Appendix A

Table A.1 Energy Conversion Factors

	Btus	quads	calories	kWh	MWy
Btus	1	10^{-15}	252	2.93×10^{-4}	3.35×10^{-11}
quads	10^{15}	1	2.52×10^{17}	2.93×10^{11}	3.35×10^{4}
calories	3.97×10^{-3}	3.97×10^{-18}	1	1.16×10^{-6}	1.33×10^{-13}
kWh	3412	3.41×10^{-12}	8.60×10^{5}	1	1.14×10^{-7}
MWy	2.99×10^{10}	2.99×10^{-5}	7.53×10^{12}	8.76×10^{6}	1
bbls oil	5.50×10^{6}	5.50×10^{-9}	1.38×10^{9}	1612	1.84×10^{-4}
tonnes oil	4.04×10^{7}	4.04×10^{-8}	1.02×10^{10}	1.18×10^{4}	1.35×10^{-3}
kg coal	2.78×10^{4}	2.78×10^{-11}	7×10^{6}	8.14	9.29×10^{-7}
tonnes coal	2.78×10^{7}	2.78×10^{-8}	7×10^{9}	8139	9.29×10^{-4}
MCF gas	10^{6}	10^{-9}	2.52×10^{8}	293	3.35×10^{-5}
joules	9.48×10^{-4}	9.48×10^{-19}	0.239	2.78×10^{-7}	3.17×10^{-14}
EJ	9.48×10^{14}	0.948	2.39×10^{17}	2.78×10^{11}	3.17×10^{4}

	bbls oil equiv.	tonnes oil equiv.	kg coal equiv.	tonnes coal equiv.	MCF gas equiv.	joules	EJ
Btus	1.82×10^{-7}	2.48×10^{-8}	3.6×10^{-5}	3.6×10^{-8}	10^{-6}	1055	1.06×10^{-15}
quads	1.82×10^{8}	2.48×10^{7}	3.6×10^{10}	3.6×10^{7}	10^{9}	1.06×10^{18}	1.06
calories	7.21×10^{-10}	9.82×10^{-11}	1.43×10^{-7}	1.43×10^{-10}	3.97×10^{-9}	4.19	4.19×10^{-18}
kWh	6.20×10^{-4}	8.45×10^{-5}	0.123	1.23×10^{-4}	3.41×10^{-3}	3.6×10^{6}	3.6×10^{-12}
MWy	5435	740	1.08×10^{6}	1076	2.99×10^{4}	3.15×10^{13}	3.15×10^{-5}
bbls oil	1	0.136	198	0.198	5.50	5.80×10^{9}	5.80×10^{-9}
tonnes oil	7.35	1	1455	1.45	40.4	4.26×10^{10}	4.26×10^{-8}
kg coal	5.05×10^{-3}	6.88×10^{-4}	1	0.001	0.0278	2.93×10^{7}	2.93×10^{-11}
tonnes coal	5.05	0.688	1000	1	27.8	2.93×10^{10}	2.93×10^{-8}
MCF gas	0.182	0.0248	36	0.036	1	1.06×10^{9}	1.06×10^{-9}
joules	1.72×10^{-10}	2.35×10^{-11}	3.41×10^{-8}	3.41×10^{-11}	9.48×10^{-10}	1	10^{-18}
EJ	1.72×10^{8}	2.35×10^{7}	3.41×10^{10}	3.41×10^{7}	9.48×10^{8}	10^{18}	1

Source: "Sustainable Energy: Choosing Among Options," Massachusetts Institute of Technology (2005)

Key: MWy = megawatt-year; bbls = barrels = 42 U.S. gallons; tonnes = metric tons = 1,000 kg = 2,204.6 lb; MCF = thousand cubic feet; EJ = exajoule = 10^{18}J. Nominal calorific values assumed for coal, oil, and gas.

Note: To convert from the first-column units to other units, multiply by the factors shown in the appropriate row (e.g., 1 Btu = 252 calories)

Appendix B

Panel-Member Biographies

Jefferson W. Tester (chair)

Dr. Tester is the H.P. Meissner Professor of Chemical Engineering at the Massachusetts Institute of Technology (MIT). For three decades, he has been involved in chemical engineering process research as it relates to renewable and conventional energy extraction and conversion, and environmental control technologies. He has published extensively in the energy area with more than 185 papers and seven coauthored books, including *Geothermal Energy as a Source of Electric Power* (1976), *Handbook of Geothermal Energy* (1982), *Heat Mining* (1987), and *Sustainable Energy – Choosing Among Options* (2005). His other appointments have included director of MIT's Energy Laboratory (1989-2001), director of MIT's School of Chemical Engineering Practice (1980-1989), and a group leader in the Geothermal Engineering Group at Los Alamos National Laboratory (1974-1980). Dr. Tester is a member of the advisory boards of the National Renewable Energy Laboratory as chair, Massachusetts Renewable Energy Trust as chair, American Council on Renewable Energy, Los Alamos National Laboratory, Cornell University, and the Paul Scherrer Institute in Switzerland. He was a member of the Energy R&D Panel of the President's Committee of Advisors on Science and Technology (PCAST) in 1997 and has served as an advisor to the U.S. Department of Energy (DOE) and the National Research Council (NRC) in areas related to concentrating solar power, geothermal energy, and other renewable technologies; and waste minimization and pollution reduction. Dr. Tester received a B.S. and M.S. with distinction in chemical engineering in 1966 and 1967 at Cornell, and a Ph.D. in chemical engineering at MIT in 1971.

Brian J. Anderson

Dr. Anderson is an assistant professor and the Verl Purdy Faculty Fellow in the Department of Chemical Engineering at West Virginia University. He received an M.S. and Ph.D. in chemical engineering from MIT, and a B.S. from West Virginia University. Dr. Anderson's research experience includes sustainable energy and development, economic modeling of energy systems, and geothermal energy development. He also has worked with molecular modeling of energy-relevant systems such as natural gas hydrates and hydrogen separation membranes. He has served as a consultant for a major bio-based energy company where he developed production flow sheets and economic models for the production of biodiesel and bio-ethanol from various feedstocks, built a knowledge database in the area of worldwide and domestic fuel production and consumption, and forecast production costs under different tax and demand scenarios.

Anthony Stephen Batchelor

Dr. Batchelor is chairman and managing director of GeoScience Limited, a specialized geothermal and geotechnical consulting/design company. Dr. Batchelor holds a B.S. in mining engineering (1968) and a Ph.D. in rock mechanics (1972) from the University of Nottingham in England. He is a chartered and European engineer, and a member of both the Society of Petroleum Engineers and the Institute of Materials, Minerals, and Mining. He is a member of the Geothermal Resources Council, and was a founding member of the International Geothermal Association and served on its board. He is an author of more than 60 papers, and a contributor to three books and a biography in "Who's Who in Science and Engineering." He taught rock mechanics at the Camborne School of Mines for more than 12 years, and developed the U.K. Hot Dry Rock Geothermal Project, of which he was project director from 1977 to 1986. During this time, he was a visiting staff member at Los Alamos National

Laboratory and held a fellowship under the NATO/Committee on the Challenges of Modern Society (CCMS) program. Dr. Batchelor helped found GeoScience Ltd. in 1986, working on geothermal projects in California, Oregon, Japan, St Lucia, the Azores, Turkey, and Indonesia, and has since consulted for many global oil companies on rock mechanics and fractured reservoirs. In addition, he has taught in-house and SPE courses on wellbore rock mechanics during the past 15 years; and worked for operators, service companies, and regulators on issues with high pressure high temperature (HPHT) wells, "kicks" in oil-based muds, wellbore stability, cuttings reinjections, and sand control. GeoScience Ltd. has established a geothermal heat pump operation in the United Kingdom under the brand name EarthEnergy™. It is currently the leading installer of such systems in the U.K.

David D. Blackwell

Dr. Blackwell received a B.S. with a major in geology and mathematics from Southern Methodist University in 1963 and his Ph.D. in geophysics from Harvard University in 1967. He joined the faculty at Southern Methodist University (SMU) after a year of postdoctoral study at the CalTech Seismological Laboratory. He has been the W. B. Hamilton Professor of Geophysics since 1982. His research specialty is the thermal field of the Earth, and he has worked extensively in geothermal exploration and resource assessment in the United States and worldwide. He has received research grants and contracts for geothermal activities from the U.S. DOE, National Science Foundation (NSF), and many other entities. He has consulted for numerous U.S. geothermal and energy companies. Most recently, he was coeditor with Maria Richards of the "Geothermal Map of North America," published by the American Association of Petroleum Geologists in 2004. Dr. Blackwell is a longtime member of the board of directors of the Geothermal Resources Council and was president in 1991/92. He has been a member of the board of the International Geothermal Association, and was extensively involved in the technical aspects of the 1995 and 2000 international geothermal conferences in Italy and Japan. The SMU Geothermal Laboratory maintains a Web site with extensive geothermal data and information at www.smu.edu/geothermal.

Ronald DiPippo

Dr. DiPippo is Chancellor Professor Emeritus of mechanical engineering and former associate dean of engineering at the University of Massachusetts Dartmouth. He is now a full-time energy systems consultant. Dr. DiPippo received his Ph.D. from Brown University and taught thermodynamics, power plant design, geothermal energy, and other energy-related courses from 1967 to 2004. His expertise is the generation of electricity from geothermal resources. He has contributed to the development of several novel power plant designs using hybrid fossil-geothermal systems, and applied the Second Law of thermodynamics to the analysis and design of geothermal power plants. He has published more than 100 professional papers and reports in areas such as transport properties of fluids, geothermal energy conversion systems, and applications of Second Law analysis to geothermal systems. He is the author of two books, *Geothermal Energy as a Source of Electricity* (1980), and *Geothermal Power Plants: Principles, Applications and Case Studies* (2005); and is an editor of and contributor to *Sourcebook on the Production of Electricity from Geothermal Energy* (1980).

Elisabeth M. Drake

Dr. Drake received her S.B. and Sc.D. degrees in chemical engineering from MIT, and worked for more than 25 years at the consulting firm of Arthur D. Little Inc. At the firm, she specialized in advising industrial and governmental clients worldwide on the risk management of hazardous facilities, ranging from petrochemical plants to offshore drilling rigs. From 1986-1988, she was vice president and leader of the firm's Environment, Health, and Safety Practice. She has been at MIT for the past 15 years, where she has served as the associate director for new technologies at the MIT Energy Laboratory. She has been part of a team that developed a graduate-level course on sustainable energy that addresses energy options in a broad context of short- and longer-term economical, societal, and environmental issues. A textbook for this course was published in 2005. From 1982-1986, Dr. Drake was the Cabot Professor of Chemical Engineering at Northeastern University and served as chairman of its Chemical Engineering Department. Dr. Drake was a visiting associate professor of chemical engineering at MIT during the 1973-1974 academic year, while on leave from Arthur D. Little. She also was a lecturer in chemical engineering at the University of California at Berkeley during the spring of 1971. She is a member of the National Academy of Engineering and a fellow of the American Institute of Chemical Engineers (AIChE).

John Garnish

Dr. Garnish earned his Ph.D. in physical chemistry in 1966 from the University of Bristol, United Kingdom, and joined the U.K. Atomic Energy Authority. He was a founding member of the Energy Technology Support Unit, established in 1974 to assist the U.K. Department of Energy with its research programs. Dr. Garnish was responsible for geothermal research in the U.K. during the 1970s and 1980s. He represented the U.K. in its participation in the NATO/CCMS and International Energy Agency (IEA) geothermal projects, and in the geothermal advisory committee of the European Commission. In 1985, he joined the European Commission to take responsibility for the commission's program of geothermal research in Europe – and, in particular, to bring together the expertise developed in the U.K.'s HDR project in Cornwall with related projects in France and Germany. This resulted in the integrated European HDR project at Soultz-sous-Fôrets in France. He was also the commission's representative in the current IEA Geothermal Implementing Agreement (chairman 2001-2002). He has been chairman of the Soultz project's Scientific Advisory Panel since retiring from the European Commission in 2002. He was a member of the Geothermal Resources Council for many years, and is currently in his fourth term as a director of the International Geothermal Association.

Bill Livesay

Dr. Livesay has more than 40 years experience in all aspects of drilling engineering for oil, gas, and geothermal resources. His varied work experience has permitted Dr. Livesay to see drilling technology from all three critical viewpoints. First, as a drilling engineer at Exxon and as a consultant; second, as a researcher and developer of drilling technology, and builder of drilling equipment for Dresser Security; and, finally, as a researcher of drilling technology as professor of petroleum and mechanical

engineering at The University of Tulsa, and through 28 years of work with Sandia National Laboratories and other clients. Dr. Livesay has authored more than 30 publications covering most aspects of drilling, drilling costs, equipment, techniques, and procedures. His educational background includes a B.S. in mechanical engineering from Oklahoma State University, and a Ph.D. in mechanical engineering from Kansas State University.

Michal C. Moore
Dr. Moore is senior fellow at the Institute for Sustainable Energy, Environment, and Economy at the University of Calgary in Alberta, where he teaches economic theory and conducts research on alternative energy technologies and markets. He is the former chief economist at the National Renewable Energy Laboratory in Golden, Colo., and a former regulator of the energy industry in California. Dr. Moore received his B.S. in geology at Humboldt State University and an M.S. in land economics from the Ecology Institute at the University of California at Davis. He obtained a Ph.D. in Economics from the University of Cambridge in England, where he is a member of Darwin College. His primary research interests lie in the areas of urban open space and agricultural land conversion, local government fiscal impacts, and the structure and rules of energy markets.

Kenneth Nichols
Mr. Nichols is the CEO emeritus of Barber Nichols Inc. He also is a senior project engineer for projects involving turbomachinery and especially high specific energy turbines. Mr. Nichols has been responsible for the design and installation of several binary geothermal plants, some of which have been in commercial operation for more than 20 years. Mr. Nichols has developed and manufactured numerous Rankine Cycle power plants that operate on the heat from cement kilns, diesel exhaust, and other heat sources. This experience provided real cost and economics of these power systems. Mr. Nichols is a graduate of the University of Colorado, holds a B.S.M.E. degree, and is a registered professional engineer in the state of Colorado.

Susan Petty
Ms. Petty has more than 25 years of experience in the geothermal industry in electrical and direct-use project economics; optimizing of power plants to meet resource conditions; reservoir evaluation; reservoir modeling; well, plant and wellfield performance data analysis; well testing; and test data analysis. She has also assisted in negotiation of geothermal lease agreements, power sales agreements, geothermal project financing agreements, and geothermal property sales and purchases. Ms. Petty has done work on geothermal electrical generation projects in Nevada at Steamboat, Dixie Valley, Rye Patch, Soda Lake, Fallon, Desert Peak, and Brady hot springs; and direct-use projects at Brady, Elko, and Moana. In California, she has worked on the Coso, Salton Sea, East Mesa, Heber, Brawley, Wendell-Amedee, Mt. Lassen, and Medicine Lake resources. She has worked on geothermal projects overseas in Indonesia, the Philippines, and Central America. For a number of years, Ms.

Petty assisted the Department of Energy in performing policy studies for geothermal energy research including economic modeling of geothermal pricing and the impact of technology improvement on the cost of geothermal power. She performed a signature study, still in use today, of the potential cost of geothermal power supply from projects across the western United States. Ms. Petty received a B.A. in geology from Princeton University in 1973 and an M.S. in groundwater hydrology from the University of Hawaii in 1979.

M. Nafi Toksöz

Dr. Toksöz is a Robert R. Shrock Professor of Geophysics; founder of the Earth Resources Laboratory and its director from 1982 to 1998; and director of the George R. Wallace Jr. Geophysical Observatory at MIT. Dr. Toksöz, an honorary member of the Society of Exploration Geophysicists (SEG), received his geophysical engineering degree at Colorado School of Mines and his M.S. and Ph.D. at the California Institute of Technology. He has been a faculty member in the Department of Earth, Atmospheric, and Planetary Sciences at MIT since 1965. Dr. Toksöz has made major scientific contributions in many areas of geophysics, including seismic exploration, plate tectonics, planetary interiors, earthquake seismology, and imaging. In 1976, he received the NASA Exceptional Scientific Achievement Medal. In 1995, he received the Distinguished Achievement Medal from the Colorado School of Mines. He is the author or coauthor of more than 300 technical papers, and has edited books, including one on seismic Wave Attenuation, published by the SEG.

Ralph W. Veatch, Jr.

Dr. Veatch Jr. is president of Software Enterprises Inc., an engineering consulting firm, in Tulsa, Okla. He holds a B.Sc. and M.Sc. in petroleum engineering, and a Ph.D. in engineering science, all from the University of Tulsa. His career began in 1960 as a petroleum engineer with Amoco Production Co. In 1970, he transferred to Amoco Production Research, serving in various staff and supervisory positions, retiring in 1993 as supervisor of the Hydraulic Fracturing and Well Completions and Production Operations groups. He has taught at Louisiana State University in Lafayette and the University of Tulsa. Since 1993, he has been involved with petroleum consulting. From 1993 to 2003, he taught a five-day industry course on hydraulic fracturing. Dr. Veatch is a professional engineer in Oklahoma and Texas, and a member of the Society of Petroleum Engineers (SPE). He is an SPE distinguished member, distinguished author and a distinguished lecturer; and a recipient of the SPE John Franklin Carll award. He has authored or coauthored 25 technical papers and 12 books. During his career, he has served on numerous advisory committees for the American Petroleum Institute, Completion Engineering Association, Gas Research Institute, Los Alamos National Laboratory, National Petroleum Council, and the U.S. DOE.

Associate Panel Members

Roy Baria

Dr. Baria is a professional geophysicist with specialties in seismic profiling and geothermal reservoir engineering. In 1980, he left the British Geological Survey and became deputy director of the U.K. Geothermal Project, operated by the Camborne School of Mines at the Rosemanowes site in Cornwall. In 1990, Dr. Baria joined the European project at Soultz near Strasbourg in France at the request of the European Commission (EC). He became one of the coordinators of the European EGS project and as "scientist in charge," he was responsible for planning the program, coordinating scientists from various nations, preparing annual reports for the EC, and developing diagnostic methods to evaluate HDR reservoirs etc. Since 2005, Dr. Baria has been the director of Mil-Tech U.K. Ltd., acting as a consultant on the EGS and associated technologies to various organizations in Europe, United States and Japan.

Chad Augustine: B.S., chemical engineering, Iowa State University (2000); doctoral candidate and graduate research assistant, chemical engineering, MIT

Enda Murphy: B.E., civil and environmental engineering, University College Cork (2004); M.S., civil and environmental engineering, MIT (2006); research associate

Petru Negraru: B.S., geophysics, University of Bucharest (1998); Ph.D., geophysics, Southern Methodist University (2005); postdoctoral researcher, SMU Geophysics Department and Geothermal Laboratory

Maria Richards: B.S., physical geography, Michigan State University (1986); M.S., physical geography, water resource management, University of Tennessee – Knoxville (1991); research associate, Southern Methodist University Geothermal Laboratory

Appendix C

Glossary of Scientific Terms and Abbreviations

AAPG – American Association of Petroleum Geologists. The professional society of petroleum geologists, the source of information on bottom-hole temperatures used in this report.

Abandonment temperature – The average temperature of the active reservoir rock volume at the time heat-extraction operations cease.

Acoustic emissions – Elastic waves produced by defects in a material when that material is placed under stress.

AFE – Authorization for expenditures. The estimated and actual expenditures for wells drilled by a company.

Annualized costs – Determined by using a fixed charge rate applied to invested capital, adding an annualized operating cost, and dividing the sum by the annual electric generation.

Annualized revenues – Calculated returns based on a full year.

Base load – The minimum amount of power that a utility or distribution company must make available to its customers, or the amount of power required to meet minimum demands based on reasonable expectations of customer requirements. Base-load values typically vary from hour to hour in most commercial and industrial areas.

Basin and Range – An area of about 800,000 km^2 extending over southeastern Oregon, Nevada, western Utah, southeastern California, southern Arizona, and southwestern New Mexico, characterized by more than 200 low mountain ranges interspersed with shallow basins generally oriented north-northeast by south-southwest. The orientation is controlled by active or recently active normal (extensional) fault systems bounding tilted fault blocks of horst/graben pairs.

Baumann rule – The isentropic efficiency of a vapor turbine operating in the two-phase, liquid-vapor region, is reduced 1% for each 1% of moisture present, on average, during the total expansion process.

BHT – Bottom-hole temperature. A measured temperature in the borehole at its total depth. The bottom-hole temperature (BHT) is taken as the maximum recorded temperature during a logging run or, preferably, the last series of runs during the same operation. BHT is the temperature used for the interpretation of logs and heat flow at geothermal gradient. Farther up the hole, the correct temperature is calculated by assuming a certain temperature gradient. The BHT lies between the bottom-hole circulating temperature (BHCT) and the bottom-hole static temperature (BHST).

Binary cycle – An energy-conversion system that uses a closed Rankine cycle having an organic working fluid that receives heat from a hot geofluid and rejects waste heat to the surroundings while generating electrical power.

Biofuel – Any fuel derived from biomass, i.e., recently living organisms or their metabolic byproducts, such as wood wastes, corn grain, or manure from cows. It is a renewable energy source often made from agricultural crops or residuals grown specifically for conversion to liquid or gaseous fuels.

Blowout preventer (BOP or BOPE) – A fast-acting valve or series of valves at the wellhead used during drilling to control wells from erupting prematurely. When zones of unexpected high pressure are encountered, the well will unload creating a "gusher" that can be extremely dangerous. A BOP can close rapidly and keep the fluid inside the well until the pressure can be released gradually.

Borehole televiewer – An instrument that provides an acoustic "image" of a borehole wall by scanning it with a narrow pulsed acoustic beam from a rotating transducer while the tool is pulled up a hole.

Break-even price – In the context of the analysis contained in this assessment, the price of delivered power to the grid, given forecast increases in technology performance, drilling techniques, and reservoir stimulation and management, where the area utilization (i.e., fraction of utilized thermal resource within a given temperature and depth regime) is limited to 2% of total capacity.

Caldera – A volcanic basin, roughly circular with steep sides, having a diameter several times larger than the depth, formed by collapse of the central part of a volcanic center due to eruption of a large volume of volcanic ash from the underlying magma chamber.

California Energy Commission (CEC) – An agency of the state of California charged with: (1) forecasting future energy needs and keeping historical energy data; (2) licensing thermal power plants with capacities of 50 MWe or larger; (3) promoting energy efficiency through appliance and building standards; (4) developing energy technologies and supporting renewable energy; and (5) planning for and directing state response to an energy emergency.

Capacity factor – The ratio (usually expressed as a percentage) of the actual electrical generation to the maximum possible generation for a given period of time (usually on an annual basis). Capacity factors for geothermal plants are typically in excess of 90%.

Casing string – An assemblage of tubular materials used to stabilize the hole – it may contain surface pressure-control equipment and downhole production equipment.

Cenozoic – The current geologic era that began about 66 million years ago.

Chemical tracers – A direct means of tracking fluid movement in a reservoir, thus allowing the determination of reservoir heterogeneity and an estimate of the magnitude and direction of any flow in the reservoir formation.

Closed-loop control system – A system that uses feedback to control states or outputs. Its name comes from the information path in the system: Process inputs have an effect on the process outputs, which are measured and processed. The result is used as input to the process, closing the loop.

Cogeneration – The simultaneous generation of electricity and process heat.

Connectivity – With regard to enhanced geothermal systems, the degree to which production wells communicate with injectors through the fractured volume. Physical boundaries due to pre-existing faults, fractures, and lithology changes may either prevent connection or make too strong a connection within parts of the reservoir. It may be possible to improve reservoir connectivity through pressure-management methods such as producing one well while injecting into another or injecting into two wells simultaneously.

COP – Coefficient of performance. A measure of the efficiency of a heat pump equal to the ratio of the heat delivered to the electrical work needed to operate the unit (in winter-heating mode) or the ratio of the heat removed to the electrical work needed to operate the unit (in summer-cooling mode).

Coproduction – As used in this report, the simultaneous production of oil and/or natural gas, together with hot aqueous fluids or brines that may be used to generate electricity by means of a binary cycle plant.

Cretaceous – The geologic period that began about 144 million years ago and ended about 66 million years ago.

Crustal permeability – The capacity for upflow through tectonically active continental crust, resulting in a pathway for geothermal fluids.

CSP – Concentrating solar power. Also known as "solar thermal power," a method of converting sunlight into electricity by means of capturing concentrated solar energy. CSP technology focuses the suns rays by mirrors, flat or curved, onto a collector or receiver to heat or boil a fluid for use in an energy conversion system such as a steam Rankine cycle for generating electricity.

Cycle – A closed set of processes whereby electricity is generated and heat is exchanged with a hot source and cold sink.

Debt/equity ratio – The comparison of the amount of capital assets financed by bank loans requiring interest payments vs. those assets financed by equity capital from investors.

Decibel, A-weighted, dBA – A measure of the relative loudness of sound in air, normalized to the sensitivity of the human ear. Decibel values are reduced in the low-frequency range (<1000 Hz) since humans are less sensitive to sounds at low audio frequencies.

Demand forecast – An assessment of future electrical demand on a given system. The impact of new technology on overall energy consumption plays an important role.

Direct heat – Any application requiring only heat transfer to accomplish some useful end.

Directional drilling – The science of drilling nonvertical wells; it is sometimes known as slant or deviated drilling.

Dispatchability – The ability of a power supply system to follow load. That is, power can be generated from a plant or collection of plants when it is needed to meet peak-system power loads.

Disruptive drilling technologies – Emerging, ground-breaking, innovative technologies with the potential to drastically improve the economics of drilling deep wells. Examples include projectile drilling, spallation drilling, laser drilling, and chemical drilling.

Double-flash plant – A type of geothermal power plant involving the separation of steam from the two-phase, liquid-vapor geofluid, followed by a pressure-reduction (flash) of the remaining liquid to produce more steam, albeit at a lower pressure; both steam flows are used to drive a steam turbine for electricity generation.

Dry-steam plant – A geothermal power plant using dry (or slightly superheated) geosteam to drive the turbine.

EGS – Enhanced geothermal system (sometimes referred to as engineered geothermal system). A system designed for primary energy recovery using heat-mining technology, which is designed to extract and utilize the Earth's stored thermal energy.

EIA – Energy Information Administration. A U.S. government agency that provides official energy statistics and predictions.

EJ – Exajoule. A measure of energy. One EJ equals a quintillion (10^{18}) joules or a quadrillion (10^{15}) kilojoules. A joule is an extremely small unit of energy; one kilojoule is slightly less than one British Thermal Unit (Btu).

Energy reserves – The estimated amount of an energy source that is available with current technology at today's energy prices.

Energy Service Providers (ESP) – A company supplying an outsourced energy management service. This service can comprise the collection of energy consumption data, the validation and estimation of these data, and the reporting and even the improving of energy efficiency.

Energy-conversion system – Any device or assemblage of devices that converts thermal energy (heat or exergy) into electricity.

EPA – Environmental Protection Agency. A U.S. government agency whose mission is to protect human health and the environment.

Equity – The value of an entity in excess of the claims against it.

Equity rate of return – An indicator of profitability determined by the net income and the growth rate of the investment.

Exergy – The maximum theoretical work (or power) that can be extracted thermodynamically from a fluid under specified conditions of pressure, temperature, etc. in the presence of a given set of ambient conditions (surroundings or dead state).

Expandable tubular casing – A novel method for completing a well. It reduces the number of telescopic steps in the casing profile and reduces the loss of diameter each time a new casing string or liner is set. It involves a cold-working process whereby the casing or liner can be expanded by up to 20% in diameter after being run downhole. This is accomplished by forcing through the pipe an expansion tool that exceeds the inner diameter of the tube by the required amount of expansion. The tool may be inserted either hydraulically, by applying mud pressure, or mechanically.

FERC – Federal Energy Regulatory Commission. An independent agency that regulates the interstate transmission of electricity, natural gas, and oil. FERC also reviews proposals to build liquefied natural gas (LNG) terminals and interstate natural gas pipelines as well as licensing hydropower projects. Among its tasks, it oversees environmental matters related to natural gas and hydroelectricity projects and major electricity policy initiatives.

Fixed charge rate – The annual interest expenses of the money borrowed to build a new construction project, plus the annual costs to operate and maintain it. Fixed charge rates include a range of factors such as construction financing, financing fees, return on debt and equity, depreciation, income tax, property tax, and insurance. The fixed charge rate, when multiplied by the cost of a new construction project, yields the annual "fixed charges."

Fixed costs – Costs that are not subject to change and do not fluctuate.

Fracture – A break in a rock caused by directed stress. Fractures may be caused by shear or tensile failure and may exist as fully or partly propped open or sealed joints.

Fracture cloud – The 3-dimensional loci of microseismic acoustic emissions that are indicative of the stimulated fracture zone in the formation.

Fracture spacing – The average distance between fractures that are open and accepting fluid.

Gas turbine – An energy conversion system consisting of a compressor, combustor, and turbine, usually powered by a gaseous fuel such as natural gas.

Gas-fired combined-cycle plant – A generating facility with both a gas turbine and a steam unit. The gas turbine operates as a normal gas turbine using the hot gases released from burning natural gas to turn a turbine and generate electricity. In combined-cycle plants, the waste heat from the gas-turbine process is directed to a waste-heat recovery heat exchanger that raises steam, which is then used to generate additional electricity by means of a steam turbine. Because of their efficient use of the heat energy released from the natural gas, combined-cycle plants are more efficient than steam units or gas turbines alone, typically with thermal efficiencies in excess of 50-55%.

GEA – Geothermal Energy Association. A trade association composed of U.S. companies who support the expanded use of geothermal energy and are developing geothermal resources worldwide for electrical power generation and direct-heat uses.

Geofluid – Any fluid produced from a geothermal well; may be dry or superheated steam, pressurized liquid, or a mixture of liquid and vapor, usually accompanied by dissolved solids and noncondensable gases.

Geopressured geothermal resource – A unique form of geofluid found in near-offshore petroleum deposits, containing significant amounts of dissolved natural gas at very high pressure and high temperature.

Geothermal – Referring to the stored thermal energy in, or heat produced from, the Earth's interior.

Geothermal gradient – The rate of increase in temperature per unit depth in the Earth. Although the geothermal gradient varies from place to place, it averages 25 to 30°C/km [14-16°F/1000 ft] in normal regions. It can be several times larger in high-grade geothermal regions.

GETEM – Geothermal Electric Technology Evaluation Model (GETEM) is a macro-model that estimates levelized cost of geothermal electric power in a commercial context. It was developed with funding from the U.S. DOE Geothermal Technology Program.

GPM or gpm – Gallons per minute.

GW_e – Gigawatts electric. A measure of electric power generation. One GW_e equals one billion (10^9) watts or 1 million kilowatts.

Greenhouse gases (GHG) – Gases that permit ultraviolet light energy to enter the Earth's atmosphere but block the transmission of infrared light energy, similar to the effect of a sheet of glass in a "hot house"; such gases notably include water vapor, carbon dioxide, and methane.

Grid – A network of conductors for distribution of electric power. The electrical transmission system is commonly referred to as a "grid."

Ground-source heat pump (GSHP) – A means of controlling the temperature in buildings using the shallow Earth as a heat source in the winter and as a heat sink in the summer; the device is cyclical and behaves thermodynamically in the same way as a refrigerator, but with appropriate control valves to allow for heating or cooling as desired.

GSA-DNAG – Geological Society of America-Decade in North America Geology. This project was established in 1988 as a commemoration of the 100th anniversary of the GSA and consists of numerous volumes on all geological aspects of the North American continent. Twelve volumes deal specifically with geothermal topics.

HDR – Hot dry rock. See also "Heat Mining." A type of geothermal power production system that utilizes the very high temperatures that can be found in rocks a few kilometers below ground. This is done by pumping high pressure water down a borehole into the heat zone. The water travels through fractures of the rock, capturing the heat of the rock until it is forced out of a second borehole as very hot water – the thermal energy of which is converted into electricity using either a steam turbine or a binary power plant system. All of the water, then cooled, is injected back into the ground to heat up again.

Heat mining – A process that includes the use of at least one injection well and at least one production well to extract heat from the Earth. Cold water is pumped down to and circulates through the fractured reservoir; the natural heat exchanger delivers hot, pressurized water to the production well(s). The thermal energy is converted into electric power by means of a turbine-generator unit; residual thermal energy in the geofluid may be used for space heating. The cooled geofluid is then reinjected deep into the reservoir to maintain a cyclic operation.

Heat rate – A measurement used in the energy industry to calculate how efficiently a power plant uses heat energy. It is expressed as the number of Btus of heat required to produce a kilowatt-hour of energy.

Heat recovery steam generator (HRSG) – A heat exchanger fitted to the exhaust of a gas turbine (or other power plant) to extract heat that would be otherwise wasted for use in a bottoming cycle for additional power generation.

Holocene – The most recent, current epoch of the Quarternary period beginning about 10,000 years ago.

Hydraulic fracturing ("hydrofracing" or "jacking") – A technique involving the application of high fluid pressure on a reservoir to enhance the existing permeability and establish interwell connectivity by opening sealed joints or by creating new fractures to allow geofluid to move more freely through the formation.

Hydroelectric plant – A plant that generates electric power from the flow of water utilizing a hydrostatic or hydrodynamic gradient. Two main types are: (1) storage units that involve a dam and a water reservoir at a higher elevation, and (2) run-of-the-river units involving the steady flow of water. Both use hydraulic turbines to drive electric generators.

Hydrothermal – In the context of geothermal systems, refers to mineralized solutions heated by contact with hot rocks and/or cooling magma and convecting within a reservoir.

IGA – International Geothermal Association. An organization that provides information on geothermal energy use around the world.

Impedance – The pressure drop experienced by the geofluid while circulating through the reservoir.

Intermediate load – Intermediate-load generating units meet system demands that are greater than base load but less than peak load.

JAS – Joint Association Survey. An annual report by the American Petroleum Institute, outlining drilling costs, overall well costs, and other geological information.

Jacking – See hydraulic fracturing.

Kalina cycle – A unique type of binary power plant that uses a mixture of water and ammonia as the cycle working fluid (instead of a simple organic fluid) together with various heat recuperators that improve the cycle thermal efficiency.

kW_t – Kilowatts thermal. A measure of thermal power or rate of heat transfer. One kW_t equals one thousand thermal watts.

Learning curve – A curve plotting performance against practice. The principle states that the more often a task is performed, the lower the cost will be to do it. The task can be the production of any good or service. An example is the decline in unit costs with cumulative output. Sometimes called an "experience curve."

Levelized electricity cost (LEC) – The levelized cost of energy (or levelized electricity cost, LEC) is the most common basis used for comparing the cost of power from competing technologies. The levelized cost of energy is found from the present value of the total cost of building and operating a generating plant over its expected economic life. Costs are levelized in real dollars, i.e., adjusted to remove the impact of inflation.

Lithology – The detailed geologic and mineralogic characteristics of a rock formation, often obtained by taking cuttings of the rock layers as drilling is carried out.

Load center – A particular geographical area within a utility's service territory where electrical energy is used.

Lost circulation – A drilling problem that arises when the circulation of the drilling fluid is interrupted and it does not return to the surface.

Microseismic events – Very weak acoustic emissions often associated with the injection or recovery of fluids from a geothermal reservoir. Magnitudes are usually too weak to be detected by humans.

MIT EGS Model – A model enhanced by the MIT Energy Laboratory as part of its research into EGS systems sponsored by the Geothermal Technologies Office of the U.S. Department of Energy; it was further modified by Brian Anderson of MIT as part of this assessment. The model has been updated using the results of this study with regard to the cost of drilling, plant costs, stimulation costs, and the learning-curve analysis.

MITDD – MIT Depth Dependent drilling cost index. This is used to normalize geothermal well costs from the past 30 years to year 2004 U.S. dollars.

Mud – Drilling fluid. Used to flush the borehole of cuttings produced during drilling and to support the walls of the hole prior to the setting of casing. For liquid-dominated and EGS reservoirs, muds consist of aqueous solutions or suspensions with various additives chosen to provide appropriate thermal and fluid properties (density, viscosity, corrosion resistance, thermal conductivity, etc.). For vapor-dominated reservoirs, air is often used for the drilling fluid to avoid the possibility of clogging the fine fractures associated with a vapor system.

MW_e – Megawatts electric. A measure of electric power generation. One MW_e equals 1 million watts or 1,000 kilowatts.

NEDO – New Energy and Industrial Technology Development Organization. Japan's largest public R&D management organization for promoting the development of advanced industrial, environmental, new energy, and energy conservation technologies.

Noncondensable gases (NCG) – Gases such as carbon dioxide, hydrogen sulfide, methane, and others in very small concentrations that are constituents of geofluids, either dissolved in geoliquids or as gaseous components of geosteam. These gases do not condense at the normal condensing temperature of steam and will build up in a condenser, raising the back-pressure on the turbine exhaust (thereby lowering the power output) unless they are pumped out of the condenser.

Nuclear plant – A plant that generates electrical power using the heat released from the fission of uranium or other radio-nuclides by moderated neutrons.

OMB – Office of Management and Budget. The White House office responsible for devising and submitting the president's annual budget proposal to Congress.

Packer – A tool with elastomer or cement seals used in a well to hydraulically isolate zones for stimulation or production.

Paleozoic – The geologic era that began about 570 million years ago and ended about 245 million years ago.

Peak load – The point in time when energy needs are highest and the system experiences the largest demand.

Permeability – A measure of the ability of a material's pores or openings to allow liquids or gases to flow through them under a pressure gradient.

Pleistocene – An epoch of the Quarternary period beginning about 1.6 million years ago and ending about 10,000 years ago.

Polycrystalline diamond compact drill bits (PDC) – A type of drill bit invented in the 1970s that is very effective in sedimentary formations, particularly in the oil and gas industry, but not used in hard crystalline rock typical of geothermal applications.

Porosity – The percentage of open space or interstices within a volume of rock.

Power – The rate at which work is done; expressed in units of joules per second (J/s) or watts (W), or multiples thereof.

Proppant – Small-sized particles that are mixed with hydrofracting fluids to hold fractures open after a hydraulic fracturing treatment. Proppant materials are carefully sorted for size and shape, hardness, and chemical resistance to provide an efficient conduit for production of fluid from the reservoir to the wellbore.

PV – Photovoltaic. A means of generating electricity directly from sunlight through solar cells containing materials that are stimulated by the solar energy to produce a flow of electrons.

Quartet configuration – A pattern of production and injection wells in which each injector is surrounded by three producers.

Rankine cycle – A power plant consisting of a closed series of four processes: (1) liquid pressurization, (2) heating-evaporation, (3) vapor expansion, and (4) cooling-condensation. There are many variations on the basic Rankine cycle in practice.

Rate of penetration (ROP) – The speed at which a drill bit proceeds through the rock being drilled.

Rate of return (ROR) – The benefits received from an investment, usually expressed as an effective annual percentage return based on an after-tax, discounted, cash-flow analysis.

Recoverable resource – The amount of an energy resource that is recoverable using current exploration and production technology, without regard to cost.

Recovery factor – The percentage of heat recoverable from a stimulated volume of rock.

Recuperator – A heat exchanger designed to capture heat from one part of a cycle for use in another part of the cycle; typically, a recuperator has no moving parts.

Regenerator – Similar to a recuperator in terms of intended function, but having moving parts, such as rotating heat-transfer elements.

Resource base – The total thermal energy in place in the Earth's crust to the depth that can be reached with current technology.

Revenue – The total income produced by a given source.

Rheology – The science of the deformation and flow of matter under the influence of an applied stress.

Risk – The degree of probability or chance for a loss.

Sedimentary basin – A geologic formation characterized by subsidence and subsequently filled by the deposit of sediments.

Seismicity, induced – The generation of acoustic energy from the opening of fractures in rock by the application of high-pressure fluid through injection wells. Normally, these events are in microseismic range, but it is possible to produce events that are perceptible by humans in the vicinity of the event.

Shear failure – The premature failure of a support element that has been cracked under stress.

Short circuit – A preferential pathway that allows cool injected water to return too rapidly to the production well without being heated by the hot rock in the reservoir.

Sidetracking – A well-drilling process that involves drilling a deviated leg in an existing well. Often accomplished by setting a packer or suitable drilling tool at a specified depth, cutting an opening in the casing of the well, and drilling a new well through the opening to access another reservoir area.

Single-expansion plant – As used in this report, a power plant that uses a very high-pressure geofluid and one pressure-reducing process to produce steam for use in a steam turbine.

Single-flash plant – A type of geothermal power plant involving the separation of steam from the two-phase, liquid-vapor geofluid, and produces steam to drive a steam turbine for electricity generation.

Skin effect – A near-wellbore permeability reduction, usually caused during drilling or work-over, which can increase pressure drop and decrease flow rates.

Solar photovoltaic plant – A power plant that directly converts the energy in sunlight to electricity by means of photovoltaic cells.

Solar thermal plant – A power plant that first collects the energy of sunlight in a thermal receiver using mirrors (flat, parabolic, dish-shaped) and then transfers the heat energy to a working fluid for use in a closed cycle (such as a Rankine cycle) to generate electricity.

Spud – The initiation of the drilling of a well.

Squeeze-cementing – A technique for cementing a section of casing to the well wall by injecting cement into the annulus between the casing and the well wall. This is used in special cases where only a portion of the casing string needs to be supported by cement.

Stimulation – In an EGS system, the enhancement of natural permeability – or its creation when none exists. Stimulation is usually hydraulically achieved by injecting fluids with or without controlling their viscosity and at variable flow rates and pressures; or chemical by injecting acids or other chemicals that will remove the rock. The stresses on the rocks and the elastic and thermal properties of the rocks in the potential reservoir, along with the design of the stimulation, control the extent of the enhanced or created fractures and their ultimate transmissivity.

Stress field – A 3-dimensional region of a solid continuum subjected to forces of either uniform or varying magnitudes and directions.

Strike-slip – A fault along which the movement is horizontal; usually associated with transform boundaries.

Subsidence – The lowering of the surface of the ground caused by the removal of fluid from underground pore spaces (reservoirs).

Supercritical fluid – A fluid that exists at conditions of pressure and temperature in excess of its critical temperature and pressure (its critical point), above which it cannot exist as a liquid but only as a dense fluid.

Supply curve – The relationship between each possible price of a given good and the quantity of that good that would be supplied for market sale at that price. This is typically represented as a graph showing the hypothetical supply of a product or service that would be available at different price points. The supply curve usually exhibits a positive slope because higher prices give producers an incentive to supply more, in the hope of earning greater revenue.

Technology diffusion model – A way to measure the amount of time and rate of speed that a technology is dispatched into the marketplace and can sustain a certain level of capacity.

Tectonics – The science of the motion of the Earth's crustal plates that results in the creation and deformation of magma and rock.

Tensile failure – An effect caused by tension or stress, often resulting in a fracture. The most likely effect of water injection under high pressures would be to create a new fracture by tensile failure, thus forming the required surface area needed for heat mining.

Tertiary – The geologic period beginning about 65 million years ago and ending about 1.6 million years ago.

Thermal conductivity – The intensive property of a material that indicates its ability to conduct heat. Heat flow is proportional to the product of the thermal conductivity and the temperature gradient.

Thermal drawdown rate – The drop in temperature per unit time of a body of reservoir rock, subject to the circulation of water in a closed loop as envisioned in an EGS facility.

Thermal efficiency – For a cycle, the ratio of the net power output to the rate of heat input to the cycle.

Thermal gradient – The rate of change of temperature with depth below the ground surface.

Thermal pollution – The discharge of waste heat into the surroundings (air, bodies of water) – this is a necessary thermodynamic consequence of all thermal engines. The lower the thermal efficiency of the plant, the greater the amount of heat that must be rejected relative to the electrical power being generated.

Transform (boundary) – An interface between tectonic plates, where the plates slide past each other without creating or destroying lithosphere.

Transmissivity – The ability of a reservoir to allow the flow of fluid through a certain area, generally in the horizontal direction. The transmissivity is the product of the permeability (a property of the rock only, related to the interconnectedness and size of fractures or pores) and the thickness of the formation through which the fluid is flowing. Transmissivities in geothermal systems are very high, often having values greater than 100 darcy-meters, compared to oil and gas reservoirs where transmissivities are typically 100 to 1,000 times smaller.

Triple-expansion plant – As used in this report, a power plant that uses a very high-pressure geofluid and three pressure-reducing processes and two separation stages to produce steam at two different pressure levels for use in a steam turbine; altogether the geofluid is subjected to three expansion processes, two of which generate electricity.

Triplet configuration – A pattern of production and injection wells in which each injector is surrounded by two producers.

Trouble (during drilling) – Unanticipated difficulties encountered during drilling, including, for example, stuck drill pipe, twist-off of the drill bit, lost circulation, blowouts, mud pump failure, failed cement jobs, casing collapse, and equipment lost downhole. The cost of trouble becomes more significant the deeper one drills.

Turbine isentropic efficiency – A measure of the performance of a turbine, defined as the ratio of the actual work (or power) delivered by the turbine to the ideal work (or power) that could be delivered if the turbine were adiabatic (no heat losses) and reversible (no friction), i.e., isentropic (constant entropy).

TVD – Total vertical depth. The vertical distance from the wellhead to the bottom of the well. For directionally drilled wells, the TVD is smaller than the total drilled length of the well.

Underbalanced drilling – The practice of intentionally drilling a well with borehole pressure less than the formation pore pressure.

Under-reaming – A method of opening up a wellbore to a larger size, often achieved by setting the drill bit below the bottom of the casing string and expanding it radially.

USGS – United States Geological Survey. A federal agency responsible for characterization and assessment of the Earth's water and mineral resources (including oil, gas, coal, and geothermal), natural hazards, and the environment.

Utilization efficiency – A measure of how close an energy conversion system comes to ideal operation. It is defined as the ratio of actual net power to maximum possible power, usually expressed as a percentage.

Variable costs – Fluctuating costs of operation of a facility. For this study, these include: fuel costs, electricity to run injection and circulating pumps, maintenance, interest and principal repayments, taxes, and depreciation.

Wellcost Lite – A computer model (developed by Bill Livesay, working with staff at Sandia National Laboratories) that estimates the cost of a well of a specific depth, casing design, diameter, and geological environment.