Sullivan, Tim Williamson, Mike Long, Doug Blankenship, Sam Abraham, Louis Capuano, Jr. Full titles and companies/organizations of all authors are listed in their respective sections.*

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## Forward

After over 100 years since the first geothermal resource was used to generate power, geothermal energy is coming of age. A global geothermal initiative has begun to explore opportunities to give geothermal energy a more prominent role in the global energy mixture. The Clean Technology Fund of the Climate Investment Funds has already released millions in funds for Indonesia, Mexico and Chile. Currently, \$327 million has been earmarked through the Clean Technology Fund (CTF) and \$3.285 billion has been earmarked by international financial institutions —including co-finance commitments – for a total of \$3.612 billion to reduce geothermal drilling risk on an international scale. China is also spending millions exploring its own resources and investments in places like Rwanda and Kenya. Japan has pledged millions for Kenya and Indonesia. The International Renewable Energy Agency (IRENA) is leading a geothermal resource identification effort for the IRENA Global Atlas, and holding regional workshops. U.S. is assisting the initiative on all continents. An unprecedented amount of funding specifically focused on making geothermal projects more viable and more attractive to energy investors. In short, geothermal energy is poised for exponential growth.

However, new approaches are needed to make the global geothermal initiative successful. For instance, in our discussions with the World Bank and International Finance Corporation, it is still not clear how these institutions can best use the new funds to reduce project risks. That is why the U.S. Department of State, U.S. Department of Energy and the Geothermal Energy Association conducted a risk reduction workshop in April 2014. The purpose of the workshop was to help develop a global framework and a unified plan for reducing global geothermal risk. The workshop was held at Washington’s Reagan Trade Center on April 23 as a follow-up activity to the GEA’s International Geothermal Showcase on April 22. The Showcase brought together geothermal experts, companies, and regulatory bodies from around the world. The workshop drew from those participants, and from the international financial institutions, to explore and develop best practices in geothermal exploration, drilling, policy and regulatory issues, and project management. In addition to financial tools for risk reduction, the workshop tried to focus on identifying better practices in exploration management and use of exploration technology. Several geothermal experts, highlighted the potential to reduce risks through management of a portfolio of prospects, focusing on exploration “fairways” that have the greatest potential for commercial success. As millions of dollars begin to be deployed, we hope these best practices and recommendations help reduce geothermal project risks and support geothermal energy becoming a more prominent technology in the global energy mixture.



## Executive Summary of Recommendations

The workshop was successful in creating a high-level dialogue and strategic conversation about the causes and potential solutions of geothermal risk, and how they affect the growth of geothermal development. The conclusions and main bullets are summarized in the following four sections.

### **What are the policy, legal, and regulatory structures that need to be in place for a geothermal power project to succeed?**

- Publish exploration data in public domain for companies to use and verify.
- Coordinate institutions into what is effectively one body governing geothermal resource development.
- Minimize the number of agencies of institutions involved with regulation—“one-stop shopping” is the ideal model.
- Develop institutional capacity and capability.
- Provide government-backed guarantees to backstop payments from utilities.
- Initiate action to develop resource information, either as donors or governments.
- Donors and governments (both national and local) may need to participate in drilling risk.
- Take the current electricity market into account. There must be a market for the electricity. Generation growth must be accompanied by grid growth.
- Develop laws and regulations that create an investment environment where risk and return are matched.
- Concessions should have limited time for the developer to act or land can be taken away again. This is a common principle in the US with due diligence expenditures.

### **What are a set of best practices for successful geothermal exploration?**

- As a starting point, consider non-resource factors when determining a project’s technical and economic feasibility. These include but are not limited to issues such as: resource access, transmission, power price, operating costs, regulatory compliance, logistics, infrastructure, equipment availability, seasonal issues, political and financial stability in the host country, license areas, neighboring license holders/areas, “off limits” areas for environmental or other reasons, etc.
- Engage with regulatory agencies early on and make them a partner in the project by informing them regularly.
- Retain a capable and experienced technical team to manage and interpret the results of exploration and drilling.
- Use the common exploration elements, but recognize that because of the uniqueness of individual resources, there is no fixed “recipe” of what type of exploration to use.
- Develop a conceptual model early in the exploration process, and update it as more data are collected and analyzed.
- Choose exploration methods that are well suited to resource conditions and serve to test the conceptual model.
- Present a clear, focused and well-justified conceptual model (even a simple one) to stakeholders. Investors can judge the quality, sophistication and experience of the resource development team by how they integrate data to form the conceptual model.
- “There are no bad wells.” Plan for failure; i.e., have a plan for what to do next if a well is not successful.
- Have an exit strategy: know when the indications suggest that there is no viable resource



## Best Practices for Risk Reduction Workshop

- Promote R&D to enable geothermal power development to become more like a manufacturing process or oil or gas production. Through technology improvements and better exploration practices, move towards a replicable process with more certainty.
- Use a robust system to develop resource estimates and profiles (similar to oil and gas industry) so that investors have confidence in resource calculations

### **How do you conduct geothermal drilling cost-effectively?**

- Inspect tools each time they are used.
- Minimize Invisible Lost Time as much as possible to increase project efficiency. Always have the information and resources when you need them. Don't scramble to acquire them once the project has already begun.
- An experienced drilling engineer will plan out options when things go wrong.
- A good drilling program requires a lot of planning and logistics.
- A lot of factors go into what a project costs. Think about well location, elevation, and ownership and applicable regulations.
- Plan for drilling related problems: what types of problems do you think could happen and what tools do we have on hand to solve them?
- Design the procurement policy based on the accessible and available resources.
- Planning and logistics: What is the purpose of the hole? Exploration? Production? Injection? Before drilling begins all the geological reports available should be accessible. Usually a driller will want to set up the equipment above target, but often times there might be directional drilling due to terrain.
- Ask the important questions and consider the important aspects before you begin, including:
  - What casings do we need?
  - What materials or tools do we need?
  - Visualize building the well from the bottom up including building the hole and setting casing appropriately.
  - Does the well cement match the temperature and geologic conditions of the well?
  - Design a general casing and drilling program, then design the well casing, and lastly, attempt to estimate the project's cost.
- Identify all potential problems before the project begins. Many problems like loss circulations, or poorly consolidated formations can be mitigated quickly with the proper tools. However, if the driller cannot obtain tools fast enough problems can occur. Good practice includes trying to have the right tools on locations and is coupled with thorough planning.
- Cost estimate should include a Cost vs. Depth and a Depth vs. Days analysis.

### **What are the best approaches to ensure successful geothermal project management?**

The panel posed the following seven "decision gates" or questions that a developer should ask about a project through its lifecycle. If all seven decision gates are fully answered and understood efficient project management is ensured.

- Decision Gate: Financial Closing – are there identified factors that will prevent the project from moving forward (legal, regulatory, control, technical or geological)?
- Decision Gate: Project Go – No Go – Does the pre-feasibility study at a +/- 30% financial accuracy meet the development team project viability requirements to proceed to the expenditure of significant exploration drilling funds?
- Decision Gate: Project Approval – Does the project support the developer's project economic requirements and meet the lender's financing requirements? Are the key contracts/entitlements in place and ready for execution?



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- Decision Gate: Financing/Start Project – Does the project have necessary internal and external approvals to allow closing of financing and start of the project?
- Decision Gate: Project Completion – Has the project been properly constructed, commissioned and tested in accordance with the project requirements? Has the developer issued the “substantial completion” notice to the contractor that the conditions of the construction contract have been satisfied and project is complete?
- Decision Gate: Project Turn-over – Does the project meet operational requirements and is it ready to be turned over to the operations and maintenance team?
- Decision Gate: Warranty – Does the project satisfy the required warranty requirements of the performance contract (typically 12 months) and is it ready to be turned over for long term asset management?





## Introduction to the Workshop

Geothermal energy is a clean, renewable energy resource that provides power from heat emanating from the interior of the Earth. This heat travels primarily by conduction and is estimated to be able to supply the equivalent of 42,000,000 megawatts (MW) of power globally.

Geothermal energy can be used for electricity production, for commercial, industrial, and residential direct heating purposes, and for efficient home heating and cooling through geothermal heat pumps. There are four commercial types of geothermal power plants: flash power plants, dry steam power plants, binary power plants, and flash/binary combined power plants.

The main benefits of utilizing geothermal energy are:

- ✓ Geothermal power is a base load power source capable of replacing coal-fired power plants and providing an alternative to natural gas.
- ✓ When engineered to do so, geothermal power can be flexible power source that can provide regulation, load following energy imbalance, spinning reserve, non-spinning reserve, and replacement for supplemental reserve.
- ✓ Geothermal power plants can last 30-50 years when their resources are managed correctly.
- ✓ Geothermal plants have negligible fuel costs once the well field and plant are built.
- ✓ Binary geothermal power plants have near-zero greenhouse gas (GHG) emissions.
- ✓ Geothermal plants use minimal land when compared to other technologies due to their compact size

The primarily challenges with expanding the use of geothermal energy globally are:

- ✓ High upfront capital costs;
- ✓ Locational limitations: geothermal plants must be placed near or above the resource;
- ✓ High risk that initial wells in a project will have low well productivity: approximately 50% of geothermal test wells are not commercially productive; and
- ✓ Transmission lines must be built near geothermal resources.

Geothermal electricity generation is currently used in 24 countries, while [geothermal heating](#) is utilized in 70 countries. However, geothermal resources are vastly underutilized on a global scale. The installed power capacity from natural geothermal resources, according to [Bloomberg New Energy Finance](#), is only 6% of global potential, estimated to be 196 GW.

To help reach this potential, an unprecedented amount of funding is being made available to make geothermal energy projects more viable and more attractive to energy investors. Currently, \$327 million has been earmarked through the Clean Technology Fund (CTF) and an additional \$3.285 billion, including co-finance commitments, has been identified by international financial institutions to reduce geothermal drilling risk on an international scale. However, there has been little consensus to date about how international financial institutions can best use these funds to reduce geothermal drilling risks. To help address this issue, on April 23, 2014, the U.S. Department of State and the Geothermal Energy Association co-hosted a workshop on “Geothermal Best Practices for Risk Reduction” in Washington, D.C. The event was designed to better understand the elements of geothermal risk and identify potential policies and initiatives to address those risks. The workshop was broken down into four sessions, tackling the following questions:

- Session I – What are the policies and regulatory structures that need to be in place for a geothermal power project to succeed?





## Best Practices for Risk Reduction Workshop

- Session II – What are the set of best practices for successful geothermal exploration?
- Session III – How do you conduct geothermal drilling cost-effectively?
- Session IV –What are the best approaches to ensure successful geothermal project management?

This document summarizes the presentations, dialogue, and discussions from the workshop, with the goal of providing an overview of geothermal risk mitigation options and recommendations, catered to project developers and financiers.



## Session 1 – What are the policy, legal, and regulatory structures that need to be in place for a geothermal project success?

### Speakers:

John Armstrong, President, Arthur John Armstrong, P.C.  
 Magnus Gehringer, CEO, Consent Energy LLC  
 John McKinsey, Partner, Locke Lord LLP

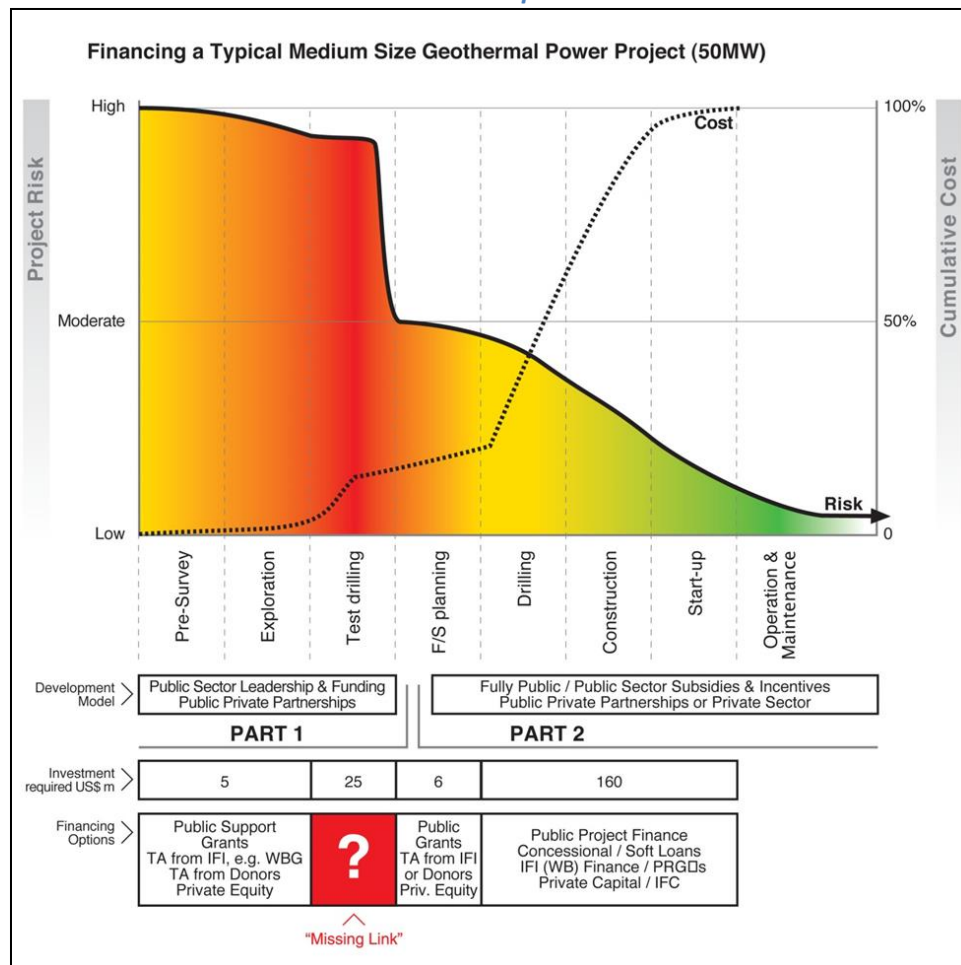
### Definitions and Focus

Drilling, with its high risk and high cost, continues to loom as a top barrier to generating electricity with geothermal resources. The unique nature of geothermal development – high risk upfront drilling costs combined with a longer development cycle overall—requires laws and policies tailored to minimize development costs, spur market access, and provide financing. In many countries there is a “financing gap” created by the high cost of test drilling. Figure 1 depicts the high risks and costs of geothermal development through the project timeline.

Most of the risk in any geothermal project occurs during the first third of total project expenditures.

*Figure 1: The Financing Gap in Geothermal Development*

*Source: ESMAP Geothermal Handbook, p. 4, June 2012, the International Bank for Reconstruction And Development*





A successful project is defined as a project that operates for its intended life in a sustainable manner and at the projected generation capacity factor. In a successful project, the geothermal energy plant operates at designed capacity and delivers electrical energy on time without major problems interrupting service. In other words, a successful project is characterized by long-term—sustainability. Long term sustainability is dependent on a strong foundation built upon four cornerstones.

## The Cornerstones of Geothermal Development

- ✓ **Resource Information:** The donors or government must initiate action to develop information and government may need to participate in drilling. The Government of Iceland is an example of public sector involvement with drilling risk in the early stages of resource development.
- ✓ **Market Access:** There must be a market. Generation growth must be accompanied by grid growth. In many areas of the world (such as the Caribbean) geothermal availability can be much greater than actual demand.
- ✓ **Financial Feasibility (Finances):** Property laws and policies must create an investment environment where risk and return are matched. There must be a credit-worthy off taker, which depends upon how the institutions are set up.
- ✓ **Policy Framework (Institutions):** Institutions must be coordinated and capable. This often means removing old governing institutions to create a single new one.

*Figure 2: The Cornerstones of Effective Geothermal Development*



### Resource Information

Information on geothermal resources needs to be made accessible as a matter of regulation and policy. Where necessary, donors and governments may need to initiate action to develop information on geothermal resources, including participation in exploration drilling.

A lack of information can thwart development at several stages in the process, including:

- ✓ **Limited identification of resource potential.** If the government has not conducted reconnaissance or has not made information widely available to potential developers
- ✓ **No commercial-quality resource.** If there is no information beyond initial inventory and surface studies; i.e., Geology, geochemical mapping, and geophysics have not been initiated.
- ✓ **No confirmation of energy supply.** If slim holes and production wells have yet to be drilled and tested.



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From a developer's standpoint, the most attractive investment regimes are ones in which governments and/or donors bear much of the exploratory risk burden. The following are international examples of successful programs:

- ✓ **Risk guarantee fund:** Geothermal Fund Facility, Indonesia.
- ✓ **International fund resources:** Geothermal Risk Mitigation Facility (GRMF) for East Africa; US AID & GEA US-East Africa Geothermal Partnership.
- ✓ **Published exploration data in public domain:** (Geological Agency & Bappenas, Indonesia; National Geothermal Data System, U.S.) Note: few developer-lenders will accept government data without independent verification.
- ✓ **Donor Grants:** such as in Kenya and Indonesia.

As an alternative to government's direct participation in exploration, the risk associated with a lack of information regarding the resource, can also be mitigated by providing developers exclusive access to large blocks of land for geothermal exploration activities. This is the model in some countries, such as Chile.

### Market Access

For a viable geothermal project, there must be (1) a market demand for additional baseload power, and (2) access, both physical (with regard to transmission) and contractual to that market. Generation growth needs to be accompanied by grid growth, to reduce risk. Depending on geography and geopolitics, a single country's market may have more risk than a broader regional grid. Determining the stakeholders and their role in the market can allow adjacent countries to collaborate with market access and temper investor risk.

The government has a pivotal role to play in creating a viable, reliable market for geothermal power. In particular, governments can manipulate the tools represented by power purchase agreements (PPAs), inducing preferred and guaranteed off-take of geothermal power.

### Market Access Problems

The following issues can cause problems with geothermal market access :

- ✓ No access to markets and manufacturing,
  - Geopolitical issues and geography can limit the market, such as in Dominica; St. Kitts & Nevis, and Bolivia.
  - Lack of reliable transmission lines and grid connectivity, such as in Chile.
- ✓ Grid connectivity,
- ✓ Proximity to developers, such as in island nations and some parts of Africa and Indonesia,
- ✓ Limited access to heavy equipment & generators, such as in the Caribbean, and
- ✓ Problems caused by terrain. For example, in Peru, Andean altitudes cause drilling problems.

Geothermal energy development should occur as part of a least-cost expansion plan. When designing a country's master plan, transmission (national and international) to access geothermal resources and local distribution where necessary must account for future expansion of geothermal generation resources.

### Market Access Policy Initiatives

The following are two possible policy suggestions geared at driving market access for geothermal power.



### **Policy 1: Enable market access to remote generation sites**

- ✓ Action: Facilitate reliable transmission lines and grid connectivity
- ✓ Tools:
  1. Regional grid and multi-nation import -export markets.
    - Example: SIEPAC -- Central American Electrical Interconnection System, the interconnection of the power grids of six Central American nations
  2. Mini-grids in remote areas. Consider local generation, distribution, transmission, monopoly as aid to universal electrification, and business models below utility-scale.
  3. Inter-island undersea grid.
    - Example: Caribbean

### **Policy 2: Enable market access to remote generation sites**

- ✓ Action: Identify real-world market access barriers & resolve to solve them.
- ✓ Tools:
  1. Familiarization Program: If proximity to developers is barrier, institute outreach plan and activities.
  2. Due Diligence Guidelines: Craft to pre-qualify developers.
  3. Promotion Director: Appoint and fund a promotion director to handle market access.
  4. Prioritize regions: Do not focus development promotion on areas inaccessible due to terrain / infrastructure – except for humanitarian and/or political reasons

## **Financial Feasibility**

In order for geothermal development to effectively take hold, it must be a financially viable and sound source of power. The following issues may cause problems with geothermal power from a financing perspective:

- ✓ Multi-year PPAs are discouraged by electricity laws.
- ✓ Today, very few model PPAs exist in which the lenders and the respective government financial agency do not impose additional scrutiny on the structure.
- ✓ A focus on short-term market costs results in insufficient long-term planning or system forecasting and hinders changes to generation status quo.
- ✓ Limited incentives exist for green field (new) facilities.
- ✓ Geothermal project development is not a conventional activity – local geothermal institutions and infrastructure are undeveloped.
- ✓ There is a failure to take into account economies of scale.
- ✓ There is a lack of Donor Coordination. International donors have financed much of the world's exploratory & high-risk geothermal activities. Many donors find their efforts uncoordinated with other donor agencies.

Furthermore, in small markets the developer has economy of scale limitations. Start-up cost may be approximately the same for a 10 MW project as it is for a 100MW project, making the costs for a small project prohibitive. Donor agencies would be well served by establishing a mechanism that allows them (at the least) to compare notes so as to avoid needless duplication.

The establishment of a tariff structure that is cost-reflective and therefore conducive to the production of geothermal energy must be sensible. The tariffs must be high enough to give the investors a reasonable return on investment, while providing a fair cost to consumers. Recognizing that the various



stakeholders will have differing agendas, the objective should be to establish a regulatory process that sets tariffs that meets the needs of all parties

The following are two policy suggestions to improve financial feasibility of geothermal development:

**Policy 1:** Establish tariff structure conducive to promoting geothermal development, as commercial risk is highly linked to tariffs and to their recovery rate

- ✓ **Action:** Set tariffs sufficiently high to allow for cost recovery & appropriate return on equity
  - Suggest 10-12% unlevered returns calculation for cost of equity financing and 6-8% unlevered returns calculation for cost of debt financing.
- ✓ **Action:** Provide conditions for appropriate recovery rate – Ensure multi-year PPAs

**Policy 2:** Institute Development Drivers

- ✓ **Action:** Streamline regulatory process,
  - *Resolve conflicts between local/national governments & conflicting agency governance, and*
- ✓ **Action:** Incentivize private sector investment.
- ✓ **Tools:**
  - Incentives (tax credits, etc.),
  - Renewable Portfolio Standard (RPS),
  - Small power grid Solutions,
  - Green pricing programs, and
  - Tariff regulations with broad government / utility support

## Policy Framework

The regulatory environment must present acceptable risk and return to the international geothermal financiers, both donors and private sector institutions.

A country's regulatory institutions need to be coordinated and mutually supportive. There should be a national geothermal law, to protect the investment of the private companies. The laws must clearly delineate the concession development process, clearly define terms, and provide a single agency for making the concessions

Policy tools used in one country are difficult to replicate with the same results in another country. There is no standard model. The best approach is to identify a country's unique resource and adapt a unique policy to its environment and its politics. Even within the same nation, various development models can be successful.

In one model, a single government is taking the majority of the risk. Another model involves the private parties doing the exploration. There is a spectrum of different tiers of local, state, federal government, working with the private sector to share risk. However, regardless of which approach is utilized an open transparent spirit of competition is required between private parties and government.

Most policy barriers lie in the institutional implementation of laws and regulations, primarily the lack of capacity on behalf of the institution. The following are policy problems associated with geothermal development:



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- ✓ Lack of **technical institutional capacity** is typical in decentralized systems & small countries, usually with only one project.
- ✓ Template PPAs **acceptable to lenders** (& inflation adjusted) are not in widespread use – & do not resolve which party takes on the risk associated with regulatory changes.
- ✓ Inability to **identify technically & financially qualified** private developers is rampant – speculators impede geothermal development worldwide

Governments and donors may spend taxpayer dollars and grants most effectively in exploration stages, reducing the risk for the companies and for the lenders, thereby encouraging investment. The publication of exploration data in the public domain is also conducive to private sector investment – although development companies will still spend money to verify that the information is correct.

Countries should develop favorable geothermal power policies that:

- ✓ Can promote and sustain private sector interest,
- ✓ Compliment the government's effort in resource mobilization for developing the geothermal potential,
- ✓ Safeguard the long-term interests of the country,
- ✓ Provide a clear and transparent process for the granting of concessions (a single agency should do this if possible), and
- ✓ Offer the private sector effective cost-sharing and risk-sharing mechanisms; though grant schemes, capital support or JV, especially for drilling costs.

An effective policy framework should include:

- ✓ Concession award agreements and procedures
- ✓ Exploration and development procedures, including requirements to IPPs for all project phases,
- ✓ Definition of geothermal resources (including heat energy and minerals),
- ✓ Power Purchase Agreements (PPA), and
- ✓ Resource and land ownership issues / resolution clauses.

The portfolio approach used in the mining sector could be employed. It is based on developing several fields in parallel. By accepting the fact that some fields might not be viable for exploitation, the government mitigates the overall risk and transfers exploration costs to successful fields which can be tendered out to IPPs.

A stable, predictable policy and institutional framework is necessary. If policies are uncertain, then it is hard to minimize the risk of investment. Policy change should be gradual and understood. In an ideal system the private sector should be expecting the policy change. When forming policy, the following questions must be asked:

### Who owns and controls the resource?

Ownership governs reconnaissance, drilling, and commercial development issues

Examples of different types of ownership:

- ✓ National Government (Kenya),
- ✓ Decentralized Governments (Indonesia),
- ✓ Groups (New Zealand Maori), and
- ✓ Individuals (U.S. landowners).





## What are the resource definitions and governing laws?

Multiple legal regimes governing the resource create development complexities in nations around the world. There should be one agency to draft, regulate, and manage policy on geothermal development.

### Examples of different governing laws:

- ✓ Sui Generis (unique geothermal law – Chile),
- ✓ Mineral (mineral law – Indonesia),
- ✓ Water (water law – some U.S. states),
- ✓ Precious Minerals (National precious mineral law – Argentina), and
- ✓ Geothermal Spa (Geothermal Spa law – Japan).

### Solutions:

- ✓ Facilitate private lender funding.
  - Incorporate all stakeholders in drafting template PPAs (deal with hard issues: inflation adjustment, indexes, and law changes).
  - Identify & develop mechanisms to do away with needless bureaucracy in the geothermal development process.
- ✓ Create stable and predictable policy and institutions.
  - Develop a single, national geothermal law.
  - Adopt solid law and policy and keep it constant.
  - Implement policy changes gradually.
- ✓ Minimize the number of agencies and institutions or create a single agency to manage geothermal development.
- ✓ Develop institutional capacity and capability.
  - Provides a cadre of national expertise that can effectively implement and monitor exploration activities.
  - Ensure that the established institution/agency can manage its responsibilities.
  - Institution must have the capacity and the authority to design appropriate policies, negotiate agreements, monitor and facilitate investor's activities.
- ✓ Provide government-supported guarantees to backstop payments from public utilities.
  - The government should be ready to provide the private sector with a PPA which is needed to obtain financing.

### Financing options:

- ✓ The portfolio approach: based on developing several fields in parallel accepts the fact that some fields might not be viable for exploration, the government mitigates the overall risk and transfers exploration costs to successful project.
- ✓ Geothermal power should be a part of a least-cost expansion plan: part of the master plan along with other power generations.

## Summary of Recommendations

- ✓ Publish exploration data in public domain for companies to use and verify.
- ✓ Coordinate institutions into one body for governing geothermal resource development.
- ✓ Minimize the number of institutional agencies involved with regulation—“one-stop shopping” is the ideal model.
- ✓ Develop institutional capacity and capability.
- ✓ Provide government-backed guarantees to backstop payments from utilities.
- ✓ Initiate action to develop resource information, either as donors or governments.



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- ✓ Donors and governments (both national and local) may need to participate in drilling risk.
- ✓ Take the current electricity market into account. There must be a market for the electricity. Generation growth must be accompanied by grid growth.
- ✓ Develop laws and regulations that create an investment environment where risk and return are matched.
- ✓ Concessions should have limited time for the developer to act or land can be taken away again. This is a common principle in the US with due diligence expenditures.

### Geothermal Regulators Should Consider

- ✓ The role of the private sector: accelerated geothermal development worldwide must involve the private sector as IPPs, PPPs, etc.
- ✓ The role of governments: governments will continue to play a facilitating or partnership role and donors are essential in up-front development
- ✓ The role of lenders: except for a rare oil company, the private sector will project-finance & lenders will be a part of the development equation
- ✓ Lenders will continue to insist on government guarantees; governments (mindful of the Asian Financial Crisis) will continue to limit risk via Finance Ministry “letters of comfort”
- ✓ The role of Investors: projects must have risk & return satisfactory to international financiers
- ✓ The needs of the public: electricity must be affordable (subsidies for all resources must be considered)
- ✓ Precedent: What are the best legal and regulatory practices? What works, what should work, or has worked? What has failed?

### FAQs and Answers

***Regulations come first, but why? How do you get regulations written if you have no resource? How do you get started? An issue with geothermal power is that it takes so long. Unless you have a lot of cash, it is going to be hard to do. Do we do this simultaneously?***

There are different ways to find out if there are resources and that has to come from government and donors. No rational developer would invest otherwise. In most countries, the resources are known and it is up to the governments to establish policies, laws, and regulations that provide the national stability conducive to energy investment. So, assuming that some resource knowledge exists, a regulatory framework conducive to investment is the chicken that comes before the egg. The government must be open-minded, sensitive to the motive for profit, and work with the private sector to win.

***What did you mean by saying that geothermal power needs to be sustainable?***

A project should be sustainable infinitely (like the injection now ongoing in the U.S. to rebuild reservoirs at the geysers to have sustainable operations). The developer cannot just extract a resource. The reason geothermal power is preferable is that it is infinitely sustainable when used responsibly. It's important to think about how to properly extract the resource. Ask yourself:

- ✓ What is economical?
- ✓ What is practical and beneficial?

The plant can be small and have a large impact and does not necessarily need to be run by a private geothermal company.

***What is the ideal structure of governing institutions to supervise developing projects?***

Regarding the institutions, one stop shopping is ideal, but may not be realistic. Policy has to be resource specific – the policy governing mining laws cannot be applied to geothermal power and be effective.



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If government institutions are coordinated and effective, “one-stop shopping” centralized in a single body may not be necessary. In fact, trying to create one stop shopping for geothermal development in an emerging economy could be very difficult to do politically. Meanwhile there are countries where “one-stop shops” are impediments. The best systems are those where the head of government understands geothermal policy and can fully support necessary actions. In general, it’s usually best to have a large, big picture, energy agency, geothermal, and renewables in mind.

It’s best to evaluate a country’s institutions, determine what needs to be added in terms of functions and where and how to add it. Along the way, if any agency can be eliminated, that generally helps. Sometimes, the evaluation indicates an agency needs to be eliminated. Few countries, developed or under-developed, though, have had the political will and courage to eliminate agencies.

### *Could governments have partners to help with the specific issues like drilling?*

Certainly, but governments have to educate themselves in order to get that kind of help. Public-private partnerships often work very well to tackle complex issues. The specific issue involved here, using drilling funds wisely and getting the drilling funds in the first place is a good marriage of public (funds) with private (expertise).



## Session 2: Geothermal Exploration Best Practices

### Speakers:

Ann Robertson-Tait, Business Development Manager/Senior Geologist, GeothermEx  
Doug Hollett, Director, U.S. Department of Energy Geothermal Technologies Office

### Panelist:

Patrick Dobson, Geological Staff Scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory  
Dr. James E Faulds, Director-State Geologist. Professor, Nevada Bureau of Mines and Geology  
Bob Sullivan, SVP of Business Development, Ormat Technologies

The second session recommended a set of “best practices” for a successful geothermal project in the early exploration phase. The speakers and panelists made a series of recommendations suggesting standard policies and guidelines for any project in the exploration phase of development. The exploration phase can be broken down into five phases listed below: project precursors, preliminary survey and detailed exploration, test drilling, feasibility, and well field build out.

### Phase 1: Project Precursors

The first phase encompasses activities that are necessary before beginning exploration. This includes employing an experienced and capable team, analyzing some basic economics of the project, and acquiring the project lease or tender. Considerations in this phase of development include:

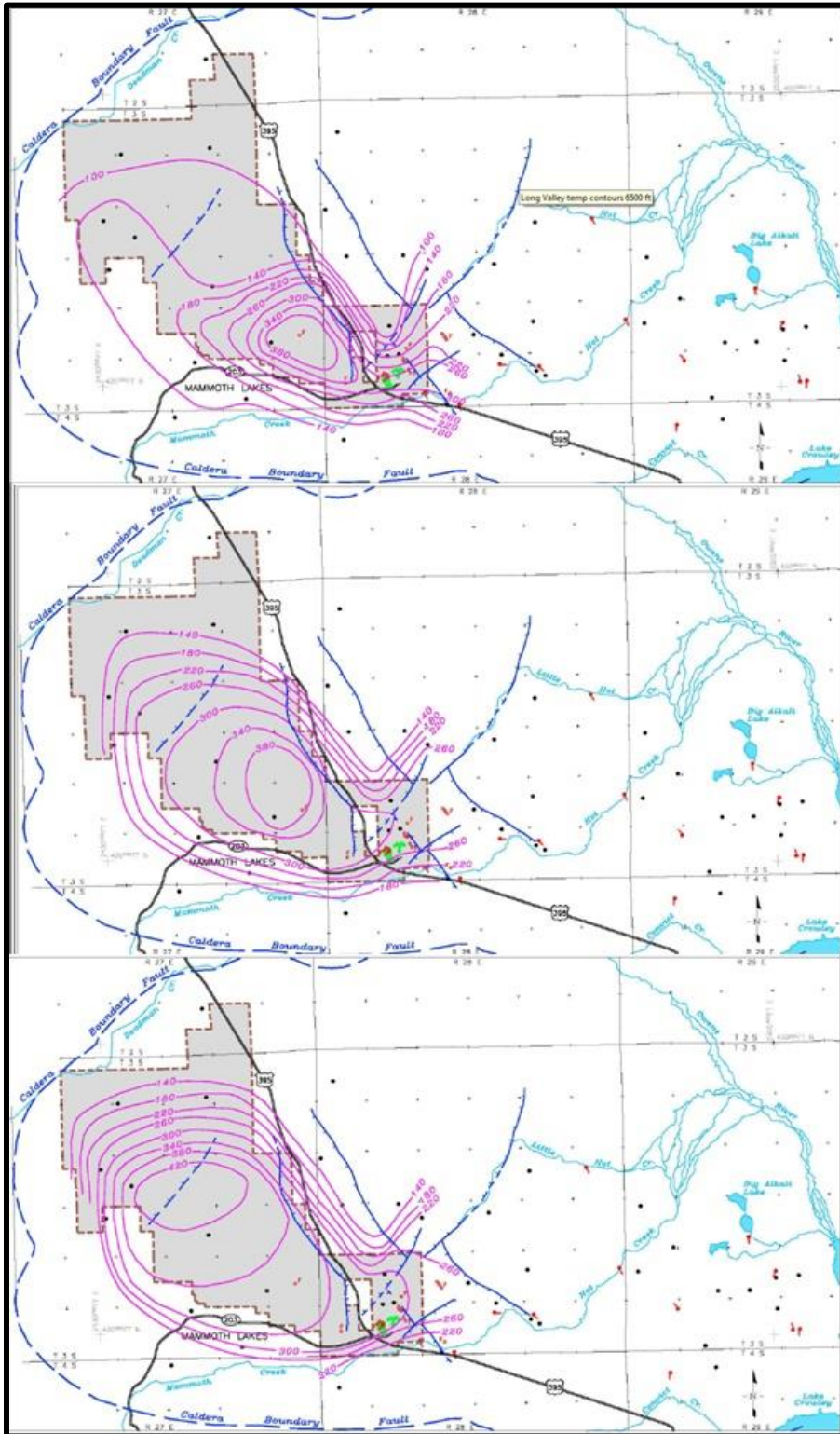
- ✓ Access to the resource, and knowledge about the land use limitations,
- ✓ The availability of transmission infrastructure ,
- ✓ An adequate power price (mandated or negotiated),
- ✓ Capable exploration teams should have good qualifications and include what the speakers called a “skeptic.”
- ✓ Land Position: the temperature gradient can shift. See Figure 3 provided by GeothermEx.

**Important Note:** Acquiring an adequate land position is an essential ingredient of successful geothermal projects. Figure 3 shows the geometry of a geothermal resource in California in relation to the developer’s land position (“lease” also referred to as license area or concession area). The lease, shown in grey, covers the resource area at all depths, demonstrating a good land position. A lease that covers an adequate portion of the resource will have a greater likelihood of hosting productive wells.

A good exploration team is composed of:

- Geoscientist
- GIS Specialist or Cartography
- Contracting / Negotiations Specialist
- Logistics / Procurement Person
- Drilling, Logging, Testing Specialist
- Reservoir Engineering Specialist
- Operations Specialist, and
- A skeptic to keep the team in check.

Figure 3: Temperature distribution in a geothermal resource at three depths & the developer's land position (shown in grey)



Note: This figure includes a shallow (top) depiction of the resource, an intermediate depth snapshot of the resource (middle) and deep depiction of the resource (bottom).



## Phase 2: Preliminary Survey & Detailed Exploration

This phase of the geothermal exploration process has two key parts: (1) data collection; and (2) data analysis and interpretation. Choosing the right exploration techniques and developing an initial conceptual model of the resource both require input and analysis by experienced geothermal professionals. Important considerations during this phase of a project include the choice of exploration methodologies, proper data collection and storage, and clear data presentation. During this stage of the project, skilled exploration teams will:

- ✓ Look for data that provide evidence of geothermal potential by doing a thorough literature search. Information is sought from different sources and disciplines, including geology, hydrology, thermal features, geochemistry, geophysics and remote sensing, with a strong focus on any existing drilling data (e.g., from mineral exploration or oil & gas exploration).
- ✓ Identify thermally anomalous areas that may have hot springs, fumaroles, warm ground and/or hydrothermal alteration that is characteristic of thermal areas.
- ✓ Undertake regional and/or local geologic mapping, covering thermally anomalous areas
- ✓ Undertake regional or local identification and sampling of waters that have or are expected to have a thermal component, as well as normal cool ground waters and surface waters.
- ✓ Evaluate regional geophysical data (typically gravity and magnetic data), if available, to help understand geologic structure.

Throughout the exploration process, results are integrated using a variety of methods and analyzed to make an initial estimate of the size, temperature and capacity of the geothermal system. Typically, few if any wells have been drilled at this stage, so analogies with other similar geothermal systems are sometimes used to help develop this estimate. Then, a capable team will:

- ✓ Prepare geological maps and cross-sections to understand the potential target and convey the overall concept to others,
- ✓ Evaluate the geochemical data to identify fluid mixing, movement, potential operational, issues, and resource temperatures (through the careful application of geothermometry)
- ✓ Make an integrated interpretation using all geological, geophysical and geochemical data,
- ✓ Estimate the geometry of the reservoir,
- ✓ Prioritize areas in which to undertake more focused exploration,
- ✓ Determine which next exploration steps are needed, and
- ✓ Report back to managers and investors.

**Important Note:** When developing a conceptual model of a geothermal system, consider the following:

- There may be areas with apparently contradicting data sets, but there is only one reality.
- Question assumptions and consider alternative conceptual models – this may help resolve apparent contradictions.
- Remember that each resource is unique; although analogy is useful, the data may mislead those who place too much reliance on it.
- Disagreements among team members probably indicate the system is not yet fully understood, but constructive debate can lead to common understanding (including about what is NOT known).

### Geological Exploration Methods to Consider at this Stage:

- ✓ Mapping of distinct geologic units and their contacts,





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- ✓ Mapping of faults, fractures, folds, and other structural features, noting orientations (this could also involve the use of satellite images, air photos, and lidar),
- ✓ Mapping of zones of hydrothermal alteration (this could also involve use of remote sensing techniques), and
- ✓ Analysis of regional and local stress fields to determine which fractures are most likely to accommodate fluid flow.

A typical work flow for geological exploration of geothermal systems includes:

1. Conducting detailed geologic mapping (Example in Figure 5),
2. Identifying stratigraphic horizons (i.e., specific rock units) that may serve as permeable subsurface reservoirs,
3. Defining the structural setting and mapping faults in and around the geothermal system,
4. Evaluating fault patterns and stress conditions to estimate the tendency for slip and dilation along mapped faults,
5. Defining areas where permeability should be enhanced through fault slip and dilation (i.e., play fairways),
6. Integrating geothermal well data (if available) and geophysical data,
7. Preparing a 3D model of the geothermal system,
8. Selecting drilling locations that target potential play fairways,

This process is shown in Figure 4 below. Following this methodology and carefully applying a structural settings approach is particularly useful when exploring for “blind” geothermal systems, i.e., those without surface thermal manifestations such as hot springs or fumaroles.



Figure 4: Methods & Work Flow for Geologic Exploration of Geothermal Systems

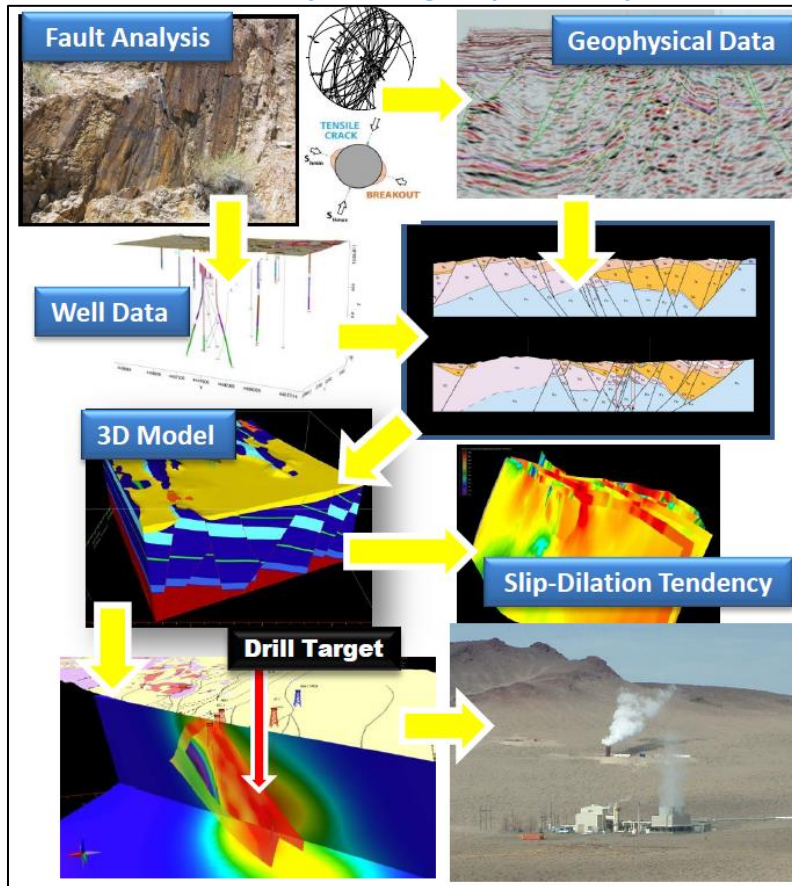
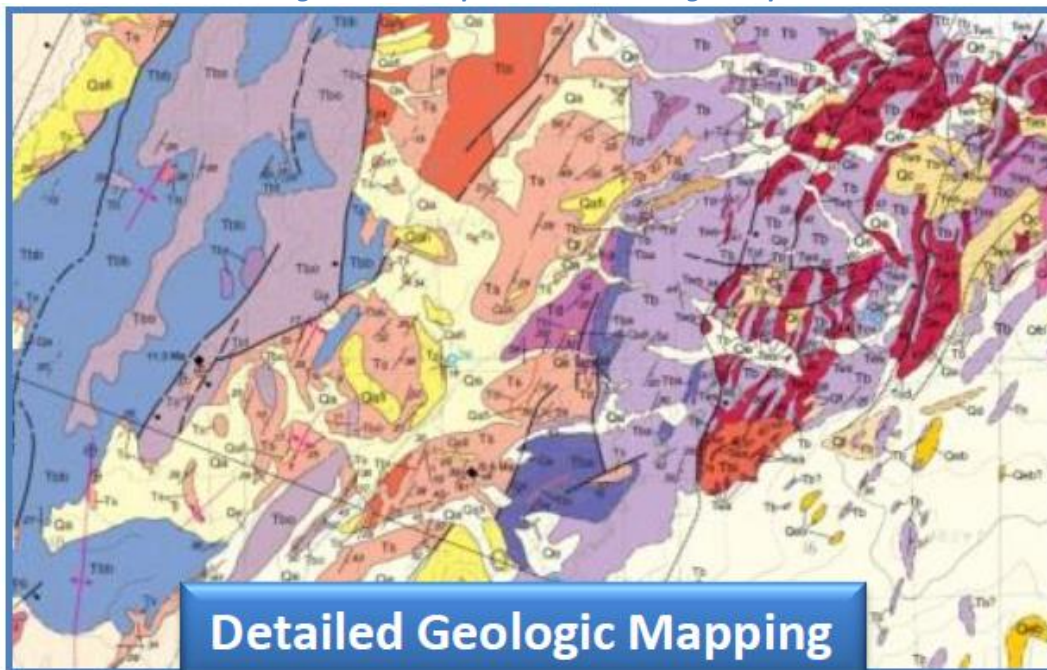


Figure 5: Example Detailed Geologic Map





### Geophysical Exploration Methods to Consider at this Stage:

- ✓ Gravity and magnetic surveys,
- ✓ Electrical methods (MT, TDEM, vertical electric soundings, etc.),
- ✓ Reflection seismic, noting the following:
  - It is not appropriate for or affordable in all geologic domains, and
  - The costs are similar to that of a full-diameter well, but when undertaken properly can provide guidance on siting several wells,
- ✓ Temperature gradient wells to measure the shallow temperature field that take into account:
  - A cost-effective method of imaging the quantity of heat ,
  - A well that is easily permitted and rapidly drilled at modest cost, and
  - Clearly delineated near-surface temperature distribution and geothermal fluid flow patterns,

With care and experience, temperature gradient wells can be used to extrapolate temperatures too deep into the center of the earth. Together with other data, these facts and data enable the developer to obtain a better “picture” of the resource, including the ability to estimate the size of the resource

### Geochemical Data Collection and Presentation

Good geochemical data collection includes a map of sample locations in addition to:

- ✓ Data table for liquid geochemistry, including
  - Field parameters (location, temperature, conductivity, pH, flow rate, etc.)
  - Analyses of Na, K, Ca, Mg, Li, Cl, B,  $\text{SO}_4^{2-}$ ,  $\text{NH}_3$ , TDS, pH, Alkalinity as  $\text{HCO}_3$  and  $\text{CO}_3$  and total alkalinity as  $\text{HCO}_3$ , and  $\text{SiO}_2$
  - Also Sr, Rb, Mn,  $\text{F}^-$ ,  $\delta^{18}\text{O}$  and  $\delta\text{D}$  stable isotopes in water and  $\delta^{18}\text{O}$  in dissolved  $\text{SO}_4^{2-}$
  - Ion charge balance or other indication of quality control on analyses
- ✓ Data table for gas geochemistry
  - Field parameters (location, temperature, flow rate, odors)
  - Geochemical analyses of  $\text{NH}_3$ ,  $\text{H}_2\text{S}$ ,  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{H}_2$ ,  $\text{N}_2$ , Ar, He,  $\text{SO}_2$ , HCl, HF,  $\text{O}_2$
  - Also preferably  $^3\text{He}/^4\text{He}$ ,  $^{40}\text{Ar}/^{36}\text{Ar}$ , other noble gas ratios, and stable isotopes in steam condensate
  - Standard deviation of each sample measurement and/or other evidence of quality control on the analyses
- ✓ Table of geothermometry calculations
  - silica (Quartz, Chalcedony, and Amorphous silica), cation (Na-K-Ca, Na-K-Ca-Mg, Na/K, K-Mg) and sulfate water isotope ( $^{18}\text{O}$ )
- ✓ Graphs of data, including
  - Piper diagrams,
  - K vs Na,
  - $\delta\text{D}$  vs  $\delta^{18}\text{O}$ ,
  - Ternary plot of major anions  $\text{SO}_4\text{-HCO}_3\text{-Cl}$ ,
  - Ternary plot of Na, K and Mg,
  - Na-K-Ca geothermometer temperature vs Cl,
  - Temp NaKCa ( $^\circ\text{C}$ ) vs Temp K/Mg ( $^\circ\text{C}$ ),
  - Discharge temperature ( $^\circ\text{C}$ ) vs Cl,
  - Gas ternary plot ( $\text{N}_2$ ,  $\text{CO}_2/100$ ,  $100*\text{Ar}$ ), and
  - Giggenbach Gas Ratio Grids ( $\text{H}_2/\text{Ar}$  vs.  $\text{CO}_2/\text{Ar}$ ,  $\text{H}_2/\text{Ar}$  vs. T,  $\text{CH}_4/\text{CO}_2$  vs.  $\text{CO}/\text{CO}_2$ ,  $\text{CO}/\text{CO}_2$  vs  $\text{H}^2/\text{Ar}$ ).
- ✓ Presentation of data maps, including contour maps of chemical species, soil gases, etc.



Upon completion of the exploration campaign, all data are evaluated and integrated into a conceptual model of the geothermal resource. Developed at an early stage of the project, the conceptual model revisited and revised as new data and interpretations are obtained. The most successful and accurate conceptual models are constructed with input from a capable team, in as much detail as the data will allow. Conceptual models can be described in words, but are best represented graphically to convey the understanding of the project to both experts and non-experts alike. These graphical representations span the spectrum from simple sketches that illustrate key concepts to complex 3D visualizations based on data from multiple wells.

Initially, the conceptual model is used as a tool to guide exploration. As more focused exploration work is completed, the conceptual model is used as the basis for estimating the size of the resource and selecting surface sites and subsurface drilling targets for exploration wells. When there is enough information to advance the conceptual model to the point at which the resource capacity can be estimated and drilling targets can be selected, the project has reached the stage of pre-feasibility. Drilling, logging and testing is the only way to reach the feasibility stage, at which point the resource capacity estimate is more certain, and conceptual model has been significantly improved and updated.

### Phase 3: Test Drilling

After completing the early exploration (maybe including temperature gradient drilling) the project reaches a decision gate. Here geothermal developers are faced with two choices: 1) drill slim holes to approach or penetrate the resource; or 2) proceed directly to full-diameter drilling. The typical “reach of these three types of wells is illustrated in Figure 6 below. The decision at this point depends on many factors, including availability of funding and the perceived certainty about the location and depth of the resource (as indicated by the evolving conceptual model). If certainty is low and/or limited funds are available, a developer may choose to drill slim holes to test their conceptual model and better characterize the resource. If the location and extent of the resource is more obvious, a developer may proceed directly to drilling full-diameter wells.

Depending on regulatory conditions, a slim hole may be used for injection testing and/or production testing, and this can prove the resource in some cases (notably for expansions of existing fields). However, slim holes have limited use in operating projects (they are often used as monitoring wells, and occasionally as injection wells, but rarely if ever as production wells). In most projects, successful full-diameter wells are required to demonstrate feasibility, since they are best suited to discovering, confirming, characterizing and quantifying the resource. Thus, the first few full-diameter wells are used to define the target areas for production and injection, and provide critical input to the selection of the power cycle and the design of the power plant.

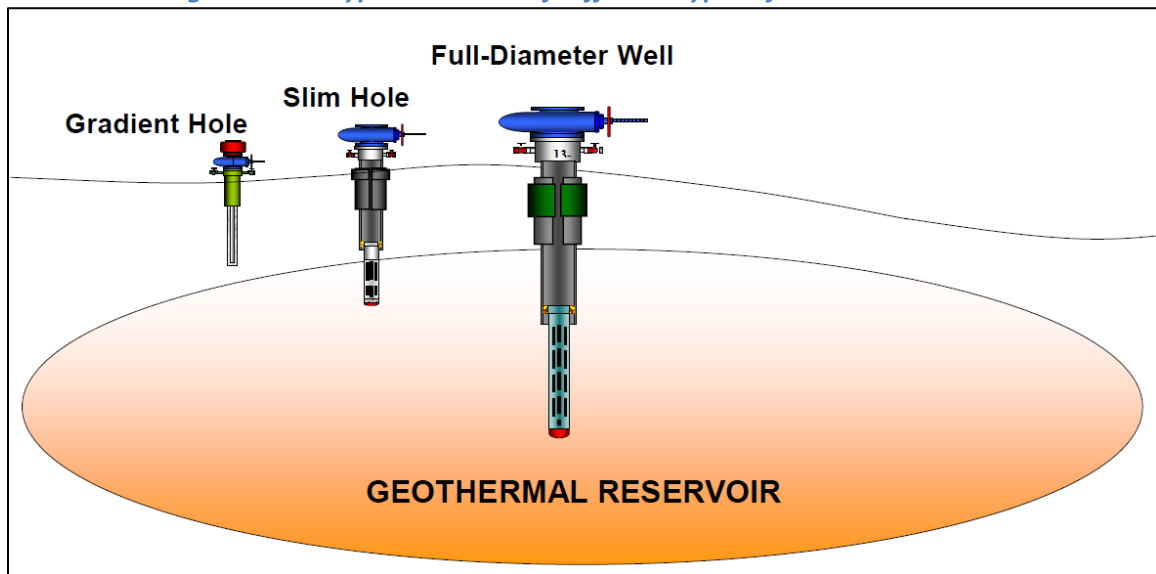
### Phase 4: Feasibility

At the “Feasibility” stage of the project lifecycle it’s important to decide what type and how many wells are necessary to confirm and develop the resource. Points to note at this stage of project development include the following:

- ✓ The number of wells required to demonstrate feasibility depends on the size of the project and the drilling success rate
- ✓ Slim holes may be drilled first to reduce risk
- ✓ Wells must be drilled, allowed to heat up, and tested
- ✓ Drilling results delineate the area for development drilling – additional wells will generally be located within the “proven” area

- ✓ Testing demonstrates the presence of commercial production suitable for supplying a power plant at a given cost

*Figure 6: The Typical “Reach” of Different Types of Geothermal Wells*



### Phase 5: Well Field Build-Out (Development Drilling)

When building out the well field, it's important to check every box listed in this section. A capable and experienced team will know all the information listed in this section before building out the well field.

- ✓ Drilling conditions are known,
- ✓ The locations and targets of the remaining wells to drill are known,
- ✓ The technical and economic viability of the project can be demonstrated,
- ✓ The risks associated with the project have been reduced significantly,
- ✓ The investors are engaged with the project and have invested capital,
- ✓ The well field build-out is “routine” as it does not carry the high risk associated with initial drilling and,
- ✓ In large projects with short timelines, multiple rigs may be brought in at this stage.

### Summary of Recommendations

- ✓ As a starting point, consider non-resource factors when determining a project's technical and economic feasibility. These include but are not limited to issues such as: resource access, transmission, power price, operating costs, regulatory compliance, logistics, infrastructure, equipment availability, seasonal issues, political and financial stability in the host country, license areas, neighboring license holders and areas, “off limits” areas for environmental or other reasons, and more.
- ✓ Engage with regulatory agencies early on and make them a partner in the project by informing them regularly.
- ✓ Retain a capable and experienced technical team to manage and interpret the results of exploration and drilling.
- ✓ Use the common exploration elements, but recognize that because of the uniqueness of individual resources, there is no fixed recipe or set of recommendations for what type of exploration to use.





- ✓ Develop a conceptual model early in the exploration process, and update it as more data are collected and analyzed.
- ✓ Choose exploration methods that are well suited to resource conditions and serve to test the conceptual model.
- ✓ Present a clear, focused, and well-justified conceptual model (even a simple one) to stakeholders. Investors can judge the quality, sophistication, and experience of the resource development team by how they integrate data to form the conceptual model.
- ✓ Assume there are no bad wells.” Plan for failure; i.e., have a plan for what to do next if a well is not successful.
- ✓ Have an exit strategy: know when the indications suggest that there is no viable resource.
- ✓ Promote R&D to enable geothermal power development to become more like a manufacturing process or oil or gas production. Through technology improvements and better exploration practices, move towards a replicable process with more certainty.
- ✓ Use a robust system to develop resource estimates and profiles (similar to oil and gas industry) so that investors have confidence in resource calculations.

## FAQs and Answers

### *Why do we have notable exploration failures even with today's technology?*

The answer lies several kilometers beneath the ground surface, and even with today's technology, ultimately we must drill to determine if our conceptual model is correct or not. It takes experience to minimize mistakes. Experience is required to minimize the impact of poor decisions, so exploration and development teams should be comprised of people of different ages and with different experience. Negative information should be used to help determine the best places to drill and the characteristics of the resource. It's important to vigorously debate what is happening in the subsurface.

For example, “AMOCO drilled 81 exploration wells around the world, and all 81 of them were unsuccessful wells.” A geologist on the project and a friend of one of the panelist said at the time, “We don't have good models for the subsurface.” With more geothermal development experience and capability in different geologic domains, conceptual models of geothermal systems are becoming more robust, if developed by a knowledgeable team, and more accurate in general. Some of the past geothermal development companies (now defunct) were impatient about the early exploration and analysis, but it can take at least 3-6 months and often longer to do a proper analysis of a geothermal field before considering exploratory drilling.

### *Many geothermal insurance companies are beginning to require 3D seismic models in Germany. How is 3D Seismic survey included in imaging geothermal resources today?*

There is a trend toward using more 3D seismic; however this technology still comes at a high price (on the order of a well) and has significant challenges related to data acquisition, processing and interpretation, particularly in volcanic domains (where most geothermal resources are found). That said, there are non-volcanic areas that host geothermal resources, and these are more amenable to seismic exploration techniques. In many places, the power price is not high enough to justify the cost of 3D seismic, but 2D seismic may be more affordable.

### *In developing countries, how much experience do geothermal developers have with 3D conceptual models, particularly when the data set is limited?*

The exploration team should try to gain as much insight as possible from the data that they have, and should design a new exploration program if the data set is inadequate. Regional modeling may provide some insight to the more local resource area in some places. At a minimum, a regional model can help



the developer target a specific area for further exploration and development, and develop a preliminary conceptual model of that area. There is a lack of understanding about the process and importance of conceptual modeling in some developing countries.

***Are banks funding the right projects? How do we select the best data and the best projects? There is sometimes a lack of information in developing countries. How do we get the banks to back up the projects with more limited data?***

By using models from all around the world and building a global catalog of information, the effective use of analogies can increase. In countries with multiple geothermal resources, it is common to develop a master plan for geothermal development that prioritizes project areas on the basis of their location (relative to the grid), capacity and ease of development. Developing maps that point out areas of high geothermal potential and prioritize resources for development can be used together with play fairway analysis, making exploration more cost-effective in areas with limited data.

Commercial banks are unwilling to accept the risk of data-poor projects, and obtaining debt financing generally requires developers to 1) have demonstrated feasibility through successful drilling and 2) have a reasonably high percentage of successful, completed wells. Development banks and government agencies have a greater risk appetite, but still require the developer to demonstrate a robust conceptual model of the field that agrees with all known geothermal data. Conducting a fatal flaw analysis can ensure that important resource and non-resource issues have been considered prior to investing in exploration. Highly experienced developers or less experienced developers that have retained the services of experienced people from a reputable firm will find it easier to attract investment as debt or equity.

***What can we do with all the data at hand to convince banks to invest?***

Geothermal knowledge has advanced significantly, and the “signatures” of geothermal reservoirs have become easier to identify over time. Exploration teams typically combine multiple parameters to build robust conceptual models to guide exploration and improve the chances of drilling successful wells. When suitably explained in lay terms, this process helps the decision making on the business and financing level.

***Why are there disagreements about a resource among exploration team members?***

Exploration team members typically disagree about the assumptions that need to be made because of limited data. In essence, the exploration team is trying to understand where sufficient temperature and permeability can be found several kilometers below the ground surface – a difficult task when there has been no drilling (or where drilling is limited). Having team members with successful experience in a similar geothermal environment is essential, but this may not be enough to sufficiently reduce uncertainty to the point where all team members agree. At this point, the team will consider how the uncertainties in assumptions can be reduced by debating the relative merits of undertaking more exploration work, such as detailed geologic mapping, collecting new geophysical data (such as resistivity or seismic data), or drilling a slim hole. The costs and benefits of each option are weighed in the context of the project’s budget and timeline, and risk is gradually reduced as more exploration data are obtained, and particularly as more wells are drilled. There is no substitute for drilling to prove a concept or a geothermal resource.



## Session 3: How do you conduct geothermal drilling cost- effectively?

### Speakers:

Doug Blankenship, Manager of Geothermal Research, Sandia National Laboratories

Sam Abraham, Business development Manager, Baker Hughes

Louis Capuano, Jr., President, Capuano Engineering Company

The third session recommended a set of “best practices” and reflected on the attributes of a successful drilling program. The speakers made recommendations and answered question to produce a standard set of practices or a checklist that an experienced and capable geothermal driller should walk through.

### Pre-Drilling Planning and Logistics Checklist

- ✓ Determine the purpose of the hole (exploration, injection, production) and what type of hole is proposed. Ask before drilling any hole,
- ✓ Review all available offset well data, geologic reports, and studies,
- ✓ The driller should identify all formation changes and faulting projections,
- ✓ Prepare a rough casing program with casing and hole sizes and setting depths and apply it to geologic projections,
- ✓ Compare projected temperature forecast to casing program and adjust as required, and
- ✓ Complete casing design with options for additional casing as needed if problems are encountered.

### Drilling Problems Checklist

- ✓ Identify all potential problems that may be encountered in the drilling of the well,
- ✓ Identify solution to problems anticipated and have tools, services and equipment to solve these problems readily available to reduce down time,
- ✓ Prepare drilling curves (Days vs. Depth and Depth vs. Cost) for a comparison. Estimates of penetration rates are required to do this,
- ✓ Design each component of the drilling program (mud, cementing, directional, bits, bottom-hole assembly, BOP, etc.), and
- ✓ Develop the initial cost estimate for the well based on casing program, hole size, and drilling curve.

### Applying the Best Drilling Practices

- ✓ Once the drilling program is designed, specify equipment, materials, and technology needed,
- ✓ Design programs should utilize best available technologies,
- ✓ Decisions should consider cost effectiveness and previous experience and
- ✓ Use experienced personnel on the first few wells to start a project on the right track

### Increase Drilling Efficiency Checklist

- ✓ Drilling experience is the most important aspect of cost control.
- ✓ Experience is needed in the following areas:
  - Engineering,
  - Rig crews,
  - Service personal,
  - On-site drilling supervision,
- ✓ Identification and mitigation of drilling risks to increase efficiency,





- ✓ Proper monitoring and collection of data, which improves rig and drilling efficiency, and
- ✓ In-depth analysis of problems, lessons learned, and continuous improvements to reduce non-productive time.

### Procurement Policies Checklist

Procurement policies and regulations for new technologies brought into new countries can be an issue. It's important to balance drill competency and optimal design, government regulation, and import / export policies that could be troublesome. A driller should think about what umbrella the equipment should fall under. The driller can't control the lead times on equipment, so a flexible procurement policy is important. For example, environmental and safety regulations may affect the driller's procurement policy. They may not be able to bring in a particular drilling fluid or the regulations may forbid a certain fluid from being used. Drillers should think ahead in order for things to run smoothly.

Drillers should also consider,

- ✓ Create an efficient procurement policy for equipment.
- ✓ Ensure the drilling program's design is based on available inventory of equipment.
- ✓ Plan logistics to include in transportation time, while the costs of the drilling program needs to consider program design, drilling curves and availability of equipment and resources.
- ✓ Consider the need for spare parts and equipment, especially in remote locations.
- ✓ Create a plan for how problems will be resolved if they occur, including full knowledge of local or regional well drilling regulations.

### Reduction of Non-Productive Time, Invisible Loss Time, and Theoretical Technical Time

The panel emphasized the importance among everything else of minimizing three categories of lost time that can raise costs of any drilling project and increase the length of any drilling operation. These three categories are listed below accompanied by suggestions to mitigate them. It's important to minimize non-productive times as much as possible since the driller cannot change the time it takes to drill the well. It costs about \$50,000 \$US a day (total cost) to operate a rig. By having a flexible drilling program the driller can minimize non-productive time. The driller must use the right materials, consider if they are locally available and determine the required procurement processes.

In addition, when hiring personnel, are there industry standards that need to be known? Are all of the tools that could be needed are in place before drilling begins? A good way to control costs it to make sure that the people who are manning the rig know how much it costs per day, ensure tools and equipment are placed and personnel know are well experienced and capable.

- ✓ Non-productive time includes tool failures, breakdowns, hole problems. The following are recommendations to minimize Non-productive time:
  - Use time analysis and trip analysis tools to help the identify category, frequency, and severity of non-productive time,
  - Mitigate risk with comprehensive planning, inspections, skilled workforce, performance monitoring,
  - Keep required tools and spares nearby, especially when drilling in remote locations, carry backup spares, and
  - Practice preemptive maintenance.



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- ✓ Invisible Lost Time includes inefficiencies in well construction process that can be mitigated by:
  - Performance benchmarking models that quantify theoretical performance capabilities; and planning to achieve the performance aiming towards the theoretical limits
  - Quantify improvement opportunities and perform cost justification
- ✓ Theoretical Technical Limit Well Time
  - Process identifies applications challenges and technology needs
  - Technology improvements or introduction of new technologies, which can improve the time on spend on operations like casing running by using Casing Running Tools.

### Summary of Recommendations

- ✓ Inspect tools each time they are used.
- ✓ Minimize Invisible Lost Time as much as possible to increase project efficiency.
  - Always have the information and resources when you need them. Don't scramble to acquire them once the project has already begun.
- ✓ Hire an experienced drilling engineer, who will plan out options and provide solutions to problems.
- ✓ Develop a comprehensive drilling program that includes detailed planning and logistics.
- ✓ Budget for various factors that affect project cost: well location, elevation, ownership, and applicable regulations.
- ✓ Plan for drilling-related problems: what types of problems do you think could happen and what tools do we have on hand to solve them?
- ✓ Design the procurement policy based on the accessible and available resources.
- ✓ Facilitate planning and logistics. What is the purpose of the hole? Exploration? Production? Injection? Before drilling begins all the geological reports available should be accessible. Usually a driller will want to set up the equipment above target, but often times there might be directional drilling due to terrain.
- ✓ Ask the important questions and consider the important aspects before you begin, including:
  - Assess the casings needed.
  - Determine the materials and tools needed.
  - Visualize building the well from the bottom up including building the hole and setting casing appropriately.
  - Match the cement to the temperature and geologic conditions of the well.
  - Design a general casing and drilling program, then design the well casing, and lastly, attempt to estimate the project's cost.
- ✓ Identify all potential problems before the project begins. Many problems like loss circulations, or poorly consolidated formations can be mitigated quickly with the proper tools. However, if the driller cannot obtain tools fast enough problems can occur. Good practice includes trying to have the right tools on locations and is coupled with thorough planning.
- ✓ Cost estimate should include a cost vs. depth and a depth vs. days analysis.

### FAQs and Answers

***In a greenfield project where there are no offset drills, you have to really prepare yourself, so how much should a driller or developer rely on the geologists?***

A lot, since the driller will always drill based on the geologic interpretations. From an oil and gas background there is a lot of money being spent on exploration technology. It's important to "listen to the well" and respond accordingly. It's essential on the first well to use experienced people and the best technology because it will save money and time in the long run.



## Best Practices for Risk Reduction Workshop



Utilize drilling optimization, the first well will teach the most. Every well drilled should increase the geologic knowledge of the resource.

Think about whom is the best driller for a project? Many of the governments will choose the lowest bidder. Unfortunately, sometimes what happens, is that the lowest bidder wins, but at a very high cost because the winner may be inexperienced and makes mistakes. In U.S. it's common to use the "best value" not "best cost." Characteristics such as availability, experience, and cost determine the best option for any given project with experience as the most weighted value in many cases.

### *Where do you find the criteria for drilling specification (IAD)?*

The driller will write the specifications. They usually will fill out an Indefinite Delivery Contract so that the developer can compare criteria.

### *How does a driller choose the rig? And people?*

Rigs often run with five man crews, 12 hours, one week on, one week off, and they look for experience.

Also, it's important to do a drill inspection, make sure everything is working on the drill rig. Consider the size of the rig and how much horse power it requires? Bigger is not always better because of the price of fuel to power the bigger rig can be expensive depending on the project's location.

Additionally, when drilling a well, even if it is a new well the developer should be collecting data, and use that data to make informed decisions about other exploration wells. Every well in the world is different. If the driller/developer has proper data you can plan your next well more successfully. Each well should be looked at as a separate entity.

### *When you start in a new field, should you drill several wells or just one?*

The driller is better off doing one well at a time. Develop the field model first.

### *Who makes the decision as to whether the well will be vertical or directional?*

Often the driller will directionally drill to multiple targets. Once a geologist chooses a target, and then then the driller can pick a location that can penetrate several targets at one location. While other times if the driller/developer has a dud, they can drill multilaterally to hit another target.

### *Oil and gas has new design approach to drilling (flex rigs), can that be adapted to geothermal drilling?*

It is being done in Kenya, top setting the wells by using a faster moving rig and then uses the larger rig to reach deeper. And some drillers have been trying to adapt old rigs to this new technology. Also, it's important to track the drilling companies in relation to the geothermal companies. Right now the AC type rigs are going only to oil and gas, not towards geothermal. Meanwhile flex rigs are better at drilling smaller holes at deeper depths, which is not always useful for geothermal wells.

### *How do you mitigate well collapse in lateral drills?*

In geothermal we are often drilling in igneous rocks not sedimentary rocks like oil and gas and therefore well collapse is less common. However, if the driller thinks that there is some weakness, then they will run another string of casing. It's important for the driller to test this at shallower depths before proceeding and have an option for additional casing strings available. The drilling fluids could be a source of this problem and are commonly overlooked. Their design and proper use can mitigate risks associated with well collapse.



***Do drilling companies follow the market developments for drilling and adjust as the market shifts?***

Often drilling companies will take initiative to test new technologies that may be used in the future. It's common to modify our own tools in order to meet the temperature variations of geothermal drilling. There are an estimated 2800 rigs running in the world and maybe 20-40 are drilling geothermal power projects currently. Oil and gas are now drilling high temperature wells which could be good for geothermal power. There could be new cross over technologies that enter the marketplace as results attract new R&D for geothermal drilling.

***Comment: There is nothing more inefficient than doing something efficiently that shouldn't be done in the first place. Wells are being drilled where they cannot be supported. We have to contain this urge to drill.***

A good driller will change the drilling program after each well and learn as the project progresses. The geologists, engineers and drillers should meet every week to talk about the project's plan and refine the project. To reduce the cost of drilling, don't drill the hole first, do everything else upfront first.

***What can we do in the future to reduce costs like new technology or better drilling tools??***

New technology is not the only path forward. For example drilling can be optimized by measuring and using mechanical specific energy (MSE) – basically the ratio of energy input/rate of penetration. By making you decisions based on minimizing MSE for a given set of drilling parameters, drilling performance can be increased. Literature shows that a major oil and gas company increased their daily penetration rate by 40% in one year. How can we make physics-based decisions with the information that we have? Ormat is currently investigating how this can be done with geothermal power.

In addition, the industry should adapt to what oil and gas companies practice today. There are technologies in these fields such as advanced drilling systems that are not being used. Baker Hughes is innovating some techniques that are showing promise and it may become the standard in geothermal. PDC bits do not have a good reputation in geothermal power but the right research could figure out how to adapt it to geothermal drilling. Drilling vibrations are a problem, how can we adapt geothermal technology to minimize these?

***What are the panel's thoughts on revolutionary or new drilling technologies that drill faster?***

Often oil and gas fund the companies developing these new technologies. There may be some game changing technology out there that could be adapted for geothermal energy but often drilling faster is not the only answer to reduce costs. While, oil and gas developers can already drill hundreds of feet an hour other factors can limit performance. For example, by drilling faster they have had to figure out how to handle drilling cuttings in a more efficient manner, however, in geothermal power it's important not to drill too fast and make a mistake. With geothermal power it's important to get those first wells right to reduce costs over the long haul of the project.

***What are the panel's opinions on the cost and benefits of drilling insurance?***

There are benefits to vibration control insurance with inspections regularly.

- The insurance that a developer can buy from the vendors does not cover the whole cost of the tool.
- The premium is very high for insurance on a well. Well output insurance – the cost of the well if it is a dry well—can be a scale (about 20% cost of the well). The developer has to do seismic in Germany, but not elsewhere.

***Are there any recommendations on rotary or top drive rigs?***



Top rod rigs are good to drill the well in and drill out. They are a little bit of added insurance. It is also a time saver. Top drive rigs seem to be preferable since the driller can do casing while drilling.

## Session 4: What are the best approaches to ensure successful geothermal project management?

### Speakers

Tim Williamson, Deputy Director in the Office of Alternative and Renewable Energy

Mike Long, Vice President of Galena Advisers, a division of Power Engineers

Bob Sullivan, SVP of Business Development, Ormat Technologies

The focus of this discussion session was to tackle some of the relevant problems related to proper implementation of a project management program. A good project management program looks at the key tools for the project developer to manage and mitigate the risk factors in a geothermal program.

This session touched on the following five topics.

1. Key Stages of Project Implementation
2. Decision Gates
3. Factors Impacting Each Stage of Implementation
4. Risk Factors at Each Stage
5. Project Management Tools to Mitigate Risk

Furthermore, as mentioned by topic one above, it is important to understand the key phases of a geothermal power project's development as described by the speakers: (1) Market and Portfolio Analysis, (2) Pre-Development Assessment, (3) Development, (4) Financing, (5) Project Execution, (6) Operations and Asset Management. The panel emphasized the importance of the initial \$1 to \$2 million expenditure during the initial analysis of the project. A diligent and thorough geological reconnaissance and market analysis will determine the viability of moving forward to the more capital intensive exploration stage of the project.

### The Key Decision Gates

The speakers emphasized key decision gates", listed below, where the project's developers should decide to advance the geothermal project or not, they are listed below, and described later in this section.

Gate 1: Fatal Flaw Analysis (Market Analysis)

Gate 2: Project Go - No Go (+/- 30% Financial Accuracy, Pre-Development Assessment)

Gate 3: Project Approval (+/- 20% Financial Accuracy, Development Assessment Decision)

Gate 4: Project Financial Assessment (+/- 10% Financial Accuracy, Management/Board Approval, Close Financing)

Gate 5: Project Testing/Completion (Project Substantial Completion)

Gate 6: Operations Turn-Over (Owner Operation Start)

Gate 7: Warranty/Asset Management (12 Month Warranty)



## The Decision-Making Phases of Geothermal Development

### Market and Portfolio Analysis: Decision Gate 1

This phase of the project represents the initial evaluation of a project opportunity. The developer should implement a rigorous plan of project assessment and fatal flaw analysis. The effort and minimal development capital expended should be focused on increasing the probability for success. Careful project due diligence at this stage of the project should be focused on the viability of proceeding to the more expensive pre-development stage of the program.

#### Key Factors:

- ✓ Definition of Market Pricing and Market Access
- ✓ Site Availability Assessment
- ✓ Site Priority Assessment
- ✓ Strategic Assessment
- ✓ Transmission Assessment
- ✓ Surface Exploration – Geo Mapping
- ✓ Geophysical Assessment
- ✓ Geologic Model
- ✓ Geothermal Development Agreement

#### Risk Factors:

- ✓ Does the regulatory framework allow market access?
- ✓ Is market pricing structure adequate to support project?
- ✓ Can you obtain site control?
- ✓ Do you have adequate development capital to mitigate risk factors?
- ✓ Does the geological/geophysical assessment provide an adequate indicator of viable geothermal resource?

#### Project Management Mitigation Tools:

- ✓ Experienced development project manager and resource experts in place
- ✓ Local representation that understands the regional requirements

Decision Gate: Financial Closing – are there identified factors that will prevent the project from moving forward, i.e. legal, regulatory, control, technical or geological?

### Pre-Development Assessment Tool: Decision Gate 2

This phase of the project represents the initial “pre-development” activities required to assess the financial viability of the project. By incorporating the best practices of exploration, the developer can conduct limited thermal gradient, core-hole and slim-hole assessment of the resource. This data will provide key inputs to the evaluation of sizing and technology match of the proposed power plant. The pre-development assessment of the geothermal resource and power plant will set the stage for the initial evaluation of the financial viability of the project.

#### Key Factors:

- ✓ Exploration Environmental Permitting
- ✓ Thermal Gradient Assessment
- ✓ Core Hole Assessment
- ✓ Slim Hole Assessment



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- ✓ Limited Flow Testing
- ✓ Preliminary Financial Model (+/- 30%)
- ✓ Site Control
- ✓ Contracting Strategy
- ✓ Ownership Strategy
- ✓ Pre-Feasibility Study

### Risk Factors:

- ✓ Adequate funding for proper resource assessment (thermal gradient/slim holes)
- ✓ Ownership/Contracting Strategy that supports project development
- ✓ Legal site control
- ✓ Exploration permitting

### Project Management Mitigation Tools

- ✓ Resource assessment funding support (possible risk mitigation funding to support slim hole and thermal gradient assessment))
- ✓ Project strategy defined by structured program, risk mitigation plan and implementation schedule
- ✓ Project pre-feasibility study prepared by qualified consultants

DECISION GATE: Project Go – No Go – Does the pre-feasibility study at a +/- 30% financial accuracy meet the development team project viability requirements to proceed to the expenditure of significant exploration drilling funds?

### Development/ Project Approval: Decision Gate 3

This phase of the project represents the expenditure of the initial high cost high risk exploration drilling funds. The execution of a successful exploration drilling program will allow the development of the detailed technical assessment, preparation of key project contracts/entitlements and completion of the “bankable” feasibility study.

### Key Factors:

- ✓ Development Schedule
- ✓ Project Environmental Assessment
- ✓ Site Agreement
- ✓ Power Purchase Agreement (that supports a business pro-forma)
- ✓ Electrical Interconnection Agreement
- ✓ Project Permitting
- ✓ Water Supply Agreement
- ✓ O&M Agreement
- ✓ Technical and Commercial Assessment
- ✓ Exploration Drilling
- ✓ Reservoir Model
- ✓ Construction Contract/EPC Contract
- ✓ Bankable Feasibility Study & Pro-Forma (EPC + FEED Study)
- ✓ Lender Term Sheet Commitment

### Risk Factors:

- ✓ Sufficient equity to fund exploration drilling program





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- ✓ Development of key project agreements and entitlements (permits)
- ✓ Accurate and financeable feasibility study
- ✓ Reservoir capacity to support long term plant operation

### Project Management Mitigation Tools:

- ✓ Exploration drilling funding support (possible risk mitigation funding to support initial exploration drilling program)
- ✓ Flow test calibrated reservoir model – with production/injection plan
- ✓ Defined project management plan
- ✓ Financing plan integrated with project requirements
- ✓ Experienced contractors, key equipment suppliers, consultants
- ✓ Development of “bankable” feasibility study
- ✓ Early involvement of financing partner(s)

DECISION GATE: Project Approval – Does the project support the developer’s project economic requirements and meet the lender’s financing requirements? Are the key contracts/entitlements in place and ready for execution?

### Financing: Decision Gate 4

This phase of the project represents the execution of necessary contracts, entitlements and management/board approval to proceed with the project and finance the project. The financing phase also represents the completion of all conditions precedent to allow release of funding to the project.

### Key Factors:

- ✓ Lender Review – Credit Approval
- ✓ Independent Engineer Review
- ✓ Independent Resource Assessment Review
- ✓ Credit Term Agreement Completed
- ✓ Agreements Finalized (PPA, Interconnection, EPC)
- ✓ Environmental and Regulatory Permits Complete
- ✓ Complete Conditions Precedent
- ✓ Sign Financing Agreement
- ✓ Corporate Social Responsibility

### Risk Factors:

- ✓ Project is financeable
- ✓ Credit Term Agreement supports the financial requirements of project

### Project Management Mitigation Tools

- ✓ Engage Financial/Transaction Advisor with experience in geothermal sector
- ✓ Engage key experts (insurance, legal, environmental)

Decision Gate: Financing and Start Project – Does the project have necessary internal and external approvals to allow closing of financing and start of the project?

### Project Execution: Decision Gate 5

This phase of the project represents the execution of the production drilling and surface facilities (gathering system, power plant and transmission interconnection). This represents the highest cost expenditure portion of the program, but the risk profile of the project is significantly reduced through



## Best Practices for Risk Reduction Workshop



the project management and due diligence efforts accomplished in phases 1-4. During this phase of the project, the project will be constructed, commissioned and tested to the requirements of the project contracts. A key focus of the developer will be to manage the schedule, budget and project performance under the requirements of the terms of the project and credit agreement.

### Key Factors:

- ✓ Loan Terms Management
- ✓ Production
- ✓ Engineering, Procurement, Construction – Plant, Gathering System, Interconnection
- ✓ Commissioning and Start-up
- ✓ Testing
- ✓ Commercial Operation

### Risk Factors:

- ✓ Execution of production drilling program under performance, budget and schedule requirements
- ✓ Execution of project construction to the performance, budget and schedule requirements
- ✓ Proper plant technology selection

### Project Management Mitigation Tools:

- ✓ Production Drilling (possible risk mitigation funding to support production and injection well drilling)
- ✓ Adequate company financial strength and contingency to overcome risks
- ✓ Project management and financial controls structure
- ✓ Experienced project execution team; including OE, accounting, controls

**DECISION GATE: Project Completion** – Has the project been properly constructed, commissioned and tested in accordance with the project requirements? Has the developer issued the “substantial completion” notice to the contractor that the conditions of the construction contract have been satisfied and project is complete?

### **Operation and Asset Management: Decision Gate 6 & 7**

These phases of the project represent the transition of the project from a development effort to an operating and sustainable asset. Key to this phase is the completion of all project testing, operations/maintenance training and development of processes to allow the turn-over of the project from the development/construction team to the operations team. This phase of the project also represents the development of a long term strategy for the proper operation of the surface facilities and management of the geothermal resource to assure the long term availability/capacity of the plant and the sustainability of the geothermal resource.

### Key Factors:

- ✓ Plant O&M
- ✓ Well field O&M
- ✓ Reservoir Management
- ✓ Financial Management
- ✓ Loan Management

### Risk Factors:



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- ✓ Proper resource management program
- ✓ Production well make-up drilling and rehabilitation
- ✓ Proper plant operation program

### Project Management Mitigation Tools:

- ✓ Experienced resource team, integrated with the plant operations team
- ✓ Adequately funded drilling and maintenance reserve accounts
- ✓ Properly trained operations team
- ✓ Adequately funded O&M budget

Decision Gate: Project Turn-over – Does the project meet operational requirements and is it ready to be turned over to the operations and maintenance team?

Decision Gate: Warranty – Does the project satisfy the required warranty requirements of the performance contract (typically 12 months) and is it ready to be turned over for long term asset management?

## FAQs and Answers

***What should the industry do for governments that don't provide sovereign guarantees? For example, the World Bank fundamentally, provided a real challenge for companies in past dealings.***

The challenge seems to be a lot of early stage projects that cannot get over the hurdle of three slim holes. It's important to do a feasibility study at this point. You have to convince yourself that you have enough data to "go." In addition, develop a realistic schedule, start working on permitting program and look at environmental issues with the project.

Lastly, weigh the benefits versus the potential costs. Plan for delays, work on reservoir models, start drilling holes, build an EPC contract that is bankable, look for legal oversight, market oversight, and obtain a preliminary document signed by a potential lender. The developer needs sufficient equity to fund the drilling program. If the developer still has not reached financial closure, drilling is a \$25 million part of the program. Does the project finance make sense? Is the reservoir big enough and sustainable? Find a way to come up with financing for the project.

For example, if the project has drilled three successful slim holes and you bring that data to the World Bank, but the developer still doesn't know where the reservoir is, from the bank perspective these are wells that can do long term testing.

***What would be the correct mix of financing?***

It all depends on the scenario, and is hard generalize. The developer is not going to see a whole loan, but at least 50% equity. Then the project could be back leveraged. Today, due to internal grant culture and credit there are no limits. If the developer can eliminate some of the risk with insurance then you can have a more complex financing. If IFC were an equity investor it could be convinced that the resource potential is there. However, sometimes, the IFC can be really restrictive in how it gives grant money.

***Developers need to understand that there is credit culture with large development banks. These banks do NOT have an equity perspective or a grant perspective that other project funders might.***

The project must make economic and geologic sense. A successful exploration fund program mitigates developer risk for prudent, disciplined developing projects and includes the following qualifications to borrow from a development bank.



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1. Pre-exploration and Geologic modeling
2. Project feasibility
3. Permits for exploration and drilling activities
4. Plan of development
5. Bankable PPA
6. Temperature/Permeability/Chemistry

And as a result, low interest non-recourse loan or a similar instrument can be used for resource confirmation expenses. The methodology summarized above is how funds in Indonesia contemplate grants.