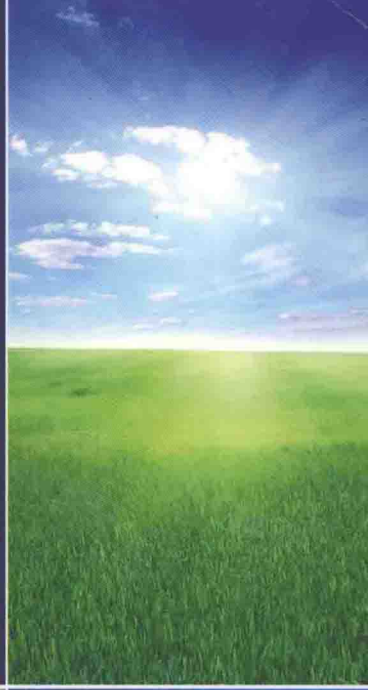
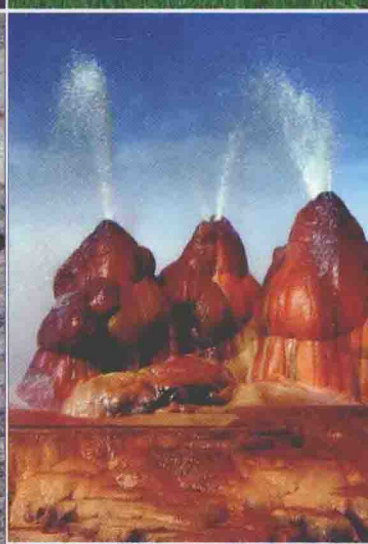
ENERGY AND THE ENVIRONMENT

Abbas Ghassemi, Series Editor

GEOTHERMAL ENERGY

Renewable Energy and the Environment





William E. Glassley

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Series Editor's Preface

By 2050, the demand for energy could double, or even triple, as the global population rises and developing countries expand their economies. All life on earth depends on energy and the cycling of carbon. Energy is essential for economic and social development but also poses an environmental challenge. We must explore all aspects of energy production and consumption including energy efficiency, clean energy, global carbon cycle, carbon sources and sinks and biomass as well as their relationship to climate and natural resource issues. Knowledge of energy has allowed humans to flourish in numbers unimaginable to our ancestors. The world's dependence on fossil fuels began approximately two hundred years ago. Are we running out of oil? No, but we are certainly running out of the affordable oil that has powered the world economy since the 1950s. We know how to recover fossil fuels and harvest their energy for operating power plants, planes, trains, and automobiles that result in modifying the carbon cycle and additional greenhouse gas emissions. This has resulted in the debate on availability of fossil energy resources, peak oil era and timing for the anticipated end of the fossil fuel era, and price and environmental impact versus various renewable resources and use, carbon footprint, emission and control including cap and trade and emergence of "green power."

Our current consumption has largely relied on oil for mobile applications and coal, natural gas, and nuclear or water power for stationary applications. In order to address the energy issues in a comprehensive manner, it is vital to consider the complexity of energy. Any energy resource—including oil, coal, wind, biomass, and so on—is an element of a complex supply chain and must be considered in the entirety as a system from production through consumption. All of the elements of the system are interrelated and interdependent. Oil, for example, requires consideration for interlinking of all of the elements including exploration, drilling, production, water, transportation, refining, refinery products and byproducts, waste, environmental impact, distribution, consumption/application and finally emissions. Inefficiencies in any part of the system will impact the overall system, and disruption in any one of these elements would cause major interruption in consumption. As we have experienced in the past, interrupted exploration will result in disruption in production, restricted refining and distribution, and consumption shortages; therefore, any proposed energy solution requires careful evaluation and as such, may be one of the key barriers to implement the proposed use of hydrogen as a mobile fuel.

Even though an admirable level of effort has gone into improving the efficiency of fuel sources for delivery of energy, we are faced with severe challenges on many fronts. This includes: population growth, emerging economies, new and expanded usage and limited natural resources. All energy solutions include some level of risk, including technology snafus, changes in market demand, economic drivers and others. This is particularly true when proposing energy solutions involving implementation of untested alternative energy technologies.

There are concerns that emissions from fossil fuels will lead to climate change with possible disastrous consequences. Over the past five decades, the world's collective greenhouse gas emissions have increased significantly even as efficiency has increased, resulting in extending energy benefits to more of the population. Many propose that we improve the efficiency of energy use and conserve resources to lessen green house gas emissions and avoid a climate catastrophe. Using fossil fuels more efficiently has not reduced overall greenhouse gas emissions due to various reasons, and it is unlikely that such initiatives will have a perceptible effect on atmospheric greenhouse gas content. While there is a debatable correlation between energy use and greenhouse gas emissions, there are effective means to produce energy, even from fossil fuels, while controlling emissions. There are

also emerging technologies and engineered alternatives that will actually manage the makeup of the atmosphere but will require significant understanding and careful use of energy.

We need to step back and reconsider our role and knowledge of energy use. The traditional approach of micromanagement of greenhouse gas emissions is not feasible or functional over a long period of time. More assertive methods to influence the carbon cycle are needed and will be emerging in the coming years. Modifications to the cycle means we must look at all options in managing atmospheric greenhouse gases, including various ways to produce, consume, and deal with energy. We need to be willing to face reality and search in earnest for alternative energy solutions. There appears to be technologies that could assist; however, they may not all be viable. The proposed solutions must not be in terms of a "quick approach," but a more comprehensive, long-term (10, 25 and 50 plus years) approach that is science based and utilizes aggressive research and development. The proposed solutions must be capable of being retrofitted into our existing energy chain. In the meantime, we must continually seek to increase the efficiency of converting energy into heat and power.

One of the best ways to define sustainable development is through long-term, affordable availability of resources including energy. There are many potential constraints to sustainable development. Foremost is the competition for water use in energy production, manufacturing, farming, and others versus a shortage of fresh water for consumption and development. Sustainable development is also dependent on the earth's limited amount of soil, and in the not too distant future we will have to restore and build soil as a part of sustainable development. Hence, possible solutions must be comprehensive and based on integrating our energy use with nature's management of carbon, water, and life on earth as represented by the carbon and hydrogeological cycles. Obviously the challenges presented by the need to control atmospheric green house gases are enormous and require "out of the box" thinking, innovative approach, imagination and bold engineering initiatives in order to achieve sustainable development. We will need to ingeniously exploit even more energy and integrate its use with control of atmospheric greenhouse gases. The continued development and application of energy is essential to the development of human society in a sustainable manner through the coming centuries. All alternative energy technologies are not equal and have risks and drawbacks. When evaluating our energy options, we must consider all aspects including: performance against known criteria; basic economics and benefits; efficiency; processing and utilization requirements; infrastructure requirements; subsidies and credits; waste and ecosystem; as well as unintended consequences such as impacts to natural resources and the environment. Additionally, we must include the overall changes and the emerging energy picture based on current and future efforts to modify fossil fuels and evaluate the energy return for the investment of funds and other natural resources such as water.

A significant motivation in creating this book series, which is focused on alternative energy and the environment, was brought about as a consequence of lecturing around the country and in the classroom on the subject of energy, environment and natural resources such as water. Water is a precious commodity in the West in general and the Southwest in particular and has a significant impact on energy production, including alternative sources due to the nexus between energy and water and the major correlation with the environment and sustainability related issues. While the correlation between these elements, how they relate to each other, and the impact of one on the other are understood, it is not significantly debated on when it comes to integration and utilization of alternative energy resources into the energy matrix. Additionally, as renewable technology implementation grows by various states, nationally and internationally, the need for informed and trained human resources continues to be a significant driver in future employment resulting in universities, community colleges, trade schools offering minors, certificate programs and even in some cases majors in renewable energy and sustainability. As the field grows, the demand for trained operators, engineers, designers and architects that would be able to incorporate these technologies into their daily activity is increasing. Additionally, we receive daily deluge of flyers, emails, and texts on various short courses available for interested parties in solar, wind, geothermal, biomass, and so on under

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the umbrella of retooling an individual's career and providing trained resources needed to interact with financial, governmental, and industrial organizations.

In all my interactions throughout the years in this field, I have conducted significant searches in locating integrated textbooks that explain alternative energy resources in a suitable manner and that would complement a syllabus for a potential course to be taught at the university while providing good reference material for people interested in this field. I have been able to locate a number of books on the subject matter related to energy, energy systems, resources such as fossil nuclear, renewable and energy conversion, as well as specific books in the subjects of natural resource availability, use, and impact as related to energy and the environment. However, specific books that are correlated and present the various subjects in detail are few and far in between. We have therefore started a series of texts, each addressing specific technology fields in the renewable energy arena. As a part of this series, there are textbooks on wind, solar, geothermal, biomass, hydro, and others yet to be developed. Our texts are intended for upper level undergraduate and graduate students and for informed readers who have a solid fundamental understanding of science and mathematics as well as individuals/organizations that are involved with design development of the renewable energy field entities that are interested in having reference material available to their scientists and engineers, consulting organizations, and reference libraries. Each book presents fundamentals as well as a series of numerical and conceptual problems designed to stimulate creative thinking and problem solving.

The series author wishes to express his deep gratitude to his wife Maryam who has served as a motivator and intellectual companion and too often was victim of this effort. Her support, encouragement, patience, and involvement have been essential to the completion of this series.

Abbas Ghassemi, PhD
Las Cruces, New Mexico

Preface

The rapidly growing influence of human activity on the environment has changed the way human beings view the world and their relationship with it. Until the middle of the twentieth century, the world was seen as an essentially stable, unchanging landscape. What changes occurred were either of small global impact or constrained to play out on time scales more familiar to geologists than the average worker, politician, or student. However, over the last 50 years the cumulative effects of industrial activity, coupled in complex ways with population growth and economic development, have become more apparent. We are now capable of monitoring every aspect of the planet's environment and have come to realize that the world and the biology it supports have long been evolving in response to our actions.

Underlying every aspect of the human juggernaut has been the ability to access and utilize what seemed to be boundless and benign fossil energy resources. With the realization that those energy resources are, in fact, exhaustible and that their use is affecting the global hydrosphere, biosphere, and atmosphere, there has developed an interest in finding and developing energy resources that have minimal environmental impact and are sustainable. Geothermal energy is one such resource.

Geothermal energy is ubiquitous, abundant, and inexhaustible. It powers the movement of the continents across the face of the planet, it melts rock that erupts as volcanoes, and it supplies the energy that supports life in the ocean depths. It has been present for 4,500 million years and will be present for billions of years into the future. It flows through the earth constantly, 24 hours a day, 7 days a week, rain or shine, eon upon eon. It has the potential to provide power to every nation in the world—in the United States alone, it has been noted that the amount of geothermal energy available for power generation exceeds by several times the total electrical power consumption of the country. All of this is possible and with minimal environmental consequence.

This book is about where that energy comes from and how to find it, how it can be accessed, the kinds of applications that have been successfully developed in the past and what could be done to improve its use in the future. This book also considers the constraints that affect the use of geothermal energy—how water must be managed, what emissions must be controlled, and when utilization may not be appropriate. Finally, this book also discusses the economic and social issues that must be addressed for wise and orderly development of this robust and bountiful resource.

The audience for this book is anyone seeking an in-depth introduction to geothermal energy and its applications. It is intended for course work at the undergraduate level; as a reference book for designers, planners, engineers, and architects; and as a source for background material for policy makers, investors, and regulators.

Geothermal energy, wisely used, can contribute in many important ways to resolving one of the fundamental challenges faced by the global community—how to acquire energy to assure the health, prosperity, and security of the global community. It is hoped this book will contribute to achieving that goal.

Acknowledgments

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Series Editor

Dr. Abbas Ghassemi is the director at the Institute for Energy and Environment (IE&E) and professor of chemical engineering at New Mexico State University. He oversees the operations of WERC: A Consortium for Environmental Education and Technology Development, the Southwest Technology Development Institute (SWTDI) and the Carlsbad Environmental Monitoring & Research Center (CERMC). As the director of Institute for Energy and Environment, Dr. Ghassemi is also the chief operating officer for programs worth over $10 million annually in education and research, and outreach in energy resources including renewable energy, water quality and quantity, and environmental issues. He is responsible for administrative duties, operation, budget, planning, and personnel supervision for the program. Dr. Ghassemi has authored and edited several text books and has many publications and papers in the areas of energy, water, waste management, process control, thermodynamics, transport phenomena, education management, and innovative teaching methods. His research areas of interest include risk-based decision making, renewable energy and water, energy efficiency and pollution prevention, multiphase flow, and process control. Dr. Ghassemi holds a BS, MS, and PhD in Chemical Engineering with minors in mathematics and experimental statistics from University of Oklahoma and New Mexico State University, respectively, and serves on a number of public and private boards, editorial boards, and peer review panels.

Author

William E. Glassley has more than 35 years experience in the analysis, modeling, and evaluation of geological processes that drive geothermal systems. He has been involved in research projects that consider thermal budgets and geochemical processes of low temperature systems in the Faroe Islands, the North Island of New Zealand, and the Olympic Peninsula in Washington State, as well as high temperature systems in northern Norway, Greenland, Sri Lanka, and the Adirondacks in New York. He has authored and co-authored over 90 scholarly and technical reports and publications. Currently, he is the Executive Director of the California Geothermal Energy Collaborative at The University of California–Davis, Energy Institute, and holds an Emeritus Research position at the University of Aarhus, Denmark. He has held research, teaching, and management positions at the University of Washington, Middlebury College, and Lawrence Livermore National Laboratory. He has been a member of scientific review panels for the National Science Foundation, the European Commission, the International Atomic Energy Agency, and research councils for several nations. He has been a reviewer for international scientific journals, and his research has been featured in several popular scientific magazines. Dr. Glassley earned his BA at the University of California–San Diego, and his MSc and PhD from the University of Washington. He was awarded a G. Unger Vetlesen Foundation Fellowship for postdoctoral research at the University of Oslo.

Contents

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1 Introduction

> It is a well-known fact that the interior portions of the globe are very hot, the temperature rising, as observations show, with the approach to the center at the rate of approximately 1 degree C. for every hundred feet of depth. The difficulties of sinking shafts and placing boilers at depths of, say, twelve thousand feet, corresponding to an increase in temperature of about 120 degrees C., are not insuperable, and we could certainly avail ourselves in this way of the internal heat of the globe. In fact, it would not be necessary to go to any depth at all in order to derive energy from the stored terrestrial heat. The superficial layers of the earth ... are at a temperature sufficiently high to evaporate some extremely volatile substances, which we might use in our boilers instead of water.
>
> **—Nikola Tesla, "The Problem of Increasing Human Energy With Special References to the Harnessing of the Sun's Energy," *Century Illustrated Magazine*, June 1900**

As the above quote demonstrates, the vision of utilizing the Earth's internal heat to benefit the world is not new. It has long been recognized that energy, in the form of heat, is constantly radiating from the Earth's surface into space. Some of that energy is solar energy that has been absorbed by soil and rock and reradiated as infrared radiation. But on average about 1% of that energy radiating into space is from the Earth itself. Although it may seem insignificant, in fact the amount of heat energy the Earth contains is staggering—there is enough heat energy in the subsurface to satisfy the energy needs of every nation of the world many times over.

That heat energy is *geothermal energy*. It is remnant heat derived from the formation of the planet four and a half billion years ago, as well as heat from the radioactive decay of naturally occurring unstable isotopes. That heat is sufficient to power plate tectonics, which is the slow movement of massive blocks of the Earth's crust and upper mantle, and to drive mountain building processes that occur when those blocks collide. It is also sufficient to melt rock, generate volcanoes, heat water to form hot springs, and keep basements at a constant temperature. It is a perpetual and inexhaustible energy resource.

With a few important exceptions, geothermal energy did not play a major role in the energy mix associated with power generation or other applications until the latter half of the twentieth century. At that time, growing interest in the environmental, economic, and social aspects of energy generation and use encouraged exploration of energy sources that would diminish reliance on *fossil fuels*. This chapter will discuss the context of those changes and their implication for the development of geothermal energy. The chapters that follow will consider specific topics that, if taken together, provide a comprehensive body of knowledge for informed consideration of geothermal energy use.

THE GLOBAL ENERGY LANDSCAPE

The Historical Role of Fuel

One of the hallmarks of the human species is the creative use of energy. Over many centuries humanity learned through experience, insight, and experimentation that fire could be controlled and used to our mutual benefit. And, with that ability and skill, the quality of life has rapidly improved for an ever-growing proportion of the planets' people.

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