Workshop for Enhanced Geothermal Systems Technology Evaluation,

June 7-8, 2007

Washington, DC

Executive Summary

A 2006 report by the Massachusetts Institute of Technology (MIT) entitled *The Future of Geothermal Energy* provides a thorough evaluation of the United States' geothermal energy potential. The study concluded that, through engineering of geothermal reservoirs (Enhanced Geothermal Systems), as much as 100,000 MW of electrical energy could be in place in the United States by the year 2050. This major study provides a strong argument that with appropriate and reasonable investment from the public and private sectors, geothermal energy could make a substantial contribution to the nation's energy portfolio.

The MIT report further concludes that there are no insurmountable technological obstacles. Most of the essential technologies already exist and are being used either by the geothermal industry or by the oil and gas industry. Although, in some cases, these technologies need improvement or need to be adapted to enable large-scale economic development, nothing suggests that they cannot be improved to the degree required.

To clarify and evaluate the assumptions, analytical methods, and conclusions presented in the MIT report, the U.S. Department of Energy (DOE) Geothermal Technologies Program (GTP) conducted an Enhanced Geothermal Systems workshop on June 7th and 8th, 2007, in Washington, DC. The workshop was attended by public and private sector experts in geothermal and related technologies. This workshop had two parts:
1. Evaluate the January 2007 MIT analysis "Enhanced Geothermal Systems, the Future of Geothermal Energy", and
2. Define the technical gaps and barriers to widespread industrial practice of enhanced geothermal systems technology.

Key individuals from the MIT panel described the study's objectives, assumptions and uncertainties, methods, and results. Panel members also identified technology gaps and barriers to development that must be overcome in order to make EGS technology economically viable.

The workshop participants concluded that the MIT analysis was comprehensive and the assumptions and models were properly addressed and applied. The workshop participants agreed with the MIT analysis that the most recent data and experience supports the potential of enhanced geothermal systems to provide a substantial contribution to U.S. energy needs. While

there are some uncertainties in the analysis and gaps in available data, the study presents the EGS opportunity in a thorough and realistic manner.

The workshop participants identified four key technological areas that the DOE needs to thoroughly evaluate and test before economic viability can be confirmed and EGS can move on to commercialization. These are: (1) the ability to attain sustained production of 200^{o}C fluid at a rate 80 kg/sec to be capable of generating 5 MWe per production well. In comparison, no EGS project has attained flow rates in excess of ~25 kg/sec; (2) demonstration of long-term sustainability. This requires stimulation and maintenance of an adequate volume of reservoir rock; however, actual existing and past stimulated volumes have not been reliably quantified; (3) that there is sufficient surface area in the reservoir for efficient heat extraction; and (4) it must be shown that EGS technology that is successful at one site can be applied successfully to other sites with different geologic characteristics.

The Workshop participants recommended that the MIT analysis be used as a starting point for identification and prioritization of the technology improvements required to enable eventual commercialization of EGS by private industry. They also recommended that technology development pathways be defined for the critical technologies of 1) reservoir enhancement/creation, 2) reservoir management and operation for commercial production and longevity, and 3) well field technology, including advanced instrumentation. Although existing energy conversion technology and much of current drilling technology are sufficient for near-term EGS development, advanced technology will be needed to meet the long term goal of 100,000 MWe by 2050.

This workshop was a precursor to three specialist workshops addressing the recommendations above.

1. Evaluation of Technologies for Enhanced Geothermal Systems

1.1. Introduction

Development of a geothermal resource requires a source of heat in the form of hot rock, permeability in the form of connected fractures in the rock, and fluids that heat up as they flow through the rock, eventually reaching the surface to drive a power plant. A large portion of the nation's geothermal resource base consists of hot rock with limited permeability and/or insufficient water for heat transport. The technology required to produce energy from this resource consists of tools that can be used to create a reservoir of interconnected fractures filled with water that cost-effectively captures the heat of the rock. The reservoir and its associated wells, pumps, power plants, and ancillary systems are called an Enhanced Geothermal System (EGS). This is in contrast to naturally occurring hot water reservoirs with adequate permeability for thermal extraction, defined as a hydrothermal geothermal resource.

An 18 - member panel of internationally recognized experts, led by the Massachusetts Institute of Technology (MIT), completed an analysis that demonstrates that EGS represents hundreds of gigawatts of domestic economic potential. The report on the MIT analysis (The Future of Geothermal Systems, MIT 2006) provides a starting point for assessment of the technology required to commercialize this type of system.

1.2. Motivation and Goals

With regard to EGS technology evaluation, the Department of Energy (DOE) is pursuing two objectives:

1. Understand the context, assumptions and uncertainties, strengths and weaknesses, and overall accuracy of the MIT analysis as applied to EGS development, and
2. Identify the technology base that will enable U.S. industry to apply EGS technology and develop geothermal resources to their full potential.

This report primarily addresses the first objective, while identifying additional activities to acquire the knowledge needed for achievement of the second objective.

1.3. Evaluation Process

In order to clarify the MIT analysis assumptions, validate its methods, and verify its conclusions, DOE's Geothermal Technologies Program (GTP) hosted a workshop on Enhanced Geothermal Systems on June 7th and 8th, 2007, in Washington, DC, with experts from geothermal and related technologies. Key individuals from the MIT panel described the study's objectives, assumptions and uncertainties, methods, and results. The MIT panel members also identified technology gaps and barriers to development that must be overcome in order to make EGS technology economically viable.

Following the presentations, work groups met with the MIT panel members in focused breakout sessions to further explore the analytical methods and assumptions, the status of relevant technologies, and deficiencies in existing technologies that should be addressed by research and development. Appendix A lists the affiliation of attending experts from industry, academia, and government.

2. MIT Analysis: General Observations

2.1. MIT EGS Analysis Structure

The MIT panel's report identified the state of the art technologies required to develop an EGS: 1) characterizing the resource, 2) drilling to access the resource, 3) creating or enhancing the reservoir, and 4) designing, constructing, and operating a surface power plant.

The best available information on EGS was collected, along with data on the results and limitations of past and current EGS experiments. The required technologies were characterized through cost-performance models. Development of these models required various assumptions, conversions of data to formulas, and extrapolation of known trends.

The technical analyses were used as the basis for an economic evaluation that was designed to determine the possibility of being able to develop 100,000 MW of EGS by 2050, and the amount of public and private investment required to achieve that level of penetration. This report examines the MIT EGS analysis procedures that affect future technological needs.

2.2. The EGS Resource

The Workshop participants concluded that the MIT report presents a sound analysis of EGS resource potential and is a significant addition to geothermal literature. The report utilizes the most current data on subsurface temperatures across the United States to estimate heat in place. These data are subject to some degree of uncertainty, but the overall results are credible. The methodology has been described in David D. Blackwell, Petru T. Negraru, and Maria C. Richards (2007), "Assessment of the Enhanced Geothermal System Resource Base of the United States," accepted for publication in *Natural Resources Research.* The MIT EGS report is the best appraisal of the resource available for EGS development to date. The resource estimates, including the temperature-at-depth projections, provide a significant consolidation of data, and represent a valuable extension of existing literature.

The basic technique combined heat flow data, a general representation of geologic lithology, and thermal conductivities for the rock underlying the contiguous United States in a GIS (geographic information system) model to calculate the temperature at depths from 3 to 10 km. The modeled volume was then segmented into 1 km thick vertical slices that were subdivided into horizontal parcels 8 km on a side, and the mean temperature was calculated for each 8 km x 8 km x 1 km volume element and was used to estimate the heat in place. Oil, gas, and water well bottom hole temperatures were used to validate the predicted results. Beyond about 5 km depth, well data are quite sparse, which increases the uncertainty of the results.

Since the United States Geological Survey's (USGS) estimate of hydrothermal-geothermal resources (Muffler, 1979) includes only the portion of the resource base shallower than 3 km, the MIT analysis does not include the thermal energy contained in hydrothermal resources identified by the USGS. Some geographic areas were also excluded because they cannot be developed (state and national parks, national monuments, urban areas, military bases, and other special use areas). Recent work on mapping of Federal lands allowed an accurate representation of these exclusion zones.

Estimation of the recoverable resource and the amount of energy that can be generated required additional assumptions, but the results are credible. The resource estimates, including the temperature at depth projections, provide an impressive synthesis of data from the available literature. The MIT EGS report is considered to be the best appraisal of the resource available for EGS development to date.

2.3. Drilling to Access the Resource

The MIT report provides an excellent summary of the state of the art in geothermal drilling technology, as well as a cogent, detailed description of well cost estimating models used to support the report's economic analyses. The MIT analysis indicates that reasonable first targets for EGS development can be accessed with existing geothermal drilling technology.

The MIT report used well costs from the third quarter of 2004 as the basis for economic calculations. The well cost models used are based on experience and have been validated with many years of field data. Below 15,000 feet depth, uncertainties in cost modeling increase because of trouble costs and a relative lack of experience at greater depths.

Overall drilling cost varies as a step function with depth due to the addition of extra casing strings. Calculation of the effects of variables such as rate of penetration and production diameter on well cost showed that increased rate of penetration is a minor part of the challenge of reducing the cost of the well. Other factors dominate the cost. The competition with oil and gas companies for drilling rigs also adds const uncertainty to the analysis.

The learning curve for drilling is based on case studies that quantify the benefits of rig crews learning how to do the job better, improved best practices, and deployment of superior technologies. Drilling cost reductions are expected to occur though improved operational knowledge of the environment and advances in technologies available to the driller. While there are uncertainties in the magnitude of the learning effect, field data validate the impact of learning on costs.

The MIT report notes the need for electronics that operate for long periods at high temperatures. The availability of suitable tools for drilling, logging, and monitoring of reservoirs over 200°C is quite limited. The high cost of tools lost or damaged within geothermal reservoirs has limited geothermal data collection. The list of potentially valuable technologies includes tools to provide the driller with real-time data such as downhole pressure, high-temperature casing inspection tools, borehole imaging tools, high-temperature down hole seismic packages, and numerous others. High-temperature batteries were cited as a technology gap. While the discussion on drill bits is fair and accurate, the report does not provide any recommendations regarding drill bit needs for EGS development.

Since casing represents a significant fraction of the total cost for geothermal wells, the chapter on emerging drilling technologies focused on relatively new oil & gas technologies related to casing design that can be adapted to EGS wells, including expandable tubulars, underreamers, low clearance casing, casing-while-drilling, multilateral completions / stimulation through side tracks and laterals, and well design variations. Because of differences in well diameters, cementing methods, and some materials, technology transfer activities will be required to introduce these technologies to the geothermal industry. These opportunities are mentioned in the MIT analysis, but were not considered in the economic evaluation. Because the MIT analysis is based on existing technology and does not include assumptions on technical advancements, the results tend to be conservative.

2.4. Reservoir Enhancement/Creation

The MIT analysis is based on the techniques for reservoir enhancement and creation used by the oil & gas and mining industries (primarily hydraulic fracturing, but potentially including chemical and explosive techniques).

The most significant uncertainties in the entire analysis are the flow rate that can be achieved in an enhanced reservoir and the thermal drawdown associated with this flow rate. The answers to both these questions are currently unknown, but the MIT analysis assumed a value of 80kg/sec (equivalent to a good naturally occurring hydrothermal reservoir). Enhancing a reservoir to produce 80 kg/sec is obviously the critical goal that must be achieved to reach the development potential cited by the report, as confirmed by sensitivity analyses. This is a reasonable target, but at present there is no experimental evidence to indicate that this productivity can be achieved. The EGS project at Soultz, France, which is the best-performing project to date, has demonstrated about 25 kg/sec well productivity. This appears to be a simple issue; however, embodied in it are all the elements that go into creating an economic EGS installation.

The report does not specifically address issues related to reservoir formation that may affect the impact of EGS over time, such as the feasibility of enhancing the reservoir in different stress regimes. However, the analysis provides insight into issues and needs related to reservoir formation based on experience from prior EGS projects. The primary conclusion from previous

EGS projects is that EGS has been shown to be technically feasible. The major challenges are to improve the performance, demonstrate long-term productivity, and reduce the risks and costs to establish commercial viability.

2.5. Energy Conversion

The MIT analysis of the EGS energy conversion system was based on the premise that energy conversion systems would be the same as those used with liquid-dominated hydrothermal resources at similar temperatures (flash steam and binary power cycles). This is a reasonable assumption, because any differences between the fluid produced from a hydrothermal resource and that produced by an EGS resource are unlikely to affect energy conversion systems. The overall approaches used in the MIT study, along with the cost and performance results obtained, are sound. However, because energy conversion efficiencies have a linear influence on the calculated recoverable resource, errors in assumed energy conversion efficiencies may represent a minor source of error in resource calculations.

Different types of energy conversion systems were optimized for different temperatures of produced fluids. Cost estimates were based on a model from GeothermEx that was adapted to fit the MIT group's analysis. Uncertainties in plant costs contribute a relatively small amount of uncertainty to the analysis. The thermodynamic analyses are based on well-understood and well-founded assumptions and data. The learning curve for plant costs may be optimistic, and the long-term cost was based on the judgment of the MIT panel. In the expected temperature range, the first EGS plants should be built with off-the-shelf technology, so additional research is not required for near-term EGS development that is expected to occur in the next three to five years. Expanded research on energy conversion would be appropriate once the initial EGS plants have been in operation for one to three years, and energy conversion will then become increasingly important as a project cost factor. Drilling and reservoir enhancement/creation costs decrease with increasing conversion plant efficiency for a specified EGS system power size or, conversely, for a fixed number of wells and reservoir size, system power output increases with increasing conversion plant efficiency. The MIT analysis did not explore the relationship between drilling and power plant costs.

2.6. Reservoir Management and Operation

The MIT report covered the principal issues involved in managing an EGS system and identified some key technical needs, including methods for assessing and controlling the stimulated volume, heat-transfer area, and flow paths; the development of high-temperature downhole tools, open-hole packers and pumps; prediction and monitoring of rock-fluid interactions; and improved reservoir models. The MIT report is a good starting point for more detailed technical analysis of maximizing flow rate while minimizing thermal drawdown.

The MIT analysis shows that some of the research required to optimize reservoir behavior and extend reservoir life is common to both traditional hydrothermal and EGS system management e.g. advances in downhole instrumentation, tracers, fracture permeability measurement tools, rock property measurement, geochemistry, reservoir models, scaling, dissolution and permeability control, and well bore life. This synergy means the existing hydrothermal industry will benefit from EGS research results.

2.7. Economics Evaluation

The economic calculations involved in the MIT study integrated the efforts of the technical analyses involved in the study within the technical constraints and limitations of those analyses. Because the analyses of various system elements are included, every element of the economic analysis has a different level of risk and different calculation requirements. The amount of integration required makes the analysis complex, but the end result appears sound.

The Geothermal Program's costing model, Geothermal Electric Technologies Evaluation Model (GETEM), was used in a batch processing mode to determine economics and to construct supply curves. Assumptions were made regarding many parameters for each EGS system element, including reservoir productivity, drilling, plant cost, resource depth, interest rates, etc. It was assumed that grid interconnection would not be a major issue. Although stimulation and reservoir connectivity are major issues, it was assumed that stimulation efforts would be consistently effective in creating productive reservoirs. The technical parameters with the highest uncertainty and risk are flow rate per production well and thermal drawdown rate (i.e. reservoir lifetime).

The analysis includes different learning curves for each technology element. Most of the technologies (drilling, conversion, etc.) had individual associated learning curves. For reservoir stimulation and production, learning is transferable across sites. The learning curve for achieving 80 kg/sec flow rates was assumed to be a one-time effect that is completed fairly quickly.

The study uses an equity rate of return of 17%, which corresponds to a fairly risky venture. The drilling cost model used a contingency factor of 20% for trouble costs. Since development of 100,000 MW will require drilling thousands of wells, well characteristics will vary significantly over time and across locations. Similarly, the surface plant can't be defined in great detail, so correlations must be used for modeling. Sensitivity analyses were performed on some variables to enable identification of those associated with more uncertainty and risk. For deeper EGS, drilling costs dominate overall costs.

Evolutionary change from 2004 costs was assumed in drilling technology and learning. Wellcost Lite, a model developed by the MIT Panel's geothermal drilling expert, was used for economic calculations. EGS well costs will vary less strongly than oil and gas wells because there may be less need to deviate the well to find the resource, and is assumed that wells will be drilled more consistently (i.e. trouble costs will be reduced). The analysis assumes that sites are selected to minimize drilling challenges. Drilling to 7,500 meters is believed to be sufficient to reach the goal of 100,000 MW on line.

There are two phases of learning associated with drilling: The first occurs as experience within a wellfield reduces costs, and the second involves incremental improvements in drilling technology over longer periods. Drilling costs in some petroleum fields have been greatly reduced through improvements in drilling of successive wells. Revolutionary changes that are usually associated with intensive R&D are not assumed in the analysis.

Surface technology costs are expected to be relatively stable and predictable compared to other cost elements in the system. Once a reservoir has been created and connectivity has been assured, the cost of the surface plant and the resulting energy production can be estimated without difficulty.

The analysis assumes that the system does not lose any fluid during stimulation and later operation. . For some systems, the cost of water dominates the stimulation cost. Water loss during operation is also a potentially important cost. These are optimistic assumptions and potential cost factors that are not accounted for in the analysis.

The thermal drawdown rate results in re-drilling of the entire system every 6 years. The actual frequency of re-drilling will vary depending on the temperature and initial heat content. Shut-in wells can be reopened after the temperature recovers, but how long temperature recovery will take is still unknown due to lack of experience. The potential for reusing well systems was not included in the model.

The MIT study used two models to determine the economics of EGS; GETEM and MITEGS. These models were used to test and refine each other. Among the parameters used in modeling, the most important were found to be the flow rate per production well (which was varied from 20 to 80 kg/sec); the thermal drawdown rate or redrilling and rework periods (3%/year or 5-10 years) [the parameters are related]; the resource grade in terms of temperature or gradient; financial parameters such as debt-equity ratio and rate of return; and drilling costs. Less important parameters identified by sensitivity analyses included surface plant capital costs, exploration effectiveness and costs, wellfield configuration, flow impedance, stimulation costs, water loss, and taxes and other policy factors. Similar user inputs are required by both models, but there are some differences between the two. Notably, the MITEGS model uses variable charge rates (allowing a more realistic calculation of financial parameters) while GETEM uses fixed charge rates. When charge rates are fixed in MITEGS it generally yields similar results to GETEM for the same scenarios. Stimulation risk is not explicitly handled by either of the models.

Some critical assumptions were made regarding baseload supply and demand. Of the 90 GW of nuclear power in the existing power plant fleet, about half are projected to be retired in the time frame of the study, and about 50 GW of coal generation is also projected to be retired. This turnover in existing plant inventory provides an opportunity for replacement with EGS.

The goal of the economic analysis was to determine whether it is possible to enable development of 100 GW of EGS, and the analysis concludes that it is possible. The major issue is consistent stimulation to create a commercial-scale reservoir capable of sustainable operation at 80 kg/s flow.

The MIT panel estimated that the total R&D expenditure required to achieve competitive costs is approximately $400 million. Performing this R&D quickly allows the technology to start replacing the fossil and nuclear plants that are being retired in the model's assumptions, offering a unique opportunity to expand capacity rapidly.

In the installed capacity - price curve generated by the study [see graphic], the inflection point (minimum) at about 200 MW represents the achievement of technically mature production rates. Subsequent inflection points as installed capacity grows indicate that the technology has moved to another grade of resource.

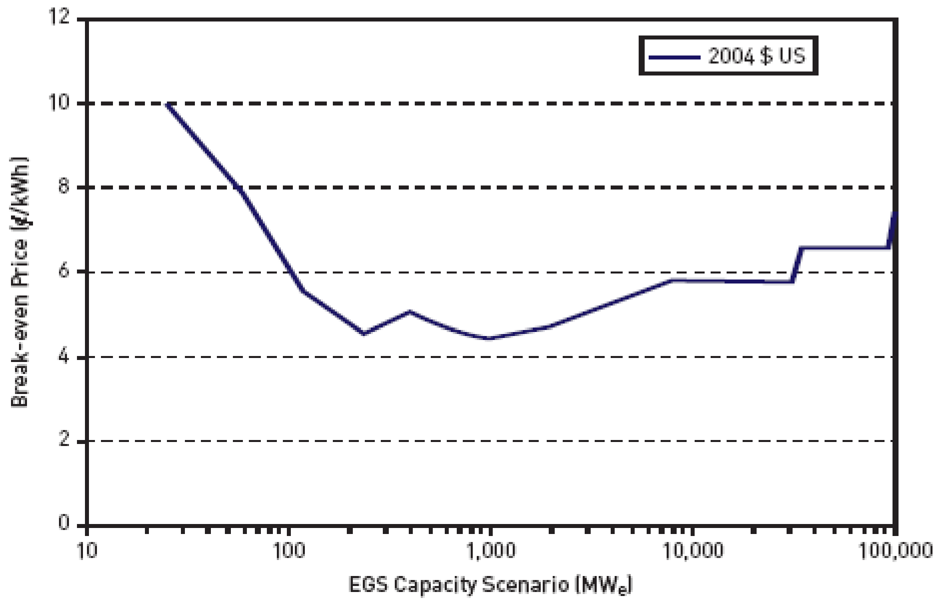

Figure 9.17 Capacity and price relationships for EGS: predicted aggregate supply of base-load power from EGS resources using the MIT EGS, variable rate of return (VRR) model with quartet well configurations (3 producers + 1 injector), and a commercially mature flow rate of 80 kg/s per well.

Sensitivity analyses at example sites (Clear Lake and Poplar Dome) were performed, indicating that flow rates and base heat conditions are the most important variables.

While the method of projecting EGS development potential was discussed in the report, the details of the assumptions made were not explicitly discussed. The Rogers equation, which was used to create the EGS technology adoption curve, requires setting two coefficients that are based on properties of the supply curve. Changing the coefficients would change the end result (i.e. long-term capacity and rate of installation), but because of model mechanics the results early in the period remain similar. The assumption is that funding for development will take place through a public-private partnership for the first seven years (equivalent to the first 200 MW); it was estimated that 200 to 250 MW are required before the tipping point of sustained development by private sector investment is reached. (There is no way to model how much investment by the government would be required before the first private sector partner begins investing.)

The key conclusions of the MIT economic analysis were:

- EGS is a natural, but not inevitable, extension of hydrothermal technology.
- Well field layout configuration and stimulation techniques affect reservoir productivity and lifespan.
- The major technical factor is the effectiveness of stimulation to achieve acceptable reservoir productivity.
- Development shows a high sensitivity to early R&D investment.
- The R&D investment is reasonable compared to other alternative energy programs.
- EGS can provide competitive baseload power in less than 15 years.
- Pursuing EGS aggressively will extend, rather than diminish, the role of hydrothermal power.
- EGS has the potential to supply about 100 GW of generation capacity by the middle of this century.

A sensitivity study examined the impact of plant cost on the cost of electricity, but did not examine how increasing conversion plant performance would impact power costs. For cases where well field and resource development costs are high, increased conversion plant performance would be likely to have an impact on generation costs roughly equivalent to the changes predicted by increasing well flow rate. While existing power plant technology appears adequate for near-term EGS needs, improved conversion technology could positively impact required EGS investment by reducing well drilling requirements or producing more power for the same investment.

The study assumed that a carbon tax of $10/ton equivalent (equivalent to seven to eight mills/kWh) would be introduced beginning in year 10. This tax was included on the assumption that policies would be adopted that would make thermal generation pay some externality cost (either through carbon capture and sequestration, or through a tax on CO_2 emissions). If the carbon tax assumption is dropped, the potential cost advantage of EGS over conventional electric generation is reduced and the rate of EGS penetration is lessened. The MIT analysis did not look at sensitivity to the amount of the carbon tax.

All components of the model have been proven to be technically feasible through numerous field experiments in the United States and the international community. The most important unaddressed variable is the result of applying stimulation technology, where it is unknown whether the necessary level of success can be achieved consistently, especially the reservoir productivity or well flow rate.

2.8. Summary of Factors Affecting Analysis

The authors of the MIT report based their assumptions on results from field tests and published reports. Table 1 is a general listing of assumptions and probable impacts for all areas of the MIT analysis.

Table 1. **Major Uncertainties and Assumptions in the MIT Analysis**

Unknown	Field Variable or Characteristic	Data, Analysis or Assumption	Important Factors	Probable Impact on MIT Conclusions
Temperature at Depth	Temperature	Data, analysis, and assumptions	Some confirmation via well bottom hole temperatures	Minor; affects reservoir depth with some impact on drilling cost
	Heat flow	Numerous data points exist	Evolving and large data bases	
	Thermal Conductivity	Some data, some models, some assumptions on geology	Core data from wells	
	Radioactive Decay	Some data, some models	Good geologic correlation	
Heat in Place –Resource Base	Temperature at depth	Minor assumption on general specific heat	Use of GIS model gives a very large value	Minor; number is so large that uncertainty has little impact
Reservoir Creation	Geologic and rock mechanics	Data	Numerous field experiments show some success	Critical stage gate; field experiments required
Recovery Factor	Reservoir geometry and permeability	Some models, e.g. Sanyal and Butler	Mid-range value of 20%, no real field data, inconsistency between recovery factor, 10°C decline for abandonment and 3%/yr cooling rate	Major; field experiments required
Reservoir Operation and Life	Reservoir productivity	Assumed 80 kg/s	Best Soultz data shows 25 kg/s	Major, field experiments required
	Thermal drawdown	Assumption of 3%/yr is arbitrary	Steamboat and Mammoth plants continue to be profitable with comparable draw downs	Moderate; affects field life or requirements for rework. Field experiments required.
	Reservoir life	10°C bulk rock temperature decline is arbitrary field	model based on analysis-Sanyal and Butler	Moderate; affects field abandonment or rework economics

Unknown	Field Variable or Characteristic	Data, Analysis or Assumption	Important Factors	Probable Impact on MIT Conclusions
		abandonment criterion		
	Water use	Assumed no water loss in fracturing or in operating the reservoir	Cost factor	Minor
Drilling	Drilling costs	Models and data	Data below 5 km is scant	Minor for first plants, significant for maturing technology as reservoirs will be deeper
Energy Conversion	Conversion efficiency	Generalized data	Reflects today's technology, tomorrow's will improve	Minor for initial installations, major opportunity for maturing technology as the conversion efficiency cascades back to drilling and reservoir requirements.
Economic Evaluation	Carbon tax on fossil alternatives	Educated assumption	Likely to happen with increased concern about global warming	Moderate; removes significant part of economic incentive for EGS relative to fossil, slows down the installation profile (new profile not addressed by MIT)
	Learning Curves	Models with some validation, some assumed coefficients.	This is an opportunity to reduce costs	Minor

The recoverability factor is the key assumption. Literature estimates of fraction of recoverable heat range from as high as 90% of the heat in place (at uneconomic low flow rates) to a more credible 42%, given an optimal production strategy. No one has operated a geothermal reservoir sufficiently long or has collected sufficient data to demonstrate an actual long-term recovery factor. The MIT analysis examined the recovery factor parametrically, and then arbitrarily selected a relatively low value of 2% for the economic evaluation. While the choice of recovery factor is subject to debate, the methodology used is sound. Eventual field data will be required to determine actual values for real situations.

The analysis also made the assumption that a well system would be abandoned when the bulk reservoir temperature had cooled by 10ºC relative to the initial bulk temperature of the field. This temperature decrement is conservative because it is less than the amount of cooling in reservoirs that have operated commercially. Examples are the plants at Steamboat in Nevada and Mammoth in California.

3. EGS Technology Assessment

The MIT report does not include a description of research and development required to support EGS commercialization. Additional planning efforts should focus on defining these R&D requirements. The results of the workshop discussions have been used as a basis for identification of additional analysis needs, characterization of technology gaps and research pathways, and prioritization of technology developments associated with the commercial demonstration of EGS. The MIT report does not include a description of research and development required for EGS.

3.1. Major Technology Challenges

Table 2 lists technical needs for near-term EGS development based on technology gaps identified by the MIT panelists and by the participants in the workshop on June 7th and 8th, working in focused breakout sessions. The needs set priorities for the near term, which is representative of the first several GW of EGS installations. As EGS technology matures, the needs and priorities are expected to change significantly. For the near term, the major challenges are to learn how to design and create reservoirs, and how to manage and operate those reservoirs sustainably to provide a base of experience for establishing commercial viability. These activities represent the stage gates for demonstrating repeatable technical feasibility and substantial reduction of risk.

As the technology matures, later activities emphasize reducing costs by addressing major cost factors related to drilling and the power plant. These technology areas are not unimportant, but the emphasis and priorities will change over time. Energy conversion technology is sufficiently developed that a suitable power plant could be built today for an EGS system, although it would not be optimal. Energy conversion research and development can be postponed, but the GTP should track industry developments and respond to any immediate needs. The same is true for most drilling technology, with the exception of some high-temperature requirements.

Table 2 Technical Needs for Near-Term EGS Development

	High Priority	Low Priority
Reservoir Creation	Perform extensive field testing at both sites of opportunity and dedicated sites	
	Improve reservoir design and management tools (models) based on an improved understanding of the effects of geologic conditions.	
	Determine physical, chemical and geologic data to characterize reservoir design and operation	
	Develop criteria for selection of field test sites.	
	Develop better reservoir characterization tools	
Reservoir Management and Operation	Define the effects of geochemistry in sustained operation	Develop alternative reservoir working fluids
	Develop techniques to detect reservoir flow short-circuiting and to seal short-circuits	
	Develop high-temperature pumps and isolation packers	
	Better understand induced seismicity	
Economics	Develop improved analytical models for economic evaluation	
	Collect economic data for validation of economic models	
Drilling Technology	Develop needed high-temperature equipment and instruments	Import developments from oil and gas drilling
		Improve hard rock drilling
Energy Conversion		Develop higher efficiency conversion cycles
		Improve air-cooled condenser performance
		Mitigate effects of seasonal temperature variation on capacity factor for an air-cooled plant
Resource Assessment		Improve EGS national resource data base

3.1.1. Near-Term High Priority Activities

3.1.1.1. Reservoir Creation/Enhancement and Operation

Technology Gap: Fracture creation, enhancement, control, and predictability are not well understood.

Successful reservoir creation requires an understanding of many geologic factors, including

- Achievable fracture aperture, spacing, length, and conductivity.
- Lithology, structure, and stratigraphy.
- Preexisting fractures, especially those susceptible to stimulation.
- Stress field.
- Pore pressure.
- Rock mass mechanical properties.

Predicting the effect of these parameters requires collecting data, developing/improving models, and understanding the boundary conditions that accurately describe fracturing under various conditions. For example, stress conditions have a dramatic effect on the results of stimulation, making stress measurements and the effect of stress on stimulation critical areas of research. Suitable stress environments for reservoir stimulation are uncertain, so tests in different environments will be necessary. This understanding is critical for selection of the initial field test sites.

Technology Development Pathway: Stimulation field tests at dedicated site(s) and sites of opportunity should be performed under various conditions. Data and analysis are critical to determine the effects of variations in geologic parameters. The geologic conditions and stress fields should be extensively characterized before, during, and after fracturing to enable modeling of fracture formation and efficacy under varied conditions. Some of the sites of opportunity may include operating geothermal fields, locations near operating geothermal fields, and abandoned oil or gas fields where relevant data is available.

Technology Gap: Reservoir design and reservoir management tools are not available or are not adequate or model input data is insufficient.

A new generation of comprehensive systems analysis tools is required for effective and economic EGS reservoir management. Mechanistic process-level stimulation models should be extended to account for the physical and chemical phenomena that may occur in EGS reservoirs. The output from these enhanced reservoir models must feed directly into economic and risk models to enable quantitative evaluation of various management scenarios and guide reservoir operation and development. These system analysis tools would both enhance the understanding and forecasting of reservoir evolution, and quantify the economics and risk associated with EGS.

Validated models are needed to enable prediction of stimulation results when multiple fractures are created. Existing models from the petroleum industry are only moderately accurate, and are probably inadequate for EGS because of important differences in rock types and stress regimes. Reservoir design and operation requires understanding and forecasting the mechanics of reservoir evolution. For example, after stimulation the reservoir's fracture system is expected to expand as the rock cools and shrinks, transferring mechanical load to adjacent rock and propagating fractures. Fracture growth is affected by the local and regional stress regimes, so growth might be managed by controlling injection and production well pressures and thermal gradients. As the local stress is relieved due to thermal and pressure gradients, the reservoir grows and the system permeability increases. Once the desired size is achieved, the pressure can be adjusted to prevent further growth and reduce fluid losses.

New numerical models for interpreting tracer tests are needed to obtain more information about the reservoir. Tracers might be able to record subsurface temperatures and the surface area available for heat transfer, which is a critical factor in thermal drawdown. This capability would assist with estimation of site longevity. To facilitate project economic analysis, models must be able to predict system evolution over time. Prediction of reservoir behavior will require an understanding of reservoir physics and chemistry. Physical and chemical reaction models associated with creating and maintaining permeability should be developed and refined. On testing and validation of the underlying physics and chemistry, theoretical models must be integrated into system models of reservoir creation and long-term operation.

Technology Development Pathway: Numerical models of stimulation and system development must be developed, based on an improved understanding of fundamental rock mechanics and the effects of physics and chemistry on fracturing behavior. This understanding should result in conceptual models that can be developed into numerical models. The conceptual models should be based on field experience, and the numerical models should be based on fundamental theory where possible—or empirically based if theory does not yield accurate results. Models should be thoroughly validated with field data, such as fracture field characterization, flow, data and heat transfer data and linked with economic and risk analysis tools.

Many millions of dollars have been invested in understanding fracturing operations in oil and gas applications. The state of the art should be reviewed and available tools should be evaluated. While there are significant differences between geothermal and oil and gas fracturing, there may also be some significant cost-saving synergy in model requirements.

Technology Gap: Physical, chemical, and geologic data are inadequate for characterization of reservoir creation and performance.

Technology Development Pathway: An extensive database should be developed to thoroughly characterize the performance of stimulation and reservoirs at both test and operating sites.

Technology Gap: Site selection criteria are required for selection of the first field test sites.

Field sites representing various conditions appropriate for first-generation EGS are needed to provide field laboratories for collection of data and testing of tools and techniques. Both dedicated sites and sites of opportunity should be used for testing.

<u>Technology Development Pathway</u>: Criteria to rank potential EGS sites are needed. For example, how do you choose between sites when one has higher drilling costs but more favorable stimulation potential? Dedicated field test sites specifically for EGS should be developed. Field testing is required for experimentation in all EGS technology areas. One or more dedicated sites should be selected and developed. All relevant site characteristics should be evaluated, and the sites should have the potential for eventual commercial development. Long-term testing and development plans should be developed and implemented. Sites of opportunity should also be identified where specific field tests can be performed, preferably at commercially developed locations. While field testing will be expensive, it can be done cost-effectively, and it is a necessary element of a research and development program. Industry is unlikely to develop test sites and perform risky experiments on its own initiative, although the Cooper Basin in Australia is an exceptional case that is privately funded.

Typical field experiments will consist of reservoir creation by large-scale fracturing and fluid circulation. Success will be measured by flow volume and the temperature profile over time. The tests will validate techniques and tools for characterizing the reservoir including seismic technology, tiltmeters, and other methods.

<u>Technology Gap</u>: Some required reservoir characterization tools are not available.

Tools and techniques are required to accurately characterize the development, extent, and pattern of fractures, and to predict the performance of reservoirs, including:

- Fracture formation and growth
- Flow channel determination
- Heat transfer characteristics
- Models and visualization techniques

<u>Technology Development Pathway</u>: Tools and techniques must be developed and field tested to validate system performance. Both surface tools and downhole tools must be capable of sustained operation at high temperature in potentially corrosive environments. The tools and techniques should be suitable for both reservoir creation and reservoir operation. Some examples of tools include:

- Advanced seismic techniques
- High-temperature televiewers and downhole cameras
- Next-generation tracers (both reactive and non-reactive)
- High-temperature / high-reliability instrumentation will be required to evaluate fractures (discriminate between open and closed fractures) before stimulation
- Pressure/temperature while drilling tools
- Development of enabling technologies (e.g., safe high-temperature batteries).

- Development of techniques for employing sidetracks and monitoring wells within the reservoir to better understand regional variations in the formation.

3.1.1.2. Reservoir Management

Technology Gap**:** The effect of geochemistry on sustained operation of geothermal reservoirs is not well defined.

Naturally occurring hydrothermal reservoirs start in geochemical equilibrium with the surrounding rock, with a transition to a non-equilibrium state as operation continues. EGS systems begin and remain in a non-equilibrium state. Depending on the chemistry of the formation, solubility and precipitation can affect flow channels, surface equipment, and injection wells.

Technology Development Pathway: A thorough understanding of the geochemistry of EGS systems must be developed. This involves refinement and generalization of existing models of multi-component solutions, collection of input parameter data, and field validation of the models.

Technology Gap: Reservoir flow short-circuiting is not well understood, and techniques for sealing short-circuit pathways are not available.

During reservoir operation, preferential flow paths may develop that reduce the amount of time that circulating water remains in contact with the hot rock that forms the fracture walls, effectively reducing the size of the subsurface heat exchange system and leading to a reduction in the temperature of the water produced at the surface. This lower temperature adversely affects energy production.

Technology Development Pathway: Sealing agents should be developed for short circuited fractures. The oil and gas industry uses sealing agents to close fractures that adversely affect production. Fluids with variable rheology and sealing agents can be used to control the growth and style of fracturing, or to divert chemical treatments from fractures that are already permeable. These chemicals cannot be used by the geothermal industry because they break down in geothermal temperatures and chemistries, and because the tools needed to isolate problematic sections of geothermal wells (packers and diverters) are not commercially available. Sealing agents analogous to those used in oil and gas reservoirs, but capable of working at high temperature, must be developed to allow both mitigation of flow in critical areas during stimulation, and repair of short circuiting that cools production wells. It may also be possible to block off short-circuiting by placing a liner across the cold water interval. Such technology exists in oil & gas operations (expandable tubulars coated with elastomeric seals for example), but such technology must be adapted and proven for high temperatures. In addition to mitigating short-circuiting, work is needed on how to design the reservoir and well completions to minimize short-circuiting potential.

The effects and benefits of these technologies have not been incorporated in existing models. The ability to model the effects of sealing agents and flow diverters must be added to existing reservoir models.

Technology Gap: Some types of equipment are not suitable for operation at temperatures much greater than 150°C to 200°C.

Technology Development Path: Researchers should work with industry as needed to develop and field-verify appropriate high temperature equipment such as:

- High-Temperature Deep-Set Pumps and Cabling: Pumping is frequently required to achieve adequate flow rates to make a project economic. Pumps can enhance production without affecting permeability, reduce parasitic power for injection, enable the use of wells that otherwise would not produce sufficient fluid for economic operation, and could extend the life of a field and improve economics.

- High-Temperature Isolation Packers: Open-hole isolation packers, frequently used in the oil and gas industry, are a critical path technology for stimulating specific zones of a geothermal well. Target zones for fracturing are isolated by setting casing above the zone to be stimulated and then fracturing the section below. Borehole packers cannot be used to isolate zones in rocks above 175°C. Packers set in steel are available, but open-hole isolation packers are not reliable in high-temperature geothermal environments. Chemical isolation methods (such as sodium silicate) can be used to create a temporary plug around the well bore to isolate a zone.

Technology Gap: Induced seismicity is poorly understood. During the creation and operation of a reservoir, microseismicity commonly occurs. Microseismicity is a critical analytical signal for reservoir growth and characterization. Additional instruments and techniques are needed for reservoir mapping with respect to time.

Geothermal energy production is occasionally associated with seismic events large enough to be felt by people nearby. Repeated seismicity may cause structural damage to buildings and create a public nuisance. Because the geomechanical processes that cause seismicity are not fully understood, research into induced seismicity is required to determine risk and identify mitigation strategies. This is considered to be a public relations challenge rather than a major problem.

Technology Development Pathway: The Program should develop analysis tools to predict induced seismicity thresholds. The background baseline for seismicity should be measured before and after stimulation. Techniques should be developed to allow better use of microseismicity for mapping the reservoir and determining changes with use and cooling.

Developers can learn to mitigate the risk or perception of risk by the public, but until the learning process is complete, development should only be undertaken in unpopulated areas. An early warning device should be developed for induced seismicity near urban areas. The geothermal industry must be able to determine why geothermal stimulation causes felt events while oil and gas stimulation does not appear to have a significant problem with seismicity.

3.1.1.3. Economic Evaluation

Technology Gap: Better analytical models are needed. There are some limitations in the GETEM and MITEGS models used in the MIT analysis, particularly in the lack of detail in some areas of the models. The low level of detail limits the models' ability to determine the effects of some performance enhancements associated with research and development.

Technology Development Pathway: A performance/economic evaluation model with extended capabilities should be developed. An economic model capable of accurately modeling site-specific costs and predicting the cost of energy for geothermal development projects should build on existing models and cost and technical data generated by the program's experimental work. The model can be used both to predict system cost and performance, and to calculate critical metrics that can be used to track the progress of research and development.

Technology Gap: Insufficient validated data are available for use in analytical evaluations. Numerous assumptions were required for performance of the MIT analysis and other EGS evaluations, such as a recent evaluation by GeothermEx.

Technology Development Pathway: A database of economic and performance metrics should be developed and populated with data on relevant factors. Information requirements include:

- The overall cost to produce a reservoir with a given flow rate.
- The cost of identifying the resource as a function of depth
- Recovery factor
- Temperature decline as a function of production strategy
- Drilling costs and cost factors
- Power plant costs and efficiencies
- Water use and costs
- Supporting data on learning curves.

3.1.1.4. Wellfield Construction

The workshop participants emphasized that the near-term focus of EGS efforts should be on the technologies needed to create the subsurface fracture network that forms the heat exchanger. The initial EGS projects probably will not operate above 200ºC, and existing drilling technology, while not optimal, is adequate to demonstrate/validate the ability to create a reservoir. With this premise, only select areas of drilling technology are a high priority in the near term. As reservoir creation technology improves, the priority for both drilling and energy conversion will increase to reflect the effect of these major cost components on system economics.

Technology Gap: Some types of equipment are not suitable for operation at temperatures greater than 150°C.

Most electronics have temperature limitations of 150°C. Instruments for drilling, logging, and monitoring of reservoirs in the 200°C range are available, and issues associated with high-temperature tools have not been solved.

Technology Development Pathway: Most components of any hardware system are more expensive and more likely to fail when operated at high temperature. Although technology is in hand to answer some of these problems, the difficulty in designing geothermal equipments exists because there are threshold temperature for electronics batteries, seals, and sensors, and these thresholds are below the limits needed form many geothermal resources.

Most electronics have temperature limitations of 150°C. Few tools for drilling, logging, and monitoring of reservoirs at temperatures above 150°C are available, and issues associated with high-temperature tools have not been solved. High-temperature, high reliability electronics are an enabling technology for several items mentioned as high priority. Improved high-temperature tools and electronics with longer service lives at high temperature should be developed. The MIT report states that batteries are an issue, but this underemphasizes the importance of high-temperature secondary (rechargeable) batteries for drilling, logging, and monitoring tools. These batteries would provide significant costs savings and reduce safety hazards in geothermal environments.

3.1.2. Long-Term Low-Priority Activities

3.1.2.1 Reservoir Management

Technology Gap: Alternative reservoir working fluids have not been investigated.

Water is probably suitable for near-term EGS reservoir creation. In the longer term, alternate fluids similar to those used in petroleum stimulation may be needed, particularly for reservoir management. The most typical is potential use of supercritical carbon dioxide, CO_2. Increasing concern for global warming has increased the possibility of CO_2 injection for long-term storage or sequestration. CO_2 can be used as a fracturing fluid, or as a potential working fluid in reservoirs with little or no water.

Technology Development Path: The program should evaluate opportunities for using alternate working fluids such as supercritical CO_2 in the geothermal environment. This could foster synergy between petroleum and EGS because of petroleum industry interest in CO_2 floods and the properties of CO_2 under geothermal conditions. The first evaluations should be paper studies, and CO_2 sequestration experience should be tracked. An EGS field experiment using CO_2 would be justified only if the analyses and field sequestration results show significant promise.

3.1.2.2. Wellfield Construction

Technology Gap: Geothermal wells are more expensive than oil and gas wells. Geothermal wells tend to be drilled to greater depths in hotter and harder rock than oil and gas wells, although the environments are slowly converging. Geothermal wells are more challenging than petroleum wells for several reasons. The rock is usually harder, fractured, and more abrasive. Production casing in geothermal wells is generally cemented to the surface, unlike in oil & gas wells. The oil & gas industry's massive support infrastructure provides greater access to cost reducing technologies not available to the geothermal industry (MWD, high performance bits, expandable tubulars, underreamers, etc.). Also, geothermal wells target specific locations within a fracture system, while oil and gas wells target broader locations within reservoirs. Borehole diameters are also greater for geothermal wells.

Technology Development Pathway: Oil and gas, minerals, and water well technology should be adapted to geothermal practice. Geothermal RD&D should address only specific drilling technologies that are required to meet EGS development challenges, and should strive to build on existing drilling technology whenever feasible.

3.1.2.3. Power Plant

Past experience with EGS field experiments has shown that off-the-shelf power plants are adequate for initial EGS development, making any power plant research and development lower priority for the near-term, as with much of the drilling research and development. Power plant improvements will be required as EGS begins to be commercialized, raising the priority at that time. Power plant conversion efficiency cascades into drilling and reservoir requirements: higher conversion efficiency allows fewer wells and smaller reservoirs, and attendant lower capital investment.

Technology Gap: Higher efficiency power plants may be required to improve EGS economics.

Improved cycle performance (specific power output or brine utilization) will benefit EGS applications which have high well field and resource development costs. Efficiency improvements of up to 20% could be achieved relative to current conversion technologies, though these improvements may increase plant capital costs, which will diminish the impact on cost of power. Technologies that could improve plant performance have not been adapted because of cost and uncertainty regarding their effect on component sizes (particularly heat exchangers). Industry has been unwilling to accept added costs or incur the risks associated with design uncertainties. These issues will remain for EGS conversion systems, but in the long term the benefits of more efficient power cycles will become increasingly significant.

Technology Development Pathway: Develop more efficient conversion cycles.

Because initial EGS development projects are expected to utilize off-the-shelf technologies, there is no immediate need to identify and develop improved power cycles. Research should be conducted on improved cycles as production fluid information is generated and needs are defined during initial EGS tests. A study should be conducted that focuses on identifying improved energy conversion systems tailored for EGS.

Technology Gap: Air-cooled condenser performance can be improved.

For an equivalent level of power production, a geothermal plant is estimated to require four to six times as much condenser make-up water as a fossil fuel plant. The additional water consumption may be acceptable for any given plant, but replacing 100,000 MW of fossil generated power will require a significant amount of water. The magnitude of water consumption makes it likely that EGS plants (including those using flash-steam conversion technology) will use sensible rather than evaporative heat rejection systems. Because air is a poor heat transfer medium, these heat exchangers will be large and expensive.

Technology Development Pathway: Improved air-cooled condensers should be developed. Research has identified potential condenser improvements that could reduce costs and/or increase power output. Additional research would reduce capital costs, increase power output, or reduce geothermal fluid flow requirements, potentially increasing generation or decreasing flow requirements by 10% to 20% in comparison with air-cooled condensers in existing hydrothermal plants.

Industry should become increasingly involved as research progresses, leading to cost sharing for a field test to demonstrate the benefits of the technologies. Because there is potential benefit to industries other than the geothermal industry, the federal government's role should diminish as this effort nears final field testing.

Technology Gap: The capacity factor of an air-cooled EGS plant varies seasonally.

Air-cooled condensers have poorer performance in the summer, increasing turbine back pressure and reducing power output. Some variation in performance can be reduced by optimizing the design to mitigate the effects of declining resource temperature, either by choosing design conditions that reduce variations in performance over the life of the plant, or by incorporating new technologies. Evaporative cooling can be added to a sensible heat rejection system to mitigate the effects of high ambient temperatures on an air-cooled plant. This consumptive use of water will have to be evaluated on a project-by-project basis to determine whether it is viable. This activity will benefit hydrothermal resources as well as EGS.

Technology Development Pathway: The benefits of hybrid cooling or evaporative cooling enhancements should be assessed.

A paper study should be conducted. Because intimate familiarity with power plants is required, this study may be best accomplished through a solicitation to industry. The results may provide justification for research in specific areas.

3.1.2.4. Resource Assessment

Resource assessment is required for general characterization of potential sites and for identification of the most likely sites for early development. The data required to characterize general potential has gaps, but these are considered lower priority. Collecting the data required to identify the best sites for early development is a high priority. The site identification data will probably require drilling or use of data from existing wells.

Technology Gap: Resource data has significant gaps.

Heat flow maps showing temperatures at 6 km are used to identify areas of interest for EGS. There are large gaps in heat flow data in some areas of the country.

Technology Development Path: Existing geothermal resource assessment efforts should be continued and extended. High-quality work being performed at SMU and elsewhere is important to EGS development. Higher resolution is needed, which will require drilling wells in some areas. More detailed information is needed on basement rock types, and the information must be correlated with heat flow information to identify site potential. The program should continue to collect and compile well bottom hole temperatures for use in validating temperature projections. The ongoing work by the United States Geological Survey to update Circular 790 should be used to expand this database, as should work with state geological surveys and offices. This effort is expected to require several years.

4. MIT Analysis: Overall Conclusions and Recommendations from the Workshop

The MIT report, *The Future of Geothermal Energy,* provides a comprehensive evaluation of geothermal energy potential in the United States. This study provides a convincing argument that with an appropriate national commitment, indigenous geothermal energy can play a substantial role in the nation's energy portfolio. 100 GW can be a reasonable goal for installation domestically by the middle of the 21st Century.

The MIT EGS analysis combines the best available data and expert opinion to construct a model of both the technical and economic potential of Enhanced Geothermal Systems. The method is sound and conservative, and the assumptions appear to be realistic. While the analysis is not without uncertainties and gaps, it does properly represent the EGS opportunity in a complete and unbiased manner.

The expert work groups at the June 7, 8 workshop convened by DOE's Geothermal Technologies Program recommended that the MIT EGS analysis be used as a starting point to define the R&D activities and additional analyses required to enable private industry to commercialize EGS technology. Recommended general activities include: collection of additional information and analysis of technical gaps, barriers, and improvements required for: 1) reservoir enhancement/creation; 2) reservoir management and operation for sustainability; and 3) drilling technology, including advanced instrumentation capability. For the near term, existing conversion technology is sufficient for EGS needs; advanced technology will be needed in the long term.

Additional data should be gathered on reservoir creation/enhancement, reservoir management and operation, and drilling technologies. Although economic evaluation is important, the needs and opportunities are cross-cutting and should be embedded in the technology areas. Existing power plant technology and much of drilling technology is deemed adequate to satisfy near-term EGS needs, and detailed R&D can be postponed for a period, although industry needs and advances should be tracked.

4.1. Workshop Format and Agenda

THURSDAY, JUNE 7, 2007

8:00 a.m.	**Attendee Check-in and Continental Breakfast**
8:30 a.m. – 8:40 a.m.	**Welcome** Allan Jelacic U.S. Department of Energy
8:40 a.m. – 9:00 a.m.	**The Geothermal Opportunity** Samuel F. Baldwin U.S. Department of Energy
9:00 a.m. – 9:30 a.m.	**The Structure and Outcome of the Analysis** Ron DiPippo Consultant Jefferson Tester (by phone) Massachusetts Institute of Technology
9:30 a.m. – 10:00 a.m.	**The Geothermal Resource** David Blackwell Southern Methodist University
10:00 a.m. – 10:30 a.m.	**Break and Networking**
10:30 a.m. – 11:00 a.m.	**EGS Reservoir Issues** Susan Petty Black Mountain Technology
11:00 a.m. – 11:30 a.m.	**Drilling Technology** Bill Livesay Consultant
11:30 a.m. – 12:00 p.m.	**Energy Conversion Systems** Ron DiPippo Consultant
12:00 p.m. – 12:30 p.m.	**Economic Potential** Michal Moore University of Calgary
12:30 p.m. – 1:30 p.m.	**Luncheon Address: *Is EGS Commercial?*** Subir Sanyal GeothermEx, Inc.

1:30 p.m. – 4:00 p.m. **Informal Breaks**	**Group Breakouts** Economic Evaluation/Analysis Reservoir Formation Reservoir Management and Operation Supporting Technology – Drilling Supporting Technology – Energy Conversion
4:00 p.m. – 5:30 p.m.	**Breakout Group Presentations** (~20 minutes each) Economic Evaluation/Analysis Reservoir Formation Reservoir Management and Operation Supporting Technology – Drilling Supporting Technology – Energy Conversion
5:30 p.m.	**Conclusion of the General Workshop**

FRIDAY, JUNE 8, 2007

8:00 a.m. – 11:00 a.m.	**Consolidate Workshop Results in Workgroups** Breakout Leads and Co-leads	**Ballroom D**
11:00 a.m. – 11:30 a.m.	**Next steps** Allan Jelacic U.S. Department of Energy	**Ballroom D**
11:30 a.m.	**Adjourn**	

4.2. Workshop Attendee List

Company or University
MIT
DOI - BLM
DOE
Exxon-Mobil
Shell Exploration and Production
Chevron
United States Geological Survey
Geothermal Energy Association
Ormat
Calpine
Caithness Corporation
Mil-Tek UK
Stanford University
Texas A&M University
SAIC

University of Utah, Energy and Geosciences Institute
Southern Methodist University
GeothermEx
West Virginia University
Black Mountain Technology
Pinnacle Technology
Geothermal Resource Council
University of Calgary
Lawrence Berkeley National Laboratory
Sandia National Laboratory
Idaho National Laboratory
National Renewable Energy Laboratory
Lawrence Livermore National Laboratory
Private Consultants
- Drilling
- Energy Conversion